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OF

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PROCEEDINGS

OF THE

ROYAL SOCIETY OF EDINBURGH.

VOL. XIII. 1884–85. No. 119.

The 102nd Session.

GENERAL STATUTORY MEETING.

Monday, 24th November 1884.

The following Council were elected:—

President.

THOMAS STEVENSON, M.Inst.C.E.

Vice-Presidents.

Rev. W. Lindsay Alexander, D.D.
Robert Gray, Esq.
A. Forbes Irvine, Esq. of Drum.
Edward Sang, LL.D.
David Milne Home, Esq. of Milne-Graden.
John Murray, Esq.

General Secretary—Professor Tait.

Secretaries to Ordinary Meetings.

Professor Turner, F.R.S.
Professor Crum Brown, F.R.S.

Treasurer.—Adam Gillies Smith, Esq., C.A.

Curator of Library and Museum—Alexander Buchan, Esq., M.A.

Ordinary Members of Council.

Professor Cossar Ewart.
Professor James Geikie, F.R.S.
Rev. Dr W. Robertson Smith.
Stair Agnew, Esq., Registrar-Gen.
Prof. Douglas Maclagan, M.D.
The Hon. Lord MacLaren.
Rev. Professor Flint, D.D.
Professor T. R. Fraser, M.D.
Professor Chiene.
J. Y. Buchanan, Esq.
Professor Chrystal.
Professor Dickson.

By a Resolution of the Society (19th January 1880) the following Hon. Vice-Presidents, having filled the office of President, are also Members of the Council:—

His Grace the DUKE of ARGYLL, K.T., D.C.L.
Sir WILLIAM THOMSON, LL.D., D.C.L., F.R.S., Foreign Associate of Institute of France.
The Right Hon. LORD MONCREIFF of Tulliebole, LL.D.

Monday, 1st December 1884.

THOMAS STEVENSON, Esq., Memb. Inst. C.E., President, in the Chair.

The President opened the Session with a short Address, and an Obituary Notice of Sir Alexander Grant.

The following Communications were read:—

1. On the Distribution of Energy between colliding Groups of Molecules. By Sir W. Thomson.

2. On the Dynamics of Reflection and Refraction in the Wave Theory of Light. By the Same.

3. On Kerr's Discovery regarding the Reflection of Light from a Magnetic Pole. By the Same.

4. On an Improved Method of Measuring Compressibility. By Professor Tait.

When the compressibility of a liquid or gas is measured at very high pressures, the compression vessel has to be enclosed in a strong cylinder of metal, and thus it must be made, in some way, self-registering. I first used indices, prevented from slipping by means of hairs. Sir W. Thomson's devices for sounding, at small depths, by the compression of air, in which he used various physical and chemical processes for recording purposes, led me to devise and employ a thin silver film which was washed off by a column of mercury. Much of my work connected with the *Challenger Thermometers* was done by the help of this process. Till quite recently I was unaware that it had been devised and employed by Cailletet in 1873, only that his films were of gold.

But the use of all these methods is very laborious, for the whole apparatus has to be opened *for each individual reading.* Hence it struck me that, instead of measuring the compression produced by a given pressure, we should try to measure the pressure required to produce an assigned compression. I saw that this could be at once effected by the simplest electric methods; *provided that glass, into which a fine platinum wire is fused, were capable of resisting very high pressures without cracking or leaking at the junctions.* This, on trial, was found to be the case.

We have, therefore, only to fuse a number of platinum wires, at intervals, into the compression tube, and very carefully calibrate it with a column of mercury which is brought just into contact with each of the wires successively. Then if thin wires, each resisting say about an ohm, be interposed between the pairs of successive platinum wires, we have a series whose resistance is diminished by one ohm each time the mercury, forced in by the the pump, comes in contact with another of the wires. Connect the mercury with one pole of a cell, the highest of the platinum wires with the other, leading the wires out between two stout leather washers; interpose a galvanometer in the circuit, and the arrangement is complete. The observer himself works the pump, keeping an eye on the pressure gauge, and on the spot of light reflected by the mirror of the galvanometer. The moment he sees a change of deflection he reads the gauge. It is convenient that the external apparatus should be made to leak slightly; for thus a *series* of measures may be made, in a minute or two, for the contact with each of the platinum wires. Then we pass to the next in succession.

I have found this method perfectly successful in practice, enabling me to do in an afternoon (and far more certainly than before) as much as I formerly could manage in a month. But I cannot properly apply it to the compression of water at various temperatures (from 0° to 100° C.) until I get a new, light but strong, steel compression apparatus, which has been ordered for this special problem.

The experiments hitherto made by this process (to satisfy myself that it would work) were made in my smaller compression apparatus; which is a massive iron cylinder, and very unwieldy for heating purposes. The results below are therefore strictly preliminary and provisional. The difficulty of knowing the interior temperature, and especially *of making sure that it has ceased to rise*, during the measures, renders them very dubious. I hope soon to supply more trustworthy results.

Temperature C.	Mean Difference of Readings of Pressure Gauge for the same three successive Wires.		
0°·5	14·5	16·7	17·7
8°·0	14·9	17·5	19·7
49°·0	24·6	22·0	21·8

If these at all represent the truth, they indicate a very curious result. But I draw no inference till I can repeat the work under more favourable circumstances.

PRIVATE BUSINESS.

The following Candidates were balloted for and declared duly elected Fellows of the Society:—Mr H. Bellyse Baildon, B.A.; Mr Robert Chambers; Dr Charles M'Bride.

Monday, 15th December 1884.

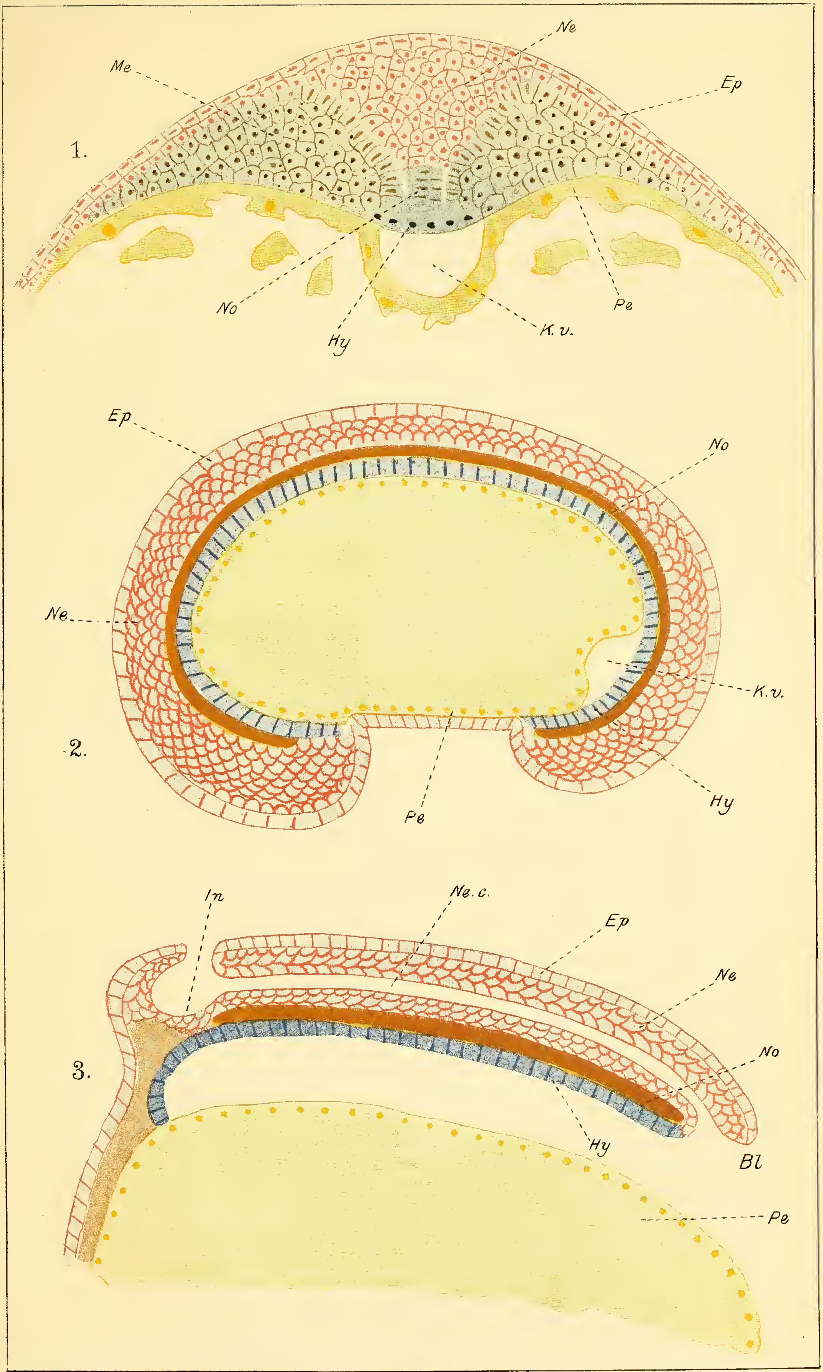
ROBERT GRAY, Esq., Vice-President, in the Chair.

The following Communications were read:—

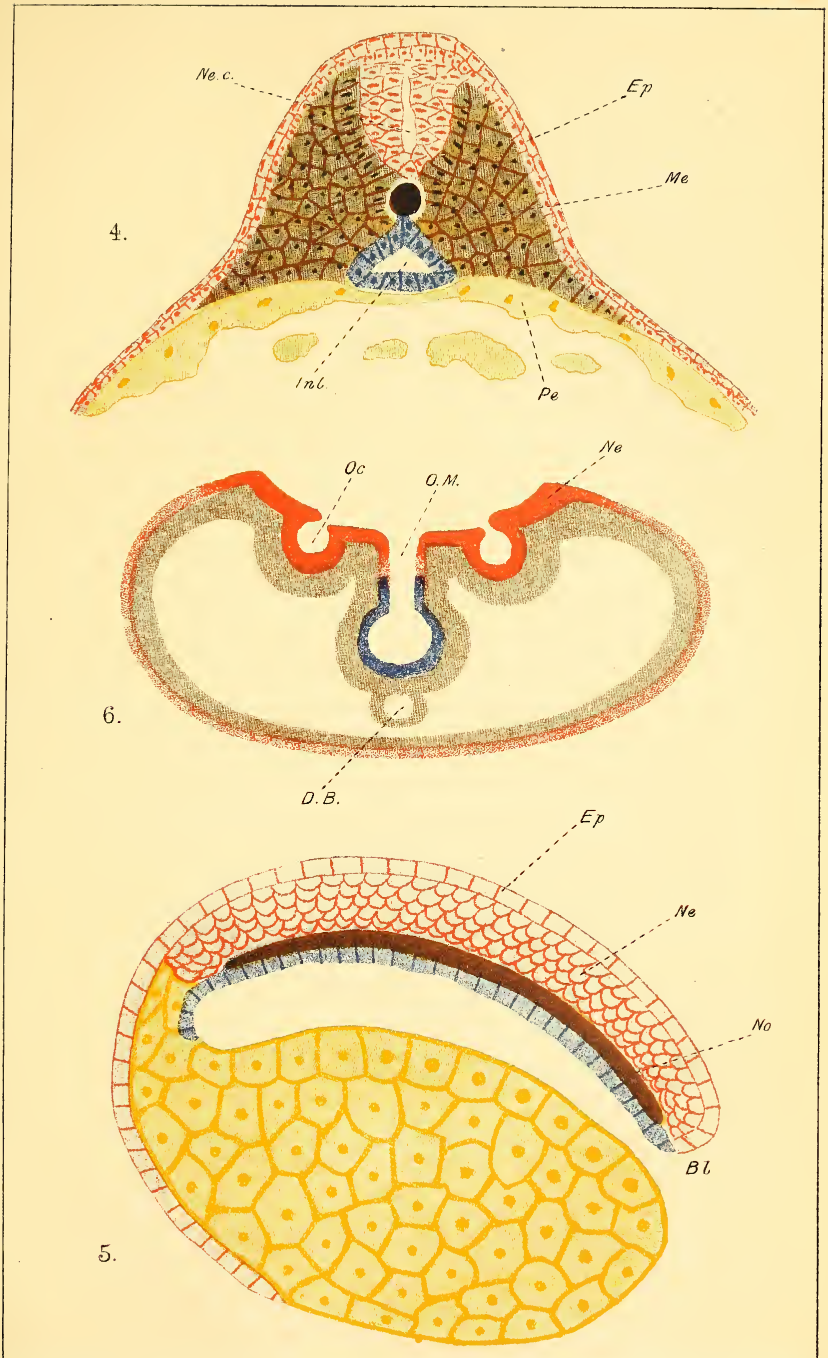
1. On the Theory of the Tides. Part I. By Edward Sang, LL.D.

2. On the Nature and Significance of the Structure known as Kupffer's Vesicle in Teleostean Embryos. By Mr J. T. Cunningham, B.A. (Plates I., II.)

The study of the development of the herring, of which the following pages contain the first results, was commenced at the beginning



J. T. C. del.   M^c Farlane & Erskine Lith^rs Edin^r



J. T. C. del.

M^c Farlane & Erskine, Lith^rs Edin^r

of last August. At that time I went to a small fishing village called Sea Houses, North Sunderland, on the Northumbrian coast, and obtained a large number of herring ova, which I fertilised artificially on glass plates when on board a herring boat off the Longstone Lighthouse. I kept the spawn in wooden boxes sunk close to the shore, and was successful in keeping a proportion of them in a healthy condition up to the time of hatching, and for several days after. When I returned to the Scottish Marine Station on September 3, I brought with me about a dozen newly-hatched larvæ in a corked bottle of sea water, and some of these were alive on September 11, having lived over nine days. I attempted to feed the larvæ by putting in the water some of the small organisms taken by the tow-net, and those which I examined on 11th September had digested food in the intestine. I had previously experimented with herring eggs in August and September 1883, when I accompanied some members of the Scottish Fishery Board to the Moray Firth, to investigate the herring question there. In March of the present year also I obtained and artificially fertilised herring ova off Anstruther, in the Firth of Forth. On neither of these occasions had I suitable opportunities for making a fruitful study of my material. At North Sunderland I spent most of my time in observing the living embryos at succeeding stages, and preserving examples at frequent intervals. These preserved specimens I have cut into sections in the laboratory of the Granton Station since my return.

The rate of development in herring eggs, as in those of most Teleosteans, varies considerably with the temperature. The eggs which I studied were exposed to a temperature varying from 53° to 58° Fahr. (11°·5 to 14°·5 C.), and they hatched on the eighth and ninth days after fertilisation.

Kupffer's vesicle, as is well known, is a small globular cavity which appears at an early stage in Teleostean development between the posterior end of the embryo and the yolk. In the herring eggs with which I had to deal the structure was visible early on the third day, and remained visible for about eight or nine hours; on the fourth day it could not be seen. At the time of its appearance the yolk was entirely enclosed by the blastoderm, the two ends of the embryo almost met at the ventral side of the ovum, and the rudiments of the eyes and ears were formed.

Historical Summary.—The vesicle was first described by Kupffer* in 1868 in *Gasterosteus aculeatus*, *Gobius minutus*, and *Gobius niger*. He described it as lying beneath the intestine, stated that it was lined with cells, and considered that it was homologous with the allantois of the Amniota. In later papers Kupffer came to the conclusion that the vesicle was connected with the development of the urinary organs and ducts.

Balfour, in his *Comparative Embryology*, considered the vesicle as homologous with the post-anal vesicle in Elasmobranchs. He gave no reasons for this view, intending probably to investigate the point at some future time.

In 1880† M. Henneguy published, in the *Bulletin de la Société Philomathique de Paris*, some researches on the development of the Perch, in which he announced that he believed he had found an opening from Kupffer's vesicle to the exterior, and considered that the structure represented the primitive intestine of Cyclostomi and Batrachia, its opening being the anus of Rusconi. In 1883 a paper on Teleostean embryology, by Messrs Kingsley and Conn,‡ appeared in the *Memoirs of the Boston Society of Natural History*. These authors had studied chiefly the pelagic ova of Ctenolabrus, one of the Wrasses. They trusted entirely to optical sections of the living embryo. They devote two short paragraphs to Kupffer's vesicle; they describe its origin from a number of small granules which coalesce, say nothing of its relation to the layers, though their figure is correct as far as it goes, and think that Balfour's view is much more probable than Henneguy's.

Finally, Professor A. Agassiz and C. O. Whitman have recently published some researches on the development of pelagic Teleostean eggs carried on at the Newport Marine Laboratory.§ Here, again, ova of Ctenolabrus were principally studied. Kupffer's vesicle is dealt with in some detail; the description of its origin given by Kingsley and Conn is confirmed, if by granules are understood small spaces; the vesicle is correctly described as lying beneath the chorda and entodermic stratum, and as having no sort of connection

* *Arch. f. mik. Anat.*, Bd. iv.

† *Ann. and Mag. Nat. Hist.*, ser. 5, vol. vi.

‡ Vol. iii. No. vi., April 1883

§ *Proc. Amer. Acad. Arts and Sciences*, vol. xx. Aug. 1884.

with any tubular structure whatever. It disappears as the intestine is formed; but the authors have not recognised the fact that the periblast aids in forming the floor of the intestine, as I shall show below. They believe that a lumen exists in the part of the intestine formed in the region of the vesicle, from the time of the latter's disappearance onwards. It is very surprising that, having thus grasped clearly the relations of the vesicle, Agassiz and Whitman have not seen its meaning; they say that they are not ready to accept Balfour's interpretation, but the views of Kupffer and Henneguy are still more unsatisfactory. I hope to show that Henneguy's is the obvious and only morphological interpretation possible of the structure in question.

I may be allowed to explain that I arrived at the view I hold independently, not having seen any account of Henneguy's results till my opinion had been formed; at present I have only been able to see an abstract of Henneguy's paper, and do not know if his foundation of fact was more or less firm than my own.

Kupffer's vesicle, then, as seen in a successful series of transverse sections through a herring ovum at the proper stage, is a hemispherical cavity, bounded above by the lowest layer of the blastoderm, and laterally and inferiorly by the periblast. The latter is simply the outer layer of the yolk containing nuclei, but not divided into cells. In the herring at this stage the hypoblast cells are not distinctly differentiated from the mesoblast. The notochord is well formed, not yet vacuolated, and, as usual, not sharply marked off from the hypoblast. The neurochord is present as a thick cord of cells derived from the epiblast, and containing no canal (see Plate I. fig. 1).

It is clear, then, that Kupffer's vesicle has the same relation to the embryonic layers as the invagination cavity in Elasmobranchs, Amphibia, and Cyclostomi (Petromyzon). The vesicle has no differentiated cell-walls of its own; it is simply a depression in the periblast. The differences between its relations and those of the cavities with which I am comparing it are—first, its small extent, and second, the want of an opening to the exterior. As to the extent, the vesicle is a rudiment, a remnant of a larger cavity; as to its opening, it is on a par with all the other cavities in the Teleostean embryo. The neural canal, the cavity of the otocyst, the cavity of the crystalline lens, none of these arises in the Teleostean by direct invagination from the exterior, as they all do in Elasmobranchs. The neurenteric canal, as a distinct lumen, does not exist in Teleostean embryos, nor does the blastopore which would give rise to it. In Petromyzon we have an interesting condition intermediate between the Elasmobranch and the Teleostean. The neural canal does not arise as a groove open to the exterior, but, as in Teleosteans appears at a later stage closed from the beginning; while the gastrula cavity, on the other hand, is formed by direct invagination. The part of the blastopore represented by the neurenteric canal has disappeared, and not the part which in the Elasmobranch remains open to the exterior longest (see Plate I. figs. 2, 3; Plate II. fig. 5).

As far as actual comparison goes, therefore, there is every reason to believe that Kupffer's vesicle represents the gastrula cavity, or that part of it which is left after deducting the body cavity; but still further evidence is offered by the subsequent history of the vesicle. In Plate II. fig. 4 is shown the condition of the herring embryo on the fourth day in the region where Kupffer's vesicle existed. The intestine is completely formed; and it will be noticed that beneath the intestine the periblast is very thin, and contains no nuclei, though these are visible laterally beneath the mesoblast. It seems clear, then, that the floor of the intestine in this region has been formed by the differentiation of cells round the nuclei of the periblast, exactly as in Elasmobranchs the periblastic floor of the gastrula cavity is transformed into the floor of the intestine.

I think there is no room for doubt that the significance of Kupffer's vesicle is completely elucidated by the facts and comparisons I have thus given; it is the last rudiment of the invagination cavity in the Teleostean.

Remarks on General Vertebrate Morphology.—The view which obtains homologies between Vertebrates on the one hand, and Chaetopoda, Crustacea, and Insecta on the other, by inverting the latter, was suggested long ago by Geoffrey St Hilaire, when he said that Vertebrates were insects walking on their backs. But the distinct hypothesis that a Vertebrate is actually descended from an ancestor which agreed in almost every point of its anatomy with a modern Chaetopod, owes its origin and support in great measure to Dr Dohrn, director of the Zoological Station at Naples. St Hilaire's suggestion was related to this theory very much as Lamarck's notions on evolution to the "Origin of Species."

The correspondence between a Chaetopod turned over, and say a fish, is very complete. On the upper side (ventral in Chaetopod's natural position) is the double nerve-cord; so also in the fish. In the axis is the intestine. Above the intestine in the inverted Chaetopod is a blood-vessel, in which the blood passes from the head towards the tail (subintestinal vessel in natural position). So also in the fish—the dorsal aorta. In the inverted Chaetopod, below the intestine, is a blood-vessel in which the blood passes from the tail to the head (dorsal blood-vessel in the natural position). So also in the fish—(subintestinal vein, heart, ventral aorta).

Moreover, in the embryo of Chaetopod, Insect or Crustacean, the blastoderm is formed on the ventral surface, along which the primitive blastopore extends, though in most cases its actual opening is narrowed to a small posterior aperture, which becomes the anus. In the Vertebrate embryo the blastoderm is dorsal, and, as Sedgwick* has shown in a recent paper, and as Miss Johnson † has confirmed, there is evidence in the Vertebrate embryo of a fusion of the layers at an early stage along the median line of the blastoderm, indicating a primitive elongated blastopore.

Sedgwick's view of the morphology of Vertebrates differs from Dohrn's in one most important point. The former considers the actual mouth and anus of Vertebrates to be identical with the primitive mouth and anus, and supposes that a portion of the nervous system, representing the supraœsophageal ganglia of Chaetopods, &c., has disappeared. On Dohrn's view, the primitive anus was terminal, and is represented (when the actual blastopore is enclosed by the medullary groove) by the neurenteric canal. Where was the primitive mouth if the actual mouth is a secondary structure? Dohrn ‡ pointed out clearly in 1875 that a primitive mouth must have existed, surrounded, as in modern Chaetopods, by nerve-cord. He first supposed that the hypophysis cerebri, or pituitary body, then believed to be developed from the intestine, was the rudiment he was seeking; but in the publication I have referred to he definitely abandoned this view, and took up the theory

* *Q. J. M.*, January 3, 1884. † *Ibid.*, October 1884.

‡ *Ursprung der Wirbelthiere*, Leipzig, 1875.

that the sinus rhomboidalis in the medulla oblongata, the fourth ventricle in fact, was the position of the primitive mouth. This view he has also since given up. The hypothesis was discussed by Balfour in his monograph on the development of Elasmobranchs.*

It is an astonishing fact that, until the publication of Sedgwick's paper, morphologists had never fully grasped the significance of the development of the central nervous system in Vertebrates. Sedgwick has pointed out that the interior surface of the lining canal is part of the original dorsal surface of the body—that is to say, the condition through which an Elasmobranch or Amphibian embryo passes, in which the nervous system is a double cord of thickened epiblast, widening out anteriorly into a plate, was the permanent condition of the Vertebrate ancestor. Sedgwick has not followed out this fact to its ultimate consequences. He has been misled by his desire to consider the present mouth and anus as identical with the original structures. At the meeting of the British Association at York in 1881, Sir Richard Owen, in his address to the Department of Anatomy and Physiology of Section D, embraced the Dohrnian view of the homologies of Vertebrates and Invertebrates, and announced as a new hypothesis that the original œsophagus was represented by what he called the conario-hypophysial bract—that is, that the œsophagus originally passed from the hypophysis to the pineal gland. This was very much the same as Dohrn's first view before 1875, which had to be abandoned. The reasons why it is

* Professor Turner has kindly pointed out to me that John Goodsir, in a paper published in the second volume of his *Anatomical Memoirs*, Edinburgh, 1868, speaks of a view he once held concerning the Vertebrate primitive mouth, which is similar to the view once held by Dohrn, as mentioned above. Goodsir's view, originally published in the *Edinburgh Philosophical Journal* in 1857, was that the primitive œsophagus passed through the pituitary body, infundibulum, and third ventricle, and opened at the roof of the fourth ventricle behind the cerebellum. This theory, therefore, was a combination of the views which have since that time been successively favoured by Dohrn, and is anterior in date to any publications on the subject by Dohrn, Owen, or any others. Goodsir, in the paper I refer to, only mentions his theory to say that he abandoned it, because Reichert had shown that the pituitary body does not perforate the skull in the embryo. We know now that this reason for abandoning the theory does not exist. Goodsir completely agreed with Geoffrey St Hilaire's view concerning the reversed positions in Vertebrate and Annelid or Crustacean, and also recognised that the dorsal blood-vessel in the latter was homologous with the subintestinal vessel and heart in the Vertebrate.—*Note added Jan.* 28, 1885.

untenable are—first, the hypophysis is developed in most cases from the epiblast of the actual mouth, and not from the hypoblast; and, second (a reason which I believe has never before been definitely stated), that the original mouth did not open on what is now the dorsal surface above the nervous system, but on the floor of the cerebral vesicles, which is part of the primitive body surface. The conditions required for the rudiment of the primitive mouth are satisfied completely, and it seems to me exclusively, by the infundibulum. This latter structure is in the embryo a diverticulum from the floor of the first cerebral vesicle, which comes into contact with the anterior end of the mesenteron. In Miss Johnson's paper "On the Newt" a pit is described at the front end of the primitive blastopore, at the bottom of which pit epiblast and hypoblast are fused. The writer believes that this pit becomes the actual mouth. I think there is little doubt that if she had traced the fate of the pit in question she would have found that it became the infundibulum. I know that in herring embryos, in front of the notochord, the neurochord comes into contact with the hypoblast. Dohrn * has come to the conclusion that the hypophysis cerebri is the rudiment of a præoral pair of gill-clefts. If this conclusion hold good, it gives support to my view of the primitive mouth, for a pair of gill-clefts would have opened into the original œsophagus, and therefore might very well in actual Vertebrates come into connection with the rudiment of the primitive mouth, as the pituitary body does with the infundibulum. As for the pineal gland, it does not concern the question in the least; it is connected with the closing of the medullary canal, and is of comparatively small importance in the present discussion.

The Notochord.—Ever since the notochord was first described in some embryos as originating from the hypoblast, morphologists have considered that it must phylogenetically be derived from the intestine. Now, comparative anatomy shows that this supposition is untenable. The dorsal aorta in the fish is homologous with the subintestinal vessel in the Chaetopod: if the notochord had been derived from the intestine, it would lie between the aorta and the intestine—its actual position is between the aorta and the neurochord. It is not consistent with the principles of evolution to

* *Mitt. der Zool. Station zu Neapel*, Bd. iv. Heft. 1.

believe that it could first arise from the intestine, and afterwards pass into its present position. The notochord must have arisen phylogenetically from the mesoblast between the neurochord and the aorta. Some of my sections of herring embryos show the notochord distinctly marked off from the hypoblast, and continuous with the neurochord. This is not to be interpreted as showing that the notochord was derived from the neurochord, a skeletal structure from an epiblastic. The reason why the notochord is at first in close relation with the hypoblast, or with the neurochord, is that its development in the embryo has come to take place at so early a stage that the fusion of the three layers along the line of the primitive blastopore has not disappeared before the notochord appears. Balfour says, that in Elasmobranchs it is difficult to ascertain whether the notochord is derived from the hypoblast or is a central column of mesoblast cells. We thus get back to the old view, that the notochord is homologous with the three giant fibres beneath the nerve-chord in the earth-worm; both are mesoblastic structures, developed in the same position for the purpose of supporting the nerve-chord. It has been suggested that the typhlosole in the earth-worm represents the notochord; as I have shown this is impossible; the typhlosole reappears in the spiral valve of the intestine of Elasmobranchs and other fishes. The fact that the notochord stops short just behind the infundibulum is fully accounted for by my theory that the latter structure is the primitive mouth.

The Vertebrate Eye.—The peculiarity in the development of the vertebrate eye, as compared with that of Invertebrates, has long ceased to be so great a mystery as it was to earlier morphologists. In his address to the Department of Anatomy and Physiology of Section D, at the British Association meeting at Swansea in 1880, Balfour pointed out that the retina was formed from the floor of the brain, that is to say, from the same portion of the primitive epidermis which formed the central nervous system. In a similar way the rhabdoms or retinal elements in the eyes of Arthropods are formed from the supraœsophageal ganglia. In his little book on Degeneration in the *Nature* series, Prof. Lankester has inferred from the consideration of the cerebral eyes of Ascidians, that the original vertebrate ancestor was transparent, and had eyes on the floor of its brain; that when the animal became opaque the eyes gradually grew out to meet the epidermis at the sides of the head. But Sedgwick's revelation that the floor of the cerebral vesicle was once the surface of the head, enables us to go a step further, and form a clear conception of the state of the eyes in the primitive vertebrate ancestor, and the transition to the present state. In the worm-like ancestor at the sides of and somewhat in front of the mouth were a pair of eyes, formed as simple pits in the epidermal nerve area, exactly similar to the simple open eye-cups which exist in Patella and Haliotis at the present day. When the mouth and nerve area were covered by the formation of the neural canal the eyes became cerebral, and were influenced by light coming through the transparent tissues. In this condition the eye has persisted in Ascidians. In Vertebrates the body has become opaque, the eye-cups have grown out towards the side of the head, where a thickening took place in the epidermis to form the crystalline lens, which afterwards was pinched off and sunk in the mesoblast. We may regard the humours, the cornea, and the lens of the vertebrate eye as parts which have retained their primitive transparency (see Plate II. fig. 6).

We have now made more compact the inversion theory of vertebrate morphology. Sedgwick has attempted to go further, and account for segmentation gill-clefts, segmental organs, and abdominal pores, by deriving them from Coelenterates similar to Zoantharians. His theory is very ingenious, and for the most part extremely probable. But it agrees much better with the view that the infundibulum represents the primitive mouth, and the neurenteric canal the primitive anus, than with Sedgwick's own view concerning these points. For, according to Sedgwick himself, the planes of segmentation are perpendicular to the direction of the elongated blastopore, while if the present anus of a fish is the primitive anus, the segments of the fish's tail are parallel to part of the primitive blastopore. And if the primitive blastopore extended from the actual mouth to the actual anus in such a fish as a cod or blenny, it would occupy almost $\frac{9}{10}$ths of the longest circumference of the body. Balanoglossus, too, seems to give evidence that openings can arise from the intestine to the exterior independently both of segmental organs and blastopore. There is one other point which Sedgwick neglects, namely, that segments in all segmented animals are formed between the telson and the last segment. I am not aware that in any Coelenterate the mesenteries are formed according to this law.

Explanation of Plates I. and II.

In all the diagrams homologous layers are of the same colour.

Reference Letters.

Bl. Blastopore.
D. B. Dorsal blood-vessel in ancestral subintestinal in actual vertebrate.
Ep. Epiblast.
Hy. Hypoblast.
In. Infundibulum.
Int. Intestine.
K. v. Kupffer's vesicle.
Me. Mesoblast.
Ne. Neurochord.
Ne. c. Neural canal.
No. Notochord.
O. m. Original mouth.
O. e. Original eye.
Pe. Periblast.

Fig. 1. Diagram of a transverse section of a herring embryo passing through Kupffer's vesicle. The colouring of the layers is the only point in which this figure differs from the drawing of an actual section.

Fig. 2. Diagram of a section through the plane of symmetry of a herring embryo at the same stage. This figure is drawn after the study of a series of transverse sections.

Fig. 3. Diagram of a section through the plane of symmetry of an Elasmobranch embryo when the blastopore and medullary groove are being closed.

Fig. 4. Diagram of a section of a herring embryo through the region where Kupffer's vesicle has given place to the intestine.

Fig. 5. Diagram of a section through the plane of symmetry of an embryo of Petromyzon, in which the gastrula cavity exists as in Elasmobranchs, but the neural canal is at first absent, as in Teleosteans.

Fig. 6. Diagram of an ideal section of the Vertebrate ancestor; the section is oblique, and passes through both eyes, and the original nearly terminal mouth, which in actual Vertebrates is represented by the infunbibulum.

3. The Relations of the Alveolar form of Cleft Palate to the Incisor Teeth and the Intermaxillary Bones. By Prof. Wm. Turner, M.B., F.R.S.

Dr Albrecht of Brussels has recently traversed the well-known and generally accepted theory originally advanced by Goethe, that in the alveolar form of cleft palate the fissure lies in the plane of the suture between the intermaxillary and superior maxillary bones, and has suggested, in substitution for this theory, that in the early embryo each intermaxilla is divided into an inner mesial bone (endognathion) and an outer lateral bone (mesognathion), and that the alveolar cleft is an open state of the suture intervening between these two divisions.

In this communication the author discussed Albrect's theory and described the observations which he had made (A) on casts of the roof of the mouth in fifteen cases of cleft palate, and (B) of hard palates where there was no cleft, with the view of ascertaining their bearing on the theory advanced by Albrecht.

A. For the opportunity of examining these casts, and for information regarding the cases, he has to express obligations to his colleagues, Professors Annandale and Chiene; to Dr John Smith, President of the Royal College of Surgeons, Edinburgh; Dr Joseph Bell, Senior Surgeon, Edinburgh Royal Infirmary; W. Bowman Macleod, Esq., L.D.S., Dean of the Dental School; and Andrew Wilson, Esq., L.D.S., Lecturer on Dental Anatomy, Edinburgh.

He has also analysed Th. Kölliker's account of forty-nine preparations of cleft palate examined in several museums in Germany.

Dr Kölliker's forty-nine preparations and the fifteen casts examined by the author, make in all sixty-four specimens in which the relations of the alveolar cleft to the teeth have been definitely observed. These specimens resolve themselves into two groups—*a*, one in which no precanine tooth intervened between the canine and the cleft, and in this group were thirteen specimens; *b*, one in which a precanine was situated between the canine and the cleft, and this consisted of fifty-one specimens. Obviously, therefore, much the larger number of persons with the alveolar form of cleft palate possess a tooth in front of the canine, which is cut off from the incisor series of teeth by the gap in the border of the jaw.

The author then discussed the homologies of the incisor teeth with reference to the intermaxillary bones, and the nature of the precanine tooth. He believed that the precanine should be regarded as In ^{3}, and that the missing incisor in the normal human dental arcade is In ^{2}. Whilst agreeing with Th. Kölliker in his criticism that the teeth and jaws arise quite independently of each other, and only become related secondarily, yet from the fact that in so large a proportion of the casts a tooth, which from its position must be referred to the incisor series, was situated between the canine and the cleft could scarcely be without some significance, and from the frequency of its occurrence, should not be regarded as a mere accidental displacement of a tooth germ. The very frequent presence of a precanine tooth may therefore be regarded as supporting Albrecht's view of the position of the cleft.

Albrecht has, however, had the advantage of examining several skulls in which the alveolar cleft was seen to separate the intermaxilla into an inner and an outer part, each carrying its appropriate incisor or incisors. In addition to the skulls of the horse and the calves referred to in his first essay on this subject, he has since described and figured an adult human skull in the University of Kiel, in which a right cleft existed in the corresponding intermaxilla, and the right maxillo-intermaxillary suture coexisted with and was quite distinct from it; a new-born infant with double cleft, in which the same suture was present; the jaw of a child about one year old, in the museum at Ghent, in which, with a left cleft in the corresponding intermaxilla, a left maxillo-premaxillary suture was present. In all these cases the part of the intermaxilla which was situated outside the cleft contained the socket for the precanine incisor. The anatomical evidence will therefore justify the statement that, in a proportion of cases of alveolar cleft palate, the cleft lies within the intermaxilla, the cleft coexisting with the maxillo-intermaxillary suture, and an incisor tooth is situated in the interval between the cleft and the canine of the same side.

In the group of cases of alveolar cleft in which no precanine tooth intervened between the canine and the cleft, it is not improbable that one may find examples of a cleft occurring in the plane of the maxillo-intermaxillary suture, and not within the intermaxilla itself. Wherever a suture exists, there, of course, a possibility of an imperfect union of the two bones may arise. Should the bones remain separate, and should the want of union be accompanied by anon-closure of the superjacent soft parts, then the imperfect development would lead to the production of a cleft in the alveolar region and in the upper lip, and the theory of Goethe might therefore be applicable to such cases.

The author then referred to the descriptions of Leidy, Callender, and Th. Kölliker on the development of the intermaxillary bones.

B. The object of examining the hard palate where there was no cleft was to ascertain if any suture, or the remains of a suture, could be seen in its anterior part, immediately behind the incisor teeth, to indicate that, as Dr Albrecht contends, the incisive or intermaxillary element of the human upper jaw had originally consisted of two bones on each side, a mesial or internal, and a lateral or external. The author described six specimens, in each of which a narrow fissure was present in each intermaxilla, which apparently represented the remains of an intra-incisive suture. It existed in conjunction with a pair of maxillo-intermaxillary sutures.

The place of origin of the intra-incisive fissure in the majority of the specimens was from the maxillo-premaxillary suture external to the incisive canal, which canal, therefore, on the theory that the intermaxilla consists of an inner and an outer division, would lie in relation to the inner division close to the articulation between it and the superior maxilla. In one instance the intra-incisive fissure penetrated into the naso-palatine canal. Obviously, therefore, some condition arising during the development of the bone determined the origin and direction of the fissure in question.

What is yet wanted, however, in order to give completeness to the evidence of the division of the intermaxillary bone into an inner and an outer part, is the discovery that the intermaxillary bone normally arises from two distinct centres of ossification, one for the inner, the other for the outer part. Of this there is at present no evidence. But, in connection with this matter, it ought not to be forgotten that it is only recently that the embryological evidence of the origin of the intermaxillary part of the human upper jaw, from a centre distinct from that of the superior maxilla, has been completed. And yet for nearly a century, on such minor evidence as was advanced by Goethe, viz., the suture on the hard palate extending through to the nasal surface, anatomists have believed and taught that the human upper jaw represented both the superior and intermaxillary bones in any other mammal. Where a question in human embryology hinges upon an examination of parts in a very early stage of development, we often have to wait for many years before an appropriate specimen falls into the hands of a competent observer.

This paper will appear *in extenso* in the *Journal of Anatomy and Physiology*, Jan. 1885.

4. Apparent Lines of Force on passing a Current through Water. By Thomas Andrews, F.R.S.E., F.C.S., Wortley Iron Works, near Sheffield.

The author has recently been engaged in a variety of electrical observations in connection with wrought iron and steels, in the course of which it occurred to him to investigate some of the effects produced in the presence of nascent oxygen, of the ozone type, by a current of sufficient strength to readily decompose these metals by oxidation whilst immersed as electrodes in distilled water, the great resistance of the latter apparently facilitating the interesting results observed and recorded below. An average of ten determinations gave the resistance of the distilled water used as 48,234 ohms, and in the following experiments, the current from forty small Leclanché cells was employed. The current was passed through distilled water contained in a beaker (the distilled water was tested for impurities, but was found free from everything except the faintest trace of chlorides), using two round electrodes of the same bright metal $\frac{297}{1000}$ inch diameter by 2 inches long, suspended as shown in the sketch on page 20 (2 inches apart). Hydrogen was rapidly given off at the kathode B, whilst there, at first, slowly exuded from the anode metal A, faint clouds accompanied by long fine streaks of ferric hydrate, which gradually increased in quantity until in about fifteen minutes the whole of the water presented a yellowish turbid appearance, and flocculent masses of oxides began to subside (these were of course reduced to protoxide near the evolved hydrogen from the other electrode B). The circumstance, however, to which the author desires to call attention is the seeming indication of lines of force, during the electrolytic disintegration. The film of oxides of iron (commencing to exude from the electrode A) appeared gradually to arrange itself into innumerable delicately curved filaments or streaks, slowly extending in a general horizontal direction from one electrode to the other. When the bars were inclined towards each other, the filaments emanated in greatest quantity from the nearest point, as indicated in the sketch. After the current had passed some ten minutes, these became increasingly numerous, and were seen proceeding from most parts of A. After a time, however, they became so interwoven and complicated in character as ultimately to present the appearance of thick streaky clouds, composed of finely divided oxide of iron, but yet retained the distinct aspect of a broad current of this nature, extending itself towards the other electrode B.

A pair of electrodes of the same size and shape were tried of each of the following metals from the author's standard samples (see table A), when similar lines of force were observed, though these

Table A.

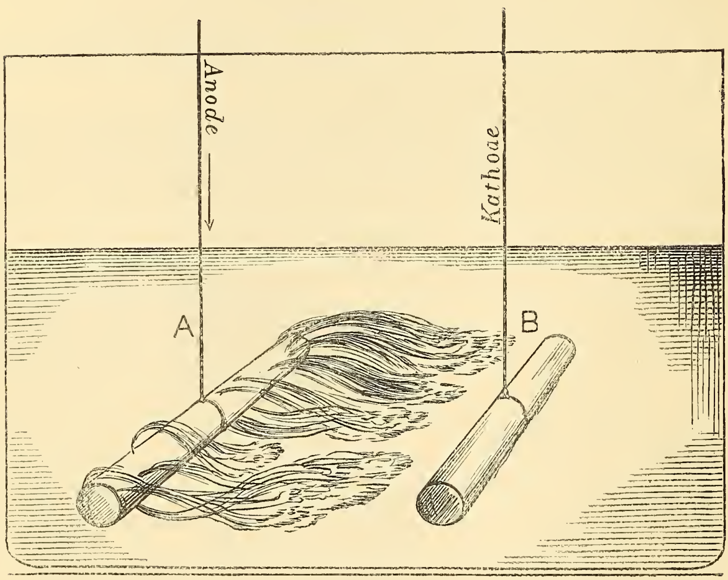
Metals used as Electrodes.	Percentage of combined Carbon.	Percentage loss in weight of the Metal forming the Anode for 65 minutes in Distilled Water.	Percentage loss in weight of the Metal forming the Anode for 65 minutes in Sea Water.
"Soft" Siemens-Martin steel, . . .	..	...	...
Wrought iron, . .	Trace	0·08	0·14
"Soft" cast steel, .	0·570	0·09	0·19
Bessemer steel, . .	0·550	0·09	0·20
Puddled steel, . .	0·440	0·07	0·19
Puddled steel (chilled), .	0·490	0·03	0·22
"Hard" cast steel, .	1·600	0·08	0·25
Cast metal, Graphitic carbon 2·400	1·000	0·10	0·26

indications were perhaps most noticeable when employing cast metal electrodes. The current was passed in each case for a total period of sixty-five minutes. Every bar was cleaned, dried at 212°, and weighed on the balance before and after each experiment, with results given on table A. The kathode metals lost nothing in weight.

In the case of distilled water, the loss was from pure oxidation in presence of the nascent oxygen.

The generally curved contour of some of the outer streaks was doubtless consequent on the mode of emission of the current from the round surface of the electrode, influenced by the resistance effects of the distilled water.

The sketch is from careful drawings, made at the time of



observation, and gives a fair representation, though the lines were perhaps not always so well defined. These effects were obtained when using distilled water (possibly owing to its very great resistance); when the salt water was substituted the curved streaks were not easily distinguishable, to some extent owing probably to the greater, and more rapid oxidation, and the much smaller resistance. The mixed ferrous and ferric oxides in this minute state of subdivision appeared to manifest magnetic properties, the polarised particles acting in magnetic fashion arranged themselves in the above manner, under the influence of the current, and indicating these apparent lines of force.

The curves presented such an interesting appearance that the author thought it desirable to record the observation.

5. Note on a Theorem of Clerk-Maxwell. By Prof. Tait.

At the last meeting of the Society Sir W. Thomson again raised the question of the validity of Boltzmann's Theorem, to which I had called attention two sessions ago. He expressed, at the same time, some doubts as to Clerk-Maxwell's Theorem (of which Boltzmann's is an extension); doubts, however, confined to the proof given by Maxwell, not as to the truth of the theorem itself. This theorem is the extremely important one, that in a mixture of two kinds of particles the average kinetic energy of the particles of each kind is the same. The proof, as given in the *Philosophical Magazine* for 1860, is so very condensed as rather to surprise the reader by the extraordinary rapidity with which it seems to show that the final average is attained. I have, therefore, expanded it so that the nature of the approximation to the average may be clearly traced.

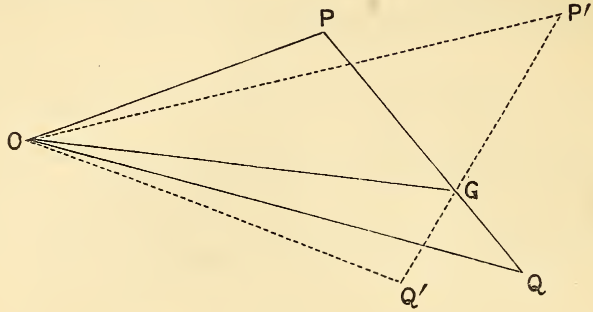
Lemma.—The mean value, of the square of the distance of any point on a sphere from an internal or external point A, is the sum of the squares of the radius of the sphere and of the distance of A from the centre.

The proof is immediate. Divide the spherical surface into pairs of elements by double cones, of very small angle, whose vertices are at the centre. For each pair of these the theorem is obviously true.

Hence if the speeds of two points be p and q, their mean square *relative speed* is $p^2 + q^2$.

Clerk-Maxwell's Prop. VI.

The following figure shows points on a sort of hodograph. Let OP represent, in direction and magnitude (p), the velocity of a particle of mass P. Similarly OQ that of Q, speed q. Let $\angle POQ = \alpha$. Let G be the centre of inertia of P and Q supposed placed at these points in the figure. After the impact G remains undisplaced, but PGQ becomes P′GQ′ where GP′ = GP, GQ′ = GQ, and (by a previous proposition) all directions of P′Q′ (in space) are equally



likely. Let the speed OP′ be called p'; OQ′, q'; and let $\angle OGP' = \theta$.

Then $$OG^2 = \frac{P^2p^2 + Q^2q^2 + 2PQpq\cos\alpha}{(P+Q)^2},$$

also $$Pp'^2 - Qq'^2 = P(OG^2 + GP^2 - 2OG \,.\, GP\cos\theta) - Q(OG^2 + GQ^2 + 2OG \,.\, GQ\cos\theta)$$

$$= (P-Q)\,OG^2 + \frac{PQ(Q-P)}{(P+Q)^2}\overline{PQ}^2 - \frac{4PQ \,.\, OG}{P+Q}\overline{PQ}\cos\theta$$

$$= \frac{P-Q}{(P+Q)^2}\left(P^2p^2 + Q^2q^2 + 2PQpq\cos\alpha - PQ(p^2 + q^2 - 2pq\cos\alpha)\right) - \frac{4PQ \,.\, OG}{P+Q}\overline{PQ}\cos\theta$$

$$= \left(\frac{P-Q}{P+Q}\right)^2 \left\{ Pp^2 - Qq^2 + \frac{4PQpq}{P-Q}\cos\alpha \right\} - \frac{4PQ \,.\, OG}{P+Q}\overline{PQ}\cos\theta .$$

Hence, taking mean values, with regard to α, to θ, and to the plane through OG in which θ is measured (which, of course, presupposes an immense number of impacts), we have

$$Pp'^2 - Qq'^2 = \left(\frac{P-Q}{P+Q}\right)^2 (Pp^2 - Qq^2),$$

which is Clerk-Maxwell's result. The above investigation, however, shows the somewhat complex process of averages by which it is obtained.

The Corollary, in which theproposition is extended to a number of systems of different sets of particles, follows in the same way;

but it specially requires the postulate (not, explicitly at least, alluded to in Maxwell's paper), *that every pair of particles, to whichever set or sets they may belong, shall be perfectly free to collide.* It does not follow that the extension would hold in cases where there is any limitation to the freedom of collision,—such as is almost certainly the case when each particle of a gas is treated as a group of particles, or as a system with a considerably greater number of degrees of freedom than a free particle has. For some of the constituents of each particle may necessarily be so situated as never to encounter the corresponding constituents of another particle.

In fact Boltzmann's generalisation of Clerk-Maxwell's Theorem, in which he asserts that ultimately the energy is equally shared among all the degrees of freedom, would seem to be at once confuted by the collisions of smooth spheres, where each has three degrees of (rotational) freedom to which no energy at all is communicated.

6. Extraordinary Occurrence at House No. 7 York Place.

(*The following notice was sent to the General Secretary, from the Office of Messrs Hunter, Blair, and Cowan, W.S.*)

An occurrence of an extraordinary nature took place in the kitchen of this house on Monday evening, the 8th inst. The kitchen is in the area, and whilst the office-keeper and his wife and servant girl were seated in front of the fire, suddenly, about twenty minutes past eight, a terrific rumbling sound was heard in the chimney. Fearing that something was about to topple about their ears, they all sprang aside, and no sooner had they done so than a large sheet of flame issued from the chimney, and without disturbing the ashes in the grate, or touching the grate itself, swept close past the office-keeper, who was standing nearest to the fire-place, and extinguished the gas. Upon the gas being relit, an extraordinary state of matters was revealed. The apartment was filled with smoke and dust, while the brick wall partition opposite the fire-place, and which would be 12 to 14 feet distant from it, was so greatly injured that had it not been for the shelving with which it was lined in front, and which held it together, it would have fallen right out. As it was it stood greatly off the perpendicular, and was cracked and wrenched from its holdfast along the ceiling, and at one part it was bulged out as if it had been forcibly struck by some soft heavy bulky article. There was no appearance of scorching, as is generally the case when any object of an inflammable nature is struck by lightning. The vent, which is swept at regular intervals, was swept shortly before, and was therefore comparatively clean. There is no iron bracketing at the top of the chimney. With the exception of the partition, no other article in the kitchen was injured, or apparently touched. The gas pipe runs across the roof or ceiling from the opposite wall towards the fire-place, and the pendant is about the centre of the apartment, rather nearer the fire-place than otherwise, but neither received any injury, although the gas was extinguished. The evening was wet and boisterous, the wind having been from the west or north-west, but a little before the occurrence the rain had passed off, and later on it became quite clear, although there was evidently a good deal of moisture in the air.

7. Remarkable Sunrises on December 6th, 8th, and 11th, 1884. Described by A. E. M'Intosh, Esq.; Lady Mary Baillie of Polkemmet; and Patrick Dudgeon, Esq.; in letters to Alexander Buchan, Esq.

THE GARDENS, LEWS CASTLE,
STORNOWAY, 11*th December* 1884.

MR BUCHAN—DEAR SIR,—On Saturday last, the 6th, at half-past 8 A.M., was observed here a very curious phenomena in the sky, due south and about 45° from the earth; it looked like oil or tar poured on water, and had all the colours of the rainbow, pink and blush being in the majority. It was observed here for about twenty-five minutes half an hour before daylight. I heard two peals of thunder, but saw no lightning, though we had lightning on Friday night. Saturday morning was fair, and I thought we were to have a fine day, but at noon it commenced raining, and continued until late at night. This morning (Thursday) I observed exactly the same phenomena and at the same time, and continued the same length of time. The morning was beautiful, but commenced at noon to rain, and is raining still (8 P.M.), but not heavy. Was this observed at Edinburgh? I must mention that it was seen to-day E.S.E., and I heard no thunder to-day. Please let me know how many months you have received of this year (the Reports I mean). —I am, dear Sir, yours truly,

A. E. M'Intosh.

Polkemmet,
Whitburn, 11*th December* 1884.

Dear Mr Buchan,—I wonder if any one has seen or noticed the wonderfully beautiful prismatic-coloured clouds which I have seen here on the mornings of the 8th and 11th. *This* morning was especially glorious about 8.30, rather a clear sky, with heavy brown clouds on the horizon, and some scudding along at a great pace. In the rifts behind these clouds, these white clouds appeared,—some like a mountain range tipped with colours,—one enormous oblong shape formed itself into a B, with pale blue in the middle; the principal one in the zenith was a flat heart shape, the edges brightly *defined* with the prismatic colours, and inside a gorgeous lake colour, *i.e.*, crimson. Sir William and I both saw it, and were amazed. You might like to take a note of this for future use.—I am, yours truly,

Mary Baillie.

Cargen,
Dumfries, 11*th December* 1884.

My Dear Sir,—I enclose a rough sketch of a beautiful and, I think, it must be a remarkable phenomenon which I observed this morning. I believe the same thing was seen on Monday morning about the same time, 9 to 9.30 a.m., but I did not observe it. The colours were remarkably fine, just like large sheets of fine mother-o'-pearl, as a lady observed when she saw them. The light spaces were almost clear of cloud apparently, and the sun was nearly behind the coloured spaces. I would like to know if you have observed the phenomenon in the country before. Weather very unsettled.—Believe me, yours truly,

Patrick Dudgeon.

Monday, 5th January 1885.

EDWARD SANG, Esq., LL.D., Vice-President, in the Chair.

The following Communications were read:—

1. Anatomy and Physiology of *Patella vulgata*. Part I.—Anatomy. By R. J. Harvey Gibson, M.A. Communicated by Professor Herdman, D.Sc.

(*Abstract.*)

This paper forms the first half of Part I. of a research into the minute anatomy, physiology, and development of *Patella vulgata*. The paper aims at giving a complete account of this form in both its physiological and morphological aspects. It treats, first of all, with the external features and rough anatomy. The epidermal system is then treated in detail. Some interesting modifications of the superficial epithelium are described. The epithelial cells are usually elongated columnar, with processes connecting them with a dense subepithelial layer of connective tissue. The attachment of the circular muscle is covered with modified epithelium, the epiblast cells not being absent in that region, as is said to occur in the case of the adductor muscles of *Anodon*. The modified epithelium at one spot near the base of the tentacle functions as an eye. The cells are there pigmented, and the cuticle is modified so as to form a double layer, with intervening trabeculæ. The retinal epithelium springs from a nerve plexus, which is supported by a mesh-work of connective tissue fibres, with large lacunæ.

The arrangement of fasciculi in this muscular system points unmistakably to the attachment of *Patella* to a rock, being the result of muscular contraction and formation of a vacuum beneath the foot.

The muscle fibres are non-striped, save in the heart.

The gills are morphologically processes of the ventral surface of the mantle, which is itself physiologically an accessory respiratory organ. The epithelium is in the mantle and gills columnar, and the cells are not close to each other, thus permitting of gaseous exchange between them.

Pactile papillæ, over one hundred in number, are found situated at intervals along the edge of the mantle skin. They lie in pockets, which open on the ventral side of the skirt. They are apparently modifications of those found in *Haliotis*, and may serve as organs of locality-sense.

The observations of Lankester, Bourne, and Cunningham on the renal system are confirmed, and in some respects extended. The history of the renal epithelium appears to be similar to that stated by Von Jhering, to be characteristic of the cells of the kidney of *Tethys.* The structure and behaviour towards reagents of the epithelium of the right and left kidneys is different, and it is suggested that the excretion of the two kidneys may be chemically distinct.

The structure of the heart (auricle and ventricle) and blood-vessels, and the lacunar system, is discussed. The blood-corpuscles are colourless, and amœboid. Coagula resemble plasmodia of *Monobia.*

The alimentary, nervous, and reproductive systems are reserved for a future paper—the second half of Part I.

2. A Theory of Solution. By W. W. J. Nicol, M.A., B.Sc.

(*Abstract.*)

This paper contained an account of the experimental evidence in support of the theory of solution enunciated in a paper * "On the Nature of Solution," communicated to the Society in January 1883.

Solution of a salt in a liquid is a consequence of the attraction of the molecules of the liquid, for a molecule of the salt (*adhesion*), exceeding the attraction of the molecules of salt for one another (*cohesion*). As the number of dissolved salt molecules increases, the attraction of the molecules of liquid for the molecules of salt becomes more and more balanced by the mutual attraction of the salt molecules. When these two forces are in equilibrium, saturation ensues.

Increase of solubility with rise of temperature is due to the *cohesion* of the salt being diminished by heat to a greater extent than

* *Phil. Mag.*, February 1883; see also *Proceedings R.S.E.*, 1880–82; *Berichte der deut. Chem. Ges.*, October 1883.

the *adhesion* of the liquid to the salt; and, conversely, diminished solubility with rise of temperature is due to the *cohesion* being less affected by rise of temperature than the *adhesion*.

Evidence in support of the above is obtained from experiments on the following physical properties of salt solutions:—

Contraction on dilution.*
Coefficients of expansion.†
Molecular volumes.‡
Boiling points.§
Saturation point.||

Further, the solution of two salts in water is governed by the same laws as that of a single salt (when no double decomposition is possible): the solubility of both salts being increased in most instances.¶ When double decomposition is possible, then the amount and nature of it is conditioned by the solubility of the possible salts and the strength of the solution.**

The molecular volume of a salt in solution is a quantity made up of two *constants*, one for the metal, and another for the acid-radical. It follows from this, that the replacement of one metal by another in combination with an acid-radical is always attended by the same change in the molecular volume of the solution, or generally,

$$(M - M')R = C'$$
$$M(R - R') = C'.$$

where M and M′ are two different metals and R and R″ two acid-radicals.††

The presence or absence of *water of crystallisation* has no effect on the above law: it therefore follows that it has the same volume in solution as the solvent water. *Water of constitution*, however, shows itself in solution by possessing a volume markedly different from water of solution.‡‡

Finally, when the molecular volumes of a series of solutions of

* *Phil. Mag.*, February 1883; *Chem. Soc. Journal*, March 1883.

† *Phil. Mag.*, February 1883.

‡ *Ibid.*

§ *Ibid.*

|| *Ibid.*

¶ *Phil. Mag.*, June 1884.

** *Ibid.*

†† *Berichte de deut. Chem. Ges.*, 1884.

‡‡ *Loc. cit.*, also *Phil. Mag.*, September 1884.

different strengths of the same salt are expressed by the empirical formula,

$$MV = 1800. + n\alpha + n^2\beta - n^3\gamma.$$

Where α, β, γ are three constants and n the number of salt molecules per 100 H_2O, it is found that $\frac{\beta}{\gamma}$ is equal to twice the solubility,—saturation is therefore reached when the further addition of a molecule of salt would produce a *diminution* of the mean molecular volume of the molecules already present. The last molecule added enters into solution with a volume sensibly equal to the above mean volume as is shown by the following equation,

$$(n\alpha + n^2\beta - n^3\gamma) - \left((n-1)\alpha + (n-1)^2\beta - (n-1)^3\gamma\right) = \alpha + n\beta - n^2\gamma.$$

when
$$n = \frac{\beta + \gamma}{2\gamma}.$$

3. On the Salinity of the Water in the Firth of Forth. By Hugh Robert Mill, B.Sc., F.C.S., Scottish Marine Station, Granton, Edinburgh. (Plates III., IV., V.)

Contents and Summary.

I. 1.—Method of collecting Water Samples from the surface and from various depths, with a description of the manner of making the neccessary observations, *e.g.*, *temperature*, *colour and transparency of water*, *and note-taking*. Illustration of Buchanan's slip water-bottle, pp. 30–34.

2.—Determination of the Density.—Description of the *hydrometer* and the manner of using it, and of *calculating* the results. Detail of experiments to determine the *error of the method;* each determination of density being in duplicate supplied data for this purpose. *Probable uncertainty* of density shown to be +0·00005, and that the method is capable of improvement, pp. 35–41.

3.—Determination of Alkalinity.—Method employed, Dittmar's modification of Tornøe's. *Accuracy* attained shows a deviation of 1·8 per cent. of carbonic acid found (total carbonic acid found being about 0·005 grammes per 1000·000), pp. 41–44.

II. 1.—Notes of previous Work in Estuary Analysis.—*Murray* in 1816, and *Davy* in 1843–44 on the Firth of Forth; *Macadam* in 1855 on the Clyde and in the Beauly and Cromarty Firths in 1866; *Kyle* on the *Plate* in 1874; and the *German and Danish Commission* for the Investigation of the German Seas, on the Baltic, Skager Rack, and Cattegat, 1877–1881, pp. 44–46.

2.—The Geography of the Firth of Forth, illustrated by a chart, pp. 46, 47. (Plate III.)

3.—Observations on the Surface Salinity of the Firth.—Particulars of four *water-sampling trips* between Alloa and the Isle of May, illustrated by five curves (A to E). Effects of the flooded state of the rivers in November. *General result,* the salinity increases very rapidly from Alloa to Queensferry, less rapidly to Inchkeith, and very gradually to the Isle of May, where it decreases slightly. The effect of Tide, pp. 48–54.

4.—Surface Water Density at the Marine Station.—Density varied slightly during July, August, September, and October, considerably in November, and greatly in December. Details given, and effects traced to the different course of the Almond at high and low water, pp. 54–59.

5.—The Bottom Water of the Firth.—Comparison of bottom and surface water at six places on the Firth. Result that the difference is greatest (tides considered) at Grangemouth, and decreases steadily to the Isle of May. Particular case of difference between surface and bottom densities at Inchgarvie, pp. 59–61.

6.—The Alkalinity of the Firth.—Particulars given of 98 observations. General conclusion, that the alkalinity is roughly proportional to the density, but subject to considerable variations in the ratio. Alkalinity of bottom water, pp. 61–64.

It is the purpose of this paper to state, with some detail, the methods employed for examining the salinity and alkalinity of estuary water at the Scottish Marine Station at Granton; to give the probable uncertainty of these methods; and to describe and record six months' observations of the water of the river and Firth of Forth, up to December 31, 1884.

I. Methods.

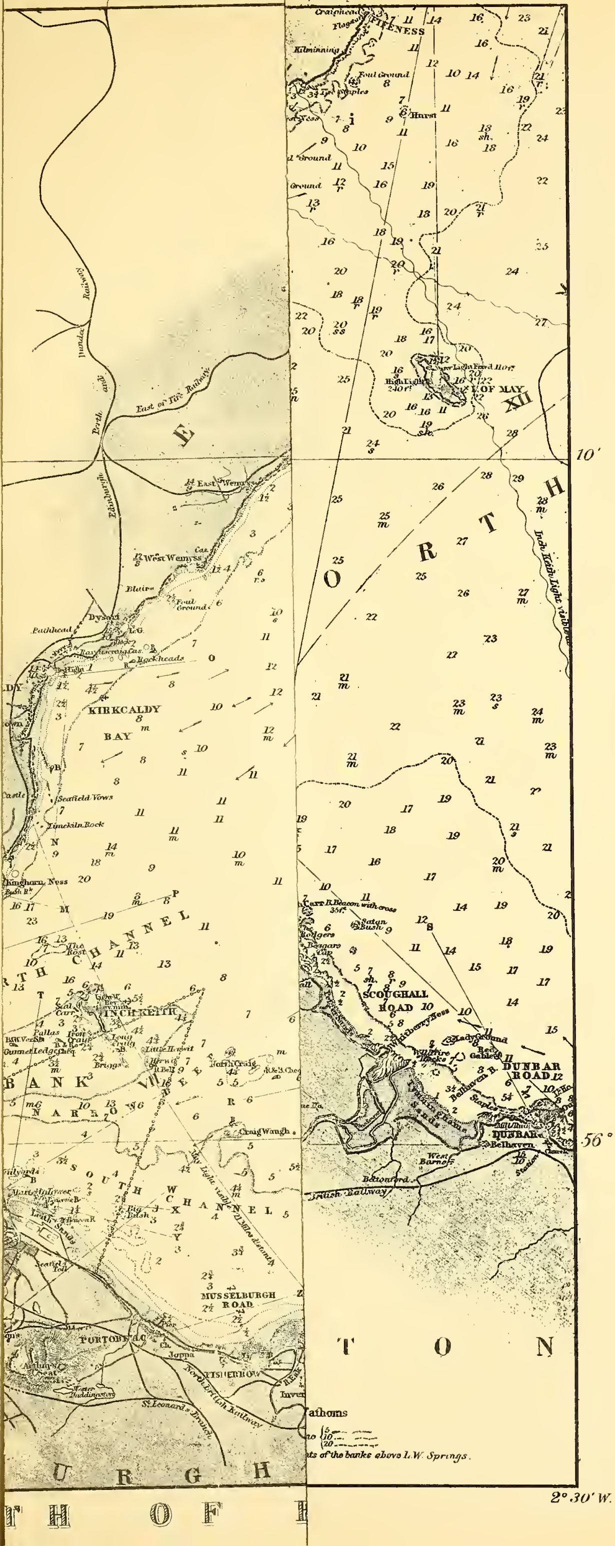
II. Results of Preliminary Work.

I. Methods.

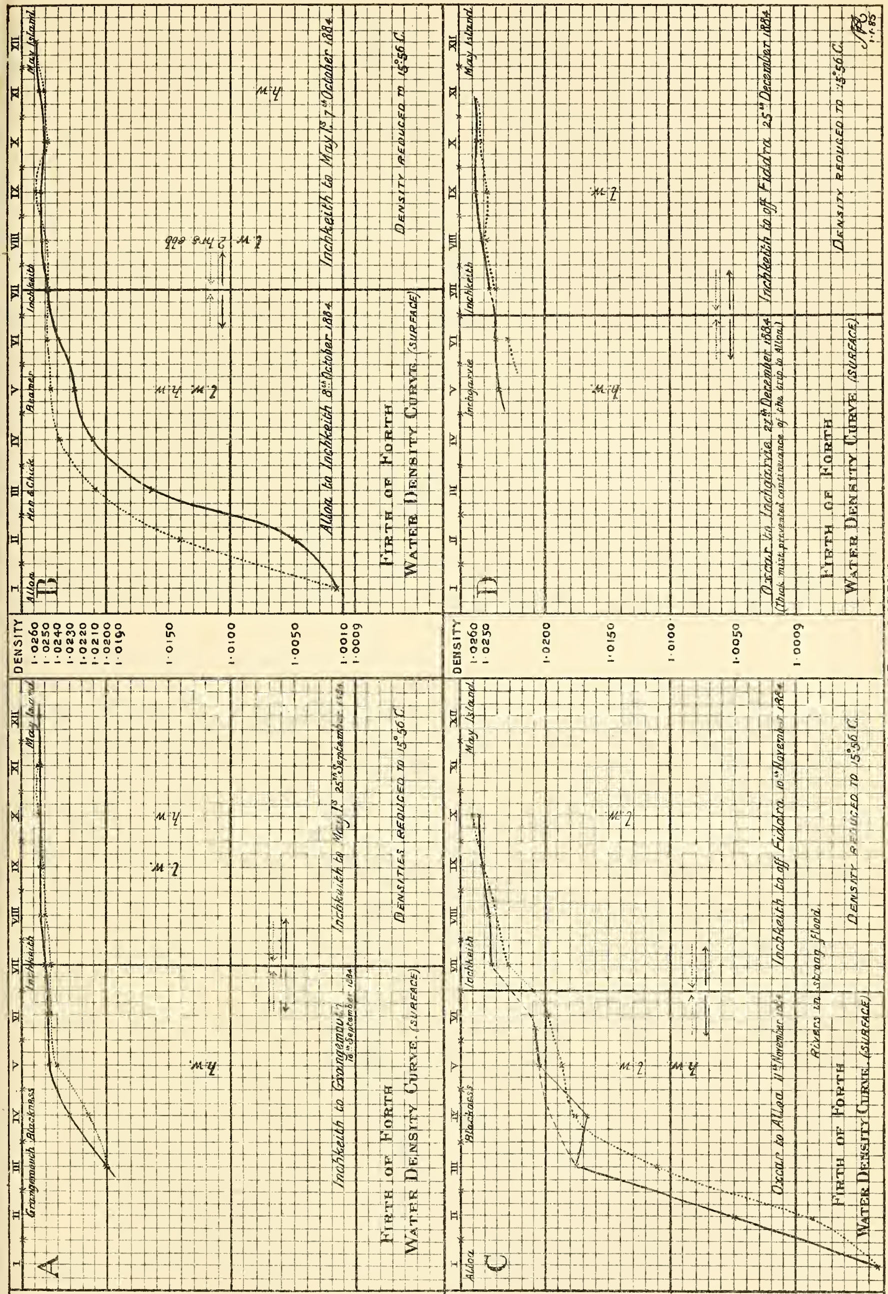
1. *Collection of Water Samples.*

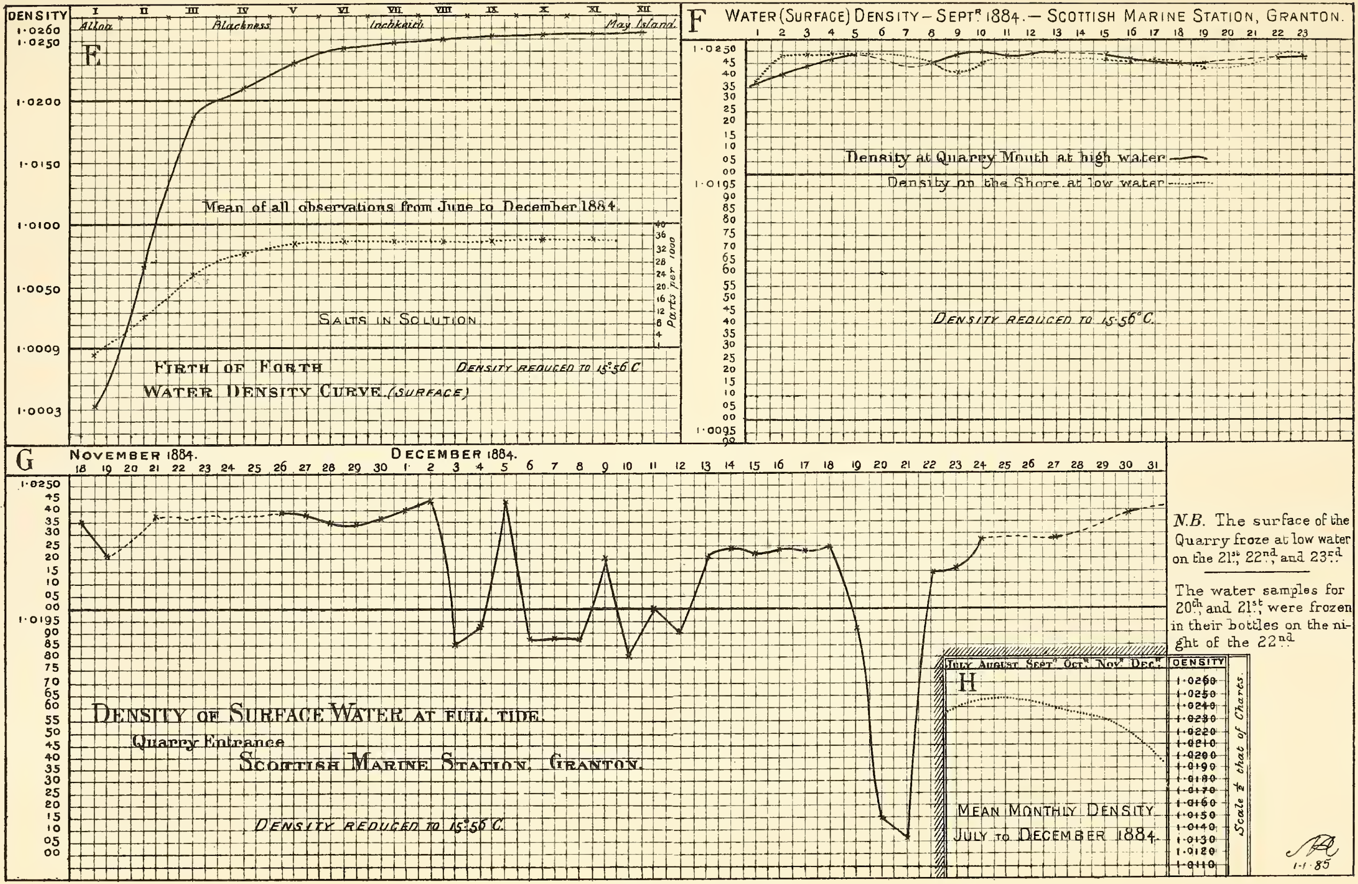
To collect a sample of surface water from a small boat it is sufficient to wash out the bottle with the water, and then hold it a few inches under the surface until it fills. The temperature of the water is taken by means of an ordinary thermometer in a copper case.

On board a larger vessel the same thing may be done, the bottle being attached to a sounding line and lowered over the side; but in the work carried on on the Firth of Forth it is desirable not to


FIFENESS
Craighead
Kilminning
Foul Ground
Hurst
East of Fife Railway
Perth and Dundee Railway
Edinburgh
East Wemyss
West Wemyss
Dysart
Pathhead
Rockheads
KIRKCALDY
BAY
Seafield Vows
Kinghorn Ness
Lynekiln Rock
ISLE OF MAY
High Light
10′
F O R T H
Inch Keith Light visible
CHANNEL
INCHKEITH
BANK
NARROW DEEP
SOUTH CHANNEL
Craig Waugh
MUSSELBURGH ROAD
PORTOBELLO
Joppa
FISHERROW
North British Railway
St. Leonards Branch
Arthur's Seat
Wester Duddingston
SCOUGHALL ROAD
Carr R. Beacon with cross
Satan Bush
DUNBAR ROAD
DUNBAR
Belhaven
West Barns
Beltonford
British Railway
Lady Ground
Whitberry Ness
56°
T O N
U R G H
T H O F
fathoms
of the banks above L.W. Springs.
2° 30′ W.

THE FIRTH OF FORTH.


A
Inchkeith to Grangemouth 18th September 1884
Inchkeith to May Is. 25th September 1884
Densities reduced to 15°.56 C.
Firth of Forth
Water Density Curve. (Surface)
B
Alloa to Inchkeith 8th October 1884
Inchkeith to May Is. 7th October 1884
Density reduced to 15°.56 C.
Firth of Forth
Water Density Curve. (Surface)
C
Oxcar to Alloa 11th November 1884
Inchkeith to off Fiddra 10th November 1884
Rivers in strong flood
Density reduced to 15°.56 C.
Firth of Forth
Water Density Curve. (Surface)
D
Oxcar to Inchgarvie 27th December 1884
(Thick mist prevented continuance of the trip to Alloa)
Inchkeith to off Fiddra 25th December 1884
Density reduced to 15°.56 C.
Firth of Forth
Water Density Curve (Surface)
McFarlane & Erskine, Lith^rs, Edin^r



M'Farlane & Erskine, Lith.rs Edin.r

stop the vessel more frequently than necessary, and surface samples are usually collected by means of a clean bucket, care being taken to draw it forward of the ejection pipe of the condenser. When brought on board a thermometer is immersed for a minute and the temperature noted. The water is then bottled, tied down, and labelled.

To get water from any desired depth below the surface the oldest method is to use a valved-box arrangement. This method was devised by Hooke more than two centuries ago, and until recently it was the only one employed. When descending, both the upper and lower valves (which open upwards) are kept open, and the water traverses the arrangement. On pulling up, the valves close, and, kept down by the pressure of the water above, they preserve the enclosed sample unmixed. A very ingenious apparatus of this nature, the cistern thermometer of Sir Robert Christison, was presented to the Station; but although convenient in many ways, it has the defect of uncertainty in action, and the result of a long series of trials decided me to employ other methods.

It was tried to collect deep samples by sinking a stoppered bottle to the required depth, and then pulling out the stopper by a special line. The two lines were frequently entangled, owing to currents making the bottle rotate; but although this could have been remedied, in part at least, by fixing the bottle in a frame provided with a vane-shaped attachment, other considerations led to the abandonment of the method. When the stopper fitted closely, the pressure of the superincumbent water prevented its withdrawal by any force less than sufficient to haul the bottle up again in spite of a heavy lead attached to it; and when the stopper did not fit closely, water from intermediate depths found its way in.

The depths in the Firth of Forth are too small (only in one place coming up to 40 fathoms) to permit stopcock water-bottles to be used, and the slip water-bottle was consequently adopted for general employment.

The instrument hitherto used was constructed as an experimental form for Mr Buchanan, and it is about to be superseded by an improved apparatus on the same principle.

Buchanan's slip water-bottle consists of a brass body A (fig. 1), in which a brass disc a' supports three radiating sheets of brass c that are surmounted by a brass dome d, on the top of which there is a ring for the line. The plate a' has an india-rubber ring a fixed upon it, and its under surface has two rings for attaching the

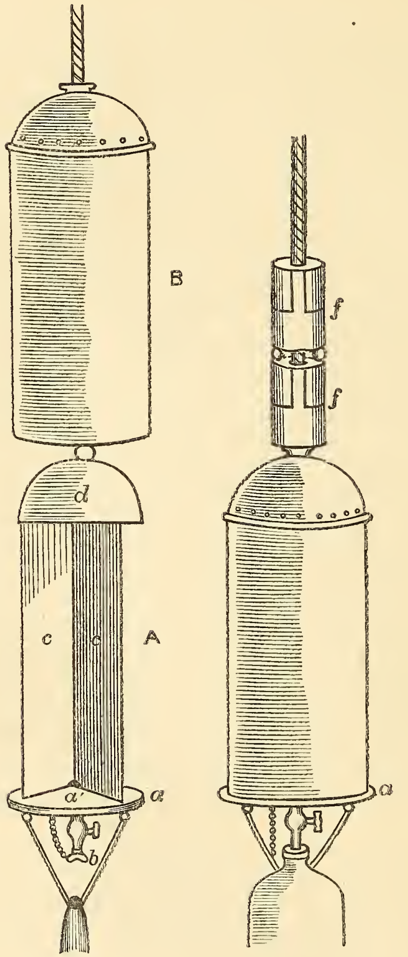


Fig. 1. Fig. 2.

lead, and a stopcock b for running off the water. There is also a brass cylinder B, the edge of which rests upon the india-rubber ring a when the instrument is closed (fig. 2).

On board the "Medusa," the steam-yacht of the Marine Station, the water-bottle is attached to the sounding line, which is wound on a drum worked by a small deck engine. The line passes from the drum through leading blocks to the derrick, which is fixed so as to project over the port bow, and when a sample of water is to be obtained from the bottom or an intermediate depth, the water-bottle has a 7-lb. lead attached to it, the stopcock is closed, and a little plug screwed in to prevent the entrance of mud should it strike the bottom. It is then lowered, the slip cylinder B being held in the hand. When the desired depth is reached the slip is let go, it crashes down on the frame, and is guided by the brass strips *c*, *c* on to the india-rubber ring, enclosing a sample of water.

A number of trials showed that when the slip came down it did not press sufficiently strongly on the india-rubber. To remedy this a heavy leaden ring was fixed to the slip, but the result was that the edge struck the dome *d* so heavily that it was indented, and so left a little channel between the rim and the india-rubber. Subsequently it has been the habit, after the slip has struck the body, to let down one or two of Captain Rung's brass weights (*f*, *f*, fig. 2). These rest on the top of the slip cylinder, and press it firmly down. Repeated trial and continuous use for several months have shown this manner of water-collecting to be satisfactory.

When the water-bottle is hove up, the mud-plug is withdrawn, about a quarter of a litre of the water is run out into a bottle which is rinsed out with it, and then filled to overflowing, the stopper inserted, and tied down.

The bottles used are glass-stoppered, blue glass, half-Winchesters, which hold about 1·5 litre. They are packed in boxes, fifteen in each, so as to be carried easily and safely. Each bottle is labelled as it is put aside, with particulars of the date, hour, and temperature.

The temperature below the surface is ascertained by means of the Negretti and Zambra thermometer in the Scottish frame, which was described to this Society in July 1884 (*Proc. Roy. Soc. Edin.*, xii. 928). The frame has been improved by using a small vice arrangement to clamp the line at the upper end, while a cork-screw-shaped attachment at the foot keeps the line alongside the frame.

This means of putting on the thermometer is a great saving of time and trouble. The thermometer has been found to answer admirably.

When each sample is taken the following observations are made and recorded :—

Date.
Hour of collection.
Position by bearings.
Depth of water.*
Depth from which sample was taken.
Temperature of the water at that depth.
Temperature of the air.
Nature of the weather, wind, and state of the sea.
State of tide.
Colour and transparency of the water.*

The colour of the water is observed by sinking a disc of iron, painted white, to the depth of a few feet or fathoms, according to circumstances, and noting its colour. The transparency may be roughly measured by observing the distance to which the disc remains visible.

It is important that the actual notes of all observations be preserved for future reference should uncertainty arise regarding them. There are difficulties in doing this, for it is not easy on a small vessel when there is any sea on to keep an ordinary note-book from getting wet, especially when it is raining; and turning wet pages in a breeze is not easy. I have employed a leather case to hold a note-book, using one page for each set of observations, and keeping it shut when not in use. The principal objection to this is the unwieldy size of the case, and I now propose to use cards, with memoranda of the observations to be made printed on them, and kept in a similar though much smaller case. As each card is used it may be slipped beneath the others, as is done in a date-case. The cards can be very easily kept in boxes, and may be readily and rapidly referred to at any time.

* These are sometimes omitted in the case of surface samples.

2. *Determination of the Density.*

The density of the samples of water collected in the firth is determined by means of a very delicate hydrometer of the form used on board the "Challenger."

The hydrometer is made of glass, the tubes for body and stem having been very carefully selected to ensure uniformity of diameter. The instrument has a body of about 5 centimetres diameter, and 12 centimetres long; the stem is nearly the same length, and has a diameter of 3 millimetres. The process of making and calibrating the hydrometer has been described in great detail by Mr Buchanan, in his "Challenger Report on the Specific Gravity of Ocean Water" (*Chall. Rep. Phys. Chem.*, vol. i. pt. ii. pp. 1–4).

The hydrometer which has been used at the Marine Station is provided with seven movable weights, which can be attached to the top of the instrument, and thus adapt it for observing densities of various amount. The first four weights slip over the top of the stem, and rest there, the others are ring-shaped, and are used to supplement the weight of the former. The hydrometer weighs *in vacuo* 150·1478 grammes. The weights have the following values:—

1. 4·0285	2. 3·2247	3. 2·4099	4. 0·8195
5. 0·8125	6. 0·5184	7. 0·3312	

As each of the first four weights can be used with any or all of the remaining three, and as, with a little trouble, any of the last three can be balanced on the top of the stem by itself, the total weight of the hydrometer may be varied from 150·1478 to 155·8384 through 36 gradations.

The volume of the body and bulb of the instrument is 150·2070 cubic centimetres at 0° C. At 25° C. it is 150·3210, the volume of the 100 millimetres into which the stem is divided is 0·85 c.c.; and as it is assumed to be uniform, the volume of each millimetre of the stem is taken as 0·0085.

Most of the density observations were made on the "Ark," the floating laboratory of the Station. As she is perfectly steady, except when there is a conjunction of full tide and high wind, it was not necessary to use a swinging table. The process of making an observation of the density is as follows:—

A tall glass jar, capable of holding a litre, is rinsed out with the water the density of which is to be determined and which has the temperature of the laboratory, and then filled up to the 800 c.c. mark. A thermometer, the error of which is exactly known, is hung in the water, read after being immersed for 1 minute, removed and the hydrometer put in, sunk up to the top of the scale, 1 centimetre from the top of the stem, and allowed to rise. A weight, sufficient to sink the instrument until not more than one-third of the stem is submerged, is then put on, and after it has come to rest, the scale is read to half a millimetre. Another weight is added, so that not less than two-thirds of the stem are immersed; after coming to rest the readings are taken, the weights removed, the hydrometer dried and replaced in its box, and the thermometer again hung in the liquid for a minute. The temperature being noted, the thermometer is withdrawn, and the water poured back into the bottle. The whole operation occupies about ten minutes, and gives data for two distinct values of the density. The hydrometer is not read closer than to half a division, although with care it might be taken to one-third.

A table giving the volume of the hydrometer at every tenth of a degree centigrade, from 0° to 25°, has been drawn up, and from this table the volume of the body at the observed temperature is taken; the volume of the stem immersed is got from a table which gives the value for each half-millimetre from 0 to 100. These added together give the immersed volume, and the weight being taken from another table and divided by this volume gives the density *at the observed temperature.* The mean of the two densities is taken, and reduced from the mean of the two corrected observed temperatures to 15°·56 C. by means of Dittmar's table (*Chall. Rep. Phys. Chem.*, vol. i. pt. i. p. 70).

The Specific Gravity Observation Book contains a copy of the observations (see p. 34) on the upper half of each page, and below it the following particulars:—

Date and hour of determination.

Temperature of Water (t'_1) and its correction.

1*st Weight on hydrometer.*

Hydrometer Reading.

2*nd Weight on hydrometer.*

Hydrometer Reading.
Temperature of Water (t'_2) and its correction.
Density at t'_1 (1).
Density at t'_2 (2).
Mean density (of 1 and 2) at t′ (mean of t'_1 and t'_2).
DENSITY at 15°·56 (specific gravity, water at 4° being unity).
Calculated value of CHLORINE (χ)
Permilleage of CHLORINE found (χ').
Alkalinity.

The numbers of the first six entries are put down in the book as read off the instruments, the others are copied from the calculation book.

In order to get some idea of the accuracy of the method—that is of the exactness of the readings, the correctness of the tables, and the accuracy of the calculations—the following determinations of the density of distilled water were made. The temperature was varied by the addition of hot distilled water.

I. Temperature varied from 4°·5 to 4°·6.

Weight 4.	Weight 6.	Weight 7.	Mean.
1·000022	1·000017	1·000014	1·0000175
		Calculated,	0·999997
		Difference,	0·000020

II. Temperature varied from 4°·6 to 4°·9.

Weight 4.	Weight 7.	Mean.
1·000019	1·000010	1·0000145
	Calculated,	0·999995
	Difference,	0·000019

III. Temperature varied from 14°·9 to 14°·2.

No Weight.	Weight 4.	Weight 7.	Mean.
0·999154	0·999331	0·999313	0·999299
		Calculated,	0·999253
		Difference,	0·000046

IV. Temperature varied from 11°·9 to 11°·4.

Weight 4.	Weight 7.	Mean.
0·999725	0·999731	0·999728
	Calculated,	0·999538
	Difference,	0·000190

Mean of four determinations,	0·9997648
Mean of calculated densities,	0·9996982
Difference,	0·0000666

Omitting the exceptionally high discrepancy of IV. the difference as a mean of three results is 0·000028, and even including it, it does not touch the fourth place.

To form an idea of the reliance to be placed on the hydrometer readings, all those cases (164 in number) in which the weights 1 and 1 + 7 were used in consecutive determinations of one water, were investigated and classified. Temperature does not appear to affect the differences.

Let r be the reading with weight 1, and r' with weights 1 and 7 in the same water, then, as these weights can only be used for water of nearly the same density, in a perfect hydrometer perfectly read r–r' should be a constant, and in an actual instrument read with ordinary care the mean of a sufficient number of observations should approximate very closely to the constant. In 164 cases $r - r'$ had the following values:—

Values,	38	37·5	37	36·5	36	35·5
Times,	2	16	48	49	40	9

The mean of all the values is 36·5. Hence out of 164 cases—

49, or 29·9 per cent.,	differed from	the mean	by	0
88, or 53·6	,,	,,	,,	0·5
25, or 15·3	,,	,,	,,	1·0
2, or 1·2	,,	,,	,,	1·5

Here the maximum variation from the mean is 1·5, while nearly 84 per cent. of the observations showed a deviation no greater than 0·5.

0·5 of a division of the hydrometer corresponds to a difference in density of 0·00003 in the case of a sample of sea water of ordinary density, while 1·5 division is equivalent to a difference of 0·00009, the temperature being the same.

The four triple determinations of distilled water give the total error as 0·000066 as a mean of the whole, and in all cases the variations were in the same direction.

As stated in describing the method, each determination of density was made in duplicate, and the results independently worked out. The two densities obtained in this way invariably differed, that obtained when the greater part of the stem was immersed being always the greater. The differences between the two readings in 204 cases have been classified and examined.

The following table (I.) exhibits the results, which are not apparently affected by temperature, deviations of each magnitude appearing in densities determined at all temperatures from 4° to 20°. The differences are given in units of the 5th place.

TABLE I.—*Discrepancies in Double Determinations.*

Discrepancy, $\delta-\delta'$.	$\angle 3$	3	4	5	6	7	8	9	10	11	12	>12
Number of cases in 204, . . .	1·3	16	4	19	32	7	25	19	4	16	19	29
Percentage, . .	6·3	7·8	1·9	9·0	15·6	3·4	12·2	9·0	1·9	7·8	9·0	14·2
Percentage of cases where one reading was greater than 80, . .	23	37·5	75	42	25	43	76	58	50	68·7	73·7	73

The mean of all these discordances is 8·4, but omitting the 14·2 per cent. over 12, as being probably due to careless readings, the mean becomes 6·9. In order to take the least favourable view of the case, the higher number will be considered, and as the mean of the two observations was always taken for the correct density, this discordance is reduced to 4·2 as deviation from the mean.

It is not allowable to change this 4·2 as *error*, since it is always positive, and since the amount of it is roughly proportional to the difference between the length of stem immersed by the addition of the second weight, and more nearly proportional to the number of the reading. The last horizontal line of the preceding table shows that (omitting $\delta - \delta' = 4$, and $= 10$ on account of the small number of cases) the percentage of readings over 80 increases, roughly speaking, as the discrepancy increases.

The reason of the difference may be that the stem of the hydrometer is slightly conical, instead of being truly cylindrical, as assumed. It might also be that the weight of the brass pieces was not correctly known, but a careful reweighing showed that this was not so. Capillarity should act equally in each case, and need not be considered. The only remaining explanation which suggests itself is the difference in weight produced by the film of water adhering to the part of the stem above the surface. To test this the density of three samples of water was determined twice with the hydrometer stem dry, and twice immediately after the the stem had been immersed. The results are shown in Table II.

Temperature unaltered, about 7°.

TABLE II.

Weights.	Water Sample No. 263, Hydrometer stem.			No. 267, Hydrometer stem.			No. 268, Hydrometer stem.		
	Dry.	Wet.	Dif.	Dry.	Wet.	Dif.	Dry.	Wet.	Dif.
1	86·5	84·0	2·5	95·5	94·0	1·5	99·0	96·5	2·5
1+7	49·0	48·0	1·0	...	...	...	62·0	60·5	1·5
1+6	...	...	...	37·5	37·0	0·5	...	...	...

Here the adhering film of water produced a sinking of the hydrometer of from 0·5 to 2·5 millimetres, according to the length of exposed stem. This is an error which is practically negligible when the reading is less than 30, but rises to a serious amount when it is greater than 80.

Taking 2·0 mm. as the amount of sinking produced by the film of water when the stem reading is over 80, and since the sinking produced by weight No. 7 (0·3312 grammes) is on an average 36·5 (see page 38) the weight of the water is $\frac{0·3312 \times 2}{36·5}$ *i.e.*, = 0·01814. In water sample No. 250(1) the reading was 80 and the calculated density 1·02734. Supposing the scale to have been wet, and adding 0·01814 grms. to the weight of the hydrometer, the density comes out as 1·02746, an increase of 0·00012.

Here there is a sufficient explanation of the discrepancy increasing with the value of the reading; and since in each case the mean of the determination when the stem was almost all out of the water, and that when the stem was almost entirely immersed, and when consequently the error from the attached film was reduced to almost nothing, the uncertainty of a determination (from this cause) is reduced by a half, and comes to be 0·00006, exactly 0·00002 more than that brought out by the discussion of the 204 discrepancies without consideration of their cause. The reason of this, assuming the above explanation to be correct, and considering that 0·00006 is the value of an extreme case, reading over 80 and weight 7, is obvious; as generally the reading is under 80, and when over it weight 6 is usually employed as an addition which immerses more of the stem. Had the scale been always used when dry greater accuracy could be expected; but, on the other hand, it must not be supposed that the weight of the film of water was always equal to 0·01814 grm., for often the reading was not taken until the greater part of the water carried up had run down again.

The occurrence of the maximum deviation from the correct reading (1·5 mm.) in the same direction as the increase due to the water film in an extreme case would certainly affect the fourth place to the extent of 1, but the probability of such an event happening is very small, and the sum and difference of the effects of the error of reading and the mean error due to the water film are respectively 0·00007 and 0·00001.

The result of the discussion is that the discrepancies between the two observed densities of one sample of water are accounted for, perhaps not fully, but satisfactorily, in so much that it is beyond question that the hydrometer gives results which for the purposes of comparison are rigorously correct to the fourth decimal place. It also shows that by taking further precautions greater accuracy may be reasonably looked for.

3. *Determination of Alkalinity.*

Sea water has an alkaline reaction which is supposed to be due to the presence in solution of carbonates, and especially of carbonate of lime. The measurement of the alkalinity is then a measurement of the amount of dissolved carbonate.

It is determined by Tornøe's method, boiling with dilute hydrochloric acid and titrating the excess with potash, using aurine as an indicator.

Practically 250 c.c. of the water are measured in a flask, poured into a porcelain basin, a few drops of neutral aurine solution added, 15 c.c. of standard hydrochloric acid run in from a burette, and the whole heated over a large spirit-lamp for from twenty to twenty-five minutes. It usually boils for from ten to fifteen minutes. The excess of free acid is then determined by means of potash, the red colour of alkaline aurine being dispelled by a few drops of acid, and restored by potash until the end point is closely defined. Each burette reading is taken down on a card, and the result copied into the Laboratory Book. The cards are preserved for future reference if necessary.

The standard acid and alkali were at first made up to be of the strength of $\frac{1}{22}$ normal, *i.e.*, $\frac{1}{22} \times 36{\cdot}5$ grms. of hydrochloric acid, and $\frac{1}{22} \times 56$ grms. of potassium hydrate per litre, so that 1 c.c. might correspond to 1 milligram of carbonic acid.

It was, however, found to be more economical of time to make up an acid roughly approximating to the desired strength, and to determine its chlorine very carefully by titration with silver nitrate. The potash was made equivalent to the acid.

Two solutions of hydrochloric acid have been used for the work described here. The first was found by the mean of five concordant experiments to have 1 c.c. equivalent to 1·007 c.c. of the potash used. More than 5 c.c. of potash is never used, except in very exceptional cases, and as the burette is not read closer than 0·05 c.c. the difference between 5·00 and 5·03 is considered negligible. The mean of the experiments with the second acid solution gave 1 c.c. of acid as equivalent to 0·990 c.c. of alkali, and this also is taken as equality. The error of considering the two acids as equal is only introduced in the titration of the excess, the quantities of acid used being reduced separately according to the amount of chlorine found in them by analysis.

Trustworthiness of the Method.—A large number of experiments were made on the same samples of water, both for the sake of practice and in order to arrive at the probable uncertainty of each experiment.

The following tables (III. and IV.) give particulars of these determinations, and of the corresponding deviations from the mean.

If the five cases out of the thirty-five in which the deviation exceeds 0·5 be omitted, as probably due to mistakes or misreadings, the mean deviation is reduced to 0·24.

It is probable that 0·2 may be nearer the truth, as it was never the practice to filter the water before determining the alkalinity, and after the bottle had stood in the laboratory for a day or two, the 250 c.c. decanted off was tolerably free from suspended particles; while, when four or five determinations were made on water contained in a bottle, each quarter litre would contain more sediment than the one before, and a minute shell makes a distinct increase in the alkalinity. Looking at the eight cases epitomised

TABLE III.—*Alkalinity Determinations.*

No.	Sample.	I.	II.	III.	IV.	V.	Mean.
a	68	11·75	12·0	12·1	...	...	11·95
b	69	11·5	11·1	10·25	11·5	...	11·09
c	70	14·05	13·9	14·65	...	...	14·21
d	71	11·9	12·15	11·75	...	...	11·93
e	72	11·0	11·55	11·9	...	...	11·48
f	73	11·65	11·55	...	...	...	11·61
g	74	12·1	11·75	...	...	...	11·92
h	92	12·8	12·4	11·7	12·4	...	12·31
i	93	12·2	11·8	...	...	...	12·01
j	261	9·2	10·65	9·9	10·65	9·8	10·04
k	262	10·05	10·1	9·85	11·0	...	10·25

TABLE IV.—*Deviations from Means.*

	a.	*b.*	*c.*	*d.*	*e.*	*f.*	*g.*	*h.*	*i.*	*j.*	*k.*
I.	·2	·4	·15	·04	·48	·05	·18	·5	·2	·84	·2
II.	·05	·0	·3	·22	·07	·05	·18	·1	·2	·61	·15
III.	·15	·8	·45	·18	·41	...	...	·5	...	·14	·4
IV.	...	·4	...	...	...	...	...	·1	...	·61	·75
V.	...	...	...	...	...	...	...	...	...	·15	...

Mean deviation 0·29.

in the preceding table (III.), where three or more determinations were made on one water, it is evident that in four (*a*, *c*, *e*, and *k*), the later determinations show an increased alkalinity.

The quantity represented by an alkalinity is very small, although the number used to express it is large. An alkalinity of 50, means that in a litre, say 1026 grammes, there is 0·05 gramme of carbonic acid as calcium carbonate; that is, a percentage of 0·00487; which, taking the worst view of the inaccuracy of the determinations, might vary from 0·00498 to 0·00476.

In the discussion of the alkalinity of the Firth of Forth in this paper, the integral figures may be viewed as correct, the decimal part being uncertain.

It would impart a greatly increased certainty to the figures if the water had always been filtered before the alkalinity was determined, and if duplicate analyses were invariably made and the rigorous zigzag system of titration adopted. This will be done in future.

A great many determinations of the chlorine, or rather total halogen, present in the samples of sea water were made, but, from various causes, the probable error of each experiment was so large as to render the results useless for the purpose of detecting the difference between the ratio of salinity to density in estuary water and in ocean water. For this reason the figures are not published.

The density of the water may be taken as an index of its salinity, although there are no data available for interpreting each density into its corresponding percentage of total salts. This can only be done in the case of ocean water proper, for which tables have been constructed by several chemists.*

II. Results of Preliminary Work.

1. *Notes of Previous Work.*

In 1816 Dr John Murray read a paper to this Society "On the Composition of Sea Water," the samples which he analysed being taken from the Firth of Forth near Leith. The paper (*Trans. Roy. Soc. Edin.* for 1816) contains results of great theoretical value, which were instrumental in modifying the theory of the existence of salts of different bases and acids in solution, and which altogether changed the mode of analysis of sea and mineral waters. Attention was given more particularly to the solid constituents, and no observations seem to have been made by Dr Murray on the variations in salinity at different parts of the firth.

Dr John Davy published a paper† in 1843, "On the Temperature and Specific Gravity of the Water of the Firth of Forth." He examined the temperature and density of the water at the end of Leith Pier on eight occasions, at intervals of about a month. His entire observations are reproduced in table (V.).

It was Davy's intention to continue the monthly observations for a number of years, but he had to leave Edinburgh, and they were stopped. Since no particulars as to how the densities were

* See Dittmar, *Phys. Chem. Chall. Rep.*, I. pt. i. 1884.

† *Ed. New Phil. Journ.*, xxxvi. p. 1.

determined were given, it is impossible to compare them with others at a later date.

TABLE V.—*Davy's Specific Gravity Observations.*

1842.	Temperature.		Density.	Tide.	Wind.
	Air.	Sea.			
Sept. 30, 3 0 P.M.	55°	54°	1·0258	Low water.	N.E.
Oct. 29, 2 0 ,,	43	45	251	½ ebb.	N.
Nov. 30, 3 0 ,,	45	42	256	,,	W.
1843.					
Jan. 5, 3 0 ,,	39	42	248	⅔ flood.	N.
Feb. 5, 3 30 ,,	35	38	197	½ flood.	N.
Feb. 19, 3 30 ,,	39	38	242	,,	S.E.
March 4, 2 0 ,,	39	38	205	,,	N.W.
April 22, 2 0 ,,	55	44	248	,,	W.

Dr Stevenson Macadam investigated the salinity of the Firth of Clyde in 1855.* He observed the specific gravity at more than fifty places, and determined the total solids and chlorine in each. He found that between Bowling and Renfrew there was a change produced by the tide between high and low water equal to that discerned in a distance of five miles along the firth at low water.

In subsequent investigations he examined the Firths of Cromarty and Inverness. The results are recorded in the *Proceedings* of this Society for 1866.†

Professor Kyle of Buenos Ayres made some observations in 1874 on the River Plate, in the same way as Dr Macadam on the Clyde. I am indebted to Mr F. Newman for a translation of Kyle's Spanish pamphlet (*Algunos datos sobre la composicion de las aguas del Rio de la Plata*), and for a chart of the Plate, with the water sampling stations.

The results brought out by Professor Kyle are interesting, but like the other observers cited above, he neglects to mention whether

* *Brit. Assoc. Reports*, 1855, ii. 64.
† *Proc. Roy. Soc. Edin.*, V. (1866), p. 370.

his specific gravities are reduced to 0°, to 4°, or to 15°·56, or whether water at 0°, 4°, or 15°·56 was taken as unity. It is therefore impossible to consider the results except as purely relative to the estuary in question, and no comparison between the different investigators can be made.

The Cattegat, Skager Rack, Baltic, and north-eastern parts of the North Sea, have been made the subject of very careful and prolonged examination by various Danish and German scientific workers. Water samples have been taken regularly for a number of years at various points along the coasts, and from lighthouses and lightships at considerable distances from land. The results of the examination of these samples, from 1872 to 1881, is tabulated in conjunction with the meteorological conditions, especially with respect to rainfall, in a recently issued paper by the Commission in Kiel for the Scientific Investigation of the German Seas.*

The general low densities of these waters, and the variations to which they are subject, make the conditions which obtain there not unlike those in an estuary, but they are in general more complicated and difficult of investigation.

While it is fully realised that it will take years of consecutive observations to thoroughly settle the relations of the fresh and salt water in an estuary; and that many conditions, such as the currents, law of the tides, and rainfall over the area drained by the principal river and its tributaries, must be taken into account, it is considered expedient to state the results observed in the six months, from June to December 1884, on the Firth of Forth. These results are purely preliminary, but as little attention has been given to such matters hitherto, they may prove of interest, and may lead to suggestions for improvements in the methods of carrying on the work.

2. *The Firth of Forth.*

The River Forth rises in the valley between Ben Lomond and Ben Venue, is joined near Stirling by the Teith, and gradually merges into the Firth of Forth, the precise point at which the river

* *Vierter Bericht für die Jahre* 1877 *bis* 1881, Berlin 1884,—Periodische Schwankungen des Salzgehaltes im Oberflächenwasser in der Ostsee und Nordsee, von Dr H. E. Meyer.

ends and the firth begins being a matter permitting of difference of opinion. Probably the best plan is to view the river as ending at Queensferry, but for convenience the term Firth of Forth may be applied as describing the river and firth proper from Alloa to the Isle of May, a distance of 55 miles. According to Keith Johnston, the area drained by the Forth is 500 square miles. Few large rivers flow into the firth, those of any importance are, on the north side the *Black Devon* at Clackmannan, and the *Leven* at Leven; on the south side there are the *Carron* at Grangemouth, the *Avon* a few miles further east, the *Almond* at Cramond, the *Water of Leith* at Leith, the *Esk* at Musselburgh, and the *Tyne* near Dunbar. All these, together with the numerous small burns, are represented on the chart (Plate III.), which also shows the depth of the water in the firth.

From Alloa the depth of the water is under 10 fathoms until within three miles of Queensferry, where it increases at first gradually, then, at the Bamer Beacon, abruptly to over 30 fathoms, and close to Inchgarvie to over 40. This is the deepest part of the firth, and the narrowest. A very strong tide runs in the channels on each side of Inchgarvie. The deep water is confined to a small area, and the 10 fathom stream runs along the northern shore until off Kirkcaldy, where it widens out in a funnel shape and approaches the coast on each side. There is a short tract over 10 fathoms to the south of Inchkeith known as the Narrow Deep. Several small depressions of more than 20 fathoms occur between Queensferry and Inchkeith, and a little to the east of that island the 20 fathom area begins as a narrow stream trending northward and spreading out off Largo. The Isle of May is connected to the mainland of Fife by a submerged plateau rising to less than 20 fathoms from the surface, and about 4 miles east of the May depths beyond 30 fathoms commence.

A line drawn from Aberlady Bay to Largo divides the firth into two very different halves. To the west of it, the slope of the bed is extremely gradual and the depth slight; to the east of it, the shore slopes down abruptly, and the bed of the firth is, with one or two insignificant exceptions, uniformly over 20 fathoms in depth.

3. *Observations on the Surface Salinity in the Firth.*

It is assumed that the amount of total salts may be deduced from the density as if estuary water were ocean water, diluted with pure water. The assumption is that the percentage composition of the total salts is the same as regards their constituents, whether the water yielding them contain 1 or 4 per cent. The constancy of composition for ocean water was shown in 1865 by Forchhammer to be highly probable, and the researches of Tornøe, Schmelk, and other chemists of the Norwegian North Atlantic Expedition, crowned by Professor Dittmar's exhaustive discussion of the "Challenger" waters, have established it as a definite certainty.

This cannot be the case with estuary water, as the salts carried down by rivers are in quite different proportion to those found in the sea, and before the processes occurring there have had time to produce uniformity of composition; that is, where river water predominates, the proportion of the salts among themselves must vary. Consequently, until exact experiments can be made on this point, the interpretation of estuary densities by ocean-water tables must be taken with reservation.

To get a preliminary view of the rate of freshening in the Firth of Forth, it was determined in September 1884 to make a monthly trip for collecting water samples from the entire firth; and on the 18th of September the "Medusa" proceeded from Inchkeith to Grangemouth for that purpose. Surface samples were taken every five miles (the positions are marked on the chart), and bottom samples at each alternate station. Observations were made both in going and in returning, and they are represented on the small diagram A (Plate IV.), the former as a dark, the latter as a light line.

The tide was $\frac{3}{4}$ flood at Inchkeith; at Grangemouth, where we turned, it was two hours ebb; and on the return to Inchkeith was $\frac{3}{4}$ ebb. The weather was fine, but hazy throughout.

The intention to make the complete tour of the firth in one day had to be reluctantly relinquished, and the Inchkeith to May section was completed on the 25th. Inchkeith was reached at 10.30 A.M. with $\frac{3}{4}$ ebb tide, and a strong south-westerly breeze. Surface samples were taken at the Stations marked on the chart VIII., IX., X., and XI. At the May the tide was $\frac{3}{4}$ flood, and a south-westerly breeze rising to a gale, which increased towards evening, prevented water samples being obtained at Stations IX., VIII., and VII. returning. This trip showed that the density of the water samples decreased steadily, gradually, and uniformly from the May to the Oxcar Beacon (V.), but that the change then became more rapid, the curve resembling a portion of a rectangular hyperbola. The weather for the previous few weeks had been dry and warm.

On October 7, water samples were taken to and from the May from 8 A.M. to 7 P.M. The weather was fine but dull, and the sea smooth. It was low water at Station VIII. going, and high water at Station XI. returning.

Next day the "Medusa" went to Alloa, in rain, slight mist, and a north-easterly breeze. Water samples were taken as before. It was low water at Inchgarvie (Station V.) going up, and high water at the same place returning.

The water, beautifully clear and transparent, and of a deep green-blue colour at the May, became light green and less transparent about Inchkeith, and from Inchgarvie onwards it was yellow and very muddy.

The curve for this trip (Plate IV., B) is less regular, but of the same general shape as the previous one.

The November trips were made on the 10th and 11th of the month. For the previous week or two there had been high wind and much rain, and the rivers had been flooded heavily, but were then subsiding. The 10th, when the eastern half of the firth was traversed, was bright, clear, and calm. The shortness of daylight prevented the yacht from getting further than Station X., at which point it was low water. On the 11th it was dull, with a stiff south-easterly breeze. It was high water at Station VI. going up, and low water at Station V. coming down. The river was greatly flooded, and the curve (Plate IV., C) is irregular, and much more abrupt than the others. The reading of the density at Station IV. going up seems too low, but there is no reason to suspect its accuracy. The influence of the flooded streams may be traced by a lowering of density down to Station IX. The effect of this "spate" was to reduce the density at Inchgarvie from 1·02382 to 1·02029, that at the Oxcar Beacon from the mean of 1·02438 to 1·02022, that at

Inchkeith from 1·02472 to 1·02403, and those at Stations VIII. and IX. from 1·02505 and 1·02518 to 1·02458 and 1·02508 respectively.

The December trip did not take place till the 25th, when my friend Mr T. Morton Ritchie was good enough to take charge of the eastern excursion. The day was fine, with a north-easterly breeze, and a slight swell. The tide was two hours ebb at Station VII. going, and one hour flood at the same place returning. On the 27th the yacht started for Alloa, but the morning, which was hazy, gave place to a day of fog, and it was impossible to proceed beyond Inchgarvie. The 29th and 30th were also misty, and this portion of the trip had, very reluctantly, to be dispensed with.

The curve D (Plate IV.) shows that the water had returned to its former value after the diluting effect of the floods of November.

The effect of the tide obscures the changes of salinity to a certain extent in these monthly cruises, but although the data are so few they are sufficient to show that between Inchkeith and the Isle of May the tidal effect is relatively slight, and the variations in density very gradual, though perceptible; while from Inchkeith to Alloa the tidal effect increases with every mile, and the rate of change becomes more and more rapid. Tables VI. and VII. give the figures observed in these consecutive trips.

In order to make some attempt at neutralising the influence of tides, the mean was taken of all the observations made since June at each of the Stations. These were made at all states of the tide, and in all weathers that the yacht could stand, and although they are not very numerous, and do not extend over more than seven months, they give some idea of the alteration in salinity with position.

The means are embodied in the diagram (Plate V., E), on which the calculated amount of total salts is also represented. It plainly shows that the parts of the firth to which least attention has, as yet, been given, those west of Inchkeith, are the most deserving of study, for there the changes are large and rapid.

The maximum, minimum, and mean density observed at each Station, together with the number of cases which give the mean, are tabulated. (Table VIII.)

TABLE VI.—*Density of the Water at* 15°·56.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
September 1884, .	...	...	1·02082	1·02285	1·02444	1·02470	1·02499	1·02533	1·02531	1·02537	1·02549	1·02555
October 1884, . .	1·00160	1·01088	1·01911	1·02272	1·02332	1·02443	1·02505	1·02512	1·02547	1·02525	1·02555	1·02558
November 1884, .	0·99923	1·00272	1·01419	1·01704	1·01946	1·02022	1·02403	1·02458	1·02501	1·02529	...	...
December 1884, .	...	...	...	...	1·02351	1·02353	1·02464	1·02511	1·02508	1·02545	1·02554	...

TABLE VII.—*Alkalinity.*

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
September, . .	...	...	...	...	49·1	50·4	49·6	...	...	...	...	...
October, . . .	...	...	...	...	...	...	...	...	...	...	...	..
November, . .	1·2	11·6	31·4	39·2	44·3	45·2	48·3	48·6	50·5	49·7	...	...
December, . .	...	...	...	...	48·6	49·6	51·2	52·3	51·4	51·7	53·9	..

The mean of the density, &c., at the Stations going and returning is given here.

TABLE VIII.—*Variations in Density.*

Station.	Maximum.	Minimum.	Mean.	No. of Obs.
I. Alloa, ...	1·00160	0·99923	1·00042	4
II. Kincardine, . . .	1·01521	1·00070	1·00680	4
III. Hen and Chickens Buoy, .	1·02169	1·01084	1·01898	11
IV. Blackness, . . .	1·02414	1·01650	1·02087	6
V. Inchgarvie, . . .	1·02461	1·01863	1·02303*	11
VI. Oxcar, ...	1·02492	1·01953	1·02355†	10
VII. Inchkeith,. . . .	1·02526	1·02380	1·02472	13
VIII.	1·02544	1·02450	1·02505	7
IX.	1·02551	1·02495	1·02518	8
X. Off Fiddra, . . .	1·02557	1·02417	1·02530	9
XI. Off Bass Rock, . . .	1·02566	1·02526	1·02547	6
XII May Island, . . -	1·02570	1·02443	1·02511	5

Differences between Mean Densities in units of the fifth place.

I. II. III. IV. V. VI. VII. VIII. IX. X. XI. XII.

638, 1218, 189, 216, 52, 113, 33, 13, 12, 17 – 36.

Note.—All the densities given are at 15°·56 C.

An examination of Table VIII. shows that for maximum and minimum, as well as for mean observed densities, the increase is perfectly continuous until the last Station is reached, when the maximum density is only probably greater than that at Station XI., the minimum is certainly less than that at Station VIII., and the mean is less than that at Station IX. It is not easy to find an explanation of this fact, for there is no river nearer than the Tyne at Dunbar, and there are no springs on the Isle of May, the lighthouse keeper being compelled to get his fresh water all carried from Crail. It is, of course, possible that there may be some submarine springs near the island, but no indication of this is given by an examination of the bottom waters, which were always salter than

* Omitting the day of high flood in the river mean = 1·02382.

† ,, ,, ,, = 1·02438.

the surface. It is also a curious fact that four samples of water from the firth beyond the Isle of May had a mean density of 1·02514, scarcely greater than that at Station XII., and distinctly less than that at Station IX. The samples at the Isle of May were all collected, as it happens, during flood tide; so that no current of the ebb carrying fresh water can be called in to account for the observation. It would almost seem as if the densities hinted at a maximum about Station IX. with lower densities on each side; if the water of the Firth of Tay is fresher than that of the Firth of Forth a ready explanation suggests itself.

In consequence of the way in which water-sampling trips were conducted, there were some Stations where the two samples were drawn at opposite phases of the tide. Inchkeith and Inchgarvie were usually in that position. Table IX. shows what difference was observed in the densities at different phases of the tides on the

TABLE IX.—*Variation of Salinity with Tides.*

Station.	Date.	Density of Water.			Alkalinity.			Tides.	
		1	2	Dif.	1	2	Dif.	1	2
II.	8–10–84	1·01521	1·00655	866	...	...	...	3½ hrs. flood	2¼ hrs. flood
,,	11–11–84*	1·00474	1·00070	404	11·1	12·1	−1·0	2 hrs. ebb	4½ hrs. ebb
IV.	8–10–84	1·02414	1·02131	283	...	...	...	¾ flood	¼ flood
V.	18–9–84	1·02461	1·02425	36	50·4	47·9	2·5	High water	½ ebb
,,	8–10–84	1·02424	1·02241	183	...	...	...	,,	Low water
,,	11–11–84*	1·02029	1·01863	166	46·5	42·1	4·4	,,	,,
VII.	18–9–84	1·02505	1·02481	24	51·1	48·2	2·9	¾ flood	¾ ebb
,,	10–11–84*	1·02427	1·02380	47	47·5	50·1	−2·6	2½ hrs. ebb	2½ hrs. flood
IX.	25–9–84	1·02522	1·02539	−17	...	...	...	1 hr. ebb	Low water
,,	10–11–84*	1·02508	1·02495	13	51·3	49·7	1·6	3¾ hrs. ebb	¾ hrs. flood
XI.	7–10–84	1·02544	1·02566	−22	...	...	...	High water	2 hrs. flood

few occasions when these were sufficiently separated. It is of course very fragmentary, as the variations in the difference between high and low water must be considerable, but it is sufficient to indicate the general rule which prevails. The difference is by far the greatest in the upper reaches of the firth, and decreases more

* River in flood.

STATIONS.—II. Kincardine; IV. Blackness; V. Inchgarvie; VII. Inchkeith.

and more gradually. Beyond Inchkeith the difference is little noticed, in fact the water is found to be sometimes denser at a lower state of tide. This effect may be due to currents, which were not taken account of in this preliminary investigation. The rate of change of density with the tide decreases very rapidly at first. At Kincardine, the difference touches the second place of decimals; calling the density of pure water 10,000, it is 100, at Inchgarvie it is about 15, at Inchkeith 4, and beyond Inchkeith about 1; that is, 1 in the fourth decimal place by ordinary notation.

The temperature observations made on the monthly trips have not been alluded to here; they are intended to form a separate paper. It was found, speaking generally, that in summer the temperature of the surface water was highest at Alloa, and steadily fell as the Isle of May was approached; the rate of fall becoming more and more gradual. In winter this state of affairs is inverted. The water at Alloa is the coldest, and the temperature rises more and more gradually towards the May. The difference also is much greater between the summer and winter temperatures at Station I. than at Station XII. For example, at Queensferry (Station V.), on July 31, the surface temperature was 58°·2 Fahr., on December 27 it was 41°·2 Fahr., a range of 17° Fahr. At the May, on June 11, the surface temperature was 50°·1 Fahr., and on December 25, within six miles of the May, it was 43°·8, a range of 6°·3.

The change of temperature produces a corresponding change in the density of the water *in situ*, which has important bearings on convection currents, and which must also influence the rate of mixture of sea and river water, especially as the temperature of the river water is, in winter, usually below that of its maximum density.

4. *Surface Water Density at the Marine Station.*

The Scottish Marine Station has a floating laboratory moored in the centre of the submerged Granton Quarry. The entrance is on the western side, and at high water it is continuous with the firth for a considerable breadth. At low water the channel is dry, and in front of it is a broad tract of sand extending out to Cramond Island, The River Almond flows into the firth just to the west of Cramond island, at low water. It is about two miles distant from the quarry.

A sample of water was taken at the quarry mouth at high water daily, with such interruptions, sometimes of considerable duration, as were to be expected at the first starting of a piece of routine work not absolutely necessary, with a small staff.

In July only three samples were taken, owing to a trip of the "Medusa" on the Clyde; their densities varied from 1·02454 to 1·02469.

In August there were 21 occasions on which water was collected at the entrance, 13 at high water, and 8 at low water. The mean for the low water was 1·02464, the extremes 1·02478 and 1·02435. The only case of special interest is one on the 12th. On that day there was a severe thunderstorm with exceedingly heavy rain for several hours. In the middle of it, during low water, when the quarry was land-locked, a bottle was filled holding its mouth just under the surface, and another at a depth of six inches. The result was that the extreme surface layer of water was found to have a density of 1·02394, the other of 1·02405, a difference of 0·00011. The high water figures differed only from 1·02405 to 1·02496, the mean being 1·02461.

During September 21 samples were taken at the quarry entrance at full tide; the mean density was 1·02446, the extremes being 1·02487 and 1·02296.

During this month a sample was taken up daily for some time at low water at a rock on the shore near the quarry. The mean density (12 observations) was 1·02461, the extremes 1·02506 and 1·02378, all higher than those at high water. The peculiarity of this result is emphasised when the curves are consulted, for there low tide is seen to produce a lower density beyond Inchkeith occasionally.

In October four samples only were collected; the mean density was 1·02319, the extremes being 1·02391 and 1·02193.

During November the density was determined on nine occasions; the mean was 1·02313, the highest 1·02390, and the lowest 1·02035.

In December samples were taken with greater regularity. They gave a mean of 1·02052, with extremes of 1·02449 and 1·00969 in 26 samples.

The figures for November and December are plotted in curve G (Plate V.), which shows the great irregularities that were observed.

It will be noticed by the dotted curve (Plate V., H) that since July the density has been continuously diminishing, though the larger curve shows that the diminution is very far from regular. On the 20th and 21st the surface water was almost fresh, indeed ice formed over the whole quarry at low water, although the temperature by a continuously immersed minimum thermometer did not fall below 32° Fahr. The bulb of this thermometer was 3 inches below the surface; and as there was a difference of over 3° Fahr. between the temperature at the depth of 6 inches, and when the bulb was just covered, at a time when the surface temperature was 34°, it is probable that the extreme surface layer was considerably colder than the minimum thermometer showed. The ice was about a centimetre thick, the upper third was hard, smooth, transparent, and quite free from air-bubbles, while the lower part was very spongy, seemingly composed of successive horizontal laminæ with water spaces between. Part of the ice collected was washed with distilled water, allowed to drain, then melted, and the chlorine determined by titration :—

	I.	II.	Mean.
Grammes per litre,	0·594	0·581	0·587

It is unfortunate that, owing to arrears of work consequent on illness, I did not determine the density of the water collected on the 20th and 21st until the 25th. The two bottles had in the interim been frozen solid during a cold night (22nd); they were found next morning with the cords securing the stopper burst, the stoppers lying on the table at a little distance, and the ice protruding above the neck of each. On the 25th the water in the quarry was as salt as usual, and of course it was too late to ascertain to what depth the freshening on the two days had extended.

It was suggested that the infiltration of fresh water from springs might lower the density of the surface water in the quarry, and so account for the peculiar temperature phenomena which have been observed there,* but on the 20th and 21st, and for several days before and after, all the sides of the quarry were sheathed in ice, the temperature of the air was below the freezing point, and, of course, at the time of sampling the tide was full. At low tide in August the water *in* the quarry was almost always found a little salter than at

* *Proc. Roy. Soc. Ed.*, xii. 927.

high water, showing the effect of evaporation to be greater than that due to springs.

On the 30th December the density was ascertained at several points at the time of high water, with the result that near a spring which falls into the quarry it was a little lower than at the entrance on the surface, and distinctly lower than at the bottom of the quarry, while half a mile outside in the firth the water was salter than near the shore (Table X.):—

TABLE X.

Position.	Depth.	Depth of Sample.	Density at 15°·56.	Temperature of Water.
Close to spring, . .	1 fathom.	Surface.	1·02372	39°·2 Fahr.
At "Ark," . .	$7\frac{1}{2}$ fathoms.	Bottom.	1·02393	39°·3 "
N.W. buoy in quarry,	8 fathoms.	Bottom.	1·02392	39°·4 "
Quarry entrance, .	$1\frac{1}{2}$ fathom.	Surface.	1·02382	39°·3 "
Half a mile outside } .	$3\frac{1}{2}$ fathoms.	Surface.	1·02436	40°·7 "
Due north, . } .	$3\frac{1}{2}$ fathoms.	Bottom.	1·02449	40°·1 "

The figures for all the quarry observations are given in Table XI.

TABLE XI.

Date.	No. of Sample.	Weather.	Water.	Tide.	Density at 15°·56.	Alkalinity.
July 29.	37	Dull—Fine.	Clear.	High Water.	1·02454	.
" 30.	38	"	Muddy.	"	469	.
" 31.	39	"	"	"	469	.
Aug. 1.	44	"	...	"	443	.
" 1.	45	Sunny, Wind E.	...	Low Water.	455	.
" 2.	46	Sunny, high W.	Very muddy	High Water.	463	.
" 4.	48	Clear, W.	Clear.	Low Water.	440	.
" 5.	49	Bright.	"	"	459	.
" 5.	50	Sunny, S.W.	Muddy.	High Water.	442	.
" 6.	51	Bright, S.	Clear.	Low Water.	435	.
" 7.	52	Sunny, N.E.	...	"	471	.
" 8.	53	Mist, N.E.	Muddy.	"	470	.
" 8.	54	Clear, N.E.	...	High Water.	468	.
" 9.	55	Cloudy, E.	...	Low Water.	469	.
" 9.	56	"	Muddy.	High Water.	492	.
" 11.	57	Sunny, Calm.	"	"	468	.
" 12.	58	Thunder and Rain.	Very muddy	Low Water.	405	.
" 13.	60	Sunny, S.E.	...	"	478	.
" 13.	61	...	...	High Water.	464	.
" 14.	62	Fine, S.	Muddy.	Low Water.	474	.
" 15.	64	Clouds, Rain.	...	High Water.	480	.
" 16.	65	Strong W.	...	"	466	.
" 18.	66	Clear, Calm.	...	"	470	.
" 21.	67	N.E. gale.	...	"	496	.
Sept. 1.	78	Calm.	Clear.	"	379	.
" 1.	79	"	...	Low Water.	378	.

TABLE XI.—*continued.*

Date.	No. of Sample.	Weather.	Water.	Tide.	Density at 15°·56.	Alkalinity.
Sept. 2.	80	Clear, S.W.	...	High water.	418	.
,, 3.	81	,,	Sandy.	Low water.	472	.
,, 3.	82	Calm, Clear.	Clear.	High water.	440	.
,, 4.	83	Calm, Dull.	,,	Low water.	475	.
,, 4.	84	Calm, light Br.	,,	High water.	456	.
,, 5.	85	Bright, W.	Sandy.	Low water.	487	.
,, 5.	86	Bright, W. gale.	,,	High water.	472	.
,, 8.	87	Calm.	Very sandy.	Low water.	473	.
,, 8.	89	,,	Sandy.	High water.	454	.
,, 9.	90	,,	Clear.	Low water.	402	.
,, 9.	91	,,	...	High water.	458	.
,, 10.	98	,,	...	Low water.	472	50·4
,, 10.	99	Clear.	Clear	High water.	482	.
,, 11.	100	Calm, Cloud.	...	,,	476	.
,, 12.	101	Fog, N.E.	...	,,	487	.
,, 13.	102		...	,,	482	.
,, 15.	103	Clouds, N.E.	Clear.	,,	482	.
,, 15.	104	Clouds, N.E. gale.	Very muddy	Low water.	467	.
,, 16.	105	Thick Mist, N.E.	Muddy.	High water.	466	.
,, 17.	106	Clear, N.E.	Clear.	,,	458	.
,, 17.	107	Clear, Calm.	Sandy.	Low water.	467	.
,, 18.	108	...	...	High water.	465	.
,, 19.	109	Calm, Mist.	...	Low water.	440	.
,, 19.	110	Calm, Haze.	Clear.	High water.	466	.
,, 22.	138	Strong S.	Sandy.	Low water.	506	.
,, 22.	139	Strong S.W.	Clear.	High water.	476	.
,, 23.	140	,,	Sandy.	Low water.	497	.
,, 23.	141	Rain, S.W.	Clear.	High water.	469	.
,, 26.	142	Calm.	,,	,,	460	.
,, 29.	152	Calm, S.W,	...	,,	338	.
,, 30.	154	Squally, S.W,	...	,,	360	.
,, 30.	155	,,	...	Low water.	389	.
Oct. 1.	156	Strong S.W.	Sandy.	High water.	388	.
,, 2.	157	Fine, Calm.	...	,,	391	.
,, 3.	158	Bright, S.W.	...	,,	303	.
,, 4.	159	...	...	,,	193	.
Nov. 21.	217	Clear, Calm.	Muddy.	,,	366	53·5
,, 26.	218	Dull, W.	Clear.	,,	390	46·0
,, 27.	219	,,	Muddy.	,,	381	51·8
,, 28.	220	Clear, W.	Clear.	,,	347	46·9
,, 29.	221	Bright, W.	,,	,,	345	45·2
,, 30.	222	Dull, E.	,,	,,	376	45·7
Dec. 1.	223	Dull, S.	,,	,,	418	52·7
,, 2.	224	Bright, W.	,,	,,	449	46·9
,, 3.	225	Bright, S.W.	,,	,,	1·01850	33·9
,, 4.	226	Clear, E.	Muddy.	,,	1·01925	44·0
,, 5.	227	Dull, W.	Clear.	,,	1·02444	52·7
,, 6.	228	,,	Muddy.	,,	1·01860	34·1
,, 7.	229	Dull, N.E.	Clear.	,,	1·01875	37·3
,, 8.	230	Dull, S.W.	Muddy.	,,	1·01858	39·7
,, 9.	231	Dull, W.	Clear.	,,	1·02160	41·1
,, 10.	232	S.W.	,,	,,	1·01780	38·2
,, 11.	233	Clear, S.W.	Muddy.	,,	1·02002	.
,, 12.	234	,,	,,	,,	1·01911	42·3
,, 13.	235	Bright, S.W.	Clear.	,,	1·02202	43·9
,, 14.	236	Clear, S.W.	,,	,,	243	46·5
,, 15.	237	Bright, S.W.	,,	,,	219	.
,, 16.	238	Clear, S.W.	,,	,,	247	.
,, 17.	239	Clear, W.	,,	,,	226	.
,, 18.	240	Dull, S.W.	,,	,,	289	.
,, 19.	241	Clear.	Muddy.	,,	1·01906	.
,, 20.*	242	Clear, N.	Clear.	,,	1·01259	31·5
,, 21.*	243	Dull, W.	,,	,,	1·00969	25·6
,, 22.	244	,,	,,	,,	1·02161	38·2
,, 23.	245	Dull, N.	,,	,,	159	.
,, 24.	246	,,	,,	,,	283	.
,, 27.	262	Dull, S.W.	,,	,,	275	48·4
,, 30.	266	Dull, Calm.	Muddy.	,,	382	.

* These samples froze in the bottle before the density was determined

A probable explanation of the freshness of the quarry surface water at times is that the River Almond when in flood, or whether wind is in certain directions, dilutes the water along the shore to the east of it. This would also account for the water near the quarry being denser at low tide, for then the Almond runs into the firth on the west of Cramond Island, and so carries its freshening influence in another direction (see Plate III.).

A number of glass floats, coloured distinctively, were thrown into the Almond on several occasions just at the turn of the tide, immediately after high water, but none of them were seen again, though all the boys of the neighbourhood were on the alert along the shore, a small reward having been offered for each float found.

5. *The Bottom Water of the Firth.*

As there was considerable time lost in devising and testing a suitable means of collecting samples of bottom water, the number of cases for consideration is small.

It may be generally stated, that the part of the firth east of Inchkeith is the region where the difference between the density of surface and bottom water is least, and that the difference decreases steadily towards the May. Towards Alloa, on the other hand, the differences in the density between surface and bottom water are great, but they are greatly influenced by the tide.

Table XII. gives details of 19 comparisons between bottom and surface water.

At the Hen and Chickens Buoy, off Grangemouth, the depth is only $5\frac{1}{2}$ fathoms, but the salinity is very much greater at the bottom than at the surface. The difference is least observed at low water, but as the flood tide sets in it appears to increase, and then to fall off again as the ebb commences. The only divergence from this rule noticed was on November 11, when the rivers were all much flooded, and the current very rapid. It would appear that these observations confirm the theory that sea water ascends rivers along the bottom under the opposite current of fresh water.

At Inchgarvie, where there is a deep depression (over 40 fathoms) in the middle of the stream, the bottom water is always much salter than that at the surface, and the result is most noticeable at low water. The difference is usually like that between

TABLE XII.—*Bottom Water.*

Date.	Samples.	Tide.	Depth.	Density.			Alkalinity.		
				Bottom.	Surface.	Dif.	Bot.	Sur.	Dif.
At Hen and Chickens (III.)									
19–6–84	20 and 21	low water	2 fm.	1·01876	1·01850	26	...	...	...
8–10–84	183 and 184	2 hr. fld.	4 ,,	1·02041	1·01693	348	...	...	...
11–11–84	206 and 208	1 hr. ebb	5½ ,,	1·02158	1·01755	403*	44·7	34·3	10·4
11–11–84	207 and 209	5 hr. ebb	5½ ,,	1·02040	1·01084	956*	47·4	28·5	16·9
At Inchgarvie (V.)									
19–6–84	22 and 24	1 hr. fld.	25 fms.	1·02478	1·02424	54	...	...	...
31–7–84	41 and 43	5 hr. ebb	31 ,,	1·02455	1·02324	131	...	...	...
18–9–84	129 and 133	½ ebb	35 ,,	1·02448	1·02425	23	56·9	47·9	9·0
8–10–84	178 and 179	low water	40 ,,	1·02437	1·02241	196	...	...	...
11–11–84	200 and 202	high water	32 ,,	1·02508	1·02029	479*	51·8	46·5	5·3
11–11–84	201 and 203	low water	35 ,,	1·02476	1·01863	613*	45·0	42·1	2·9
27–12–84	259 and 260	high water	38½ ,,	1·02509	1·02351	158	53·9	48·6	5·3
At Inchkeith (VII.)									
18–9–84	119 and 123	¾ ebb	15½ fm.	1·02491	1·02481	10	50·4	48·2	2·2
7–10–84	160 and 161	low water	13¼ ,,	1·02517	1·02519	2	...	...	...
8–10–84	174 and 175	¾ ebb	10 ,,	1·02501	1·02494	7	...	...	...
25–12–84	247 and 248	2 hr. ebb	17 ,,	1·02531	1·02470	61	48·6	48·6	0
At Station IX.									
11–6–84	13 and 15	5 hr. ebb	22 fm.	1·02424	1·02417	7	...	...	...
At Station XI.									
4–6–84	1 and 3	½ ebb	23 fm.	1·02542	1·02528	14	...	...	...
At May Island (XII.)									
11–6–84	16 and 17	2 hr. fld.	7 fm.	1·02532	1·02443	89	...	...	...
7–10–84	167 and 168	¾ fld.	9 ,,	1·02562	1·02547	15	...	...	...

* River in flood.

1·0240 at the bottom and 1·0220 at the surface. On November 11 the bottom density was 1·02476 at low water, the surface was only 1·01863, a difference of 0·00613. This was evidently due to the unusual rapidity of the surface current caused by the swollen rivers, being sufficient to retard the process of diffusion between the two kinds of water. As an ordinary thing, the bottom water at Inchgarvie is nearly as salt as that at Inchkeith, while the surface water is much fresher; in fact, in a heavy flood there is river water on the surface and sea water below it. The following comparison of water from half the depth with that at the bottom and surface shows that the denser water extends at any rate to half the depth, so that one would be inclined to view the heavy sea water filling up the hollow as part of the river bed, over which the fresher upper water flows. Experiments with a current gauge at various depths would be certain to give much valuable information on this subject.

	a.	*b.*	*c.*
Bottom,	1·02478	1·02455	1·02448
Half-Depth,	1·02461	1·02440	1·02426*
Surface,	1·02424	1·02324	1·02425

The salinity of the bottom water was never found less than that of the surface.

6. *The Alkalinity of the Firth of Forth.*

Table XIV. gives particulars of 98 determinations of alkalinity arranged according to magnitude.

Speaking roughly, it shows that waters having an alkalinity under 40 (that is in which there is less than 0·04 grammes of carbonic acid as carbonate of lime per litre) have a density under 1·0200, alkalinities under 25 correspond to densities under 1·0100. The only strikingly anomalous case is that of sample No. 189, a bottom water from off Alloa, when the river was low and very dirty. The density was 1·00146, the alkalinity 47·9, which usually corresponds to a density of 1·024. The presence of sewage in the river might account for this observation to some extent, but more probably it is due to the presence of particles of calcium carbonate, to which cause the very exceptional alkalinities of Nos. 94 and 70 may also be referred.

* Uncertain.

With an alkalinity between 40 and 50 water has a density between 1·024 and 1·025 as a general rule, and when the alkalinity is over 50 the density is almost invariably over 1·025.

There are a number of exceptions apparent on looking over these tables, and the exceptions are too numerous to be accidental.

To discuss the bearings of alkalinity on the other properties of the water with any degree of satisfaction, it would be necessary to translate the number representing alkalinity per litre into that representing alkalinity per 100 parts of total salts. If it could be correctly assumed that the composition of the total salts is constant, like the composition of ocean-water salts, this could easily be done by calculation from the density. But it is evident from purely *à priori* considerations, that such an assumption cannot be made, for the composition of the dissolved salts of river water is quite different from that of the salts of sea water, and consequently estuary water is not a solution of sea-water salts diluted more and more with pure water, but a solution of sea-water salts mixed more and more largely with a much more dilute solution of salts in a different proportion.

In consequence of inability to compare the alkalinites with the total salts, it is impossible to form a correct idea of the difference between bottom and surface alkalinities, as this difference may be entirely due to the different salinity of the water.

The following table (XIII.) shows that the difference in alkalinity, like that in salinity between surface and bottom water, is greatest at the highest point in the river, and decreases rapidly as the sea is approached.

TABLE XIII.

	Bottom.	Surface.	Difference.	Mean difference.
Station III., near Grangemouth.				
	44·7	34·3	10·4	...
	47·4	28·5	18·9	14·7
Station V., near Inchgarvie.				
	56·9	47·9	9·0	
	51·8	46·5	5·3	
	45·0	42·1	2·9	
	53·9	48·6	5·3	5·6
Station VII., near Inchkeith.				
	50·4	48·2	2·2	
	48·6	48·6	0·0	1·1

For particulars as to density, &c., see Table XII.

TABLE XIV.

Water Sample.	Alkalinity.	Density at 15·°56.	Position.	State of Tide.
212	1·2	0·99923	I	½ Ebb (*f*).
213*	4·8	0·99939	,,	,, (*f*).
210	11·1	1·00474	II.	¼ Ebb (*f*).
211	12·1	070	,,	¾ Ebb (*f*).
243	25·6	969	Q	High water.
207	28·5	1·01084	III.	Low water.
242	31·5	259	Q	High water.
225	33·9	850	,,	,,
228‡	34·1	860	,,	,,
206	34·3	755	III.	,, (*f*).
205	37·1	758	IV.	Low water (*f*).
229	37·3	875	Q	High water.
204	38·2	650	IV.	,, (*f*).
232	38·2	780	Q	,,
244	38·2	1·02160	,,	,,
230‡	39·7	1·01858	,,	,,
231	41·1	1·02160	,,	,,
201	42·1	1·01863	V.	Low water (*f*).
234‡	42·3	911	Q	High water.
199	43·9	953	VI.	,, (*f*).
235	43·9	1·02202	Q	,,
226‡	44·0	1·01925	,,	,,
208*	44·7	1·02158	III.	,, (*f*).
203*	45·0	476	V.	Low water (*f*).
221	45·2	345	Q	High water.
222	45·7	376	,,	,,
218	46·0	390	,,	,,
198	46·5	091	VI.	,, (*f*).
200	46·5	029	V.	,, (*f*).
236	46·5	243	Q	,,
220	46·9	347	,,	,,
224	46·9	449	,,	,,
209*	47·4	040	III.	Low water (*f*).
215‡	47·4	346	Q	High water.
190	47·5	427	VII.	¼ Ebb (*f*).
133	47·9	425	V.	½ Ebb.
189*	47·9	1·00146	I.	¼ Flood (*f*).
214	47·9	1·02230	Q	High water.
261	47·9	297	VI.	¼ Ebb.
249	48·1	521	VIII.	½ Ebb.
123	48·2	481	VII.	¾ Ebb.
191	48·2	450	VIII.	½ Ebb (*f*).
262	48·4	275	Q	High water.
247	48·6	470	VII.	¼ Ebb.
248*	48·6	531	,,	,,
259	48·6	351	V.	High water.
250	48·9	551	IX.	½ Ebb.

Q stands for "Quarry Mouth," and (*f*) for "river in flood."

* Bottom sample.
† Sample from intermediate depth.
‡ Water noted as full of particles.

TABLE XIV.—*continued.*

Water Sample.	Alkalinity.	Density at 15°·56.	Position.	State of Tide.
196	49·0	467	VIII.	¼ Flood (*f*).
115*	49·2	498	VII.	¾ Flood.
194	49·7	563	X.	Low water (*f*).
195	49·7	495	IX.	,, (*f*).
216‡	50·1	035	Q	High water.
197	50·1	380	VII.	¼ Flood (*f*).
112	50·2	492	VI.	¼ Ebb.
98	50·4	472	Q	Low water.
119*	50·4	491	VII.	¾ Ebb.
124	50·4	472	VI.	High water.
125	50·4	469	,,	¾ Ebb.
128	50·4	461	V.	High water.
113	50·8	479	VI.	¾ Ebb.
95	51·1	526	VII.	High water.
111	51·1	508	,,	Low water.
116*	51·1	505	,,	¾ Flood.
117†	51·1	510	,,	,,
118	51·1	505	,,	,,
254	51·1	545	X.	Low water.
72	51·3	552	VII.	,,
131†	51·3	426	V.	½ Ebb.
192	51·3	508	IX.	,, (*f*).
193	51·3	557	X.	¾ Ebb (*f*).
258	51·3	410	VI.	High water.
69	51·5	500	VII.	¼ Ebb.
114	51·5	447	V.	¾ Ebb.
120*	51·5	493	VII.	¾ Ebb.
97*	51·7	528	,,	High water.
202*	51·8	508	V.	Low water.
219‡	51·8	381	Q	High water.
96†	51·9	531	VII.	,,
73†	52·0	554	,,	Low water.
122	52·2	493	,,	¾ Ebb.
251	52·3	545	X.	,,
223	52·7	418	Q	High water.
227	52·7	444	,,	,,
253*	53·0	556	XI.	¾ Ebb.
71†	53·3	533	VII.	¼ Ebb.
74*	53·3	554	,,	Low water.
68	53·5	498	,,	¼ Ebb.
217	53·5	366	Q	High water.
257	53·7	458	VII.	¼ Flood.
93†	53·8	542	St Abb's Head.	...
260*	53·9	509	V.	High water.
255	54·0	465	IX.	Low water.
252	54·9	552	XI.	¾ Ebb.
92	56·0	547	St Abb's Head.	...
256	56·4	502	VIII.	Low water.
129	56·9	448	V.	½ Ebb.
94*	60·0	551	St Abb's Head.	...
70*	63·6	519	VII.	¼ Ebb.

Monday, 19*th January* 1885.

A. FORBES IRVINE, Esq., Vice-President, in the Chair.

The following Communications were read:—

1. Notes on the Chemical Composition of the Cobalt and Nickel Ores of New Caledonia, with some Remarks on the Properties and Uses of Metallic Nickel and Oxides of Cobalt. By J. B. Readman, Esq.

The island of New Caledonia, from which these ores of nickel and cobalt are derived, is situated in the South Pacific Ocean, distant about 600 miles east from Queensland, Australia. The island is about 200 miles long by about 30 miles broad, and is extremely mountainous. New Caledonia belongs to the French, and it is there that they have established one of their principal penal settlements.

The nickel ores of New Caledonia were discovered rather more than twenty years ago by Garnier, in an exploring expedition of the island undertaken under the auspices of the French Government. The ores of cobalt were a more recent discovery.

Beginning with the deposits of cobalt ores in New Caledonia, I shall mention briefly—(1) The kind of deposits of cobalt ore; (2) their physical state; and (lastly) their chemical composition, with some of the properties and the uses of the oxides of cobalt.

1. *The kind of Deposits of Cobalt Ore.*—The surface deposits of cobalt ore are found in the midst of certain aluminous ferruginous masses, which seem to come from the decomposition of eruptive aluminous ferruginous rocks plentifully scattered in these districts. These masses are very much developed at the surface, and form immense ferruginous plateaux, which sometimes crown the top of the principal serpentine upheavals, but which occupy specially the ridges of the less elevated ranges of hills. This peculiarity causes the cobalt ores of New Caledonia to be found generally at low altitudes and not far from the sea, where the branches of the great

mountain chain of the interior die away. The cobalt ores of New Caledonia habitually contain veins of chrome ore, which appear to come from chrome ore contained in the subjacent serpentine.

2. *The Physical Condition of the Cobalt Ore.*—The ore from the ferruginous masses containing cobalt is solid, round, and sometimes a little hard. I have here some specimens that show the appearance it presents on the ground. It resembles iron ore, rotten or scoriaceous, the cavities of which are filled with bluish-black cobaltiferous manganese.

3. *The Chemical Composition of the Cobalt Ores, &c.*—The average percentage of the ore, taken from a large number of analyses, runs about 3 to 5 per cent. oxide of cobalt, along with about 1¼ per cent. of oxide of nickel. Besides these two oxides, the ore contains binoxide and protoxide of manganese, peroxide of iron, alumina, lime, magnesia, silica, chrome ore, and water. The following are the detailed analyses :—

Mean.						
Oxide of cobalt, (5·11)	3·48	3·41	4·16	5·56	6·40	7·76
Oxide of nickel, (1·46)	1·05	1·32	1·64	1·48	1·64	1·64
Binoxide of manganese,	23·34	18·78	22·37	15·94	28·20	34·10
Protoxide of manganese,	2·12	2·33	0·82	3·40	4·90	3·50
Sesquioxide of iron, .	15·71	14·39	10·06	16·06	13·04	8·91
Alumina, . . .	21·20	31·73	13·44	10·30	16·76	14·29
Lime, . . .	2·68	1·95	0·32	1·53	1·70	1·59
Sulphuric acid, . .	...	0·42	...	...	...	...
Magnesia, . . .	2·16	Trace	...	0·70	0·70	0·79
Silica and chrome ore, .	9·20	1·81	30·00	23·00	5·32	2·20
Combined water, .	17·84	19·22	17·19	9·23	12·14	9·42
Moisture, . . .	1·70	4·63		12·86	9·20	15·80
	100·48	99·99	100·00	100·06	99·80	100·00

It will be seen from the analysis of the six samples of cobalt ore (and which are representative analysis of several hundred tons), that the composition of the ore varies very considerably,—the silica and chrome ore being as high as 30 per cent. in one representative sample, and as low as 1·81 per cent. in another.

In the numerous samples submitted to analysis, I have not heard of copper, sulphur (either in free state or as a sulphide), or arsenic, being found in these ores of cobalt.

It has not been found advisable to attempt to utilise as yet any portion of the constituent of these cobalt ores except the cobalt and the nickel they contain, so it is needless at present to mention them further.

Cobalt is almost entirely consumed in the arts in the state of oxide, and there are two fairly well-defined oxides of this metal that are so employed. The first of these, or what is known as the ordinary *black oxide of cobalt* of commerce, is a sesquioxide (Co_2O_3), corresponding to the ferric oxide Fe_2O_3; and the other oxide is partly protoxide and partly sesquioxide of cobalt, corresponding to, though not so well defined, as the magnetic oxide of iron Fe_3O_4. This oxide is known in the arts as *prepared oxide of cobalt*, and is made from the black or sesquioxide by heating to whiteness for some time, and thus depriving it of a part of its oxygen.

In physical character the two oxides of cobalt are somewhat unlike, the higher oxide being *blacker* than the lower oxide, and less *dense*, and though the former is apparently much lighter, I was surprised to find that the specific gravity of the two oxides are not very widely different, as will be seen from the following results:— The specific gravity of two different representative samples of black oxide being 5·82 and 5·82 respectively, while the specific gravity of four different samples of prepared oxide were found to be 5·93, 6·48, 6·38, and 6·12.

I have here two specimens of the cobalt oxides just described, and which have been produced from the cobalt ores of New Caledonia. The following are the analyses:—

Black Oxide of Cobalt.

Sesquioxide of cobalt,	96·15 = 68·3 per cent. Co	96·91
Protoxide of nickel,	2·06	1·12
Sesquioxide of iron,	0·68	0·40
Tetroxide of manganese,	0·44	Nil.
Lime,	0·76	1·80
Magnesia,	Trace	0·50
Insoluble, silica, &c.,	Trace	0·16
	100·09	100·89

Analysis of Prepared Oxide of Cobalt.

	Per cent.	
Protoxide of cobalt (CoO),	*93·85	94·27
Protoxide of nickel,	1·79	1·17

* Equal to Sesquioxide of cobalt, Co_2O_2, 103·86
Do. Tetroxide of cobalt, Co_3O_4, 100·52
Do. Metallic cobalt, Co, 73·84

Sesquioxide of iron,	1·04	1·08
Sesquioxide of manganese,	0·16	0·14
Lime,	0·32	0·60
Magnesia,	0·25	0·40
Silica,	0·32	0·44
Oxygen by difference,	2·27	1·90
	100·00	100·00

It will be seen from the analysis of the prepared oxide of cobalt that it is not a well-defined oxide, but is rather a combination of protoxide with sesquioxide.

The principal use of black oxide of cobalt is in the manufacture of pottery ware, where it is employed to counteract the yellow colour the ware would otherwise possess after the process of firing,—the cobalt here playing the part of the blue of the laundry. So intense is the colouring power of cobalt that about 6 oz. to the ton of china clay is sufficient, and if more than about 1 lb. to the ton of clay be used, the ware has a distinct blue colour. I have received from a large pottery two specimens of china ware, one of which has had the usual admixture of cobalt, while another one has had no cobalt added to the clay from which the dish was made. In daylight a very decided yellow tint is visible in the latter.

The other uses of *black* oxide of cobalt are in colouring glass, and in the manufacture of cobalt ultramarine.

The principal use of *prepared* oxide of cobalt is as a pigment, especially in painting china (I have here a familiar specimen of a plate painted with this pigment), cobalt being the only blue colour that will stand the high temperature required in this case.

Up to the present time I have not heard of cobalt being found in any well-defined veins in New Caledonia—in this matter cobalt differs from the ores of nickel, which are found also in the island.

The nickel ores of New Caledonia contain no cobalt, but the cobalt ores, as we have seen from the analyses, contain a considerable percentage of nickel compared with the cobalt present.

It is rather troublesome to separate all the nickel from the oxide of cobalt in the process of refining, and in no sample that I have examined is the nickel entirely absent in the finished oxide of cobalt.

Nickel exists in the ores of New Caledonia as a silicate,—possibly a double silicate of nickel and magnesia,—and this ore is probably one of the most easily refined of all the ores of nickel. This is readily seen from the following analyses of six representative samples :—

Oxide of nickel,	7·00	11·08	12·68	18·04	19·00	24·28
Oxide of iron, .	4·47	7·34	7·14	0·88	6·60	3·80
Alumina, . .	2·53	1·56	1·50	1·24		
Lime, . .	2·30	1·90	0·72	Trace	Trace	0·58
Magnesia, . .	31·42	22·50	21·80	16·37	16·30	15·75
Silica, . .	40·96	37·96	44·00	45·74	44·00	40·24
Water, . .	12·00	17·30	12·16	17·28	20·00	16·21
	100·68	99·64	100·00	99·55	99·90	100·86

The average ores worked contain about 10 per cent. of a metallic nickel. I have here as representative a set of specimens of the nickel ores as could be obtained. It has a green colour, and was mistaken for an ore of copper at one time.

The refined nickel is usually sent into the market either in shape of small cubes or round cakes. I have here specimens of each of these. The nickel rounds are prepared by mixing, intimately, the oxide of nickel refined from the ore, along with wood charcoal, and after stamping into the round shape (shown in the specimen), the cakes are dried, and the oxide is reduced to the metallic state at a high temperature, the round cakes still retaining their shape. Nickel made in this way is chiefly employed in the manufacture of German silver, or other alloys of nickel and copper; it is brittle, and has a distinct crystalline appearance on being broken. Before proceeding to speak of malleable nickel and other uses of the metal and its alloys, I shall give a few of the analyses that have been made of the oxide and of the metallic nickel manufactured from the ores of New Caledonia. I may here mention that these analyses are representatives of a great many hundred tons of refined oxide and metallic nickel derived from New Caledonia, which is believed to be the largest source of nickel supply in the world.

Analyses of Oxide of Nickel.

Nickel, . . .	77·51	77·67
Copper, . . .	None	None
Iron, . . .	0·54	0·47
Oxygen, . . .	21·30	21·50
Impurities, . .	0·65	0·34
	100·00	99·98

Four Analyses of Nickel Cakes.—Metallic nickel 98·25 per cent., 98·82 per cent., 98·83 per cent., 98·37 per cent. I am not able at present to give greater detail in the last analysis, the difference, however, is made up of some carbon, iron, and silicon.

Of recent years a process has been patented to make nickel malleable, and render the metal suitable for rolling and stamping. This process consists in adding to the fused nickel contained in a crucible a small quantity of metallic magnesium, the effect of this, according to some authorities, is to deprive the nickel of a minute quantity of oxygen. The metal that this sheet was made from, and the various nickel articles here, have been manufactured from nickel treated in this way. The importance of malleable nickel for many purposes in the arts is very great.

Pure nickel is not a readily oxidisable metal, and its resistance to the action of the atmosphere, and also to the action of both fresh and salt water, admits of its being ranked in these respects with the precious metals.

This valuable property of not being readily tarnished or oxidised offers special inducements to employ nickel for the exposed parts of machinery and engines, for surgical, optical, and scientific instruments and apparatus, for artistic and ornamental work of all sorts, in jewellery, and in a great variety of other ways.

Another important property of nickel is its whitening effect upon copper when alloyed with it, forming the well known "German" or "nickel silver." Some very beautiful alloys of nickel, copper, and tin have been quite recently obtained, and these alloys have received the name of "New Caledonia silver." This alloy is peculiarly white in colour, whiter indeed than pure nickel itself. It is also very malleable. I have obtained specimens of sheets made of this composition, and likewise of some articles, which may be of interest to this Society, made from the same alloy.

Another very important use of nickel is in the sheathing of ships; perhaps sufficient trials have not yet been made to speak confidently, but I may perhaps be allowed to quote the remarks of a gentleman present at the docking of a ship on which some experiments had been made. He was present at the docking of the "Roma," and writes as follows:—

"The whole ship, as far as it had been in the water, was covered with a band of sea-weed and shells for a thickness of several inches; the nickel plates were, however, completely free of all growth, and quite clean, the only alteration in appearance being a slight violet discoloration, such as tarnished silverplate. Otherwise they were without any dirt or slime, so that they could have been written on with a lead pencil. The sheets seemed to be bright eyes or windows, and the nickel plates were not blistered or damaged in any way. The plates having been brushed were as clean as new ones. It should be remembered that the 'Roma' was at sea for eleven months, and that she was in some of the worst places—such as the Straits of Magellan—for the accretion of sea-weed and barnacles."

Recently culinary and other vessels made of sheet iron, coated inside and out with thin sheets of malleable nickel, have been the object of manufacture. These articles, of which I have here some specimens, are indistinguishable of course from vessels made of pure nickel throughout. (I have here some examples of the latter for comparison.) The object of coating these vessels is to save expense compared with the pure metal. Lastly, I may just mention that another important outlet for nickel is in the coinage. Many countries have now a nickel coinage, and it is probable the use of nickel in this direction will be soon largely extended.

In conclusion, I should like to give a few details of some experiments I have recently made in regard to the solubility of nickel in acids, and its behaviour in some other ways.

First, in regard to the solubility of nickel in acids. I began with acetic acid, and the treatment in this acid was repeated very much in the same way as in case of other acids—that is, the nickel was boiled in a large quantity of acid of various strengths, and allowed to remain under this treatment four to five days.

1. In acetic acid, 0·21 per cent. of nickel dissolved.

2. In tartaric acid, the nickel was not acted upon.

3. In a mixture of solution of citric and tartaric acids, the nickel upon the treatment as described lost 0·08 per cent.

4. In oxalic acid, the loss amounted to 0·14 per cent.

5. In cold dilute hydrochloric acid, no loss was sustained (the HCl sol. was 1 to 6); but on heating the solution the nickel dissolved.

6. In cold dilute sulphuric acid (1 to 4), the nickel lost 0·14 per cent., and behaved on heating as with the last acid.

When nickel articles, such as those before you, are heated over an Argand or Bunsen burner, a thin unweighable coating of oxide is formed (which can be removed by sand-paper), the nickel vessel becoming very dark in colour.

Caustic soda can be fused in a nickel basin with scarcely any change in weight. In one experiment, where the caustic soda was fused for one hour in a small nickel basin, the gain in weight amounted to 0·013 per cent.

These, then, are a few of the experiments that I have been able to make with this metal; some of them proving the value of nickel for many purposes to which it has hitherto not been applied.

2. Note on a Singular Passage in the *Principia*, By Professor Tait.

In the remarkable *Scholium*, appended to his chapter on the Laws of Motion, where Newton is showing what Wren, Wallis, and Huygens had done in connection with the impact of bodies, he uses the following very peculiar language:—

"Sed et veritas comprobata est a *D. Wrenno* coram *Regiâ Societate* per experimentum Pendulorum, quod etiam *Clarissimus Mariottus* Libro integro exponere mox dignatus est."

The last clause of this sentence, which I had occasion to consult a few days ago, appeared to me to be so sarcastic, and so unlike in tone to all the context, that I was anxious to discover its full intention.

Not one of the Commentators, to whose works I had access, makes any remark on the passage. The Translators differ widely.

Thus Motte softens the clause down into the trivial remark "which Mr Mariotte soon after thought fit to explain in a treatise entirely on that subject."

The Marquise du Chastellet (1756) renders it thus:—

". . . . . . mais ce fait *Wrenn* qui les confirma par des Expériences faites avec des Pendules devant la Sociétè Royale: lesqelles le célèbre *Mariotte* a rapportées depuis dans un Traité qu'il a composé exprès sur cette matière."

Thorp's translation (1777) runs:—
"which the very eminent Mr Mariotte soon after thought fit to explain in a treatise entirely upon that subject."

Finally, Wolfers (1872) renders it thus:—
"der zweite zeigte der Societät die Richtigkeit seiner Erfindung an einem Pendelversuche, den der berühmte Mariotte in seinem eigenen Werke aus einander zu setzen, für würdig erachtete."

Not one of these seems to have remarked anything singular in the language employed. But when we consult the "entire book" in which Mariotte is said by Newton to have "expounded" the result of Wren, and which is entitled *Traité de la Percussion ou Choc des Corps*, we find that the name of Wren is not once mentioned in its pages! From the beginning to the end there is nothing calculated even to hint to the reader that the treatise is not wholly original.

This gives a clue to the reason for Newton's sarcastic language; whose intensity is heightened by the contrast between the *Clarissimus* which is carefully prefixed to the name of Mariotte, and the simple *D.* prefixed, not only to the names of Englishmen like Wren and Wallis, but even to that of a specially distinguished foreigner like Huygens.

Newton must, of course, like all the scientific men of the time (Mariotte included), have been fully cognizant of Boyle's celebrated controversy with Linus, which led to the publication, in 1662, of the *Defence of the Doctrine touching the Spring and Weight of the Air.* In that tract, Part II. Chap. 5, the result called in Britain *Boyle's Law* is established (by a very remarkable series of experiments) for pressures less than, as well as for pressures greater than, an atmosphere; and it is established by means of the very form of apparatus still employed for the purpose in lecture demonstrations. Boyle, at least, claimed originality, for he says in connection with the difficulties met with in the breaking of his glass tube:—

". . . . an accurate Experiment of this nature would be of great importance to the Doctrine of the Spring of the Air, and has not been made (that I know) by any man. . . ."

In Mariotte's *Discours de la Nature de l' Air*, published FOURTEEN years later than this work of Boyle, we find no mention whatever of

Boyle, though the identical form of apparatus used by Boyle is described. The whole work proceeds, as does that on *Percussion*, with a calm ignoration of the labours of the majority of contemporary philosophers.

This also must, of course, have been perfectly well known to Newton :—and we can now see full reason for the markedly peculiar language which he permits himself to employ with reference to Mariotte.

What was thought of this matter by a very distinguished foreign contemporary, appears from the treatise of James Bernoulli, *De Gravitate Ætheris*, Amsterdam, 1683, p. 92.

"Veritas utriusque hujus regulæ manifesta fit duobus curiosis experimentis ab Illustr. Dn Boylio hanc in rem factis, quæ videsis in *Tractatu ejus contrà Linum, Cap.* V., cui duas Auctor subjunxit Tabulas pro diversis Condensationis et Rarefactionis gradibus."

In order to satisfy myself that Newton's language, taken in its obvious meaning, really has the intention which I could not avoid attaching to it, I requested my colleague Prof. Butcher to state the impression which it produced on him. I copied for him the passage above quoted, putting A. for the word *Wrenno*, and B. for *Mariottus;* and I expressly avoided stating who was the writer. Here is his reply :—

"I imagine the point of the passage to be something of this kind (speaking without farther context or acquaintance with the Latinity of the learned author) :—

A established the truth by means of a (simple) experiment, before the Royal Society; later, B thought it worth his while to write a whole book to prove the same point.

I should take the tone to be highly sarcastic at B's expense. It *seems* to suggest that B was not only clumsy but dishonest. The latter inference is not certain, but at any rate we have a *hint* that B took no notice of A's discovery, and spent a deal of useless labour."

This conclusion, it will be seen, agrees exactly with the complete ignoration of Wren by Mariotte.

When I afterwards referred Prof. Butcher to the whole context, in my copy of the first edition of the *Principia*, and asked him whether the use of *Clarissimus* was sarcastic or not, he wrote—

"I certainly think so. Indeed, even apart from the context, I thought the *Clarissimus* was ironical, but there can be no doubt of it when it corresponds to *D.* Wren."

In explanation of this I must mention that, when I first sent the passage to Prof. Butcher, I had copied it from Horsley's sumptuous edition; in which the *D*s are omitted, while the *Clarissimus* is retained.

Alike in France and in Germany, to this day, the Law in question goes by the name of Mariotte. The following extracts, from two of the most recent high-class text books, have now a peculiar interest. I have put a word or two of each in Italics. These should be compared with the dates given.

"Diese Frage ist schon frühzeitig untersucht und zwar *fast gleichzeitig* von dem französischen Physiker Mariotte (1679) und dem englischen Physiker Boyle (1662)." Wüllner, *Lehrbuch der Experimentalphysik*, 1882, § 98.

"La loi qui régit la compressibilité des gaz à température constante a été trouvée *presque simultanément* par Boyle (1662) en Angleterre et par Mariotte (1676) en France; toutefois, si Boyle a publié le premier ses expériences, il ne sut pas en tirer l'énoncé clair que donna le physicien français. C'est donc avec quelque raison que le nom de loi de Mariotte a passé dans l'usage." Violle, *Cours de Physique*, 1884, § 283.

On this I need make no remark further than quoting one sentence from Boyle, where he compares the actual pressure, employed in producing a certain compression in air, with "what the pressure should be according to the *Hypothesis*, that supposes the pressures and expansions to be in reciprocal proportion." M. Violle has probably been misled by the archaic use of "expansion" for volume.

It must be said, in justice to Mariotte, that he does not appear to have *claimed* the discovery of any new facts in connection either with collision or with the effect of pressure on air. He rather appears to write with the conscious infallibility of a man for whom nature has no secrets. And he transcribes, or adapts, into his writings (without any attempt at acknowledgment) whatever suits him in those of other people. He seems to have been a splendidly successful and very early example of the highest class of what we now call the *Paper-Scientists.* Witness the following extracts from

Boyle, with a parallel citation from Mariotte of *fourteen* years' later date *at least.* The comparison of the sponges had struck me so much, in Mariotte's work, that I was induced to search for it in Boyle, where I felt convinced that I should find it.

"This Notion may perhaps be somewhat further explain'd, by conceiveing the Air near the Earth to be such a heap of little Bodies, lying one upon another, as may be resembled to a Fleece of Wooll. For this (to omit other likenesses betwixt them) consists of many slender and flexible Hairs; each of which, may indeed, like a little Spring, be easily bent or rouled up; but will also, like a Spring, be still endeavouring to stretch itself out again. For though both these Haires, and the Æreal Corpuscles to which we liken them, do easily yield to externall pressures; yet each of them (by virtue of its structure) is endow'd with a Power or Principle of Selfe-Dilatation; by virtue whereof, though the hairs may by a Mans hand be bent and crouded closer together, and into a narrower room then suits best with the Nature of the Body, yet, whils't the compression lasts, there is in the fleece they composeth an endeavour outwards, whereby it continually thrusts against the hand that opposeth its Expansion. And upon the removall of the external pressure, by opening the hand more or less, the compressed Wooll doth, as it were, spontaneously expand or display it self towards the recovery of its former more loose and free condition till the Fleece hath either regain'd its former Dimensions, or at least, approached them as neare as the compressing hand, (perchance not quite open'd) will permit. The power of Selfe-Dilatation is somewhat more conspicuous in a dry Spunge compress'd, then in a Fleece of Wooll. But yet we rather chose to employ the latter, on this occasion, because it is not like a Spunge, an intire Body; but a number of slender and flexible Bodies, loosely complicated, as the Air itself seems to be."

And, a few pages later, he adds :—

". . . . a Column of Air, of many miles in height, leaning upon some springy Corpuscles of Air here below, may have weight enough to bend their little springs, and keep them bent: As, (to resume our former comparison,) if there were fleeces of Wooll pil'd up to a mountainous height, upon one another, the hairs that compose the lowermost Locks which support the rest, would, by the weight of all the Wool above them, be as well strongly compress'd as if a Man should squeeze them together in his hands, or imploy any such other moderate force to compress them. So that we need not wonder, that upon the taking off the incumbent Air from any parcel of the Atmosphere here below, the Corpuscles, whereof that undermost Air consists, should display themselves, and take up more room than before."

Mariotte (p. 151). "On peut comprendre à peu près cette différence de condensation de l'Air, par l'exemple de plusieurs éponges qu'on auroit entassées les unes sur les autres. Car il est évident, que celles qui seroient tout au haut, auroient leur entenduë naturelle: que celles qui seroient immédiatement au dessous, seroient un peu moins dilatées; et que celles qui seroient au dessous de toutes les autres, seroient très-serrées et condensées. It est encore manifeste, que si on ôtoit toutes celles du dessus, celles du dessous reprendroient leur étenduë naturelle par la vertu de ressort qu'elles ont, et que si on en ôtoit seulement une partie, elles ne reprendroient qu'une partie de leur dilatation."

Those curious in such antiquarian details will probably find a rich reward by making a careful comparison of these two works; and in tracing the connection between the *Liber integer*, and its fons et origo, the paper of Sir Christopher Wren.

Condorcet, in his *Éloge de Mariotte*, says:—"Les lois du choc des corps avaient été trouvées par une métaphysique et par une application d'analyse, nouvelles l'une et l'autre, et si subtiles, que les démonstrations de ces lois ne pouvaient satisfaire que les grands mathématiciens. Mariotte chercha à les rendre, pour ainsi dire, populaires, en les appuyant sur des expériences, &c." *i.e.*, *precisely* what Wren had thoroughly done before him.

"Le discours de Mariotte sur la nature de l'air renferme encore une suite d'expériences intéressantes, et qui étaient absolument neuves." This, as we have seen, is entirely incorrect.

But Condorcet shows an easy way out of all questions of this kind, however delicate, in the words:—"On ne doit aux morts que ce qui peut être utile aux vivants, la vérité et la justice. Cependant, lorsqu'il reste encore des amis et des enfants que la vérité peut affliger, les égards deviennent un devoir; mais au tout d'un siècle, la vanité peut seule être blessée de la justice rendue aux morts."

Thus it is seen that even the turn of one of Newton's phrases serves, when rightly viewed, to dissipate a widespread delusion:—and that while Boyle, though perhaps he can scarcely be said to have been "born great," certainly "achieved greatness;" the assumed parent of *La Loi de Mariotte* (otherwise *Mariottesches Gesetz*) has as certainly had "greatness thrust upon" him.

3. The Graphic Analysis of the Kinematics of Rigid-Bar Mechanisms. By Professor R. Smith. Communicated by Professor Tait.

4. Note on the Necessity for a Condensation-Nucleus. By Professor Tait.

The magnificent researches of Andrews on the Isothermals of Carbonic Acid formed, as it were, a nucleus in a supersaturated solution, round which an immediate crystallization started, and has since been rapidly increasing.

They gave the clue to the explanation of the paradoxical result of Regnault, that hydrogen is less compressible and other gases more compressible, under moderate pressures, than Boyle's Law indicates; and to that of the companion result of Natterer that, at very high pressures, all gases are less compressible than that law requires. Thus they furnished the materials for an immense step in connection with the behaviour of fluids *above* their critical points.

But they threw at least an equal amount of light on the liquid-vapour question—*i.e.*, the behaviour of fluids at temperatures *under* their critical points. In Andrew's experiments there was a commencement, and a completion, of liquefaction; each at a common definite pressure, but of course at very different volumes, for each particular temperature.

In 1871 Professor J. Thomson communicated to the Royal Society a remarkable paper on the *abrupt* change from vapour to liquid, or the opposite, indicated by these experiments. He called special attention to the necessity for a "start," as it were, in order that these changes might be effected. [It is to this point that the present note is mainly directed, but I go on with a brief analysis of

Thomson's work.] He pointed out that there were numerous experiments proving that water could be heated, under certain conditions, far above its boiling point without evaporating; and that, probably, steam might be condensed isothermally to supersaturation without condensing. Hence he was led to suggest an isothermal of continued curvature, instead of the broken line given by Andrews, as representing the *continuous* passage of a fluid from the state of vapour to that of liquid; the whole mass being supposed to be, at each stage of the process, in the same molecular state.

In Clerk-Maxwell's *Treatise on Heat*, this idea of J. Thomson's was developed, in connection with a remarkable speculation of W. Thomson,* on the pressure of vapour as depending on the curvature of the liquid surface in contact with it. This completely accounts for the deposition of vapour when a proper nucleus is present. Maxwell showed that it could also account for the "singing" of a kettle, and for the growth of the larger drops in a cloud at the expense of the smaller ones.

The main objection to J. Thomson's suggested isothermal curve of transition is that, as Maxwell points out, it contains a region in which pressure and volume increase or diminish simultaneously. This necessarily involves instability; inasmuch as, for definite values of pressure at constant temperature within a certain range in which vapour and liquid can be in equilibrium, Thomson's hypothesis leads to three different values of volume: two of which are stable; but the intermediate one essentially unstable. According to Maxwell, the extremities of this triple region correspond to pressures, at which, regarded from the view of steady increase or diminution of pressures, either the vapour condenses suddenly into liquid, or the liquid suddenly bursts into vapour.

If this were the case, no nucleus would be *absolutely* requisite for the formation either of liquid from vapour or of vapour from liquid. All that would be required, in either case, would be the proper increase or diminution of pressure;—temperature being kept unaltered. The latent heat of vapour, which we know to become less as the critical point is gradually arrived at, would thus be given off in the explosive passage from vapour to liquid. It is difficult to

* *Proc. Roy. Soc. Edin.*, 1870.

see, on this theory, how it can be explosively taken in on the sudden passage from liquid to vapour.

Aitken's experiments tend to show, what J. Thomson only speculatively announced, that possibly vapour may not be condensed (in the absence of a nucleus), when compressed isothermally, even at ranges far beyond the *maximum* of pressure indicated in Thomson's figures. Hence it would appear that the range of instability is much less than that given by Thomson's figures, and may (perhaps) be looked on as a vanishing quantity ; the corresponding part of the isothermal being a finite line parallel to the axis of pressures, corresponding to the sudden absorption or giving out of latent heat.

Monday, 2nd February 1885.

THOMAS STEVENSON, Esq., Memb. Inst. C.E., President, in the Chair.

The following Communications were read :—

1. The President delivered the following Address :—

With the prospect of addressing you for the first time since you did me the very great honour of asking me to act as your President, I felt somewhat at a loss to determine on what subject I should venture to speak to you; but, at last, I resolved to refer to an exceedingly important question of maritime engineering practice, which gave rise to very lengthened inquiries before Committees during the last two Sessions of Parliament, involving a contemplated expenditure of many millions sterling, and deeply affecting, for good or evil, the entrance from the sea to the great port of Liverpool. I refer to the proposed Manchester Ship Canal.

That scheme (for the following remarks have, of course, no reference whatever to the scheme as now proposed for sanction by Parliament) cannot but be regarded as involving one of the most momentous physical questions that ever was raised in Britain, and although such a question may, perhaps, never again become one of national import in this country, still, I think, no apology is necessary for bringing it before the notice of this Society.

About half a century ago a principle was admitted into the practice of the maritime engineer, which was considered at the time to be sound, and which the majority of the profession until lately regarded of universal application, from its having for many years been practically tested in many different cases with the most gratifying success.

The principle to which I allude is the confining of the ebb and flow of the river and tidal water to one fixed channel of a certain width by means of what are called *training walls.* These are low structures of stone or timber, placed in tidal estuaries, and carried to such a height only as is just sufficient to guide the direction of the first of the flood tide and last of the ebb. It was found, in practice, that a very small elevation of those walls above the bottom was sufficient to restrain and direct the course of the heaviest land floods and strongest tide currents; and this, because such floods and currents always increase in volume more or less slowly, so that if the walls project only high enough to guide the comparatively gentle beginnings of those discharges, they will be sufficient to direct them after they have attained their greatest volume and highest velocity; for, as the flood increases gradually, the depth will in like manner always go on increasing in the line of the directing wall, since the flood must necessarily continue to follow the line of least resistance, which will always be in the line of greatest depth; so that (excepting in very rare cases) all that is needed to control the direction of the heaviest land flood or the highest tide is to fix the direction of the first of either tide or freshet—*obsta principiis* by the time that either flood or tide has submerged the training walls; the line of direction of such flood or tidal current has been already permanently fixed.

Principally, by means of those walls and steam dredging, the river Clyde has been increased from a depth of 13 feet 8 inches to no less than 26 feet up to Glasgow; but the soundness of this system, which was so triumphantly carried out on the Clyde, has also been, as I have said, proved over and over again to be no less applicable to other rivers as well.

The Ribble, the Tyne, the Tees, the Nith, the Lune, &c., though varying in many of their physical characteristics, have all been improved in the same way, without producing any reduction in depth by the silting up of their sea approaches.

This modern mode of improvement was therefore naturally generally regarded as thoroughly safe, and almost free from any suspicion of danger; yet, nevertheless, we have within the last year or two witnessed the greatest suspicion and excitement about the risk of silting in connection with the intended Manchester Ship Canal, as originally proposed to be carried out, by the erection of training walls in the estuary of the river Mersey. But a few months ago very eminent engineers were ranged on opposite sides in Parliamentary Committees; and it was only, after an almost unprecedented struggle that a physical question was decided, which, in the opinion of many, myself among the number, might—settled otherwise than it was—have ended in something very like a national calamity, namely, the silting up of the sea approaches to Liverpool.

After not much short of half a century of the most varied experience in different parts of the United Kingdom, the profession hesitated to answer with a united voice either aye or no, one of the most important questions ever laid before them by the public. Thirty years of practice, and of successful practice, might have been thought enough to give a satisfactory solution; but when the question was laid before us, with regard to this particular river, it took a new shape. New considerations arose, and new criteria were evolved. This was a lesson to me, and, I think, it should be one to the profession. Among those who from the first confidently predicted that disastrous consequences from silting would follow in the Mersey, I may mention the names of Mr Vernon Harcourt, C.E.; Mr Lyster, the engineer of the Liverpool Docks; and Captain Hills, the marine surveyor of the port of Liverpool.

The Mersey was, at first sight, no exceptional river. The rise and maximum velocity of tide was much the same as in the Ribble; the breadth of estuary was similar to that of the Tees; and the matter in suspension was much less than in the Lune. Yet training walls and steam dredging had increased the depth in the Ribble to between 7 and 8 feet up to Preston; in the Lune to 4 feet up to Lancaster; and in the Tees from 3 to 20 feet as high as Stockton.

With such facts before me, I was slow in coming to any decided view. My instincts or "my feelings," as Smeaton would have expressed it, no doubt warned me against the adoption of training walls at the Mersey, but without telling me why. My brother and myself had successfully improved eleven different navigable rivers by means of training walls and dredging. There was not one physical characteristic of the Mersey which, viewed by itself, would render inapplicable the same treatment, and it had not yet occurred to me that certain characteristics, any one of which was harmless in itself, might, when taken together, justify fears of disaster; so that it was not until I had resurveyed three of the rivers I had formerly improved on the system of training walls that I concluded it was solely due to the existence of certain characteristics which existed in all the three rivers, that the deposits of sand had so quickly followed the erection of the training walls. Hence I concluded that it would be unsafe to risk training walls in the Mersey, where similar characteristics were not only more numerous, but much more strongly marked.

The river Lune was the navigation that first startled me. It was improved by training walls and by steam dredging of the channel, with an eye solely to improving the navigation, and with no afterthought of reclaiming land by accretion. The walls were but 3 feet high, and placed strictly parallel to the stream, nor was any part protected, still less enclosed, by cross walls. Two years after the completion of the work, however, it was found that a considerable accretion of sand had taken place. In 1851, being only two years after the works were finished, a marine survey was made, which showed that the amount of accretion behind the walls had already amounted to 3000 cubic yards of sand, although that amount of deposit was quite balanced by a gain of additional water admitted from the sea through the deepened channel. In 1884, however, thirty-four years after the completion of the works, I had the Lune once more surveyed, when it was found that 230 acres were covered with grass, thus establishing the important physical fact that the deposit had risen to the level of high-water neap tides, and the total accretion had reached the amount of 5,536,060 cubic yards. In the same year I had a fresh survey taken of the river Nith below Dumfries,—a navigation which had been improved by training walls alone,—and the accretion was found to amount to 3,192,970 cubic yards; and again, in the same year, I revisited the third river, to which I have referred,—the Ribble below Preston,—and found that about 5000 acres of what was formerly estuary were grassed over.

These three rivers had, therefore, since the completion of the training walls, been undoubtedly subject to large deposits of sand; but the original improvement in depth, and increased velocity in the propagation of the tidal wave, were still maintained, so that, as navigation works, they must be held to have been quite successful. Indeed, if similar improvements had to be done over again, I should not propose to make any change whatever in the mode of carrying out the works. It will be seen, however, from these cases, that training walls exert a double influence—one directly for good, by enlarging and deepening the main channel; another directly for evil, since the deposit of silt behind the walls must reduce the scouring power by diminishing the area filled at each tide, and thus keeping back a corresponding quantity of tide-water from entering the estuary. Thus the ultimate result for good or for evil must be in each case determined by a comparison of the relative amounts of these *plus* and *minus* quantities.

Here, then, we have the first and elementary ground of that negative answer, which I and others of my professional brethren returned to the question proposed for solution in the case of the Mersey.

If, for instance, the waters of a navigation contained no matter in suspension, the system of training walls would give merely a plus result, and their influence be therefore wholly beneficial; but even where there was matter in suspension in the land-locked portion of the estuary,—by which I mean that portion between the training wall and the river bank behind it, where alone siltage can go on,—and supposing the area of that portion should happen to be very small in comparison to the whole extent of the open estuary, the *plus* result would still outweigh the *minus*, and the balance of the influence be for good. What naturally is land-locked might no doubt be silted up, and lost to the navigation; but then, if that extent be small compared with what still remains open to the entrance of the tides, the river on the whole will be improved. If, on the other hand, the land-locked portion of the estuary be very large, the total deposit may not only far more than counterbalance the additional water gained by extra water passing up the improved channel, but leave so little space for the reception of tidal water in the estuary, that the amount of scouring water that can in future come in from the sea will be insufficient any longer to keep open either the bar or the lower channels, then the navigation will be ruined.

This possibility once admitted, that the benefit of the application of training walls really depends on the relative proportion of the good and evil influences, it becomes necessary next to consider in more detail the natural features which I believe tend to the formation and deposit of matter in suspension, and which ought, therefore, to be regarded as dangerous in the application of training walls to any river where there is a wide estuary. These characteristics have, so far as I know, not been before referred to in connection with the subject now under consideration.

In future, then, I consider it essential that in every case the following characteristics ought to be fully inquired into and taken into account before training walls are resorted to :—

I. *A High Rise of Tide.*

Because if there be matter in suspension in the sea (due to the action of the waves on the bottom when they reach shoal water), the higher the rise of tide the greater will be the amount of solid matter that will be brought from the sea.

II. *A Rapid Tidal Flood Current.*

Because, from erosion of the sides and bottom, the more rapid the current the greater the amount of sandy and silty matter that will be disturbed and carried up the river.

III. *Tidal Bore.*

Where there is a tidal bore with a cresting or breaking head, which, from its necessarily acting in shallow water, and with a very high velocity, greatly cuts up the bottom and sides of the channel, so as to set free a large amount of matter.

IV. *A Bar.*

Because if there is either a bar or extensive sandbanks, with heavy breaking waves, at the mouth of a navigation, large quantities of matter are set loose, which may be carried inward by the flood tide, so that a bar and the adjoining sea shores may be regarded as natural *silt producers*, which never fail to generate a constant and large supply of matter for deposit.

V. *Natural Limit to the Erection of Walls.*

Given the above features, the only known expedients for counteracting the evil of the reduced amount of scouring power, consequent on siltage, are those proposed by my brother, Mr D. Stevenson, about forty years ago—first, by continuing the training walls down to the sea, and thus concentrating what yet remains of the reduced scouring power upon the lower channel of the navigation; and, second, by the erection of breakwaters in deep water to shelter the bar from the beating of the sea upon its surface, and thus to neutralise, if not to annihilate, these great originators of silt. If, owing to the local circumstances of the case, both of these plans be impracticable, we may almost regard these circumstances as presenting a fifth and serious element of danger.

VI. *Amount of Matter in Mechanical Suspension.*

But, again, instead of arguing from principles, *the amount of matter in suspension* may be ascertained by direct observation, and will thus form another definite element in the comparison of rivers.

VII. *The Existence of a Wide Land-locked Estuary.*

And last, and one of the most dangerous of all, *the existence of a wide land-locked estuary*, as already referred to.

Such are the criteria which we shall now proceed to apply to the comparison of the *river Mersey* with six rivers which have all been improved by training walls.

In three of these—the *Nith*, *Lune*, and *Ribble*—there have been, as we have seen, great accretions; in the other three—the *Clyde*, *Tyne*, and *Tees*—although training walls have been also long since employed, there have been hardly any or no deposit.

Let us look first at the three last cases, as to which it was very strongly and pertinently urged before Parliament that no deposit has ever taken place, although training walls have been in existence for many years.

Now it is not surprising that the introduction of training walls has not produced deposit in all rivers, for the fact seems just as certain, on physical grounds, that they will not produce accretion in some rivers as that they will produce it in others. It is essential that before accretion can, in any case, take place there must be matter in suspension, or, in other words, there must in some part of the river be water in such rapid motion as to break up and move the materials of the bottom and sides of the channel, while at some other part of the river there must be such retardation of the velocity of the water as to cause the deposit of the matter in suspension; and, besides this, there must be a large receptacle to contain this matter, and sufficiently sheltered from waves and currents to retain it after deposit.

The Clyde.—Having for the last twelve years acted as engineer to the Clyde Lighthouses Trustees, who are the Conservators of the lower estuary of that river, and having during that time been engaged in conducting very extensive dredging operations, I am necessarily fully acquainted with its peculiarities, and can state that there is only one point of resemblance of any consequence between that river and the Mersey, viz., that the lower land-locked estuary of the Clyde is about the same in width as that of the widest part of the Mersey below Halehead. But then there is no training wall *connected with the shore* for guiding the channel through this wide estuary, so that we can get no information on the subject at issue. The walls which do exist in the Clyde are mainly in the upper part of the river, where the navigable channel is only about 400 feet wide, and where there is no large space left for silting up to take place between these walls and the land.

With the one exception of the wide estuary to which I have referred, none of the characteristics which are favourable to deposit exist in the Clyde, as I will now show. The rise of tide in the Clyde is only 10½ feet, as against 30 feet at the Mersey. The maximum velocity of the tidal flood current is only about half a mile per hour, as against 7 at the Mersey. There is no tidal bore at the Clyde, and a very rapid one at the Mersey. There is neither a bar nor any heavy breaking waves at the Clyde, but there are both at the Mersey. There is only 1 cubic inch of silt to 1 cubic yard of water at the Clyde, and 33 cubic inches to 1 cubic yard at the Mersey.

There is a depth of 20 fathoms at low water where the Clyde joins the sea, which is land-locked and sheltered, while there is only $1\frac{1}{2}$ fathom at low water on the bar at the Mersey, which is in the open and stormy Irish Channel.

In short, no two sandy rivers can well be more different in their main features than the Mersey and the Clyde. It is therefore quite what might be expected, that there should be scarcely any accretion in the Clyde.

The Tyne.—At the Tyne matters are, on the whole, in much the same state as at the Clyde, for the rise of tide is only 13 feet. There is no bore, and the bar has been deepened and sheltered by the extensive breakwaters now in progress; and though there are training walls, they have been erected so close to the land as to leave no large receptacle for silt to be deposited, so that there is hardly any similarity between the Tyne and the Mersey.

The Tees.—As at the Tyne, the best means have in the case of the Tees been already employed of counteracting the risk of silting by the extension of the training walls down to the sea, and the erection of sheltering breakwaters which protect the bar, where there used to be only 3 feet of depth, whereas there is now a depth of 20 feet; and, besides, there is only 15 feet of a rise of tide, with a flood tide current of only $4\frac{1}{2}$ miles an hour, so that no argument applicable to the Mersey can be derived from the Tees, any more than from the Clyde or the Tyne.

From these rivers we turn to the facts relating to those in which silting has really taken place, and where training walls have been adopted, but where there are dangerous characteristics, but those of a comparatively subdued nature compared with those which are in the Mersey.

The results of the statements already made may be thus shortly summarised. That silting up to grass level may take place in an estuary, though the rise of tide may be no greater than 24 feet, as at the Ribble; where there is no bore, as at the Lune and Ribble; where there is no bar, as at the Nith; and where the ratio of matter in mechanical suspension may be as low as 3·68 cubic inches, as at the Nith.

It is obvious, therefore, that there is every possible reason to expect that if walls be erected accretion will take place up to the grass level in the Mersey, where we find combined every one of these characteristics of danger, which is not the case in any of the other rivers referred to. Not only so, but in every case those characteristics are more strongly marked. To all this must be added the all-important fact that if silting take place, as must be expected, there seems no practical mode of remedying the evil; for, owing to local circumstances, the walls cannot be extended so as to shelter the bar, as that would require no fewer than ten miles of breakwater to be erected in the stormy waters of Liverpool Bay.

But while the erection of training walls on the Nith, Lune, and Ribble has thus been followed by large deposits of silt, it is still, and with truth, contended that these navigations have been, upon the whole, greatly improved.

We are here thrown back once more upon the question of ratio between the effects for good and evil; of ratio between the extra amount of tidal water gained by deepening and enlarging the mid-channel, and the amount of scouring water altogether excluded by accretion in the land-locked estuary, on which ratio, as already stated, the whole question mainly depends.

But how is the value of this ratio to be determined, and what limit is it safe to observe?

I can only here refer to the case of another river, not yet alluded to, viz., the *Tay*, which, during the years 1833 to 1844, was improved according to designs of my late father, so that an additional depth of 4 feet and a tidal acceleration of 50 minutes were got up to the quays at Perth. But no training walls were ever proposed to be erected in the lower and wider part of the estuary, where there is sand and silt.

In the year 1845, however, certain riparian proprietors proposed to embank land in the lower and wider estuary, and the authorities of the important harbour and docks of Dundee became alarmed for the safety of their interests, and applied to the Admiralty to send an engineer of eminence to report on the whole subject. The engineer selected was the late Mr James Walker, the then permanent President of the Institution of Civil Engineers, and the acknowledged head of the profession in all maritime matters. In an elaborate report he condemned the proposed works, on the ground that they would exclude *one-twentieth* of the scouring tidal power of the Tay.

In the opinion, then, of Mr Walker, the first engineer of his day, and the one who carried out most of the later improvements of the river Clyde between Glasgow and Dumbarton, the loss of *one-twentieth* of the natural tidal scouring power at the Tay ought to be firmly resisted. But is this caution to be accepted, or should it be regarded as excessive?

Turning to ascertained fact, the only one to which I can appeal is that observed at the Lune, for I have no means of knowing what has actually taken place at either the Nith or the Ribble.

The loss of tidal scouring water due to the training walls at the Lune was found to be *one-tenth*, but from this loss no evil consequences appear to have resulted. We have then, by way of criteria, only two to guide us, viz., Mr Walker's opinion that a loss of *one-twentieth* would prove injurious at the Tay, and the ascertained fact that a loss in the case of the Lune of *one-tenth* of the scouring power did no harm.

Turning now to the case of the Mersey, and assuming, as we have more than sufficient reason for doing, that deposit of sand will take place up to the grass level in the land-locked estuary of that river, as it has done already in the kindred but less dangerous cases referred to, we have next to ascertain what would be the ratio of loss in that case.

The total amount of deposit, as ascertained from actual soundings, would be about 460,000,000 cubic yards, measuring from the present bottom up to grass level, while the additional tidal capacity which will be simultaneously gained through dredging and scouring the improved channel will amount to about 14,000,000 cubic yards; and, deducting the one from the other, we find a balance of loss of 446,000,000 cubic yards.

But in order to judge of the effect of this loss, we must contrast it with the total amount of tidal water above the level of low-water spring tides, which at present enters the estuary from the sea at the mouth of the river, and which fills the tidal basin up to Runcorn. This amounts to about 733,000,000 cubic yards, to which must be added the average fresh-water drainage of the Irwell and Mersey districts, which I compute at about 9,000,000 cubic yards in twelve hours, making a total scouring power of 742,000,000 yards.

Compare this with the resulting loss, and we find that not *one-twentieth,* which Mr Walker feared to authorise at the Tay—not *one-tenth,* as has actually taken place at the Lune—but *one-half of the whole scouring power would be excluded from the estuary of the Mersey.*

With such a result as this, I cannot for a moment doubt that the promoters of the Manchester Canal, and Mr E. Leader Williams, their engineer, before going to Parliament for the present Bill, exercised a wise discretion in resolving to adopt the suggestion of Mr Lyster of Liverpool to keep the new Ship Canal—*i.e.*, the one now before Parliament—altogether outside of, and therefore clear of the land-locked estuary of the Mersey, so as no longer to expose the works to the rapid tides and land floods, as in the first scheme.

The lesson, then, as it seems to me, which is to be derived from all that has been said, is simply that where there is a conjunction of an extensive land-locked estuary, with all, or with many of those conditions favourable to silting which I have defined, such a state of matters should in all cases be regarded as more or less dangerous, and especially so in any river where the depth is already reduced by the existence of a shallow bar lying beyond the mouth of the river, and exposed to a heavy breaking sea, from the action of which it cannot be protected by breakwaters.

2. On Evaporation and Condensation. By Professor Tait.

(*Abstract.*)

While I was communicating my Note on the *Necessity for a Condensation Nucleus* at the last meeting of the Society, an idea occurred to me which germinated (on my way home) to such an extent that I sent it off by letter to Professor J. Thomson that same night.

J. Thomson's idea, which I had been discussing, was to preserve, if possible, physical (as well as geometrical) *continuity* in the isothermal of the liquid-vapour state, by keeping the *whole* mass of fluid in one state throughout. He secured geometrical, but not physical, continuity. For, as Clerk-Maxwell showed, one part of his curve makes pressure and volume increase simultaneously, a condition essentially unstable. The idea which occurred to me was, while preserving geometrical continuity, to get rid of the region of physical instability, *not* (as I had suggested in my former Note) by retaining Thomson's proposed finite maximum and minimum of pressure in the isothermal, while bringing them infinitely close together so far as volume is concerned, and thus restricting the unstable part of the isothermal to a finite line parallel to the pressure axis; but, *by making both the maximum and minimum infinite.* Geometrical continuity, of course, exists across an asymptote parallel to the axis of pressures; so that, from this point of view there is nothing to object to. On the other hand there is essentially physical discontinuity, in the form of an impassable barrier between the vaporous and liquid states, so long at least as the substance is considered as homogeneous throughout.

It appeared to me that here lies the true solution of the difficulty. As we are dealing with a fluid mass essentially homogeneous throughout, it is clear that we are not concerned with cases in which there is a molecular surface-film.

Suppose, then, a fluid mass, somehow maintained at a constant temperature (lower than its critical point), and so extensive that its boundaries may be regarded as everywhere infinitely distant, what will be the form of its isothermal in terms of pressure and volume?

Two prominent experimental facts help us to an answer.

First. We know that the interior of a mass of liquid mercury can be subjected to hydrostatic *tension* of considerable amount without rupture. The isothermal must, in this case, *cross* the line of volumes;—and the limit of the tension would, in ordinary language, be called the cohesion of the liquid. I am not aware that this result has been obtained with water free from air; but possibly the experiment has not been satisfactorily made. The common experiment in which a rough measure is obtained of the force necessary to tear a glass plate from the surface of water is vitiated by the instability of the concave molecular film formed.

Second. Aitken has asserted, as a conclusion from the results of direct experiment, that even immensely supersaturated aqueous vapour will not condense without the presence of a nucleus. This may be a solid body of finite size, a drop of water, or fine dust-particles.

Both of these facts fit perfectly in to the hypothesis that the isothermal in question has an asymptote parallel to the axis of pressure ; the vapour requiring (in the absence of a nucleus) practically infinite pressure to reduce it, without change of state or of temperature, to a certain finite volume; while the liquid, also without change of state or temperature, may by sufficient hydrostatic *tension* be made to expand almost to the same limit of volume.

This limiting volume depends, of course, on the temperature of the isothermal; rising with it up to the critical point.

The physical, not geometrical, discontinuity is of course to be attributed to the latent heat of vaporisation. The study of the adiabatics, as modified by this hypothesis, gives rise to some curious results.

It is clear that the experimental realisation of the parts of the here suggested curve near to the asymptote, on either side, will be a matter of great difficulty for any substance. But valuable information may perhaps be obtained from the indications of a sensitive thermo-electric junction immersed in mercury at the top of a column which does not descend in a barometer tube of considerably more than 30 inches long, when the tube is suddenly placed at a large angle with the vertical; or from those of a similar junction immersed in water, when it has a concave surface of great curvature from which the atmospheric pressure is removed.

Nothing of what is said above will necessarily apply when we have vapour and liquid in presence of one another, or when we consider a small portion of either in the immediate neighbourhood of another body. For then we are dealing with a state of stress which cannot, like hydrostatic pressure or tension, be characterised (so far as we know) by a single number. The stress in these molecular films is probably one of tension in all directions parallel to the film, and of pressure in a direction perpendicular to it. Thus it is impossible to represent such a state properly on the ordinary indicator-diagram. This question is still further complicated by the possibility that the difference between the internal pressures, in a liquid and its vapour in thermal equilibrium, may be a very large quantity.

3. Note on Ectocarpus. By John Rattray, B.Sc. Communicated by John Murray, Esq.

4. Some remarkable Concretions, collected in the neighbourhood of Philadelphia by the Rev. J. M. Macdonald, were exhibited.

PRIVATE BUSINESS.

The following Candidates were balloted for, and declared duly elected Fellows of the Society:—Professor W. R. Hodgkinson; Mr Hugh Robert Mill, B.Sc.; Mr John Rattray, M.A., B.Sc.; Mr William Miller, S.S.C.; Dr Alfred Daniell, M.A.; and Captain W. de Wiveleslie Abney, F.R.S.

Monday, 16th February 1885.

JOHN MURRAY, Esq., Ph.D., Vice-President, in the Chair.

The following Communications were read:—

1. Preliminary Report on the Cephalopoda collected during the Cruise of H.M.S. "Challenger." Part I. The Octopoda. By William E. Hoyle, M.A. (Oxon.), M.R.C.S.

(*Published by permission of the Lords Commissioners of the Treasury.*)

The collection of Cephalopoda made by H.M.S. "Challenger," though not extensive, is of great interest, not only because a considerable number of new species were discovered, but also because several rare forms were found in fresh localities, and because a few specimens (many of them fragmentary) were obtained, which bear interesting relations to those already known.

The following synopsis will indicate the general nature of the collection :—

Genera.	Previously known species.	New species.
Octopus, Lamk.,	7	11
Alloposus, Vll.,	1	...
Eledone, Leach,	1	2
Japetella, Hoyle,	...	2
Cirroteuthis, Eschr.,	...	3
Amphitretus, Hoyle,	...	1
Tremoctopus, d. Ch.	2	...
Argonauta, Linn.	1	...

The distribution of the species obtained furnishes an important instance of the general rule that while pelagic forms belong to but few species, each of which has a wide range of distribution, littoral genera are represented by very many species each confined within a narrow area. In the case of the Cephalopoda this law has been expressed by Professor Steenstrup in his division of both Octopoda and Decapoda into two groups, *littorales* and *pelagici* ;* to the former of these belongs the genus *Octopus* of which a distinct type was furnished by almost every resting-place of the expedition. Out of about eighteen species collected sixteen came not from dredging stations, but from shore collections; and of those obtained by the dredge or trawl only two were found in depths exceeding 500 fathoms.

The genus *Eledone* furnished two new species; one characterised by a short stumpy contour, and the other interesting as purporting to come from a great depth (1950 fathoms).

The most striking novelties of the Octopoda are to be found among the pelagic forms. The genus *Cirroteuthis*, hitherto known only from the coast of Greenland, has been found also in the Southern and Pacific Oceans; and the specimen from the former locality is remarkable for its size, which exceeds one yard in length.

Allied to *Cirroteuthis* is the new genus *Amphitretus*, which possesses a modification, unique among Cephalopoda, in the fusion

* Oversigt k. dansk. Vid. Selsk. Forhandl., p. 69, 1861.

of the mantle with the siphon, so as to leave two openings into the branchial cavity.

Some fragments which were picked up on the surface of the North Atlantic are beyond all reasonable doubt referable to the curious *Alloposus mollis*, Verrill.

The two specimens which for the present constitute the new genus *Japetella* are of great interest, and may be described shortly as a kind of pelagic *Eledone;* but one of them, *J. diaphana*, shows characters which approximate it to the Cranchiæformes, and it seems quite possible that it will ultimately prove not to be congeneric with *J. prismatica.*

Subjoined are diagnoses of the new forms of Octopoda.

Octopus, Lamarck.

Octopus verrucosus, Hoyle.

Octopus verrucosus, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xv. p. 222, 1885.

The *Body* is rounded, but so distorted by compression that no further details can be given. The *mantle-opening* extends fully halfway round the body, terminating a little below and behind the eye. The *siphon* is long, evenly conical, and pointed, and extends nearly halfway to the umbrella-margin.

The *Head* is short, not so broad as the body, and with *eyes* but slightly prominent.

The *Arms* are unequal in length, the second pair being considerably the longest, and almost six times as long as the body; they are comparatively stout, and taper gradually. The *umbrella* extends about one-fifth up the longest arms. The *suckers* are fairly close, deeply cupped and marked with radial grooves, between which are numerous very minute papillæ. About four suckers on each lateral arm opposite the umbrella-margin are larger than the others; beyond these they gradually diminish. The *hectocotylus* is present in both specimens, and is very minute (about 2 mm. long in the larger); it is acutely pointed, and the median groove has three transverse ridges.

The *Surface* of the back, dorsal surface of head, and umbrella is covered with irregular closely-set warts, which attain a maximum diameter of several millimetres in the nuchal region; the warts extend on to the ventral surface of the body, where they become much smaller, more even, and average less than 1 mm. in diameter. Above each eye there seems to have been a short cirrus, but these have been rather damaged.

The *Colour* is a dull purplish-grey, very dark above, much lighter below.

Habitat.—Inaccessible Island, Tristan da Cunha. 2 specimens, ♂.

Octopus Boscii (Lesueur), var. *pallida.*

Octopus Boscii (Lesueur), var. *pallida*, Hoyle, *Ann. and Mag. Nat. Hist.* ser. 5, vol. xv. p. 223, 1885.

The *Body* is evenly rounded, with a slight depression in the median ventral line. The *mantle-opening* extends less than half-way round the body, terminating immediately below the eye, and further from it than from the base of the *siphon*, which is long and pointed, has rather a small opening, and extends two-thirds the distance to the umbrella-margin.

The *Head* is short, and not so broad as the body; the *eyes* are only slightly prominent.

The *Arms* are subequal, nearly four times the length of the body, and taper evenly to fine points. The *umbrella* extends one-third up the arms, and is a little wider laterally than dorsally. The *suckers* are closely set, deeply cupped, and marked with regular radial grooves; their biserial arrangement commences immediately after the first. One arm bears a supernumerary sucker in the larger specimen. The *hectocotylus* is of the usual shape and of medium length; it bears fourteen transverse ridges, each subdivided into four minute papillæ. The *circumoral lip* is low and narrow.

The *Surface* is covered with warts, which are largest and most numerous on the dorsal surface of the body, head, and umbrella, and dorsal aspects of the arms, where they have a quadrifid or quinquefid form, usually with a small wartlet in the centre, each forming a figure like a star or rosette. Towards the ventral surface and on the sides of the arms the warts are simple, and much smaller. On the back are about ten long cirri, which are rough with small warts, and above each eye is a very large arborescent cirrus with six or seven smaller ones beside it.

The *Colour* is a pale purplish-grey, shading off to a creamy white on the ventral surface.

Habitat.—Off East Moncœur Island, Bass Strait; 38 fathoms (Station 162). 1 specimen, ♀.

Off Twofold Bay, Australia; 150 fathoms (Station 163 A). 2 specimens, 1 ♂, 1 *juv.*

Octopus australis, Hoyle.

Octopus australis, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xv. p. 224, 1885.

The *Body* is rounded, and wider behind than in front; depressed, and with a well-marked ventral median groove. A sharp narrow ridge extends along either side of the body to the posterior extremity.* The *mantle-opening* extends nearly half round the body. The *siphon* is of medium size, at first the lateral margins are parallel and then tapering rapidly to a blunt point; it extends less than halfway to the umbrella margin.

The *Head* is narrower than the body, and the *eyes* somewhat prominent, dorsally rather than laterally.

The *Arms* are unequal, the lateral being slightly the largest, and about three times as long as the body; they are slender and tapering. The *umbrella* is longer than the length of the body; larger ventrally than dorsally, and larger laterally than ventrally. The *suckers* are prominent and closely set; they are altogether larger on the lateral arms, and extend in a double row to the centre; the radial grooves are deep, and extend quite to the margins. The *hectocotylus* is absent.

The *Surface* of the back of the body, head, and dorsal aspects of the umbrella and arms is covered with thick-set hemispherical pimples, which are also found on the inner side of the membrane between the two dorsal arms, and on the inner surfaces of the arms between the suckers. They are smaller and more sparse on the ventral surface of the body. A large rough cirrus and a few larger pimples are found over each eye. A raised ridge passes backwards from the base of the siphon along the ventro-lateral margin of the body, meeting its fellow of the opposite side at the posterior extremity.*

* I have considerable doubt whether this be really one of the specific characters; but as it occurs in both specimens, I have thought it well to mention it

The *Colour* is deep purplish on the back, mottled on the sides, and cream below.

Habitat.—Port Jackson, Australia, 6–15 fathoms. 2 specimens, 1 ♀, 1 *juv.*

✓ *Octopus hongkongensis*, Steenstrup, MS.

Octopus hongkongensis, Steenstrup, MS., in Copenhagen Museum.
,, ,, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xv. p. 224, 1885.

The *Body* is rounded with a median ventral furrow, and depressed (? from pressure). The *mantle-opening* is slightly less than half the circumference, and terminates midway between the siphon and the eye, and a little behind the latter. The *siphon* is comparatively short and conical, and extends one-third the distance to the umbrella-margin.

The *Head* is comparatively broad, almost as broad as the body, and the *eyes* appear to have been prominent.

The *Arms* are unequal, the ventral considerably shorter than the dorsal and dorso-lateral, on an average six times as long as the body, stout and tapering very rapidly towards the ends. The *umbrella* reaches up one-fifth of the length of the dorsal arms, and is a little wider between the lateral and a little narrower between the ventral arms. The *suckers* are not closely packed, and not enlarged on the dorsal arms, notwithstanding the sex of the specimen. The *hectocotylised* arm is very short, but the modified extremity is long and narrow, with parallel sides tapering only at the extremity to a blunt point; a narrow fillet runs between the two marginal ridges.

The *Surface* of the body is sprinkled dorsally with minute hemispherical warts, which become smaller and gradually disappear on the sides and lower surface; they are also found on the dorsal surface of the head and of the umbrella. Above each pupil stands a small cirrus, immediately behind which is a larger one.

The *Colour* is a dull red on the dorsal surface, lighter and brighter below, sprinkled with dull reddish-brown dots.

Habitat.—The *Hyalonema*-ground south of Japan, 345 fathoms (Station 232). 1 specimen, ♂.

Octopus tonganus, Hoyle.

Octopus tonganus, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xv. p. 225, 1885.

The *Body* is rounded, depressed, and broader than long, with a marked but shallow median groove on the ventral surface. *Mantle-opening* extends about one-third round the circumference of the body, terminating nearer to the funnel than to the eye. The *siphon* is short and conical, and extends rather more than halfway to the umbrella margin.

The *Head* is small and the *eyes* prominent.

The *Arms* are unequal, the order being 3, 2, 4, 1; on an average they are nearly ten times as long as the body, and taper gradually to very fine points. The *umbrella* is very small, and slightly narrower dorsally than laterally. The *suckers* are for the most part small and closely packed; the first four are arranged in a single row; in the male there are four large ones on each lateral arm opposite the margin of the umbrella, beyond which they gradually diminish. The *hectocotylus* is very minute.

The *Surface* is in general smooth; the back bears a few small papillæ, but owing to the compression of the specimens it is impossible to make out their exact number. There are three minute cirri over each eye.

The *Colour* is on the whole grey, paler below; this is due to dark specks sprinkled more or less closely over a cream-coloured ground. One specimen has a purplish patch at either side of the mantle-opening.

Habitat.—The reefs, Tongatabu. 3 mutilated specimens, 1 ♂, 2 ♀.

Octopus vitiensis, Hoyle.

Octopus vitiensis, Hoyle, *Ann. and Mag. Nat. Hist.*, ser 5, vol. xv. p. 226, 1885.

The *Body* is nearly oblong, but becomes somewhat narrower posteriorly. The *mantle-opening* extends nearly one-third round the body, and terminates some distance below and behind the eye. The *siphon* is long and acutely pointed, and extends about half-way to the umbrella-margin.

The *Head* is broader than the body, with large laterally prominent *eyes*.

The *Arms* are subequal, the two lateral pairs being a little longer than the others ; on an average they are nearly three times as long as the body, and taper rather rapidly about the middle of their length and then evenly to fine points. The *umbrella* extends nearly one-third up the arms, least along the dorsal pair. The *suckers* are sunken, comparatively large, with a dark margin and very well-marked radial grooves. The first two in each arm are in a single row, owing to compression of the arms laterally ; there are no enlarged suckers on the lateral arms. The *hectocotylus* is not developed.

The *Surface* of the dorsum of the body bears minute warts scattered here and there; over each eye there is a rather large branched cirrus, with a few small ones scattered round it. The internal surfaces of the arms are covered with minute hemispherical warts, so as to resemble shagreen.

The *Colour* is very dark grey, almost black on the dorsal surface and outside the arms; paler grey below and on the inner surfaces of the arms. The dark covering of the body is not continued over the inner surface of the membrane covering the two dorsal arms.

Habitat.—The reefs, Kandavu, Fiji. 1 specimen, ♀.

Octopus duplex, Hoyle.

Octopus duplex, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xv. p. 226, 1885.

The *Body* is short and evenly rounded, with the merest trace of a median ventral groove. The *mantle-opening* extends about half round the circumference, and terminates halfway between the siphon and the eye. The *siphon* is relatively long, conical and pointed, and extends about halfway to the umbrella-margin.

The *Head* is small, and the *eyes* rather prominent.

The *Arms* seem to have been unequal, the lateral the longest, but so many have been mutilated that it is difficult to be certain; they are about four times the length of the body. The *umbrella* extends about one-third up the arms, the furthest between the lateral pairs. The *suckers* are large, close, and prominent, with a narrow margin marked off from the basal portion; the radial grooves extend to the margin and form notches in it. The *hectocotylus* is not present; the third right arm has been mutilated, but the stump shows no groove running up the outer ventral margin.

The *Surface* is smooth; an interrupted ridge starting from the base of the siphon passes backwards along the ventro-lateral margin of the body, probably due to contraction. There are three small papillæ above each eye.

The *Colour* is a pale bluish-grey above, shading into cream below.

Habitat.—Off Twofold Bay, Australia, 150 fathoms. (Station 163 A). 2 specimens, 1 ♀, 1 *juv.*

Octopus bandensis, Hoyle.

Octopus bandensis, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xv. p. 227, 1885.

The *Body* is rounded and depressed (? from pressure), and with a slight ventral groove. The *mantle-opening* terminates immediately below and behind the eye. The *siphon* extends as far as the umbrella-margin, and is acutely pointed.

The *Head* is broader than the body, and flattened by compression; the *eyes* are very prominent.

The *Arms* are unequal, the third pair being much the longest and stoutest; on the average they are four times as long as the body; they taper gradually at first and then more rapidly. The *umbrella* is very small. The *suckers* are prominent, the first four being disposed in a single row; and none are enlarged on the lateral arms. The *hectocotylus* is not developed.

The *Surface* is smooth in general, but there are about twelve warts on the back and sides of the body, and a large cirrus over each eye, with several small ones near it.

The *Colour* is deep black, apparently owing to treatment with osmic acid.

Habitat.—Banda. I specimen, *juv.*

Octopus marmoratus, Hoyle.

Octopus marmoratus, Hoyle, *Ann. and mag. Nat. Hist.*, ser. 5, vol. xv. p. 227, 1885.

The *Body* is round, not depressed and a little longer than wide. The *mantle-opening* extends somewhat less than halfway round the body, terminating nearer to the siphon than to the eye, and considerably behind the latter. The *siphon* is small and acutely conical, and extends about one-third the distance to the umbrella-margin.

The *Head* is narrow, and the *eyes* are prominent, where they have not suffered from compression.

The *Arms* are subequal, eight times as long as the body; they are very long and slender, the last property being more marked in the females than in the male; they taper more rapidly at first than near the extremities, which are much attenuated, where it extends almost one-third up the arms; in the females its extent is only one-sixth. The *umbrella* is very wide, especially in the male. The *suckers* are rather large, and closely set; in the male a few suckers opposite the umbrella-margin are slightly, but not markedly, larger than the others. The *hectocotylus* is small, and has about ten small transverse ridges.

The *Surface* appears to have been smooth, except for a few short ridges placed longitudinally on the back and sides; but the skin is shrivelled by the action of the spirit, so that it is difficult to be certain. A conical cirrus is situated above and slightly behind each eye; but in some cases this has been destroyed.

The *Colour* is a stone-grey, with dark pigment disposed in veins like those of marble on the dorsal surface of the body, head, and umbrella; the male is much darker, so that the marbling is almost concealed. Traces of an oval spot are seen in front of and below the eye on both sides of one female specimen and on one side of the other; but this spot is concealed by the dark colouring in the male even if it exist.

Habitat.—On the reefs, Honolulu, Sandwich Islands. 3 specimens, 1 ♂, 2 ♀.

Octopus bermudensis, Hoyle.

Octopus bermudensis, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xv. p. 228, 1885.

The *Body* is spheroidal, acuminate behind, and with a median groove ventrally. The *mantle-opening* extends rather less than half round the circumference of the body, and terminates some distance behind and a little below the eye. The *siphon* is long and smooth, and attached by nearly all its length to the head; it extends fully halfway to the umbrella-margin.

The *Head* is much narrower, and more depressed than the body; the *eyes* are scarcely at all prominent.

The *Arms* are unequal, in the order 1, 2, 3, 4; about six times as long as the body; they are very long and slender, tapering but slightly. The *umbrella* is small. The *suckers* are small, prominent and closely set, and the first four stand in a slightly zigzag line. The *hectocotylus* is absent.

The *Surface* is smooth for the most part, but the skin is wrinkled over the posterior acuminate extremity, owing to the action of the spirit; there is one very small wart over each eye.

The *Colour* is yellow ochre, with two pale sienna patches on the back and on the head.

Habitat.—Bermuda. 1 specimen, ♀ *juv.*

/ *Octopus levis*, Hoyle.

Octopus levis, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xv. p. 229, 1885.

The *Body* is oblong, depressed, and bulges a little at the sides. The *mantle-opening* extends about one-third round the circumference, terminating about midway between the siphon and the eye. The *siphon* is short and small, extending scarcely one-third the distance to the umbrella-margin.

The *Head* is almost as broad as the body; and the *eyes* are large, spheroidal, and prominent, with very small circular apertures.

The *Arms* are subequal and short, compared with the body, being about three times its length; they taper gradually to moderately fine points. The *umbrella* is large, extending about one-third of the arms. The *suckers* are small and prominent, and arranged in two rows from the commencement; a narrow well-marked groove runs across the arm between each two suckers (possibly due to contraction). The *hectocotylus* is well-developed, short, and tapering rapidly to a blunt point; the median groove has about ten transverse bars. The *circumoral lip* is unusually thick.

The *Surface* appears to have been perfectly smooth, but is now covered with wrinkles, due to the action of the spirit.

The *Colour* is a dull grey, inclining to stone-colour below.

Habitat.—Off Heard Island, Southern Ocean; 75 fathoms (Station 151). 4 specimens, 1 ♂, 1 ♂ *juv.*, 2 ♀ *juv.*

Octopus januarii, Steenstrup, MS.

Octopus januarii, Steenstrup, MS., in Copenhagen Museum.
,, ,, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xv. p. 229, 1885.

The *Body* is rounded, widening a little posteriorly; the ventral groove is very faint. The *mantle-opening* terminates just below the eyes. The *siphon* is bluntly conical, and extensively attached to the umbrella; it extends less than halfway to the umbrella-margin.

The *Head* is small, and the sides are entirely occupied by the enormous *eyes*, which are swollen and globular, but with very small palpebral openings. The skin covering them is so thin that the dark pigment within is distinctly visible.

The *Arms* are unequal, the dorsal pair being the largest; on an average they are four times as long as the body. The *umbrella* is about equally wide all round, except that it is a little shorter between the two ventral arms. The *suckers* are comparatively small, prominent, and separate; more widely in one specimen than in the other, probably owing to its being less contracted by spirit. None of the suckers on the lateral arms are enlarged, notwithstanding the sex. The *hectocotylus* is well-developed; it is broad, and tapers rapidly to an acute point; in one specimen about seven transverse ridges can be counted in the proximal half of the median groove; in the distal half and in the other specimen they are indistinct.

The *Surface* is perfectly smooth all over.

The *Colour* is a pale purplish-pink; deeper above than below.

Habitat.—Off Barra Grande (Station 122), 1 specimen, ♂; (Station 137), 1 specimen, .

ELEDONE, Leach.

Eledone rotunda, Hoyle.

Eledone rotunda, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xv. p. 230, 1885.

The *Body* is spheroidal, very little longer than broad, and the ventral groove is not marked. The *mantle-opening* extends one-third round the body, ending some distance directly below the eyes. The *siphon* is slightly tapering, and extends one-third the distance to the umbrella-margin.

The *Head* is short, nearly as broad as the body, and the *eyes* are round and rather prominent.

The *Arms* are equal, and about twice as long as the body; they are very stout, and taper gradually to blunt points; their section shows a triangle projecting inwards, and a rounded surface looking outwards; the former much more prominent than the latter. The *umbrella* is wide, extending one-third up the arms, a little further dorsally than ventrally. The *suckers* are comparatively small, closely set, and deeply cupped. There is no trace of a *hectocotylus.*

The *Surface* is perfectly smooth.

The *Colour* is dull purple, palest on the body, and deepest on the inner surface of the umbrella.

Habitat.—The Southern Ocean (Station 137); 1950 fathoms. South Pacific; 2225 fathoms (Station 298). 1 specimen, ♀; 1 specimen, arms only.

Eledone brevis, Hoyle.

Eledone brevis, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xv. p. 230, 1885.

The *Body* is short, rounded, and depressed; blunt behind, and deeply grooved below. The *mantle-opening* extends one-third round the animal, and terminates immediately below the eyes. The *siphon* is short, acutely pointed, and extends less than halfway to the umbrella-margin.

The *Head* is short, and nearly as broad as the body. The *eyes* are spheroidal, and very prominent.

The *Arms* are equal, and about half as long again as the body; they are short, stout, and taper gradually to blunt points. The *umbrella* extends halfway up the arms,—rather more in the largest specimen. The *suckers* are round, prominent, and deeply cupped, and there are about 30 on each arm. The *hectocotylus* is not developed.

The *Surface* is smooth, with the exception of three cirri arranged in a triangle over each eye. Behind the left eye in the largest specimen the skin is elevated into a number of small papillæ, and a few similar ones are seen on the back of the medium-sized specimen.

The *Colour* is a dull purplish-grey above, inclining to pale ochre below.

Habitat.—South Atlantic, 600 fathoms (Station 320). 3 specimens, ♀

JAPETELLA, Hoyle.*

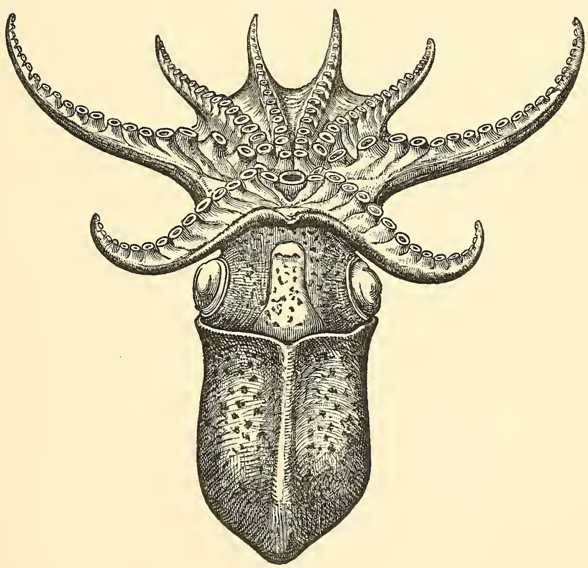
The *Body* is gelatinous in consistency and semitransparent, and more or less oblong in form. The *mantle-opening* is very wide.

The *Arms* are unequal, and the longest only about equal in length to the body. The *umbrella* is small, and the *suckers* arranged in a single row.

Japetella prismatica, Hoyle.

Japetella prismatica, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xv. p. 231, 1885.

The *Body* is of gelatinous consistency and semitransparent; it is somewhat longer than broad, flat on the dorsum, and with the median ventral region raised into a prominent ridge, which gives the body a



Japetella prismatica, Hoyle (natural size.)

prismatic form. The *mantle-opening* appears to have been wide, and to have terminated behind the eyes; but as it has been torn away from the head dorsally, it is impossible to be certain of this. The

* Named in honour of Professor Japetus Steenstrup.

siphon extends almost to the margin of the umbrella, and is but slightly conical, with a broad truncated extremity. There is no *median septum* in the branchial cavity.

The *Head* is about as broad as the body; the *eyes* are rounded, and prominent laterally, the spherical lens protruding from the middle of each.

The *Arms* are unequal, the third being the largest, one quarter longer than the body, and about one-third longer than the fourth, which is slightly longer than the second, and this than the first, so that the order of length is 3, 4, 2, 1. The arms are stout, and taper gradually to blunt points. The *umbrella* extends about halfway up the dorsal arms and one-fourth up the ventral arms, its extent being intermediate between these extremes in the case of the other arms. The *suckers* are round and prominent, and in many cases show a double margin, due to a thin membrane surrounding the thickened edge of the sucker; they commence one sucker's breadth from the oral margin, and become gradually larger and wider apart as far as the middle of the arm, where they are one sucker's breadth apart, after which they are smaller and closer, and towards the extremity stand in contact. There is no trace of a *hectocotylus.*

The *Surface* of the body appears to have been perfectly smooth; it is covered with torn remains of epithelium, but there are neither warts nor cirri.

The *Colour* is a pale yellowish-grey, and there are numerous reddish-brown chromatophores.

Habitat.—Off the Rio San Francisco, Brazil (Station 125), probably surface. 1 mutilated specimen, sex ?

Japetella diaphana, Hoyle.

Japetella diaphana, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xv. p. 232, 1885.

The *Body* is gelatinous and semitransparent; it is ovoid in form, and considerably longer than broad. The *mantle-opening* is very wide, extending up behind the eyes on either side. The *siphon* extends two-thirds of the distance to the umbrella-margin, and is truncated at the extremity. There is a *median septum* in the branchial cavity.

The *Head* is nearly as broad as the body, and the *eyes* are large and prominent; they consist of a larger darkly pigmented spheroid, from which protrudes the opaque white smaller spherical lens.

The *Arms* are unequal; the longest (the third pair) are almost as long as the body, and are nearly twice as long as the fourth, which are the shortest, the order of length being 3, 2, 1, 4; they taper rapidly to fine points. The *umbrella* is very small, extending about one-fourth up the dorsal and ventral arms, a little further up the dorso-lateral and lateral arms, and being least developed in the space between the ventral and ventro-lateral arms. The *suckers* have assumed, owing to shrinking, a quadrangular or triangular form; they are prominent, and marked by two constrictions, one at the base, separating them from the arm, the other rather more than halfway up. There is no trace of any *hectocotylus*.

The *Surface* appears to have been smooth originally, but the epithelium has been to a great extent stripped off.

The *Colour* is very pale yellowish-grey, marked with numerous longitudinally disposed oblong chromatophores.

Habitat.—North of Papua (Station 220); surface. 1 specimen, sex?

CIRROTEUTHIS, Eschricht.

Cirroteuthis magna, Hoyle.

Cirroteuthis magna, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xv. p. 233, 1885.

The *Body* is oblong, about twice as long as broad, and rather broader than deep. The *mantle-opening* is circular, but little larger than the base of the siphon, and its margins are continuous with two ridges on the sides of the latter. The *siphon* is conical, and slightly swollen at the tip; it is not connected to the head by ligaments. The *fins* are obovate in form, about four times as long as broad, and thickened along the posterior margin. The *dorsal cartilage* is saddle-shaped, and elongated from side to side, not antero-posteriorly.

The *Head* is directly continuous with, and somewhat narrower than the body; the *eyes* are spheroidal, the lens spherical, and the palpebral opening circular.

The *Arms* are subequal, three and a half times as long as the body; they are slender, and more resemble thickenings of the web than independent arms; they are thickest about two-thirds the distance along them, and terminate in a delicate slender tip, which projects beyond the web. The *umbrella* is a thin delicate membrane, very largely developed, and when fully expanded its diameter was probably nearly three times as large as its depth. It extends from the tip of the ventral arm on either side backwards, and becomes gradually narrower, so that it only extends along the proximal two-thirds of the next arm, and passes beneath it to be attached in a crescentic line to the outer surface of the web, which similarly passes backwards from the tip of this arm; this arrangement is usually described by saying that the arm does not lie in the umbrella for the proximal two-thirds of its length, but is joined to it by a vertical web, but this does not so correctly represent the disposition of the parts. The umbrella stretches across from tip to tip of the two dorsal arms, between the proximal two-thirds of the two ventral arms. The *suckers* commence about 1 cm. from the oral margins, and the first four lie pretty close together within a space of less than 2 cm., after which they gradually become further apart, an interval of 2–3 cm. intervening between each two; about two-thirds along the arm they stand closer together, and are very large, but after this they again become smaller, and stand in close contiguity with each other. The proximal suckers are small, prominent, and rather soft, and seem to contract by folding the lateral margins over towards each other, so as to present the appearance of a half-closed eyelid; but the largest suckers are firm and muscular, and consist of a globular basal portion imbedded in the arm and a short cylindrical projecting portion. The *cirri* commence between the fourth and fifth suckers as very minute prominences, which gradually increase in length until halfway along the arm they attain a maximum length of 8 cm., after which they decrease rapidly, and cease opposite the attachment of the web to the ventral aspect of the arm.

The *Surface* of the body has been entirely denuded of epidermis, so that it is impossible to ascertain its nature; the web is perfectly smooth.

The *Colour*, so far as preserved, is a dull madder.

Habitat.—Between Prince Edward Island and the Crozets; 1375 fathoms (Station 146). 1 specimen, sex?

Cirroteuthis meangensis, Hoyle.

Cirroteuthis meangensis, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5 vol. xv. p. 234, 1885.

The *Body* is much distorted, but appears to have been subglobular in form. The *mantle-opening* is very small, and fits closely around the base of the *siphon*, which is small and bluntly conical, with a still smaller pimple-like extremity; on either side there extends from the dorso-lateral base a curved fold of membrane, which loses itself in the mantle. The *fins* are about equal in length to the breadth of the body, narrow and pointed at the extremity, and thickened towards the posterior margin. The *dorsal cartilage* is elongated transversely.

The *Head* is exceedingly short, and the *eyes* large and spheroidal.

The *Arms* are subequal, and about three times as large as the body in the present shrunken condition of the specimen; they taper rather rapidly to slender points. The *umbrella* extends on the dorsal side of each arm to within 1 cm. of its extremity, whilst on the ventral side it reaches only four-fifths along it; the arms lie in the umbrella and are not united to it by any intermediate vertical web. The *suckers* are about sixty to seventy in number, small and subequal; they are at equal intervals for the greater part of the arm, but closer near the extremity. The *cirri* are short, stout, and conical, the largest 2 mm. in length; on the ventral arms they commence between the fourth and fifth suckers, and extend to the fiftieth sucker, beyond which there are twenty-one, which gradually decrease; on the dorsal arms the cirri commence between the sixth and seventh suckers, and continue to the fifty-fifth, beyond which there are nine.

The *Surface* is smooth.

The *Colour* of the body is creamy white, of the arms and umbrella deep madder-brown. The suckers and cirri are paler.

Habitat.—Off the Meangis Islands, near the Philippines, 500 fathoms (Station 214). 1 specimen, sex?

Cirroteuthis pacifica, Hoyle.

Cirroteuthis pacifica, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xv. p. 235, 1885.

The *Body* is almost entirely absent. The *fin* is obovate in form, and thickened along the posterior margin, thin and membranous at the extremity and along the anterior margin. The proximal end of its cartilage is exposed, and presents a long grooved articular surface. One *branchia* is visible, and presents the appearance of a spheroidal nodule with meridional grooves. The *mantle-opening* is circular, and closely embraces the base of the *siphon*, which is long, thin, and conical.

The *Head* is exceedingly short, and the *eye* appears to occupy all the available space between the fin and the arms.

The *Arms* are subequal, thick, rounded, and soft, and taper rapidly towards the extremities. The *umbrella* is attached directly to the arms, which are somewhat more prominent on its inner than on its outer surface; it is attached to the dorsal aspect of every arm almost to the tip, and to the ventral aspect for somewhat more than half its length, and at its attachment is a firm cartilaginous (?) nodule. The *suckers* are about fifty-two in number, and commence close to the oral lip, and the first half-dozen stand near together; half-way up the arms they are farther apart, and the largest are situated opposite the attachment of the membrane to the ventral aspect of the arms; they are prominent, but not so hard and firm as those of *C. magna.* There are faint radial markings upon them. The *cirri* commence on the dorsal arms between the seventh and eighth suckers, and continue till the last; on the ventral arms they commence between the sixth and seventh, and here also are continued to the tips of the arms. They begin as small papillæ, gradually increase in length, attaining the maximum about halfway along the arms.

The *Surface* is smooth.

The *Colour* is a deep purplish madder, paler outside the umbrella and on the fin.

Habitat.—Pacific Ocean, between New Guinea and Australia; surface (Station 181). 1 mutilated specimen, sex?

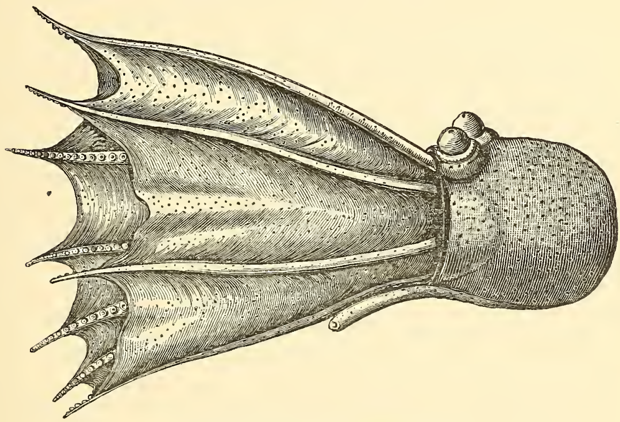
AMPHITRETUS, Hoyle.

Amphitretus pelagicus, Hoyle.

Amphitretus pelagicus, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xv. p. 235, 1885.

The *Body* is short, rounded, of gelatinous constituency, and semi-transparent. The *mantle* adheres to the sides of the siphon, so that the *mantle-opening*, which is single in all other known Cephalopods, is here divided into two pocket-like openings, which lie one beneath each eye. The *siphon* is very long and narrow, and extends forwards anteriorly to the margin of the mantle, for a distance almost equal to the length of the body, and is a little swollen at the extremity.

The *Head* is not marked off from the body, except by the possession of the *eyes*, which are situated near together on the dorsal



Amphitretus pelagicus, Hoyle ($\frac{3}{2}$.)

surface; they consist of a larger basal spheroid, through the walls of which pigment is clearly visible, upon which stands a smaller very prominent spheroid, white, opaque, and of glistening surface.

The *Arms* are equal, and rather more than twice as long as the body; they are slender, and taper at first gradually and then more rapidly to comparatively blunt points. The *umbrella* extends more than two-thirds up the arms, and is thin, delicate, transparent, and much damaged. The *suckers* are firm, muscular cups embedded in the softer tissue of the arms, as in *Cirroteuthis;* there are about twelve placed at some distance apart on that portion of the arm up which the web extends, and eleven closely set, and showing a tendency to biserial arrangement on the free extremities. There are no *cirri*, nor is there any trace of the formation of a *hectocotylus*.

The *Surface* appears to have been quite smooth originally; there is no sign of any cirri or warts.

The *Colour* is a dull yellow, apparently due to preservation in picric acid, and the mantle and umbrella are thickly sprinkled with small brown chromatophores.

Habitat.—Near the Kermadec Islands, South Pacific; on the surface (Station 171). 1 specimen, sex?

2. On Energy in Vortex Motion. By Sir William Thomson.

(*a*) Energy in Vibrations.
(*b*) Unlimited augmentation of Energy of a simply continuous fluid mass in a space of given shape, by changes from and back to this shape.
(*c*) Annulment of Energy under same conditions.
(*d*) Reduction of Energy to absolute minimum in a multiply continuous space of given shape.
(*e*) Unlimited augmentation of Energy in a multiply continuous space.

3. The Theory of Determinants in the Historical Order of its Development. Part I. Determinants in General (1693–1800). By Dr Thomas Muir.

4. On Bipartite Functions. By Dr Thomas Muir.

5. Note on Galois' Theorem regarding the Continued Fraction Representation of the Roots of an Equation. By Dr Thomas Muir.

6. Letter from Professor Michie Smith on the Zodiacal Light, and on the Origin of Atmospheric Electricity.

MADRAS CHRISTIAN COLLEGE
LABORATORY, 21*st January* 1885.

MY DEAR PROFESSOR TAIT,—I have just got back from an expedition to the top of "Dodabettah" (over 8600 feet), where I have been trying to get the spectrum of the zodiacal light under more favourable circumstances than are possible here. I cannot say that I have met with much success, for though, when the sky was clear, the light was rather brighter than it is here at present, yet I *have* seen it quite as bright here. Still the spectrum was fairly bright, and I don't think that I could have helped seeing bright lines if there had been any to see. I got no photograph. I made, however, one observation, which seems to me to be of importance, and recalls a former observation made in the West Indies. We had sunset about 6 o'clock (M.M.T.), and by 7.15 or 7.30 all trace of the sunset colours (reglow and all) had disappeared, and the Z. L. showed very clear and a little brighter than the milky way. It was broad below, but much narrower above—being about 15° at the horizon and only 6° at an altitude of 30°, and was distinctly visible up to about 60°. Now the point that I noticed was this, that it did not seem to *set* at all, but only to fade out. Even at 10 P.M., four hours after sunset, you could trace it up as high as before, and it had still the same shape—broad below and narrow above. This was not a solitary observation, but was repeated every night on which the moon and the mists—of which I had unfortunately too many—would permit of it. I suppose that if this is really the case, it must belong to the earth, and not to the sun.

I did not confine myself to the Z. L., but did what I could at atmospheric lines and at atmospheric electricity. I made hourly observations of the latter from 6 or 7 A.M. to 10 or 12 P.M., and have got a very fair approximation to the curve of variations for the day between these hours showing a maximum, very well marked, about 2 P.M., and probably a minima near 7 A.M. and 7 P.M.; but the evening observations were so interfered with by mists that they are not of much use for giving points in the curve. But the mist observations seem to me by far the most interesting from another point of view, viz., that of the formation of thunderstorms. Dodabettah, being the highest point of the Niligres, was usually above the clouds in the afternoon, but at times mist was blown over from the comparatively cool easterly side, and was dissipated as it reached the crest of the hill, now in such a dissipating mist, the *air potential was below the normal for that time of day.* On the other hand, with a heavy condensing mist, the *air potential was far above the average.* It seems to me that this is direct evidence in favour of the condensation theory of thunderstorms. I have now an immense mass of electrical observations on hand, some of them of great interest, but it is almost impossible to get the time to make certain ones necessary to connect them or to work them up. I hope, however, now that we have got a new Mathematical Professor, that I will get a little more time for such work.

By the way, I have discovered that the "green sun" spectrum can be exactly represented by combining the spectrum of the sun seen through a fairly thick mist—the sun's disk being still visible—and the spectrum of a moist atmosphere, showing the rain band strongly. This would explain all cases in which the sun has been seen green.

There is one point in regard to measuring atmospheric electricity on which I am not quite clear. In using the water-dropping collector, Thomson seems to say that you must have the reservoir inside, so that part may be on one side and part on the other of the neutral line. I have tried comparisons between the lighted match and the water-dropper entirely outside, and they seemed to agree fairly well. I can get no good exposure here if I simply put the water-dropper at a window, and I would like to have it on the roof of the house, but will that do?—I remain, yours very sincerely,

C. MICHIE SMITH.

7. On a New Form of Chromotrope. By John Aitken, Esq.

8. On an Application of the Atmometer. By Professor Tait.

The Atmometer is merely a hollow ball of unglazed clay, to which a glass tube is luted. The whole is filled with boiled water and inverted so that the open end of the tube stands in a dish of mercury. The water evaporates from the outer surface of the clay (at a rate depending partly on the temperature, partly on the dryness of the air) and in consequence the mercury arises in the tube. In recent experiments this rise of mercury has been carried to nearly 25 inches during dry weather. But it can be carried much farther by artificially drying the air round the bulb. The curvature of the capillary surfaces in the pores of the clay, which supports such a column of mercury, must be somewhere about 14,000 (the unit being an inch). These surfaces are therefore, according to the curious result of Sir W. Thomson (*Proc. R. S. E.* 1870, p. 63), specially fitted to absorb moisture. And I found, by inverting over the bulb of the instrument a large beaker lined with moist filter-paper, that the arrangement can be made extremely sensitive. The mercury surface is seen to become flattened the moment the beaker is applied, and a few minutes suffice to give a large descent, provided the section of the tube be small, compared with the surface of the ball.

I propose to employ the instrument in this peculiarly sensitive state for the purpose of estimating the amount of moisture in the air, when there is considerable humidity; but in its old form when the air is very dry. For this purpose the end of the tube of the atmometer is to be connected, by a flexible tube, with a cylindrical glass vessel, both containing mercury. When a determination is to be made in moist air the cylindrical vessel is to be lowered till the difference of levels of the mercury amounts to (say) 25 inches, and the diminution of this difference in a definite time is to be carefully measured, the atmospheric temperature being observed. On the other hand, if the air be dry, the difference of levels is to be made *nil*, or even negative, at starting, in order to promote evaporation. From these data, along with the constant of the instrument (which must be determined for each clay ball by special experiments), the amount of vapour in the air is readily calculated. Other modes of observation with this instrument readily suggest themselves, and trials, such as it is proposed to make at the Ben Nevis Observatory during summer, can alone decide which should be preferred.

Monday, 2d March 1885.

ROBERT GRAY, Esq., Vice-President, in the Chair.

At the request of the Council, an Address on the Recent Progress of the Geological Survey of the United Kingdom was given by Professor Archibald Geikie, F.R.S., Director of the Survey.

On the motion of the Chairman, a vote of thanks was accorded to Professor Geikie for his Address.

PRIVATE BUSINESS.

The following Candidates were balloted for and declared duly elected Fellows of the Society:—Professor Elgar, Dr Orme Masson, and Dr J. M. Macfarlane.

Monday, 16th March 1885.

THOMAS STEVENSON, Esq., Memb. Inst. C.E., President, in the Chair.

The following Communications were read :—

1. Hooke's Anticipation of the Kinetic Theory and of Synchronism. By Professor Tait.

(*Abstract.*)

While collecting materials for a Text-book of the *Properties of Matter*, the author had occasion to consult the very curious pamphlet by Robert Hooke, entitled *Lectures de Potentia Restitutiva, or of Spring* (London, 1678). In this work there is a clear statement of the principle of Synchronism, which was applied by Stokes to the explanation of the basis of Spectrum Analysis. There is also a very remarkable statement of the elementary principles of the modern Kinetic Theory of Gases, the first mention of which is usually fixed sixty years later, and ascribed to D. Bernoulli in his *Hydrodynamica* (Argentorati, 1738).

2. On the Hexagonal System in Crystallography. By Professor Crum Brown.

The forms of the uniaxial systems may be regarded as derived from forms, or parts of forms or combinations, of the regular system by uniform expansion or contraction in a direction parallel to the axis of the uniaxial system, *i.e.*, normal to a face of the cube for the tetragonal, and normal to a face of the octahedron for the hexagonal system. Faces, therefore, which are, in the regular form or combination, at right angles to or parallel to such axis, retain their relative angular position unchanged in the uniaxial form or combination, and can be represented by means of indices referring to the rectangular axes of the regular system, whatever be the amount of the deformation (expansion or contraction). These faces are prism faces, parallel to the axis, and basal faces at right angles to it. All other faces have their angular position affected by the deformation.

These other faces are pyramid faces. Each pyramid face lies between, and in the same zone with, a prism face and a basal face. It may, therefore, be represented by the symbol

$$as + \frac{1}{\rho} bt,$$

where s and t are the symbols of the prism face and the basal face respectively, a and b are small whole numbers, and ρ is the ratio of the length of a line parallel to the axis after, to the length of the line before deformation. We may put

$$\frac{b}{a} = n,$$

when this becomes, for the tetragonal system

$$(hk0) + \frac{1}{\rho} n (001),$$

which is

$$\left(hk \ \frac{n}{\rho} \right)$$

the Miller symbol for a pyramid face in this system, with the ratio of the parameter of z to that of x or y, expressed by ρ. In the hexagonal system the symbol

$$s + \frac{1}{\rho} nt$$

takes the form

$$(hkl) + \frac{1}{\rho} n (111), \text{ where } h + k + l = 0.$$

We may leave ρ understood, as it is constant for the same substance and same temperature, and write this in the contracted form (hkl, n). This gives

$$h + \frac{n}{\rho}, \ k + \frac{n}{\rho}, \ l + \frac{n}{\rho},$$

as the coefficients of x, y, and z in the equation of the face referred to the rectangular axes of the regular system. These axes are, of course, not crystallographic axes of the hexagonal system, but some advantages arise from their use. They are rectangular, and therefore the ordinary formulæ of solid geometry can be used; the symbol of the general form (hkl, n), where hk and l are free to change places and change sign together, and n changes sign independently, gives a clear oversight of all the faces of the holohedral form, and enables us to derive from the symbol the various kinds of hemihedry.

3. On the Effect of Temperature on the Compressibility of Water. By Professor Tait.

4. Chemico-Physiological Investigations on the Cephalopod Liver, and its identity as a true Pancreas. By Dr A. B. Griffiths, Ph.D., F.C.S. (Lond. and Paris), Lecturer on Chemistry and Physics, Technical College, Manchester, &c. Communicated by W. E. Hoyle, Esq., M.A.

In a memoir published in the *Chemical News*, vol. xlviii. page 37, and the *Journal of the Chemical Society*, 1884, page 94, I gave some account of a peculiar excretory product found in the *Sepia's* "liver." The product was found to be albumin in pseudo-crystalline aggregations when examined under the microscope. These bodies are not of a constant occurrence in this organ of the *Sepia*. Since the publication of the above paper, which is a year and a half ago, I have made a thorough examination of this organ in *Sepia*, which substaniate and extend the observations of Krukenberg,* Fredericq,† and Jousset de Bellesme.‡

After carefully dissecting it out of the cavity of the body of a fresh Sepia, I performed the following experiments:—

1. A small portion of the organ was placed on starch paste. The starch granules disappeared, with the exception of their celluloid covering, and on treating with water and testing the solution with Fehling's solution, sugar in the dextrose form was found.

2. The organ gave an alkaline reaction to litmus paper.

3. When a small portion of the organ was placed in a tube with a little oil and agitated, an emulsin was produced;—this emulsin had first an alkaline reaction, and after some time became acid, owing to the formation of butyric acid and other acids of the fatty series.

4. The action of it on milk was to render the milk transparent in four hours' time. 15 cubic centimetres of milk were rendered transparent by 6 milligrammes of the tissue of the organ.

5. When a few drops of the secretion of this organ were examined

* *Untersuch. physiol. Inst. Heidelberg*, Bd. i. p. 327, 1878.

† *Bull. Acad. Sci. Belgique*, t. lvi. p. 761, 1878 ; *Rev. Internat. Sci.*, iii. p. 263, 1879.

‡ *Comptes Rendus*, t. lxxxviii. pp. 304, 428, 1879.

with chemical reagents under the microscope, the following reactions were observed :—

On running in between the slide and cover-slip a solution of iodine in potassium iodide, a brown deposit was the result; and on running in concentrated nitric acid on another slide, containing a drop or two of the secretion, a yellow coloration was formed, due to the formation of xanthoproteic acid. These reactions show the presence of albumin in the secreted fluid of the organ.

Isolation of the Ferment of the Organ.

The process I followed to obtain the ferment or ferments in a crude state from the fluid of the organ was that devised by Wittich and used by Kistiakowsky (Pflüger's *Archiv für Physiologie*, vol. ix. pages 438–459) in his researches on pancreatic ferments. The process consists in hardening the organ in alcohol for three days, and then cutting it up into very small pieces, extracting with *glycerin* and filtering.

On the addition of alcohol to the filtrate, the ferment is precipitated.

The action of this ferment on starch was its complete conversion into dextrose right-handed glucose, which was proved by Fehling's solution; and the formation of crystals ($C_6H_{12}O_6NaClH_2O$) with a solution of sodium chloride, a distinction between levulose or left-handed glucose, which does not form these crystals with salt solution.

The action of the ferment on fibrin from the muscular fibres of a young mouse was the formation of leucin and tyrosin; for on treating the fermented mass with hot water and filtering, a solution is obtained which contains leucin and tyrosin. To this solution was added acetic acid, when acicular crystals are deposited insoluble in ether, but soluble in boiling water, and gave with a neutral solution of mercuric nitrate a red flocculent precipitate, which is characteristic of tyrosin ($C_9H_{11}NO_3$).

The acetic acid solution after precipitating the tyrosin is evaporated, when leucin ($C_6H_{13}NO_2$) is deposited in white shining plates, which melt at 98° C. These shining plates of leucin, when heated with barium oxide, yield amylamine and carbonic dioxide,

$$C_6H_{13}NO_2 = N(C_5H_{11})H_2 + CO_2 .$$

I obtained by digesting the organ itself with boiling water a filtrate containing leucin and tyrosin. The ferment has no action on cellulose. From these investigations I am led to the conclusion that the so-called "liver" of *Sepia officinalis* (the cuttle-fish) is not a true liver,—but is a *pancreas,*—for the juices of the organ in question are purely digestive in function, digesting starch, oil, and similiar bodies; and transforming fibrin into leucin and tyrosin. Then again albumin is found in its secretion, which is characteristic of the pancreatic fluid of the higher animals,—no albumin being found in the liver, for albuminoids are decomposed by that organ. This organ of the Sepia digests oil-globules, and the secretions from a true liver are incapable of digesting fats without the pancreatic fluid.

No glycocholic and taurochloic acids nor glycogen were obtained from the organ, nor could the slightest trace of them be detected in the organ or its secretion. The above investigations prove that this so-called "liver" of the Cephalopod is a true pancreas or digestive organ.

I may mention here that the leucin and tyrosin from the organ I have mounted as microscopic slides.

Monday, 6th April 1885.

JOHN MURRAY, Esq., Ph.D., Vice-President,
in the Chair.

The following Communications were read:—

1. Chromomictors. By Mr John Aitken.

The instruments which we have called chromomictors, have been designed for the purpose of mixing lights of different colours for experiments in physiological optics. There are already a considerable number of instruments for this purpose, but none of them are perfectly satisfactory. We shall here describe one or two new forms of apparatus which have been recently experimented with, and though they may not be suitable for many colour experiments, yet they seem to possess some advantages over several of the instruments now in use. The colours produced by them are very brilliant and beautiful, and the secondary ones, such as yellow, blue, purple, are brilliant and at once recognised by the eye, not being of that dull low tone given by the rotation of coloured discs, while the white is so pure and bright that it cannot be distinguished from that produced under ordinary conditions.

In two forms of this instrument a lens or lenses are used for combining the colours. One of these instruments is simply a camera obscura with a single lens. Suppose now there is a bright white object in front of the lens. The rays coming from any point of that object pass through all parts of the lens, some through the upper half and some through the lower, after which they are again brought to a focus on the field of the camera. If, now, we place in front of the upper half of the lens a transparent red screen, then half of the entering rays will be red and the other half uncoloured, and the image will be of a reddish hue. Let us now place in front of the lower half of the lens another screen of a different colour—say green; the one-half of the entering rays will now be red, and the other half green, and these being combined on the field we get the resultant colour, namely yellow. In this way we can combine on the field of the camera any colours we desire, and by altering the amount of the lens covered by the different screens we can combine the colours in any desired proportion.

Another method of combining colours by means of lenses is to look at the colours through a short focused lens, the coloured objects being placed at a considerable distance. Suppose we have a long camera obscura, closed at one end, and having a short focused lens fitted into the other end. If we now make a small opening anywhere near the axis of the lens in the far end of the camera, so as to admit a little light, and look at the opening through the lens, we shall see a round disc of light, but the disc is not seen exactly in the direction of the opening, but in the axis or centre of the lens. Now make another small opening also near the axis of the lens, say on the side opposite the first. If we now look through the lens, we shall not see two discs of light, but apparently only the one we saw at first, but now it is brighter. We may go on in this way making a number of holes, and the light passing through them will be combined into one round disc of light. Now place over these holes coloured transparent media of any kind, or direct them towards coloured surfaces, then on looking through the lens all the colours will be combined and we shall see the resultant colour.

The following is a short description of an instrument, which I have constructed on this principle, and used with satisfactory results. It consists of a long wooden box about 70 cm. long by 12 cm. deep and 12 cm. wide. In one end of the box are two round openings, placed a short distance apart, one over the other. The lower opening has a diameter of about 5 cm., and has three radial bars fixed in it, dividing the circle into three equal sectors. Into these divisions are fitted pieces of glass of different colours. What these three colours are I shall presently state. The upper opening is of a less diameter than the lower, and is covered with clear glass; the purpose of this opening will be referred to presently.

Each of the sectors in the lower opening is provided with a shutter to regulate the amount of light passing through it. The upper opening is also provided with a movable shutter. Into the opposite end of the box are fitted two eye-pieces, so that, if desired, observations can be made with both eyes at the same time. The lenses of the eye-pieces are similar to a Ramsden eye-piece, and each consists of two plano-convex lenses, mounted at one end of a tube about 30 cm. long. These tubes slide in sockets fixed in the end of the box. The shutters for regulating the quantity of light entering the apparatus are each mounted on the end of a horizontal shaft, which is pivoted at the front end of the box, and passes back to the end next the eye-pieces, where levers are fixed to the end of each, so that each shutter can be moved separately. By this means the amount of the different colours may be conveniently regulated by the observer, while his eye is applied to the instrument. For some observations an opening of 5 cm. for admitting the different coloured lights is too large, as it separates the colours too far; *stops* of different sizes are therefore provided for reducing this opening to the size necessary to suit the experiment.

The colours produced by this instrument are brilliant and beautiful, reminding one of the varied and delicate colours produced by selenite plates and polarised light, and by it we can easily combine the colours so as to give white.

In making white there is, however, always a difficulty in saying when it is white, as there seems to be a range of tints, all of which seem nearly white. To overcome this uncertainty, the instrument is so arranged that either of two methods may be employed to supply the eye with a standard of white light of the correct brilliancy, with which to compare the compound white. By one arrangement the whole field can be alternately filled with white light, or with the white produced by the coloured lights. By this means a very true white can be produced. The adjustment can be made so that no difference can be detected whether the illumination is the result of the coloured lights, or of the white light. Another plan is to fill only one-half the field with the coloured lights, and the other half with white light.

For making these comparative tests, the opening over the coloured glasses is used, and a horizontal division is placed in the box, dividing it into two from end to end. This dividing screen is hinged at the front end, just above the opening filled with the colours. The other end of the screen next the eye-pieces is moved up and down by means of a lever placed outside the box; when the end of the screen next the eye-pieces is raised, the coloured lights fall on the eye-piece, and when it is lowered the coloured lights are cut off, and white light from the upper opening enters the lens. The amount of white light entering this opening requires to be carefully regulated, by means of the shutter, to the same brightness as the white produced by the colours before a match can be made. When properly adjusted it is very difficult to tell whether we are looking at natural white, or the white of the combined colours.

When we wish to illuminate only one-half of the field with white light, the horizontal screen is lowered till it is half-way across the lens, and the division must be carried up to the *stop* in front of the lens. When this is done, the upper half of the field is illuminated with white light, and the lower with the combined colours, and if the eye is kept steady it is simply a question of very nice adjustment to make a perfect match between the two halves, and the field made to look like a white disc with a black bar across the middle. When half the field is filled with white light the conditions are very favourable for observing the various combined colours on the other half; the comparison seems to make them more distinct. This is particularly the case with delicate tints, as they are not easily distinguished if not contrasted with white.

Other forms of apparatus with lenses may be used for combining colours ; an ordinary telescope answers fairly well, but an opera-glass will not do. The colours to be combined are held close to the front of the object-glass end of the tube, if they are transparent, such as glass plates ; if the colours are opaque, they are placed in a good light, and the tube directed towards them. On looking through the eye-piece we get the result of combining the colours in the proportion in which they are exposed to the end of the tube. The object-glass of the telescope is not necessary for these experiments. The lenses of the eye can also be made to combine the colours without any assistance, but the results are not very satisfactory. If we fix the coloured transparent media with their edges close to each other on a piece of glass, and hold them very near to the eye, confining the entering light to a small angle, we shall then see the colours change through the different combinations, as they are moved across the eye.

With regard to the selection of the colours for these experiments, a few words are necessary. We may of course select any colours we please, and the instruments will combine them for us, and show us the resultant colour or sensation. We shall find that there is an infinite variety of colours which, when combined in proper proportions, will give us white. If, however, we wish to arrange the apparatus, so that it will not only give us white, but will also produce all possible colours, with their shades and tints, then the only three colours which, so far as I am aware, will produce these results, are red, green, and violet. With these three colours we can make white and all colours, such as yellows, blues, and purples of their different shades and tints, but by no combination of colours with which I am acquainted can we make red, green, or violet.

In selecting the colours for the instruments, I took for red a ruby-red glass, dark enough to give only a band in the red when examined with the spectroscope ; for green, a glass which passed a narrow band of light in the green of the spectrum, and is about what is known as emerald green ; and for violet a glass which passed only the light of the violet end of the spectrum. It is impossible to describe these colours more definitely by means of the lines in the spectrum, as the bands have not a definite boundary. It will be observed that neither the yellow nor the blue light of the spectrum passes into the box, neither of these colours being passed by any of the glasses.

There is considerable confusion as to the names of the colours at the violet end of the spectrum, which for clearness I must refer to here. The colour of the violet glass in the apparatus is often called dark blue, while the colour that is generally known as violet has a reddish hue in it, and when examined with the spectroscope is found to have light of both ends of the spectrum. This reddish-violet is therefore not the violet of the spectrum, but is a compound colour. It is desirable that we should not give the same name to two different colours, and, as the spectrum is an excellent standard of colour, we had better call by the name of violet that colour which corresponds to the violet of the spectrum. It is no objection to this alteration to say that this colour is often called dark blue, because, though it is sometimes called blue, yet it is not the colour which is most generally recognised as blue. All blues contain green, and can be produced by mixing the violet of the spectrum with the green. The blues have a wide range, and run into violet on the one side and into green on the other. Prussian blue, for instance, contains as much green as violet; while ultramarine blue contains comparatively little green. It is, therefore, desirable that the colour, which has neither green nor red in it, and which contains only the light of the violet end of the spectrum, should be called violet.

In experimenting with the apparatus above described, some practice is necessary to enable the observer to keep the eye steady in the correct place, as any movement tends to cause changes in the colour. To overcome this difficulty another form of apparatus has been constructed without lenses. It consists of a rather large camera obscura, divided vertically into two compartments by a thin metal partition. One compartment is lighted by an opening in the top, provided with a shutter to regulate the brilliancy of the light falling on a piece of white paper placed on the bottom of this compartment. The other compartment is lighted by a large circular window, also in the top. This window is divided into three sectors, and is glazed with red, green, and violet glasses. Each sector is provided with a shutter to regulate the amount of light of each colour entering and falling on the white paper at the bottom of this compartment. An opening is made in one side of the box, and arrangements made, so that while light is excluded, the observer can look down on the bottom of both compartments of the box, and observe the colour of the illumination on the paper. When one eye is placed directly in front of the thin metal partition it can see the bottom of both compartments at once, divided by the thin line of the partition. The paper in the one compartment, lighted by white light, is thus only separated by a fine line, from the other one illuminated by the coloured lights, and comparison is thus easily made. When working with this colour box it is taken outside or placed at an angle of about 45 degrees at an open window. By opening the shutters over the coloured glasses to the proper degree, the paper on the bottom of this compartment may be made to appear of any colour or tint we may desire. The other compartment of the box is illuminated with white light, and the shutter is opened to the desired amount to provide the eye with a standard of white.

When the three colours are combined in the proper proportions, so perfect a white can be produced with this apparatus that it is impossible to distinguish between the standard white and the white produced by the three brilliant colours. In order to get this perfect match of the two whites, great care must be taken in the construction of the apparatus. The surface of the interior of the box must be *dead* white ; if there is the smallest amount of polished surface reflection, such as that given by most paints, then the field of observation will not be flat, but will be differently tinted at different points. If the surfaces in the interior were perfectly flat, these reflections would not interfere with the result; but, owing to the unavoidable curvatures of these surfaces, the colours are unequally reflected to the paper. The source of the illumination required for working this box ought to have as wide an angle as possible. A bright sky does very well, but if the sun shines on the instrument, ground glass or thin white paper must be hung up in front of the glasses.

One advantage of this colour box is the ease to the eye with which the observations can be made, and the secondary colours, such as yellow, blue, and purple, produced by it are brilliant. If we open the red and green shutters, the colour produced is a canary-yellow of considerable brightness and strength. To get this bright yellow we must be very careful in the selection of the glasses in the window, and also be very certain that every ray from the violet glass is excluded by its shutter, as a very little violet light causes the yellow to grow pale and change to white.

An interesting and beautiful experiment can be made with this box. If, after having adjusted the colours to produce white, we introduce an opaque body into the compartment lighted with the coloured glasses, there is at once formed a striking display of prismatic-like colours. The paper on the bottom of the box is no longer white, but covered with most varied and brilliant hues, caused by the penumbra of the opaque body being lighted with different colours on the different sides. These effects can be intensified by placing over the coloured glasses a shutter with three round openings cut in it, so as to separate the sources of the different coloured lights. The colours on the bottom of the box will now be found to be further separated, more distinct, and fuller in tone. The form of the shadow-producing body may be varied, but perhaps the most beautiful effects are got when it is in the shape of a flat ring, placed a short distance from the paper. With that form it is interesting to follow the manner in which the different colours are produced. Confining our attention to the light passing through the centre of the ring, we can distinguish on the bottom of the box three overlapping circles of light—one red, another green, and the third violet; where the red and green overlap a brilliant yellow is produced; where the green and the violet overlap are the blues; and the red and the violet give the purples; while in the centre, where all three circles overlap, white is produced. The purity of these colour effects is increased by having the inside of the box painted of a dull black, as this destroys all internal reflections which would dilute and weaken the colour effects. In order that the same apparatus may do for both kinds of experiments, the inside of the box is provided with two folding screens, each the same size as the side of the compartment; one side of each screen is black and the other white. By folding the screens one way, the inside of the box is made all white, for experiments in combining colours; and by folding them the other way, the interior is made all black, to prevent reflections which would destroy the brilliancy of the coloured shadow experiments.

These colour experiments explain why there is so little appearance of coloured light in our Cathedrals, even when there is much coloured light entering through the stained glass windows, and they show us that we might glaze the windows with the most brilliantly coloured glass, and yet the light in the interior might be quite white.

It is hoped these colour-combining instruments will be found useful for teaching physiological optics, for experiments on colour perception, and also for measuring the qualities of lights from different sources. The possibility of making a perfect match, and the extreme nicety of the adjustment necessary to produce a perfect balance, indicate that these instruments are capable of considerable accuracy.

2. On Chlorophyll from the Deep Sea. By W. W. Hartley, F.R.S., Royal College of Science, Dublin.

The shells of certain molluscs which are obtainable on the seashore between tides are seen to be more or less coloured green. I have noticed a fine rich colour on the operculum of a *Turbo* from the Pacific Ocean, which had been killed and the shell preserved dry. The shell has a high polish, the colour is the rich green of an ivy leaf, and the pigment is contained in the shell material. When the mollusc dies, and the shell is left exposed to air, light, and water, the green becomes a brownish-yellow colour. Some specimens of spirit, which had been poured off shells and fragments of coral obtained by dredging in deep waters, were examined by me for Mr J. Y. Buchanan. He informed me that some of the shells were of a beautiful green colour, but there was no appearance of any growth of algæ adhering to them. When placed in spirit, the colour became dissolved. After evaporation of the spirit, a mixture of green and yellow pigments was found in the residue, and nothing else. The green pigment was insoluble, while the yellow appeared to be slightly soluble in water. On shaking the substance with hydrochloric acid and ether, I did not at first get Fremy's reaction ; but subsequently shaking ether with the strongest hydrochloric acid and then adding an ethereal solution of the colouring matter, a bluish aqueous solution was formed, and a brownish-yellow solution in ether. The general reactions indeed were those of blue chlorophyll, which has been described by Sorby as existing in the leaves of land plants and in certain sea-weeds. The yellow substance was one of the colouring matters which result from the alteration of chlorophyll. On heating the alcoholic solution with zinc dust in a sealed tube at 100° C., the green colour became very much brighter, and the yellow being removed the tint was much purer. After four hours the liquid was partially decolorised. The spectrum of the solution was carefully examined, the details of the examination here follow.

Spectrum of a Green Colouring Matter derived from Ocean Shells.—The shells were preserved in alcohol, which dissolved the colouring matter. A bottle was received from Mr J. Y. Buchanan in January 1884, which bore the following label:—

"S.S. 'Dacia,' 17th Nov. 1883.
Lat. 33°·42′ N. Long. 14°·7′ W.
Depth, 533 fathoms. Coral Patch."

The original liquid, which measured about three ounces, was examined just as it was poured from the bottle, and again after undergoing concentration by evaporation. It was of a pale green colour and slightly yellowish, but after being concentrated it became a dull olive-green.

The spectrum was observed with a small spectroscope of the usual form, fitted with a compound prism capable of dividing the D lines; the measurements were made upon a divided arc; a pointer shaped like a broad finger was placed in the eye-piece. One side of the finger was perfectly straight and vertical, the other was curved and brought to a fine point like a pen nib; when this was moved over an absorption band, a reading was taken as soon as the fine point ceased to be visible. The arc measurements were reduced to wave-lengths and oscillation frequencies by means of two interpolation curves obtained from those flame and spark spectra recommended as affording good lines of reference in the Report on Spectrum Analysis, in the volume published by the British Association for the year 1881:—

Thickness of layer of liquid.	Description of Spectrum.	Arc measurements.	Oscillation frequencies.	Wave-lengths.
10 mm.	Termination in the red, .	41°·4′	1411	7085
	ABSORPTION BAND in the red overlying the Solar line C.			
	Less refrangible edge, .	41°·20′	1490	6711
	More refrangible edge, .	41°·35′	1560	6410
	Visible spectrum ends at .	43°·48′	2038	4907

A solution of chlorophyll, prepared from dried *Anacharis* by extraction with pure dried ether, was of a very bright green colour, when approximately of the same shade, and when seen in layers of 10 mm. thickness, the spectrum measurements corresponding to the above were the following :—

Thickness of layer of liquid.	Description of Spectrum.	Arc measurements.	Oscillation frequencies.	Wave-lengths.
10 mm.	Termination in the red, .	41°·4′	1411	7085
	ABSORPTION BAND.			
	Less refrangible edge, . .	41°·18′	1480	6754
	More refrangible edge, . .	41°·35′	1560	6410
	Visible spectrum ends at .	44°·14′	2100	4700

In February 1884 I received from Mr John Murray a series of twelve bottles of spirit in which some of the "Challenger" dredgings had been preserved for periods of eight to ten years. They were labelled as follows :—

1. St. 186, 8th Sept. 1874; Cape York; 8 fathoms.
2. St. 151, 7th Feb. 1874; off Heard Isle; 75 fathoms.
3. 7th March 1875; Admiralty Isle; 16–25 fathoms.
4. 22d July 1874; Tongatabou; 18 fathoms.
5. St. 209, 22/1/75; Zebu; 95–100 fathoms.
6. St. 157, 3d March 1874; 1950 fathoms.
7. 23d Sept. 1874; off Arrou Isle; 800 fathoms.
8. 16th October 1874; 17 fathoms.

9. St. 344, 3d April 1876; 420 fathoms.
10. 25th April 1876; off St Vincent; 15–20 fathoms.
11. January 1874; Royal Sd. Kerguelen; 30 fathoms.
12. H.M.S. "Triton" St. 10, 24/8/82; 516 fathoms.

As none of the liquids were strongly coloured, they were examined in a tube eight inches in length, closed at the ends with parallel plates of glass. Though all the specimens had the yellowish-brown or brownish-green appearance of altered chlorophyll, only three showed measurable bands, namely, those from 15–20 fathoms, 516 fathoms, and from 800 fathoms.

No. of Specimen.	Description of Spectrum.	Arc measurements.	Oscillation frequencies.	Wave-lengths.
10	Termination in the red	41°·2′	1400	7143
	ABSORPTION BAND in the red (1), . .	41°·18′ to 41°·27′	1481 to 1524	6752 to 6561
	The same with rather less light (2), . .	41°·20′ to 41°·27′	1490 to 1524	6711 to 6561
	Very faint band in the yellow, discernible about . . .	41°·53′ to 42°·3′	1635 to 1676	6116 to 5966
	Very faint band in the green, . . .	42°·45′ to 43°·8′	1833 to 1914	5455 to 5224
	Spectrum darkens at this point, . .	43°·30′	1980	5050
	Spectrum terminates at	44°19′	2114	4730
12	ABSORPTION BAND in the red, . . .	41°·18′ to 41°·30′	1481 to 1536	6752 to 6510
	No further accurate measurements could be taken.			
7	ABSORPTION BAND in the red, . . .	41°·18′ to 41°·28′	1481 to 1530	6752 to 6536
	No further accurate measurements could be taken.			

The source of illumination was a bat's-wing gas-burner placed end on to the slit.

No. 10, 25th April 1876, off St Vincent, 15–20 fathoms. Colour of liquid as seen in tube eight inches long, brownish olive-green.

No. 12. H.M.S. "Triton" 516 fathoms. St. 10. 24/8/82. Colour of liquid as seen in tube, brownish shade of orange colour.

No. 7. Off Arrou Isle, 23d Sept. 1874, 800 fathoms. Colour, brownish-orange.

The close agreement of the measurements of the band in the red with those of the same band in fresh chlorophyll is evidence of the nature of the substance. It may be of interest to point out that the green colouring matter from liquid No. 10 was insoluble in water, but soluble in alcohol and ether; boiling with dilute sulphuric acid showed that it was not a glucoside, as it had subsequently no action on Fehling's solution. The yellow colouring matter from the same specimen was soluble in water; it had a very feeble action on Fehling's solution. Both specimens No. 12 and No. 7 yielded yellow residues soluble in water, which reduced copper solution at once on boiling.

According to Sorby, blue chlorophyll in strong solutions shows three bands at the red end of the spectrum, the least refrangible being the most intense (*Proc. Roy. Soc.*, vol. xxi. p. 442). I have observed only one band in solutions corresponding in strength to the liquids numbered 12, 10, and 7, when examined in the same way, and it is that which is figured in the paper just quoted; the bands in the yellow and green are due to the colouring matters derived from chlorophyll.

An examination was made of living green sea-weed brought out of the Irish Channel by trawlers. The fronds being thin and filmy, can be easily laid upon glass and placed before the slit of the spectroscope to be examined in layers of different thicknesses by direct sunlight. One thickness showed a dark band in the red, with an extension towards the orange, which was undoubtedly the second and weaker band of blue chlorophyll; but there were no traces of bands in the orange and green. The spectrum ended just beyond the magnesium green triplet *b*. Two thicknesses caused the band to be much increased in density; no band in the orange; green practically unaltered, the end of the spectrum nearly approaches the triplet in the green. Three and four thicknesses transmitted no trace of red, but only the green and part of the yellow rays. No band in the green was observed at all.

When the sea-weed was rapidly dried and extracted with pure dry ether, no other bands were seen with distinctness; but an alcoholic solution of the colouring matter from the same specimen, and much stronger, exhibited three absorption bands.

Pure dry ether does not take up so much colouring matter as alcohol, and it appears as if the ethereal solution contained but two substances, namely, blue chlorophyll, and a yellow body which causes absorption only beyond the *b* group. The spectrum of the ethereal solution very closely resembles that of the fronds of the living sea-weed, while the alcoholic solution differs therefrom.

The Absorption Spectrum of Chlorophyll as seen in the Fronds of living Sea-Weed.

Description of Spectrum.	Arc measurements.	Oscillation frequencies.	Wave-lengths.
Termination in the red, .	41°·	1390	7194
ABSORPTION BAND in the red, ...	41°·15′ to 41°·35′	1466 to 1560	6820 to 6410
Termination in the blue,	43°·39′	2010	4975
A second series of Measurements.			
ABSORPTION BAND in the red, ...	41°·16′ to 41°·37′	1468 to 1568	6812 to 6377

The Absorption Spectrum of Chlorophyll extracted from the dried Sea-Weed by Alcohol.

Description of Spectrum.	Arc measurements.	Oscillation frequencies.	Wave-lengths.
Termination of spectrum in red, . . .	41°·	1390	7194
ABSORPTION BAND in red,	41°·17′ to 41°·39′	1475 to 1576	6779 to 6343
Feeble *Absorption band* in the orange, . .	41°·52′ to 42°·	1631 to 1664	6131 to 6008
Feeble *Absorption band* in the green, . .	42°·23′ to 42°·57′	1753 to 1875	5702 to 5333

The bands in the orange and green were much weaker in the green colouring matter extracted from sea-weed than they usually appear when an alcoholic extract of leaves is examined, as they are caused in the latter case by substances of the xanthophyll group (Sorby, *loc. cit.*) and alteration products.

I am indebted to Mr John Murray for the following note, in answer to a query as to the possibility of floating molluscs containing colouring matters of the nature of chlorophyll, and after dying falling to the bottom of the ocean :—

"The green colouring matter from the 'Dacia,' 533 fathoms, must have come, I think, from the corals and other organisms lying on the bottom, and not from the floating molluscs or other surface organisms."

The occurrence of chlorophyll in the depths of the ocean does not necessarily imply the presence of plant life, since spongilla have been found coloured by this substance (Ray Lankester, *Quarterly Journal of Microscopical Science*, 1882, p. 253), but it opens up the question whether rays of light are at all necessary for its production.

The penetration of light to the bottom of the deep sea is a possible if not a probable phenomenon. It it true that in the clear waters of Lake Leman photographic dry-plates are affected at mid-day at no depth beyond 120 fathoms; but Messrs Fol and Sarasin are led to suppose that the greater transparency of sea-water will admit of the extreme limit of luminous rays reaching a still lower level. ("Sur la Pénétration de la Lumière du Jour dans les Eaux du Lac de Genève," *Comptes Rendus*, xcix. p. 783.)

Facts at present at our disposal do not warrant the assumption that light cannot pass beyond this depth, for though the violet and ultra-violet certainly do not, as proved by Messrs Fol & Sarasin, yet water may transmit the green rays under circumstances which enable it to obscure the rest of the spectrum—the less refrangible portion by absorption, the more refrangible partly by absorption and partly by scattering. (See M. J. L Soret's "Memoir Sur la Couleur de l'Eau," *Journal de Physique*, 2nd series, vol. iii. 1884.)

The reason why we have very little evidence at present of the penetration of great depths by green rays is owing to the fact that gelatine emulsion containing silver bromide is very slightly sensitive to such light. If any rays are necessary for the production of chlorophyll in plant life, which is extremely doubtful, they are those in the yellow and green lying between the solar lines D and E, this portion of the spectrum being transmitted by the substance. We have accordingly no grounds for the conclusion that because chlorophyll has been found at a depth of 553 fathoms, even if the pigment be produced *in situ*, therefore light has not penetrated so far, and has not operated in its formation.

3. On the Termite as the Tropical Analogue of the Earth-Worm. By Professor Henry Drummond.

My object in this paper is to call attention to a few observations which occurred to me during a recent scientific survey of part of Central Africa, regarding the larger economy of tropical nature. And I wish especially, and with much deference, to attempt to supplement a well-known theory of Mr Darwin's, by bringing forward another claimant to the honour of being, along with the earth-worm, the leading organic agricultural and geological agent in nature.

By means of inorganic agencies—the air, the frost, and the rain—nature has no difficulty in any part of the world in preparing surface films of disintegrated soil for the growth of vegetable life. But though the elaboration of a surface film by these agencies would produce crops for a few years, a much more radical system of agriculture must be in operation before a prolonged succession of crops can be kept up from year to year, and from century to century. The lower layers of soil, exhausted with bringing forth, must be constantly transferred to the top; while the upper layers, restored, disintegrated, and saturated with the fertilising products of organic decomposition, must be lowered down to where the rootlets spread themselves in the under soil. The patient series of observations by which Mr Darwin established the conclusion that this function was discharged by the earth-worm are too well-known for repetition. On every acre of land in England, Mr Darwin calculates that more than 10 tons of dry earth are passed through the bodies of worms, and brought to the surface every year; and he assures us that the whole soil of the county must pass and repass through their bodies every few years. "The plough," he says, "is one of the most ancient and most valuable of man's inventions; but long before he existed the land was, in fact, regularly ploughed by earth-worms. It may be doubted whether there are many other animals which have played as important a part in the history of the world as have these lowly organised creatures."*

Now, while admitting to the fullest extent the influence of worms in countries which enjoy a temperate and humid climate,

* *Vegetable Mould and Earth-Worms*, p. 313.

it can scarcely be allowed that the same influence is exerted, or can possibly be exerted, in tropical lands. No man was less in danger of taking a provincial view of nature than Mr Darwin, and in discussing the earth-worm he has certainly collected evidence from different parts of the globe. He refers, although sparingly, and with less than his usual wealth of authorities, to worms being found in Iceland, in Madagascar, in the United States, Brazil, New South Wales, India, and Ceylon. But his facts, with regard especially to the influence on the large scale of the worm in warm countries, are few or wholly wanting. Africa, for instance, the most tropical country in the world, is not referred to at all; and where the activities of worms in the tropics are described, the force of the fact is modified by the statement that these are only exerted during the limited number of weeks of the rainy season.

The fact is, for the greater portion of the year in the tropics the worm cannot operate at all. The soil, baked into a brick by the burning sun, absolutely refuses a passage to this soft and delicate animal. During the brief period of the rainy season worms undoubtedly carry on their function in some of the moister tropical districts; and in the sub-tropical regions of South America and India worms, small and large, appear with the rains in endless numbers. But, on the whole, the tropics proper seem to be poorly supplied with worms. In Central Africa, though I looked for them often, I never saw a single worm. Even when the rainy season set in, the closest search failed to reveal any trace either of them or of their casts. Nevertheless, so wide is the distribution of this animal, that in the moister regions even of the equatorial belt one should certainly expect to find it. But the general fact remains. Whether we consider the comparative poorness of their development, or the limited period during which they can operate, the sustained performance of the agricultural function by worms, over large areas in tropical countries, is impossible.

Now, as this agricultural function can never be dispensed with, it is more than probable that nature will have there commissioned some other animal to undertake the task. And the animal we are in search of, and which I venture to think equal to all the necessities of the case, is the termite, or white ant. This animal, the popular name of which is misleading, seeing that it belongs to the

Termitidæ, and is not an ant at all, is a small ant-shaped insect, with a bloated, yellowish-white abdomen, and a somewhat large thorax, oblong-shaped, and in colour a disagreeable oily brown. There are three or four different species of termites, and their geographical range is probably second in extent only to that of the earth-worm. The white ants are found in enormous numbers throughout the length and breadth of Africa and India; they occur in South America, Australia, and Ceylon; and every sub-tropical region is more or less infested by them. The insects themselves, owing to a peculiarity in their habits, are rarely seen, but throughout large districts in Africa the ground is literally living with them. On the Tanganyika plateau I have camped at night on ground which was as hard as adamant, and as innocent of white ants apparently as the pavement of St Paul's, and wakened next morning to find all the wooden articles in my tent almost gnawed to pieces. The termite lives almost exclusively upon dried wood, and it is upon a peculiarity in its mode of securing this that its agricultural and geological functions largely depend, so far at least as Central Africa is concerned.

I have just said that the white ant is never seen above the surface of the ground; and yet, without coming to the surface, it cannot secure the decaying branches, fallen trunks, and dead wood on which it lives. How does it solve the difficulty? It takes some of the ground out along with it. I have seen white ants working on the top of a high tree, and yet they were underground. They took up some of the ground with them to the tree-top; just as the Esquimaux heap up snow, building it into the low tunnel-huts in which they live, so the white ants collect earth, only in this case not from the surface but from some depth underneath the ground, and plaster it into tunnelled ways. Occasionally these run along the ground, but more often mount in endless ramifications to the top of trees, meandering along every branch and twig, and here and there debouching into large covered chambers which occupy half the girth of the trunk. Millions of trees in some districts are thus fantastically plastered over with tubes, galleries, and chambers of earth, and many pounds weight of subsoil must be brought up for the mining of even a single tree. The building material is conveyed by the insects up a central pipe with which all the galleries communicate, and which at the downward end connects with a series of subterranean passages leading deep into the earth. The method of building the tunnels and covered ways is as follows:—At the foot of a tree the tiniest hole cautiously opens in the ground close to the bark. A small head appears with a grain of earth clasped in its jaws. Against the tree trunk this earth-grain is deposited, and the head is withdrawn. Presently it reappears with another grain of earth; this is laid beside the first, rammed tight against it, and again the builder descends underground for more. The third grain is not placed against the tree but against the former grain; a fourth, a fifth, and a sixth follow, and the plan of the foundation begins to suggest itself as soon as these are in position. The stones or grains, or pellets of earth, are arranged in a semi-circular wall, the termite, now assisted by three or four others, standing in the middle between the sheltering wall and the tree, and working briskly with head and mandible to strengthen the position. The wall, in fact, forms a small moon-rampart, and as it grows higher and higher it soon becomes evident that it is going to grow from a low battlement into a long perpendicular tunnel running up the side of the tree. The workers, safely ensconced inside, are now carrying up the structure with great rapidity, disappearing in turn as soon as they have laid their stone and rushing off to bring up another. Each stone as it is brought to the top is first of all covered with mortar. Of course, without this the whole tunnel would crumble into dust before reaching the height of half an inch; but the termite pours over the stone a moist sticky secretion, turning the grain round and round with its mandibles until the whole is covered with slime. Then it places the stone with great care upon the top of the wall, works it about vigorously for a moment or two till it is well jammed into its place, and then starts off instantly for another load.

Peering over the growing wall one soon discovers one, two, or more termites of a somewhat larger build, considerably longer, and with a very different arrangement of the parts of the head, and especially of the mandibles. These important-loooking individuals saunter about the rampart in the most leisurely way, but yet with a certain air of business, as if perhaps the one was the master of works and the other the architect. But closer observation suggests that they are in nowise superintending operations, nor in any immediate way contributing to the structure, for they take not the slightest notice either of the workers or the works. They are posted there in fact as sentries, and there they stand, or promenade about, at the mouth of every tunnel, to keep at bay the warlike hordes of *Formicidæ*—the real ants—who forage about in every tropical forest in unnumbered legions. To every hundred workers in a white ant colony, which numbers many thousands of individuals, there are perhaps two of these fighting men. The division of labour here is very wonderful, and the fact that besides these two specialised forms there are in every nest two other kinds of the same insect, the kings and queens, shows the remarkable height to which civilisation in these communities has attained.

Now where is this tunnel going to, and what object have the insects in view in ascending this lofty tree? Thirty feet from the ground, across innumerable forks, at the end of a long branch are a few feet of dead wood. How the ants know it is there, how they know its sap has dried up, and that it is now fit for the termites' food, is a mystery. Possibly they do not know, and are only prospecting on the chance. The fact that they sometimes make straight for the decaying limb argues in these instances a kind of definite instinct; but, on the other hand, the fact that in most cases the whole tree, in every branch and limb, is covered with termite tunnels, would show perhaps that they work most commonly on speculation, while the number of abandoned tunnels, ending on a sound branch in a *cul-de-sac*, proves how often they must suffer the usual disappointments of adventurers.

The extent to which these insects carry on their tunnelling is quite incredible until one has seen it in nature with his own eyes. The tunnels are perhaps about the thickness of a small-sized gas-pipe, but there are junctions here and there of large dimensions, and occasionally patches of earth-work are found embracing nearly the whole trunk for some feet. The outside of these tunnels, which are never quite straight, but wander irregularly along stem and branch, resembles in texture a coarse sand-paper; and the colour, although this naturally varies with the soil, is usually a reddish-brown. The quantity of earth and mud plastered over a single tree is often enormous; and when one thinks that it is not only an isolated specimen here and there that is frescoed in this way, but often the whole of the trees of a forest, some idea will be formed of the magnitude of the operations of these insects and the extent of their influence upon the soil which they are thus ceaselessly transporting from underneath the ground.

In travelling through the great forests of the Rocky Mountains or of the Western States, the broken branches and fallen trunks strewing the ground breast-high with all sorts of decaying litter frequently make locomotion impossible. But in an African forest not a fallen branch is seen. One is struck at first at a certain clean look about the great forests of the interior, a novel and unaccountable cleanness, as if the forest-bed was carefully swept and dusted daily by unseen elves. And so, indeed, it is. Scavengers of a hundred kinds remove decaying animal matter—from the carcase of the fallen elephant to the broken wing of a knat—eating it, or carrying it out of sight, and burying it in the deodorising earth. And these countless millions of termites perform a similar function for the vegetable world, making away with all plants and trees, all stems, twigs, and tissues, the moment the finger of decay strikes the signal. Constantly in these woods one comes across what appears to be sticks and branches and bundles of faggots, but when closely examined they are seen to be mere casts in mud. From these hollow tubes, which preserve the original form of the branch down to the minutest knot or fork, the ligneous tissue is often entirely removed, while others are met with in all stages of demolition. In attacking a small branch the insects start apparently from two centres. One company attacks the inner bark, which is the favourite morsel, leaving the coarse outer bark untouched, or more usually replacing it with grains of earth atom by atom as they eat it away. The inner bark is gnawed off likewise as they go along, but the woody tissue beneath is allowed to remain to form a protective sheath for the second company who begin work at the centre. This second contingent eats its way outward and onward, leaving a thin tube of the outer wood to the last as props to the mine till they have finished the main excavation. When a fallen trunk lying upon the ground is the object of attack, the outer cylinder is frequently left quite intact, and it is only when one tries to drag it off to his campfire that he finds he is dealing with a mere hollow tube a few lines in thickness filled up with mud.

But the works above ground represent only a part of the labours of these slow-moving but most industrious of creatures. The arboreal tubes are only the prolongation of a much more elaborate system of subterranean tunnels which extend over large areas and mine the earth sometimes to a depth of many feet or even yards.

The material excavated from these underground galleries and from the succession of doomed chambers—used as nurseries and granaries—to which they lead, has to be thrown out upon the surface. And it is from these materials that the huge ant-hills are reared, which form so distinctive a feature of the African landscape. These heaps and mounds are so conspicuous that they may be seen for miles, and so numerous are they and so useful as cover to the sportman, that without them in certain districts hunting would be impossible. The first things, indeed, to strike the traveller in entering the interior are the mounds of the white ant, now dotting the plain in groups like a small cemetery, now rising into mounds singly or in clusters, each 30 or 40 feet in diameter, and 10 or 15 in height, or again standing out against the sky like obelisks, their bare sides carved and fluted into all sorts of fantastic shapes. In India these ant-heaps seldom attain a height of more than a couple of feet, but in Central Africa they form veritable hills, and contain many tons of earth. The brick houses of the Scotch mission-station on Lake Nyassa have all been built out of a single ants' nest, and the quarry from which the material has been derived forms a pit beside the settlement some dozen feet in depth. A supply of bricks as large again could probably still be taken from this convenient depôt, and the missionaries on Lake Tanganyika and onwards to Victoria Nyanza have been similarly indebted to the labours of the termites. In South Africa the Zulus and Kaffirs pave all their huts with white-ant earth; and during the Boer war our troops in Praetoria, by scooping out the interior from the smaller beehive-shaped ant-heaps, and covering the top with clay, constantly used them as ovens. These ant-heaps may be said to abound over the whole interior of Africa, and there are three or four distinct varieties. The most peculiar, as well as the most ornate, is a small variety from 1 to 2 feet in height, which occurs in myriads along the shores of Lake Tanganyika. It is built in symmetrical tiers, and resembles a pile of small rounded hats, one above another, the rims depending like eaves, and sheltering the body of the hill from rain. To estimate the amount of earth per acre raised from the water-line of the subsoil by white ants would not in some districts be an impossible task, and it would be found probably that the quantity at least equalled that manipulated annually in temperate regions by the earth-worm.

Let me now attempt to show the way in which the work of the termites bears upon the natural agriculture and geology of the tropics. Looking at the question from the large point of view, the general fact to be noted is, that the soil of the tropics is in a state of perpetual motion. Instead of an upper crust, moistened to a paste by the autumn rains, and then baked hard as adamant in the sun; and an under soil, hermetically sealed from the air and light, and inaccessible to all the natural manures derived from the decomposition of organic matters—these two layers being eternally fixed in their relation to one another—we have a slow and continued transference of the layers always taking place. Not only to cover their depredations, but to dispose of the earth excavated from the underground galleries, the termites are constantly transporting the deeper and exhausted soils to the surface. Thus there is, so to speak, a constant circulation of earth in the tropics, a ploughing and harrowing, not furrow by furrow and clod by clod, but pellet by pellet and grain by grain. Some idea of the extent to which the underlying earth of the tropical forests is thus brought to the surface will have been gathered from the facts already described; but no one who has not seen it with his own eyes can appreciate the gigantic magnitude of the process. Occasionally one sees a whole trunk or branch, and sometimes almost an entire tree, so swathed in red mud that the bark is almost completely concealed, the tree looking as if it had been taken out bodily and dipped in some crystallising solution. It is not only one tree here and there that exhibits the work of the white ant, but in many places the whole forest is so coloured with dull red tunnels and patches as to give a distinct tone to the landscape—an effect which, at a little distance, reminds one of the *abend-roth* in a pine forest among the Alps. Some regions are naturally more favourable than others to the operations of the termites, and to those who have only seen them at work in India, or in the lower districts of Africa, this statement may seem an exaggeration. But on one range of forest-clad hills on the great plateau between Lake Nyassa and Tanganyika I have walked for miles through trees, every one of which, without exception, was ramified, more or less, with tunnels. The elevation of this locality was about 5000 feet above the sea, and the distance from the equator some 9°; but nowhere else have I seen a spot where the termites were so completely masters of the situation as here. If it is the case that in these, the most elevated regions of Central Africa, the termite colonies attain their maximum development, the fact is of much interest in connection with the geological and agricultural functions which they seem to serve; for it is here precisely before the rivers have gathered volume, that alluvium is most wanting; it is here that the tiny headwaters of these same rivers collect the earth for subsequent distribution over the distant plains and coasts; and though the white ant may itself have no power, in the first instance, of creating soil, as a denuding and transporting agent its ministry can scarcely be exaggerated.

The direct relation of the termites' work to denudation will still further appear, if we try to imagine the effect upon these accumulations of earth-pellets and grains of an ordinary rainy season. For two or three months in the tropics, though intermittently, the rains lash the forests and soils with a fury such as those in temperate climates have little idea of; and though the earth-works, and especially the larger ant-hills, have marvellous resisting properties, they are not invulnerable, and must ultimately succumb to denuding agents. From a geological point of view, these ant-hills, which occur in such numbers all over Africa that the whole country may be regarded as one vast ant-city, are to be looked upon simply as heaps of decomposed rock waiting to be removed from the surface of the earth. The tunnels, again, being only required for a temporary purpose, are made substantial enough only to last the occasion; and in spite of the natural glue which cements the pellets of earth together, the structure, as a whole, after a little exposure, becomes extremely friable, and crumbles to pieces at a touch. Many trees, from which all the earthy material has been long since swept away, still bear upon their trunk and branches the long, irregular stain which indicates former termite sites. And although the insects will sometimes repair in a single night the ravages of the day, there must be thousands of miles of disused workings annually left to their fate. When the earth-tubes crumble into dust in the summer season, the débris is scattered over the country by the wind, and in this way tends to increase and refresh the soil. During the rains, again, it is washed into the rivulets and borne away to fertilise with new alluvium the distant valleys, or carried downward to the ocean, where, along the coast-line, it "sows the dust of continents to be."

4. On Peroxides of Zinc, Cadmium, Magnesium, and Aluminium. By J. Gibson, Ph.D., and R. M. Morrison, D.Sc.*

(Read July 5, 1880.)

During the course of an investigation on the cerite metals we found that peroxide of hydrogen, added to the precipitated hydrates in presence of excess of alkali, is a very delicate test for cerium, even in presence of Lanthanum and Didymium, owing to the formation of a dark yellow or brown compound, probably a peroxide, which differs from that produced by chlorine under the similar circumstances.

While examining a residue obtained by boiling a solution of La and Di with magnesite, to free it from cerium, we observed, on using this test, the following reaction, which led us to suspect the existence of a peroxide of magnesium, namely, that when H_2O_2 was added to a solution containing chloride of magnesium and free ammonia, a copious white precipitate was formed. On repeating the experiment with solutions of a number of metals, we obtained precipitates which possessed the properties of peroxides.

On referring to the literature of the subject, we found that the greater number had been already prepared in a similar manner by Thenard and others; but we were unable to find any mention of peroxides of cadmium, magnesium, or aluminium. Thenard states that he was unable to obtain the peroxides of magnesium or aluminium; and though he mentions having obtained a peroxide of zinc by means of peroxide of hydrogen, yet he regarded it apparently as too unstable to isolate. In spite of this assertion of

* The printing of this paper was postponed for reasons stated in the following paper (see page 152 below).

Thenard's, it does not seem to have been generally believed that zinc did form any definite oxide higher than ZnO, if, in fact, it formed any other at all. The following quotation from Brandis seems to represent fairly the general idea on the subject held by chemists:—

"Thenard has described a peroxide of zinc obtained by agitating the hydrated oxide with oxygenated water; at all events, this is no permanent compound, and certainly forms no distinct salts with the acids. We may therefore reject the suboxide and the peroxide of zinc as indefinite compounds, and consider this metal as susceptible of one degree of oxidisement only, forming the protoxide."

Under these circumstances we thought the subject of sufficient interest to warrant us in bringing it before the Society, although we have not as yet obtained any of the peroxides mentioned in the title of this paper in a state of purity, nor are we as yet prepared to assign any formula to any one of them. Yet the results we have obtained prove the existence of peroxides of these metals, and tend to suggest the formula of the peroxides of zinc and cadmium.

The preparation of these peroxides in a state of purity, or even an approximation to purity, demands attention to minute details, comparatively slight variations making a very decided difference in the products obtained or even preventing their formation.

After a considerable number of experiments we obtained zinc and cadmium compounds containing a high percentage of oxygen; but we have not been so successful in the case of magnesium or aluminium, partly perhaps, because we have not had time at our disposal to try a sufficient number of experiments under varying circumstances.

The following are the results we have obtained:—

To a solution of zinc sufficient ammonia is added to redissolve the precipitated hydrate, and to prevent its reprecipitation on dilution with water to two or three times its former volume. If to this solution a dilute solution of peroxide of hydrogen be added, a copious white or slightly yellow precipitate is formed. This in itself points to some alteration having taken place, as if the precipitate were still hydrate of zinc, there is apparently no reason why it should not dissolve in the ammonia which is present. This precipitate, when filtered from the liquid and washed on the Bunsen pump six or seven times with cold water, possesses the properties of a peroxide. On adding a portion to a solution of iodide of potassium acidified with hydrochloric acid iodine is set free. After drying at a temperature of 100° C. it still retains its properties. It gives off oxygen on heating (from one sample of about $\frac{1}{4}$ of a gramme we collected 15 cc. of oxygen); on treatment with strong hot hydrochloric acid it gives off chlorine, it oxidises acid solutions of ferrous sulphate. These properties it retains almost undiminished after prolonged exposure to a temperature of 140° C.

In preparing the zinc compound we used a solution containing 5 grm. of zinc sulphate to the cc. To a 100 cc. of this solution 450 cc. of a solution of ammonia (0·037 NH_3 to the cc.) was added, and the whole filtered to remove the small quantity of precipitate left undissolved. To 100 cc. of the filtered solution 350 cc. of a dilute solution of peroxide of hydrogen was added, which produced a copious precipitate. This was collected on a filter, and washed rapidly with cold water on the Bunsen pump, and then dried on a water bath. The substance thus obtained is a yellowish-white powder, which on ignition yields protoxide of zinc, water and oxygen being evolved. It dissolves readily in cold dilute acids, and this solution gives, on shaking it up with chromic acid solution and ether, the blue coloration characteristic of peroxide of hydrogen.

In order to estimate the peroxide oxygen, we dissolved weighed portions in standard solution of ferrous sulphates acidified with sulphuric acid, and then titrated with standard solution of permanganate of potash. The percentages of oxygen estimated in this way, in three different portions, were 6·92, 6·92, and 6·42 respectively. On ignition the substance lost 20·9 per cent.

The composition, and notably the percentage of oxygen, vary very considerably when the method of preparation is slightly modified. We prepared three portions, A, B, and C, in different ways.

A. 100 cc. of the ammoniacal solution of zinc were poured into 250 cc. H_2O_2 solution, 100 cc. H_2O_2 solution added, and the precipitate filtered, and washed with a very dilute solution of H_2O_2.

B. 350 cc. of H_2O_2 solution were poured into 100 cc. zinc solution and filtered, and the precipitate washed with very dilute H_2O_2 solution.

C. 350 cc. H_2O_2 solution were poured into 100 cc. of the same zinc solution, and the precipitate filtered and washed with cold water.

The three portions were all dried at 100°, and yielded on titrating the following percentages of oxygen :—

A, ...	6·27.
B, ...	7·2.
C, ...	5·6.

The analysis of Zn, B gave the following results :—

ZnO	= 77·1
H_2O	= 13
CO_2	= 4·1
O	= 7·2
	101·4

Deducting carbonate of zinc represented by 4·1 per cent. CO_2, and the water the percentage of O = 9·66.

On heating B to 140° for ten hours it lost 9·36 per cent., and the residue on titration gave 5 per cent. of oxygen. This shows a loss of oxygen as well as water.

In the preparation of the cadmium compound we used a solution of nitrate of cadmium containing 0·5 grm. to the cc. On the addition of ammonia and then of H_2O_2 solution, a precipitate is obtained which varies very considerably in colour according to the quantity of ammonia added. On adding 27 cc. of our ammonia solution to 100 cc. of the cadmium solution, a buff-coloured precipitate is produced by the H_2O_2 solution; but if a very little more or a very little less ammonia is added, the precipitate is much paler in colour, and approaches in appearance more nearly to the ordinary white hydrate of cadmium.

Three portions, A, B, and C, were prepared as follows :—

A. To 100 cc. of the cadmium solution 27 cc. of the ammoniacal solution were added, and then an equal bulk (127 cc.) of H_2O_2 solution, the precipitate filtered, and washed with cold water.

B. The same quantities were used, but the liquid was filtered from the precipitated cadmium hydrate, and H_2O_2 solution added to the filtrate.

C. Was obtained by washing the precipitated hydrate from B with H_2O_2 solution.

A B and C were then dried at 100° C., and on titration yielded the following percentages of O :—

A, ...	5·95 per cent.
B, ...	5·25 „
C, ...	4·93 „

The analysis of A gave the following results :—

CdO	=85·8
H_2O	= 6·9
CO_2	= 3·1
O	= 5·95
	101·75

The properties of this substance resemble closely those of the zinc compound. It is more decidedly yellow in colour, however, and readily yields on ignition the ordinary brown oxide of cadmium, water and oxygen being given off. On heating a portion of A to 140° for several hours, it was partially decomposed, and became browner in colour. This substance, on titration, gave 7·4 per cent. of oxygen, deducting carbonate of cadmium as represented by 3·1 per cent. CO_2 and the water the percentage of O = 7·34, in the anhydrous oxide.

For the preparation of the magnesium compound we used several solutions of sulphate of magnesium of different strengths, and adding varying quantities of the ammonia solution. The quality of the product varied in each case according to the mode of preparation.

Magnesium A was precipitated from a solution containing chloride of ammonium and free ammonia, and was filtered, after standing all night in contact with the liquid from which it was precipitated. The precipitate, dried at 100° C., on titration, was found to yield only 0·29 per cent. of O, showing that it was nearly all magnesia. The effect produced by varying the quantity of ammonia added, while all the other conditions were kept as nearly as posssible the same, is well shown in the following three oxygen estimations :—

Magnesium B contained 3·92 per cent. O.
„ C „ 3·1 „
„ D „ 2·63 „

Magnesium B was prepared from a solution to which ammonium was added till a very slight turbidity was produced, and then peroxide of hydrogen added.

In the case of magnesium C, the quantity of ammonia was somewhat increased, and in magnesium D to a still greater extent.

Other portions of the magnesium compound were prepared under slightly different conditions, and two portions were dried over sulphuric acid *in vacuo*, but without showing any decided difference.

The dry powder obtained from these precipitates, by drying them at 100° C., possessed properties similar to those of the zinc and cadmium compounds, viz., they set free iodine from an acidified solution of iodide of potassium, &c.

Magnesium B was selected for further analysis, as it contained the greatest percentage of available oxygen. On ignition it lost 36·15 per cent., and was found to contain 2·17 per cent. of CO_2, 30·9 per cent. of water, and to leave a residue of 60·85 per cent. of magnesia.

The percentage composition was therefore—

MgO	63·85
H_2O	30·9
CO_2	2·17
O (by titration) . .	3·92
	100·84

Deducting carbonate of magnesium represented by 2·17 per cent. CO_2 and the water the percentage of O in the anhydrous oxide = 6·03.

In the case of aluminium our methods had to be somewhat altered, owing to the insolubility of alumina in ammonia. We tried a solution of alumina in caustic soda, containing no more alkali than just sufficient to dissolve the alumina. 100 grs. of ammonia alum were dissolved in the smallest quantity of water, and caustic soda added until the hydrate at first precipitated was nearly all, but not quite, redissolved. When this solution was filtered and peroxide of hydrogen added, a copious white precipitate was obtained, which was filtered off, washed, and dried—one portion at 100° C., and another over sulphuric acid *in vacuo*. A third portion was allowed to stand in contact with some of the mother liquor till the next day, and then filtered and dried at 100° C. We called these respectively A, B, and C.

On titration they gave the following results :—

A, 1·04 per cent. of oxygen.
B, 1·6 „ „
C, 1 less than on percentage of O.

B was selected for further analysis. On ignition it lost 41·35 per cent. The percentage of water found was 36·05, and that of CO_2, 3·5. The percentage of alumina 58·65. The percentage composition was therefore

Al_2O_3	58·65
H_2O	36·05
CO_2	3·5
O (by titration) . . .	1·6
	99·70

On deducting the water and CO_2 the percentage of oxygen equals 2·69 in the anhydrous oxide.

The presence of carbonic acid in this preparation is probably due to absorption from the atmosphere during the preparation. The water and carbonic acid were estimated directly; the oxygen by oxidising a standard solution of ferrous sulphate, and titrating the excess of ferrous salt by means of a standard permanganate of potash solution; the oxide by igniting a portion of the substance, and estimating the residue.

Although the above analyses show that the substances we have prepared are not pure, yet they hold out the hope that, by modifying our experiments, we may yet succeed in preparing the pure peroxides in a state fit for analysis and for the determination of their formulæ.

5. On Papers, by MM. Haas, Clève, and Lecoq de Boisbaudran, on the Production of Peroxides by means of Peroxide of Hydrogen. By J. Gibson, Ph.D., and R. M. Morrison, D.Sc.

The foregoing paper was read on 5th July 1880. We postponed, however, its publication, feeling that however interesting the formation of the bodies therein described might be, much careful quantitative research would have to be undertaken before any definite conclusion as to the true nature of these bodies could justifiably be drawn. Only the title of our paper was therefore published in the *Proceedings* of this Society.* The old University Laboratory being in many respects unfitted for the prosecution of accurate quantitative work, our researches were repeatedly postponed in the hope of being able to continue them in the new University Laboratory, which, however, only now approaches completion. This delay has been to us a subject of much regret, the questions involved being of no little interest.

We have still in our possession specimens of the various preparations now nearly five years old. When last examined, viz., during the Tercentenary Celebration of the University in April of last year, when they were shown to several of the distinguished visitors, they retained their properties to all appearance unchanged.

A week or two ago we observed a communication by M. Lecoq de Boisbaudran,† which commences as follows:—

"La récente publication d'un travail étendu de M. Clève relatif á l'action de l'eau oxygénée sur les terres rares (Yt_2O_3, Ce_2O_3 ThO_2 etc.) m'engage à ne pas poursuivre les essais que j'avais commencés dans la même voie. Je me bornerai à exposer ici quelques observations se rapportant à la peroxydation de Ce_2O_3 et de ThO_2."

M. Clève, in his valuable paper (published January 1885),‡ which deals mainly, though not exclusively, with peroxides of the rare earths, refers to a paper by R. Haas, § entitled "Ueber Peroxyde in der Zinc Magnesiumgruppe," dated 30th September 1884, which we had not previously noticed, and which covers very much the same ground as our paper, dated 5th July 1880. Under these circumstances, the verbatim publication of our paper is rendered necessary, in order to maintain our right to continue our researches. There can be no doubt that further investigation is very desirable.

In the first place, Messrs Haas and Clève state that they have not been able to obtain peroxides of aluminium and beryllium by means of peroxide of hydrogen. This we claim to have done in the case of aluminium, and some preliminary experiments lead us to the belief that beryllium also is capable of similar peroxidation. There

* Vol. x. page 706.
† *Comptes Rendus.*
‡ *Bul. Soc. Chim.*
§ *Ber. d. d. Chem. Ges.*

seems little doubt, however, that in these cases the compounds are much more difficult to obtain.

In the second place, the true character of these bodies is still uncertain. It is certain that the substances described by Messrs Haas and Clève, as well as those obtained by us, were not pure substances but mixtures. Haas states that he endeavoured to obtain the peroxides of zinc free from admixed hydrate, but that he never succeeded in producing the precipitation of peroxide when the formation of hydrate was prevented with sufficient care (sorgfältig genug). This statement is, however, too indefinite, and leaves one very much in the dark. It is easy to prepare ammoniacal solutions of zinc salts which remain perfectly clear when diluted with three or more times their bulk of water, but in which the addition of their own volume of hydrogen peroxide solution produces an abundant precipitate. This behaviour makes it difficult to understand how the formation of the zinc peroxide is necessarily a secondary product depending upon a previous formation of hydrated oxide. Our experiments lead us to a quite contrary conclusion, viz., that the hydrated oxide is a secondary product, the result of the decomposition of the peroxide. The mere determination of the peroxide oxygen and of basic oxide does not give a satisfactory insight into the composition of these bodies unless the absence of acids (carbonic, nitric, &c.) is proved. How far this was the case with the substances obtained by Herr Haas cannot be gathered from his paper. Our preparations, as well as those of M. Clève, contained one or other of these acids. We expect shortly to be in a position to communicate the results of the continuation of our researches to the Society.

6. On Supersaturation. By W. J. Nicol, Esq.

PRIVATE BUSINESS.

The following Candidates were balloted for and declared duly elected Fellows of the Society:—Professor Steggall; James Pringle, Esq.; A. P. Laurie, Esq., B.Sc.; R. J. Harvey Gibson, Esq.; Professor Dyce Davidson; and George Smith, Esq.

PROCEEDINGS

OF THE

ROYAL SOCIETY OF EDINBURGH.

VOL. XIII. 1884-85. No. 120.

Monday, 20th April 1885.

ROBERT GRAY, Esq., Vice-President, in the Chair.

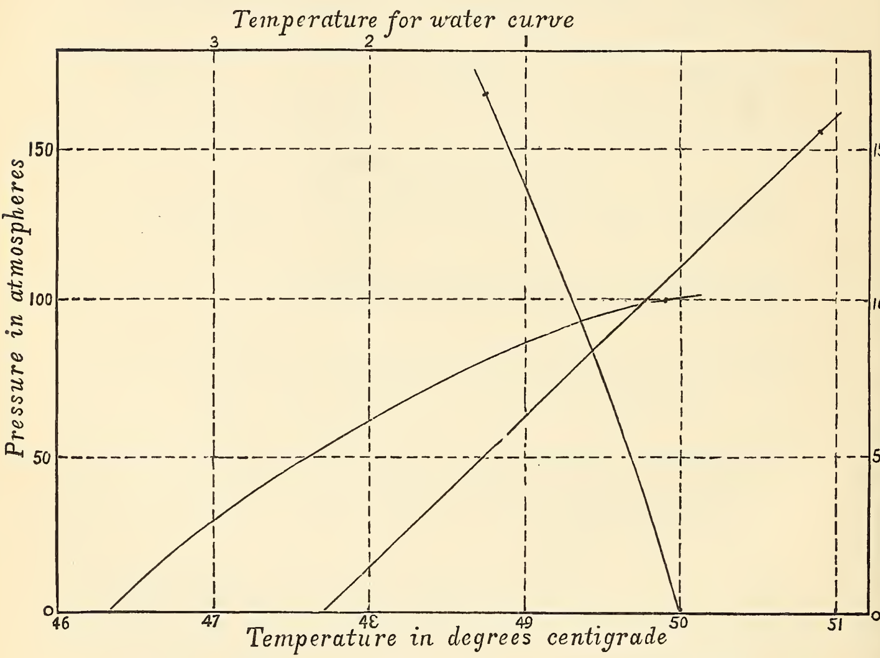
The following Communications were read:—

1. Effect of Pressure on the Temperature of Minimum Compressibility of Water. By Professor Tait.

2. Note on the Variation by Pressure of the Melting-Point of Paraffin, &c. By W. Peddie, Esq. Communicated by Professor Tait.

As the result of Andrews' experiments on the boiling-points of substances, we have the law enunciated that There is a critical temperature for every vaporous or gaseous substance; such that, only when its temperature is below this, can the substance be reduced to the liquid form by any pressure, however great. Similarly, a law may be laid down regarding the passage from the liquid to the solid state, or *vice versâ*. Thus we may say that There is a critical temperature for every solid substance, which contracts in the act of liquefaction, such that only when its temperature is above this, can the substance be reduced to the liquid form by any pressure, however great; and for every liquid substance, which contracts in the act of solidification, such that only when its temperature is below this, can the substance be reduced to the solid form by any pressure, however great.

There is as yet no experimental evidence for this law, but I hope to be able to communicate before long to the Society the result of experiments in this direction. Meantime I wish to draw attention to the peculiar behaviour of paraffin under pressure, as brought out by some experiments of Bunsen's, undertaken for a different purpose.* His results are shown graphically in the accompanying diagram. The curved lines represent the variation of the melting-point with

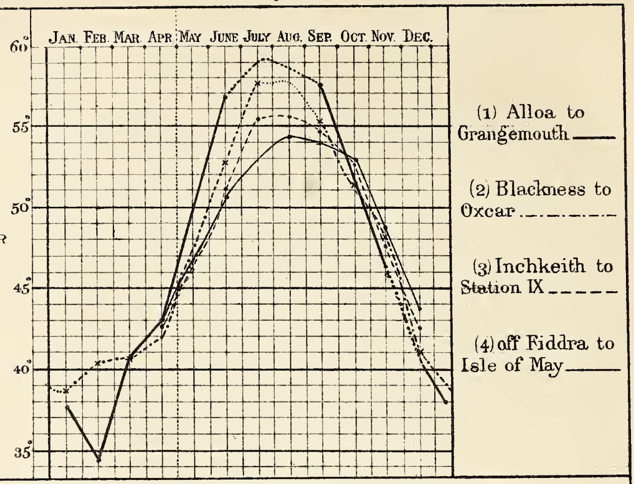


pressure. Pressure is measured upwards, and temperature horizontally. The least curved line sloping up is that of spermaceti. The markedly curved line is that of paraffin. The line sloping down is that of water. The direction of slope shows that the substance expands in the act of freezing, as its melting-point is lowered by pressure. If the paraffin curve continues to bend at the same rate as the pressure is increased, beyond the point reached in Bunsen's experiments, its tangent line will become horizontal, and the curve will be concave to the temperature axis. That is to say, paraffin under these pressures will behave as water does, *i.e.*, will expand in the act of freezing. The temperature corresponding to the point

* *Pogg. Ann.*, lxxxi., Dec. 1850.

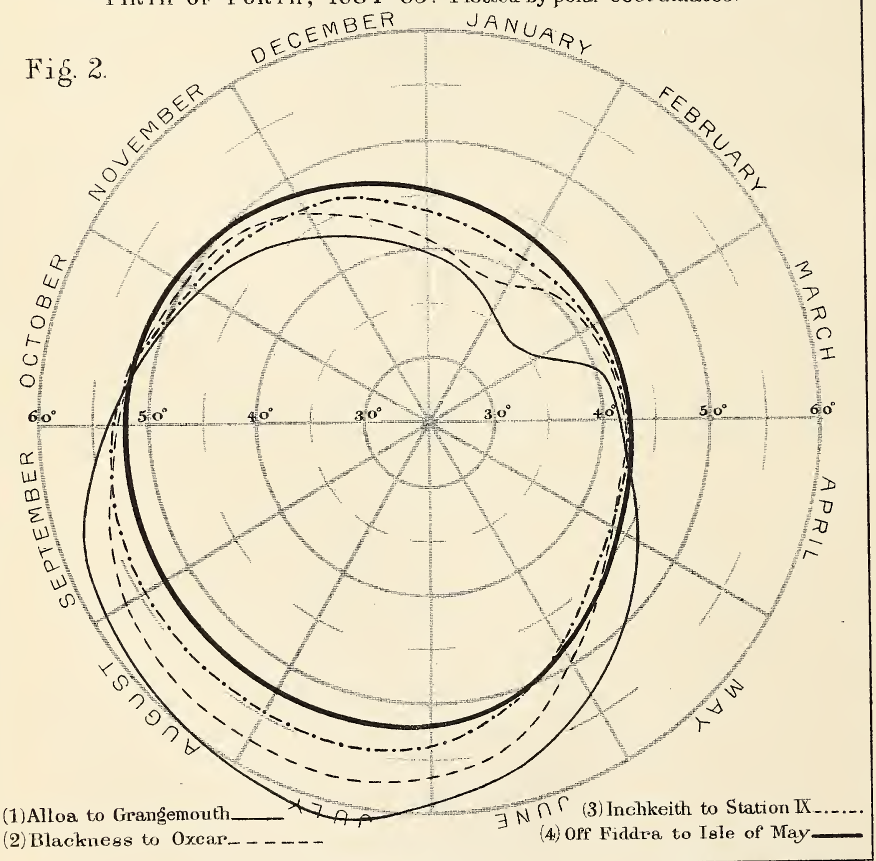
Fig. 1.

MEAN MONTHLY TEMPERATURE OF THE SURFACE WATER IN THE FIRTH OF FORTH, 1884-85. Plotted by rectangular coördinates



MEAN MONTHLY TEMPERATURE OF THE SURFACE WATER IN THE FIRTH OF FORTH, 1884-85. Plotted by polar coördinates.

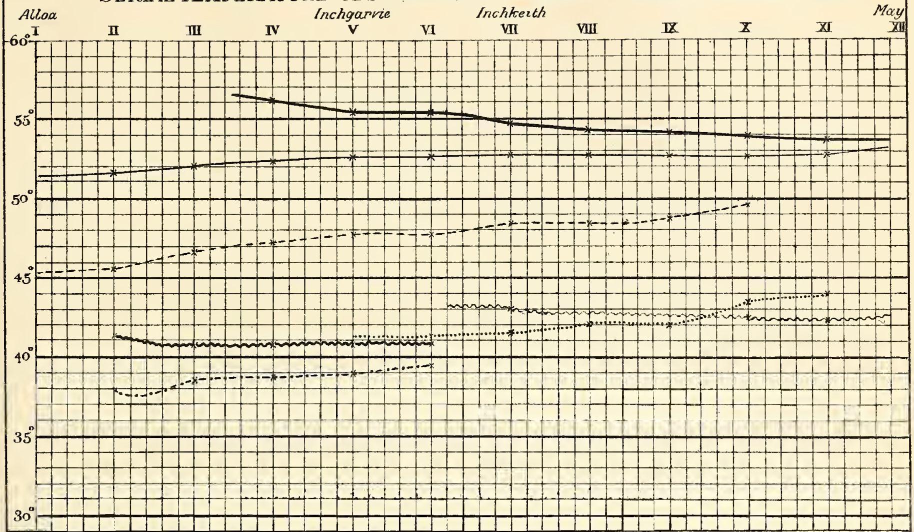
Fig. 2.



McFarlane & Erskine, Lithrs. Edinr.

Fig. 1.

SERIAL TEMPERATURE OBSERVATIONS: SURFACE WATER OF FIRTH OF FORTH.

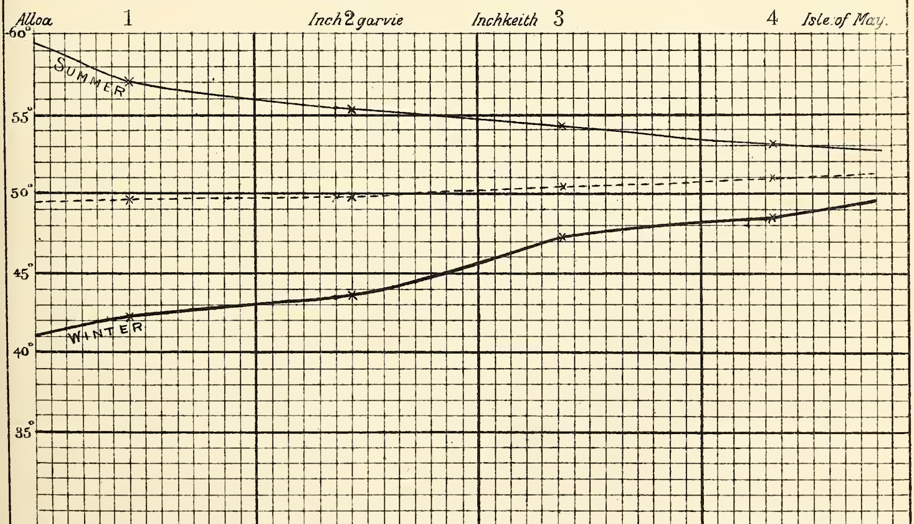


September 1884 ———— November 1884 - - - - - -
October 1884 ———— December 1884 ....
January 1885 -.-.-.-.- March 1885 ~~~~ April 1885 ~~~~

Fig. 2.

SURFACE WATER.

MEAN DISTRIBUTION OF TEMPERATURE SUMMER (June - Sept.) AND WINTER (Oct.-Jan.)



McFarlane & Erskine, Lithrs. Edinr.

where the tangent is horizontal would be a critical temperature of a peculiar nature, both forms of the above law applying to it. I hope to be able to settle this point in the experiments above proposed.

3. Note on the Thermal Effects of Tension in Water. By G. N. Stewart, Esq. Communicated by Prof. Tait.

4. On the Temperature of the Water in the Firth of Forth. By Hugh Robert Mill, B.Sc., F.C.S. (Plates VI., VII.).

The temperature of water can be ascertained much more easily than that of air, and with far greater accuracy; yet comparatively little has been done by meteorologists in the way of obtaining data bearing on the distribution of temperature in rivers and in estuaries. Some observations of great value have been discussed by Mr Buchan in the Scottish Meteorological Society's Journal,* but these were discontinued after a few years.

It would be extremely interesting, and would lead to valuable results, if at a number of stations on the River and Firth of Forth, for example, the temperature of the water could be ascertained daily, and also the temperature of the tributary streams at short intervals of time. The value of such work would of course be enormously increased if it could be applied to other river-systems, so as to admit of comparisons between them. A very complete system of observation is at present being arranged by the Tweed Commissioners, from which interesting results regarding the Tweed may be expected.

The temperature of a large river depends, in the first place, on the temperature of the deep lakes which supply it, where, as on the Forth, such lakes exist; secondly, on the temperature of the feeders, which is affected by the temperature of the rain falling, and by that of the land over which it runs. In the third place, the colour and transparency of the water, depth of river, rapidity of flow, and nature of the banks modify the effect of radiation; and, lastly, the proximity of the sea, and consequent effect of tide, must be considered.

Observations have been made at the Scottish Marine Station since May 1884, and although nothing final can be said, it has been

* *Jour. Scot. Met. Soc.*, new series, i. p. 256; v. p. 251.

considered advisable to make the results public. This is done not only to suggest the general law governing the distribution of temperature in an estuary at different seasons, but to get the benefit of any suggestions that may be made as to the carrying on of the work in future.

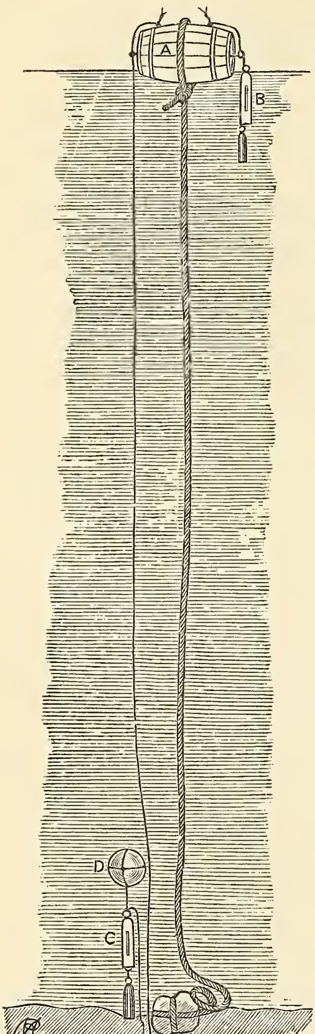


Fig. 1.

The methods of observing the temperature of water are extremely simple. For the surface it is sufficient to place a thermometer for a few seconds—the time must be greater the more sluggish the instrument—in a bucket of the water, or to dip the thermometer in the water and read it rapidly on its withdrawal. In using the latter method, the thermometer case must terminate in a little cup to contain enough water to cover the bulb. For depths below the surface the Negretti and Zambra thermometer in the Scottish frame * has been found most suitable.

A special arrangement requires to be made in order to fix continuously immersed self-registering thermometers at the surface and bottom, so that they will not have their distance from the bottom and surface altered by the rise and fall of the tide. This was accomplished at Granton by hanging the surface thermometer B (fig. 1), an ordinary Miller-Casella self-registering maximum and minimum instrument, to an anchored buoy A. The bottom thermometer was also attached to the buoy with a line long enough to reach the bottom at the highest spring tides. In order to prevent the ther-

* *Proc. Roy. Soc. Edin.*, xii. p. 927.

mometer C from lying on the mud at low water, a glass float D was employed, which was strong enough to keep the thermometer upright, but not to lift the weight attached to it. The accompanying illustration (fig. 1) represents the arrangement at low water.

In the observations to be described the corrections for the thermometers have not been applied, as from the small number of readings obtained at each station the true temperatures can be of little importance, and since the same thermometer was used during each set of observations, the value for comparative purposes is not diminished.

The mean temperature of the sea for each month during a period of five years (1858–1863) at Dunbar and at North Berwick, and for a similar period (1864–1866) at the Chain Pier, Trinity, is given in the following table (Table I.).* All three stations show

TABLE I.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Trinity, .	39·4	36·4	38·7	43·8	49·0	53·7	56·0	56·2	53·6	49·6	44·9	43·8	47·1
North Berwick,	40·5	40·0	41·1	44·2	47·8	52·2	55·6	55·6	54·8	50·9	45·5	42·2	47·5
Dunbar, .	41·1	40·1	41·7	44·5	48·2	52·4	55·4	55·8	54·8	50·7	46·2	42·9	47·7

one well-marked annual maximum between July and August, and one minimum in February. The range is greatest at Trinity and least at Dunbar; and twice in the year, about April and November, the three curves almost coincide.

Table II. shows the means for one year at Granton Quarry of the

TABLE II.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Granton, .	37·5	38·8	40·4	42·0	50·4	54·7	57·4	58·6	55·3	49·4	44·4	39·7	47·3

surface temperature, and Table III. gives the same with the bottom temperature, and that of the air at 9 A.M. and 9 P.M., and the respective maxima and minima observed. In the quarry the effects of the proximity of land are very clearly observable, and the

* *Jour. Scot. Met. Soc.*, new series, i. p. 256.

thermal conditions are complicated by the nature of the tidal basin* and by the peculiar relations borne to it by the River Almond and Cramond Island.†

TABLE III.

Month.	Temperature of Air.				Of Surface Water.				Of Bottom Water.			
	Max.	Min.	Mean. at 9 a.m.	Mean. at 9 p.m.	Max.	Min.	Mean. at 9 a.m.	Mean. at 9 p.m.	Max.	Min.	Mean. at 9 a.m.	Mean. at 9 p.m.
1885.												
Jan.	49·0	22·0	37·0	37·4	39·5	32·1	37·4	37·6	40·0	35·1	37·8	37·7
Feb.	58·0	24·0	41·0	41·3	42·0	32·9	38·8	38·9	41·7	37·0	39·2	39·2
Mar.	50·8	29·0	40·9	39·9	43·5	39·4	40·3	40·5	46·0	39·3	40·4	40·7
Apr.‡	49·0	30·0	42·6	41·2	43·7	38·9	42·0	41·9	43·5	38·9	41·8	42·1
1884.												
May§	69·5	36·5	50·6	49·6	53·5	48·7	50·0	50·8	52·0	49·1	50·1	50·4
June	70·0	41·4	56·0	54·4	58·2	50·0	54·4	55·1	57·0	50·7	54·1	54·2
July	74·0	41·7	57·3	57·0	60·7	52·7	57·3	57·5	59·2	55·0	57·1	56·9
Aug.	77·8	43·1	58·8	57·4	60·5	56·2	58·7	58·4	59·6	55·0	58·1	58·2
Sept.	69·3	30·0	55·1	54·2	56·0	50·5	55·4	55·2	56·3	52·0	54·7	54·9
Oct.	70·1	32·0	48·7	48·2	53·5	41·3	49·3	49·5	54·1	43·7	49·6	49·9
Nov.	63·0	23·0	41·9	41·6	50·0	37·5	44·3	44·4	50·0	39·3	44·8	44·7
Dec.	58·0	25·0	39·1	39·0	44·0	32·0	39·6	39·8	45·0	37·0	40·6	40·6
Year,	77·8	22·0	47·1	47·2	60·7	32·0	47·3	47·3	59·6	35·1	47·3	47·4

The curves for these data show precisely the same state of matters as those for Trinity, North Berwick, and Dunbar, so far as the date of maximum and minimum is concerned. They show, too, that from May to September the surface water is warmer than the bottom water, while from October to April it is colder, and that the temperature of the air is on the whole lower than that of the water.

The peculiar conditions of Granton Quarry make it impossible to accept its temperature indications as being applicable to the Firth outside; they must be viewed merely as exaggerated examples of the effects of land on water.

All the observations of surface temperature made in the Firth, several hundreds, have been classified for each month into four regions (see Table IV.). Under 1 is given the mean of all observations made at the stations marked on the chart (Plate III.); I., II., III., that is, from Alloa to the Hen and Chickens buoy; under 2, those made at IV., V., VI., from Blackness to Oxcar; under 3, those

* *Proc. Roy. Soc. Edin.*, xii. p. 927.

† *Ibid.*, xiii. p. 59.

‡ Up to 17th.

§ From 15th.

at VII., VIII., IX., from Inchkeith ten miles seaward; and under 4 all farther to the east.

TABLE IV.

Place.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	37·9	36·5	41·0	44·5	...	56·7	...	...	57·4	51·7	46·1	...
2	38·7	40·3	40·7	43·0	49·0	52·7	57·8	...	55·2	52·2	48·1	40·8
3	...	...	...	42·9	...	51·0	55·3	55·6	54·9	52·8	47·6	42·3
4	...	...	...	42·5	...	50·9	...	54·3	54·0	52·8	48·8	43·7

The general result of the observations is that in the landward part of the Firth the range of temperature is greater and the period of the maximum earlier than farther seaward; and that as the sea is approached the range becomes less and the date of the maximum is retarded. Thus in 2 and 3 the maximum occurs in July, in 4 not until the end of August. No doubt observations made at Alloa would show a winter minimum of 32°, or nearly so, and the summer maximum would probably approach 70°. The extreme probable range at Alloa is 40° in the year; at Queensferry a range just half of that, 20° from 58° to 38°, has been observed; and at the Isle of May it is most likely that the annual range will not much exceed 10°. The extreme temperatures observed near the Isle of May were in fact 55° in August and 43° in December.

The mean temperature for the year appears not to vary more than half a degree from 47°·5 in any part of the Firth; but an extended series of observations is necessary in order to clear up this point.

In order to show the continuity of the seasons, the temperature curves for surface water at North Berwick and at Granton were drawn on a new plan. A circle is divided into 12 sectors, one for each month, and the temperatures are measured on the radii, concentric circles being drawn for 30°, 40°, 50°, and 60°. The line representing the temperature becomes a closed curve, and the regularity of its form is very striking. The curves on Plate VI. fig. 2, representing the monthly means in the four divisions of the Firth, are less regular, in consequence, probably, of the intermittent nature of the observations. In Plate VI. fig. 1 the same curves are shown.

This plan of plotting curves by means of polar instead of rectangular co-ordinates will be found to have many advantages in meteorological work. I do not know whether it has been employed before for the purpose.

The daily range of temperature is not known. It is believed not

Table V.

Month.	Station.	June to September.		
		Surface.	Inter-mediate.	Bottom.
June,	V.	52·4	51·3	50·9
July,	,,	57·8	54·2	54·2
September,	,,	55·3	54·9	55·3
Mean,		55·2	53·5	53·5
June,	VII.	51·0	48·5	48·0
August,	,,	57·8	54·2	54·2
September,	,,	55·0	54·2	54·0
Mean,		54·6	52·3	52·1
June,	XII.	50·9	47·4	47·7
August,	,,	54·3	53·6	54·0
September,	,,	54·5	54·3	54·1
Mean,		53·2	51·8	51·9
		October to April.		
October,	V.	52·4	52·6	52·5
November,	,,	47·7	49·1	49·1
December,	,,	41·2	42·3	42·6
January,	,,	38·8	39·4	39·5
March,	,,	41·0	40·3	40·3
Mean,		44·2	44·7	44·8
October,	VII.	52·7	52·8	53·0
November,	,,	48·3	49·4	49·4
December,	,,	41·7	42·2	43·1
Mean,		47·6	48·1	48·5

to exceed 1° in the open sea, but in shallow or muddy water it must be much greater. In the intensified conditions of the Granton Quarry, the greatest daily range observed during September, October and November, by means of the registering thermometer, was 8°·7, and the average 1°·9. It is almost certain, arguing from analogy, that the daily range is, like the annual range, greatest in the river and least in the sea.

The number of observations made at depths beneath the surface has not been so great; but a considerable mass of facts has been accumulated on the subject of the bathymetrical distribution of temperature in the Firth.

The surface, bottom, and intermediate temperatures were regularly ascertained at Inchgarvie in from 30 to 40 fathoms; at Inchkeith in from 15 to 20 fathoms; and near the Isle of May, where the depth varied from 20 to 25 fathoms. Table V. gives the means for each month, and for the summer and winter periods.

From June (or probably May) to September the water at the surface is warmer than that below; but from October to April this effect is reversed, the water at the surface being then colder. It was pointed out some months ago* that the density of bottom water in the Firth was always slightly greater than that of surface water at the same temperature, and it is probable that the difference in density is sufficient to account for the apparent anomaly of cold water overlying warmer water during at least half the year. The reductions necessary to settle this point are tedious, and have not yet been completely worked out.

Table VI.

	1. Alloa to Blackness.			2. Blackness to Oxcar.			3. Oxcar to Inchkeith.			4. Farther Seaward.		
	Surf.	Bot.	S. – B.	Surf.	Bot.	S. – B.	Surf.	Bot.	S. – B.	Surf.	Bot.	S. – B.
Mean for May to September,	57·1	56·4	0·7	53·7	51·4	2·3	54·2	52·2	2·0	52·5	51·3	1·2
Mean for October to January,	45·2	45·8	– 0·6	44·9	45·9	– 1·0	47·6	48·4	– 0·8	50·8	51·2	– 0·4
Mean for the Year,	50·0	50·0	0·0	49·3	48·6	0·7	51·3	50·6	0·7	51·7	51·2	0·5

Table VI. gives the seasonal means for *all* the comparisons of bottom and surface temperatures in the four divisions of the Firth,

* "On the Salinity of the Water in the Firth of Forth," *Proc. Roy. Soc. Edin.*, xiii. p. 32.

TABLE VII.

	Alloa. I.	II.	III.	IV.	Inch-garvie. V.	VI.	Inch-keith. VII.	VIII.	IX.	X.	XI.	Isle of May. XII.
September, . .	...	...	57·4	56·7	55·3	55·7	55·3 54·6	... 54·2	... 54·1	... 54·0	... 53·9	... 53·8
Fall in each 5 miles				0·7	1·4	−0·4	0·4	0·4	0·1	0·1	0·1	0·1
October, . .	51·4	51·5	52·1	52·3	52·4	52·5	52·7	52·8	52·8	52·6	52·9	53·0
Rise in each 5 miles		0·1	0·6	0·2	0·1	0·1	0·2	0·1	0·0	−0·2	0·3	0·1
November, . .	45·1	45·6	46·9	47·2	47·8	47·7	48·3	48·4	48·9	49·6	...	...
Rise in each 5 miles		0·5	0·3	0·3	0·6	−0·1	0·6	0·1	0·5	0·7		
December, . .	...	...	...	...	41·2	41·3	41·6	42·2	42·4	43·6	43·8	...
Rise in each 5 miles						0·1	0·3	0·6	0·2	1·2	0·2	
January, . .	...	37·6	38·2	38·7	38·9	39·7	...	...	...	...	...	...
Rise in each 5 miles			0·6	0·5	0·2	0·8						
March, . .	...	41·2	40·8	40·8	41·0	41·0	...	...	...	...	...	...
Rise in each 5 miles			−0·4	0·0	0·2	0·0						
April, . .	...	...	...	...	...	43·2	43·0	...	...	43·2	43·2	43·5

including the cases considered in Table V. The former table shows that the upper half of the water has nearly the whole difference of the temperature to account for, and it is probable that quite a small layer is heated above or cooled below the temperature of the great bulk of the water.

The figures already given may be considered as describing the variation of temperature with the seasons at the various parts of the Firth; the variation of temperature with position at the same time of year must also be considered. The temperatures observed in the various long water-sampling trips are given in Table VII. They show how, in the 55 miles between Alloa and the Isle of May, the temperature is never at any one time uniform, and this is very distinctly brought out by the curves of these figures. With the exception of the first expedition (in September), all of these were made in the water-winter, that is at a time when the radiation from the land and sea at night was greater than that to them by day, and when as a consequence the shallower and more land-locked waters were colder than those deeper and nearer the sea. The curves have all an upward slope towards the sea in consequence, with the exception of that for September and that for April. The latter is a nearly straight line, showing that at present (20th April 1885) the lower reaches of the Firth are at an almost uniform temperature of 43° (see Plate VII. fig. 1). Collecting all the available observations of surface temperature, and taking the mean of those in the four divisions of the Firth for each half-yearly period, the following table (VIII.) is arrived at:—

Table VIII.

	1.	2.	3.	4.
Summer (June–September) .	57·0	55·3	49·2	48·0
Winter (October–January) .	42·3	43·7	47·3	48·4

The diagram (Plate VII. fig. 2) shows that in summer the temperature falls pretty rapidly from Alloa to Inchgarvie, and more slowly right out to sea. In winter this state of matters is exactly reversed, the temperature rising continuously from the river seawards. The mean of the two is a nearly straight line which almost coincides with the line of 50°. The number of observations made use of in drawing the winter curve was much greater than that available for the summer line, a fact which possibly accounts for the mean between the two not being parallel to the axis of x.

The mean rise or fall of temperature going along the central line of the Firth at any time during the year is 0°·07 per mile. In April and October it is much less; in December and August much more.

A great deal has to be done in the way of studying the effect of shallow water, and of the proximity of land in modifying the temperature in cross sections of the Firth. From what has been done already, it appears *possible* that if a large number of temperature observations could be taken at different parts of the Firth during all seasons for a few years, data would be procured which might render the thermometer a valuable aid in determining the position of a vessel at night or in a fog.

At present (April 1885) the temperature of the River and Firth of Forth is in a position something like the following:—

Loch Ard, the principal source of the Forth proper, is at a temperature of 42°·5, so far as regards the water in the six feet nearest the surface at any rate. The shallow river issuing from the loch and flowing slowly over a stony bed was, on the day of my visit last week, of the temperature 45°. At Kippen, 16 miles farther on, it was 47°·3, and some of the small tributary burns were as high as 49°·5. At Gargunnock, 7 miles from Kippen, the temperature of the water was 46°·6. The Teith, which is a larger river than the Forth, and joins it near Stirling, had a temperature of 42°·3 at Callander, which was reduced to 42° at Doune, 9 miles farther on, and 6 miles from the junction. This evidently shows that the lochs that feed the Teith—Vennachar, Katrine, and Lubnaig—must be colder than Loch Ard: but I had not time to ascertain this by a visit. At Stirling the river had the temperature of 45°, which gradually fell to 43°·5 at Kincardine; and the whole Firth, from there to beyond the Isle of May, is at a temperature not more than half a degree different from this. This uniformity will probably not last for a week. It is a state of matters represented by the upward sloping winter-temperature curve being in a horizontal position preparatory to its assuming the downward direction characteristic of summer.

It is curious how great a difference there is between the temperature of rivers in the same district and apparently under the same conditions; and the only way to arrive at an understanding concerning it is by having simultaneous observations at different places.

The basin of the Forth is very poorly supplied with meteorological stations, and if anything like thorough knowledge of the physical conditions of this river system is to be obtained, such stations must be set in action. This could be best done by the assistance and co-operation of the proprietors on the banks of the river, who would doubtless in time reap practical advantages from the work done.

I have to thank Mr T. Morton Ritchie, B.Sc., for his valuable help in making many of the observations described in this paper; various members of the scientific staff of the Scottish Marine Station, where the work was carried on; and in particular the crew of the "Medusa," without whose care and assistance it would have been impossible to do much of the deep-sea work.

5. The Relations of the Yolk to the Gastrula in Teleostean Embryos. By J. T. Cunningham, B.A.

(*Abstract*).

In the course of my studies on the development of marine osseous fishes, I have recently made at the Scottish Marine Station some observations on the living ova of the cod (*Gadus morrhua*, L.), haddock (*G. æglefinus*, L.), and whiting (*G. merlangus*, L.). The eggs of all these species are pelagic; that is to say, they are not adhesive, and are of less specific gravity than the sea water into which they are shed by the parent fish, and they consequently undergo development at or near the surface of the sea. They float at the surface of still sea water in a glass vessel such as was used to contain them in the laboratory, and at the surface of the sea in calm weather. But if the glass vessel be shaken the eggs are dispersed throughout the water within it, and when the surface of the sea is agitated by wave motion, a similar effect is produced, the buoyant eggs are dispersed through the water to a depth depending on the

intensity of the agitation. Like most pelagic eggs, those under consideration are transparent, and each egg is separate and spherical. The eggs of the whiting are the smallest of the three species, the cod's next in size, and the haddock's largest. The diameter of the latter measures 1·45 mm. Owing to their convenient size and perfect transparency, the changes which occur in the embryonic period of development—that is, from fertilisation to hatching—can be followed with great ease by placing eggs at successive stages under the microscope, a combination of lenses being used magnifying about 40 diameters. The eggs were obtained and fertilised by squeezing them from the ripe fish on board a fishing boat into a bottle of sea water, into which milt from a ripe male had previously been allowed to fall.

The eggs of all the species mentioned have a very similar structure; the yolk is perfectly structureless, the vitelline membrane very thin, and the pervitelline space of moderate size. At one pole of the yolk is the blastodisc, a cap of protoplasm tinged at the earlier stages of development of a light terra-cotta colour. This colour gradually disappears towards the end of the process of simple segmentation.

The processes of the development in pelagic Teleostean ova have been recently described by various naturalists, and there is a general agreement in the descriptions concerning the main features. Full details of my own observations will appear shortly in the *Quarterly Journal of Microscopical Science.* All I wish to do here is to review synthetically certain phenomena of the development, their probable significance as evidences of remote ancestral conditions, and their homological relations to phenomena in the development of other vertebrate forms.

The development of a pelagic Teleostean ovum, and doubtless of all Teleostean ova, differs from that of all other vertebrate ova in the fact that invagination takes place round the whole periphery of the blastoderm simultaneously. This invagination is completed before the blastoderm begins to grow over the yolk mass, and the invaginated layer causes the peripheral region of the blastoderm to be thicker than the central part. The thickened part is known as the germinal ring. Along one radius the blastoderm is thicker than elsewhere, even before the inflected layer appears, and beneath this radius the inflected layer when it is formed extends further inwards than elsewhere. The inflected or invaginated layer when it appears constitutes part of the blastoderm, and is situated between the rest of the blastoderm and the yolk mass. The superficial layer of the yolk mass beneath the blastoderm is protoplasmic and nucleated, though not divided into cells. This layer is called the periblast, and at a later stage forms a continuous covering all over the yolk mass, from which it is never distinctly separated. The thickened radius of the blastoderm is the first indication of the embryo, and is known as the embryonic rudiment. As the blastoderm grows over the yolk, the germinal ring, exclusive of the embryonic rudiment, remains of the same breadth, but the rudiment grows in length at its posterior end, while the anterior end, that which is at first situated near the centre of the blastoderm, does not alter its position. The posterior end of the embryonic rudiment is always at the edge of the growing blastoderm. Towards the close of the process of envelopment of the yolk by the blastoderm, the germinal ring is gradually absorbed into the embryonic rudiment, and finally the whole of it is seen to form part of the dorsal region of the embryo. In this way the whole of the invaginated layer comes to lie beneath the axis of the embryo. There can be little doubt from what is known concerning the development of other vertebrate forms, that the invaginated layer ultimately forms the dorsal wall of the intestine, the floor of which is derived from the periblast.

It was maintained some years ago by the German embryologists, His and Rauber, that the explanation of the formation of the dorsal region of the embryo out of the germinal ring was, that the two halves of the ring were gradually fused together by concrescence taking place at the point where they were continuous with the posterior end of the embryonic rudiment, and that the edge of the blastoderm was the blastopore, which was thus situated along the median dorsal line of the embryo. This view is generally accepted by more recent students of Teleostean development, but no examination has been made of the theory or process in detail. His and Rauber, in their exposition of the concrescence theory, connected it with the discussion of facts concerning the development of the medullary folds in Elasmobranchs. It seems to me important that it should be clearly understood that the process of concrescence which undoubtedly takes place in Teleostean ova is simply the closing of the dorsal blastopore, which has become distended by the increased bulk of the yolk developed in the ventral hypoblast of the original gastrula. The nerve cord in its original condition was a thickened line of epiblast surrounding the blastopore, and the formation of the medullary canal by which the nerve cord is removed from the surface of the body, is a process which originally took place after the closing of the blastopore. The two processes are only accidentally connected with one another in actual development; morphologically they are quite independent.

Since the dorsal hypoblast in the Teleostean ovum is invaginated round the whole edge of the blastoderm, this edge forms the lip of the true primitive blastopore, and is homologous with the lip of the blastopore in the ancestral gastrula. As far as can be judged from the study of living pelagic ova, the posterior end of the blastopore is on the dorsal surface, and no part of it extends round the end of the body to the ventral side of the embryo. In the Amphibian ovum invagination of the dorsal hypoblast does not occur round the whole edge of the blastoderm simultaneously; the invagination takes place first beneath the embryonic rudiment, and the rest of the lip of the blastopore is not inflected till a late stage when the yolk cells are almost completely enveloped by epiblast. But ultimately the whole edge of the blastoderm is inflected, and thus in the Amphibian, as in the Teleostean, the yolk blastopore or aperture by which the yolk protrudes, coincides with the true primitive blastopore.

In the Elasmobranch ovum this is not the case. Only a proportionally small arc of the edge of the blastoderm is ever inflected, and the dorsal region of the embryo is entirely formed by concrescence out of this part of the blastoderm. As far as the evidence goes at present, the inflected part of the blastodermic rim extends when it is folded together as far as the neurenteric canal, and the aperture by which the yolk protrudes after the coalescence has reached this point is a hernia in the ventral wall of the body. Thus only the inflected arc of the edge of the blastoderm in the Elasmobranch is homologous with the whole lip of the blastopore in the ancestral gastrula, the rest of the edge corresponds to a rupture in the ventral wall of the body of the ancestor, or of the Teleostean embryo.

In the Sauropsidan blastoderm, no part of the edge is ever inflected, nor does the embryo ever extend to the edge of the blastoderm, as it does in Elasmobranchs and Teleosteans. In the median dorsal line of the Sauropsidan embryo there is a linear structure called the primitive streak divided into two parts by the neurenteric canal. Along the anterior part the hypoblast and epiblast are originally continuous; the posterior part belongs to the ventral surface of the body. The anterior part of the primitive streak represents the original blastopore, the posterior part, the coalescence of the non-inflected part of the edge of the blastoderm in Elasmobranchs. The edge of the blastoderm in Sauropsida corresponds to a new ventral hernia apparently not continuous with the hernia in Elasmobranchs represented by the posterior part of the primitive streak. Thus no part of the edge of the blastoderm is homologous with the lip of the ancestral blastopore, or with the edge of the blastoderm in Teleosteans or Amphibia, or with the edge of the blastoderm in Elasmobranchs.

The working out of these general views in detail will form an interesting subject for future researches in the comparative embryology of vertebrates. There is one point at present which is ripe for settlement, and that is, whether any part of the primitive blastopore extends in any vertebrate to the ventral side of the body. From the evidence of Teleostean development the answer to the question seems to be negative, but Sedgwick and Miss Johnson of Cambridge have brought forward some evidence that the posterior end of the blastopore in Triton gives rise to the permanent anus.

Monday, 4th May 1885.

JOHN MURRAY, Esq., Ph.D., Vice-President, in the Chair.

At the request of the Council, an Address was given by R. T. Omond, Esq., on two years' Residence and Work at the Ben Nevis Observatory.

On the motion of the Chairman, a vote of thanks was accorded to Mr Omond for his Address.

The following Communication was read:—

On Detached Theorems on Circulants. By Thomas Muir, Esq., LL.D.

PRIVATE BUSINESS.

The following Candidates were balloted for and declared duly elected Fellows of the Society:—Johnson Symington, Esq., M.B.; J. F. Pullar, Esq.; Professor J. M. Dixon; and J. Macdonald Brown, Esq., M.B.

Monday, 18th May 1885.

EDWARD SANG, Esq., LL.D., Vice-President, in the Chair.

The following Communications were read:—

1. On the Hessian. By Professor Chrystal.

2. On the Distribution of Potential in a Thermo-Electric Circuit, open or closed. By Professor Tait.

3. On the Volume of Mixed Liquids. By R. Broom, Chemical Laboratory, Glasgow University. Communicated by J. T. Bottomley, Esq.

After seeing in the course of one of Sir W. Thomson's lectures an experiment showing the contraction which takes place when a solution of common salt is mixed with water, I resolved upon making a number of experiments with a view to noting the result of mixing various solutions.

I find that a number of experiments of a somewhat similar nature have been made by MM. Bussy and Buignet (*Compt. Rend.*, 59), Mr F. D. Brown (*Jour. Chem. Soc.*, 1881), and by Mr W. Nicol (*Jour. Chem. Soc.*, 1883). The first two of these papers deal with organic liquids, and Mr Nicol has noted the result of mixing various salt solutions, whereas the experiments I have made give the results of mixing salt solutions with water.

The apparatus which I used in my experiments consisted of a wide glass tube of convenient length, with a narrower tube attached to one end, and the whole tube was accurately graduated, and contained 262 c.c. up to a convenient point in the small tube. If equal volumes are to be experimented upon, 131 c.c. of the denser liquid are poured into the tube, and on this an equal quantity of the lighter liquid is poured, which can be done without any apparent mixing. The tube is now placed in a cylinder of cold water, and the liquid brought exactly to the 262 c.c. mark. The tube is then taken out, and after inverting till no farther streakiness is observed, is again placed in the cylinder of water, and as soon as the temperature has become the same as at the beginning of the experiment, the alteration in volume is noted.

The following are the results of experiments which I have made with solutions of some of the common salts saturated at 10° C., using equal volumes of the solutions and water :—

Water with equal vol. of sat. sol. of following salts.	Parts of anhyd. salt dissolved by 100 parts of water at 10° C.	Contraction when mixed.
KCl	31·97*	·325 per cent.
K_2SO_4	10·1	·082 ,,
KNO_3	20·77	·144 ,,
K_2CO_3	88·72	2·682 ,,
NaCl	35·75	·490 ,,
Na_2SO_4	8·04	·107 ,,
$NaNO_3$	84·3	·975 ,,
Na_2CO_3	16·66	·206 ,,
NH_4Cl	36·6	·273 ,,
$(NH_4)_2SO_4$	...	1·302 ,,
NH_4NO_3	185·	·772 ,,
$CaCl_2$	63·3	1·135 ,,
$BaCl_2$	33·3	·235 ,,
$MgSO_4$	30·5	·677 ,,
$ZnSO_4$	48·36	·835 ,,
$FeSO_4$	19·9	·327 ,,
$Al_2K_24SO_4$	4·99	·033 ,,
$CuSO_4$	20·92	·218 ,,
$Pb2NO_3$	48·3	·228 ,,

It will be observed that there is contraction in every case; in

* The results in this column are from Storer's *Dictionary of Solubilities*, and are chiefly from the experiments of Gay-Lussac and Poggiale.

fact, the only inorganic solution that I have met with, which when mixed with water expands, is ammonium hydrate. When equal volumes of NH_4HO (sp. gr. ·880) and water are mixed, the total volume expands ·33 per cent.

Sulphuric and nitric acids show the greatest amount of expansion, while hydrochloric acid, when mixed with water, neither expands nor contracts.

Monday, 1st June 1885.

ROBERT GRAY, Esq., Vice-President, in the Chair.

The following Communications were read:—

1. The Visual, Grating and Glass-Lens, Solar Spectrum, as observed in the Year 1884. By C. Piazzi Smyth, F.R.S.E., Astronomer-Royal for Scotland.

(*Abstract.*)

This paper is the outcome of 12 months' private spectroscope building, two months' observing therewith, and ten months' computing and graphical presenting of the observations. The result is a Solar Spectrum map, extending through so many as 60 double quarto plates, but capable of being arranged for the cheapest photo-lithographic reproduction, in a manner very easy to examine, convenient for reference, and yet at the same time affording at every point new and severe tests for its degree of accuracy.

This latter important feature has been chiefly obtained by exhibiting on each plate, vertically one under the other, and on the same large, clear scale, five successive and independent series of observations of the same Spectrum piece. *Two* of these several series are eclectic collections from the best Solar spectra hitherto published elsewhere; and *three*, are as many successive and perfectly distinct sets of observations by the Author, made during the summer of 1884 near Winchester. That city being chosen because it was both as far South as he could go within the limits of the British country; and be free at the same time from a most serious evil in the atmo-

sphere of the far larger, and still growing, historic city of Edinburgh; viz., the excessive quantity of coal-smoke now vitiating its atmosphere, and almost prohibiting any of the nicer observations of Practical and Physical Astronomy.

The *three* several Winchester spectra so taken, have been kept equally separate during all the following stages of computation, and even up to their very insertions into the final collective plate-forms. In the meantime the *two* eclectic spectra already mentioned, had been introduced in pen and ink on those plates for the Author, by Mr Thomas Heath, First Assistant Astronomer, R. Ob. Edin.; ensuring thus not only better draughtsmanship, but a still further degree of independence whenever a questionable case, whether of agreement or disagreement, should occur, between any of the 6, or 7,000 lines 5 times repeated.

Three, however, only of the five, sets, viz., the Author's three, appertain to the year 1884;—a period of well marked anomaly in the higher regions of the earth's atmosphere, as shown by the broad halo apparently around, or rather in front of, the Sun during the whole of that time,—a condition which is considered in the course of the paper.

2. On Knots. Part III. (Amphicheirals). By Prof. Tait.

3. On the Chemistry of Japanese Lacquer. By Hikorokuro Yoshida, Chemist to the Imperial Geological Survey of Japan. Communicated by Hugh Robert Mill, B.Sc.

The lacquer tree (*Rhus vernicifera*) is indigenous to Japan; it supplies a valuable timber, and its fruit yields vegetable wax, but it is chiefly cultivated on account of its juice—lacquer (*Urushi*)—which forms the basis of the famous Japanese varnishes. The juice is obtained by making incisions in the tree, and it is made into a varnish by simply stirring in the sun in order to drive off an excess of moisture. Different colours may be imparted to the varnish by the addition of various metals, oxides, and sulphides; and after it has been applied to an object it must be hardened by exposure to a moist atmosphere at a moderately high temperature.*

* For particulars as to the preparation and use of lacquer, see the essay in *Forestry and Forest Products*, Edinburgh, 1885, p. 515, of the chemical part of which this paper is an abstract.

Specimens of lacquer juice for this research have been received from different parts of the country. That on which I worked was kindly supplied by Mr Magaribuchi from Yoshino. As this juice was originally intended for chemical investigation, and as it was collected in the best place in the Empire, under strict official inspection, it must have been in the purest form obtainable.

The pure juice is a thick greyish fluid of dextrinous consistency, which, under the microscope, is found to consist of minute globules, of darker or lighter colour, mixed with small particles of opaque brownish matter, the whole being held mixed in the form of an intimate emulsion. It has a characteristic sweetish odour. The specific gravity is 1·0020 (20° C.); but some specimens, such as that obtained from Hachiôji, contained bark, dust, and other impurities, which raised the specific gravity to 1·038. If the juice be exposed to the air in a thin layer at 20° C., it rapidly darkens in colour, and dries up to a lustrous translucent varnish.

Mr S. Ishimatsu (now S. Hiraga), in a paper on *Urushi*, which was written some years ago at Tokio University, and afterwards communicated to the Manchester Literary and Philosophical Society,* by Professor Roscoe (Feb. 18, 1879), has shown that the constituents of the juice are a resin, a gum, water, and a small residue insoluble in water or in alcohol. The method of separation which I employed was the same as that adopted by Mr Hiraga. A resinous acid (urushic acid), together with a small quantity of the volatile matter, is separated from the other substances of the juice by treating it with absolute alcohol, evaporating the solution, and drying the acid at 105° to 110° C. The residue is boiled for some time with water, and the extract evaporated on a water-bath until it acquires a constant weight. This gives the quantity of gum. The residue, from the water extract, consisting of a coagulated diastatic matter, with small quantities of insoluble colouring substances, is dried at 100° C., and weighed. The difference of the sum of the percentages from 100 gives the amount of water and volatile matter. Thus pure Yoshino lacquer was found to have the following composition:—

* Memoirs, Manchester Literary and Philosophical Society, 3rd ser., vol. vii. p. 249.

	I.	
Part soluble in alcohol (urushic acid), . .	85·15	per cent.
Gum arabic, ... , ...	3·15	,,
Residue (nitrogenous matter), ...	2·28	,,
Water and volatile matter, ...	9·42	,,
	100·00	

The other unadulterated samples of the juice, some of which were analysed by Mr J. Takayama in our laboratory, had the following composition :—

	II. Hotta-mura Hitachi.	III. Sagami (southern district).	IV. Yechigo (northern district).	V. Hachiōji Sagami.	VI. Origin unknown. Bought at Tokio.	VII. Origin unknown. Bought at Tokio.
Urushic acid, . .	64·62	68·83	66·92	80·00	64·07	58·24
Gum arabic, . . .	5·56	5·02	4·75	4·69	6·05	6·32
Nitrogenous matter, .	2·10	2·01	1·72	3·31	3·43	2·27
Oil, ...	0·09	0·06	0·06	?	0·23	?
Water and volatile matter, . . .	27·63	24·08	26·55	12·00	26·22	33·17
	100·00	100·00	100·00	100·00	100·00	100·00

The juice which contains the largest amount of urushic acid is considered the best; in this respect No. I. Yoshino sample is superior to the rest, whilst VI. and VII. represent the average quality of the juice found in commerce.

I. *Examination of the alcoholic extract, Urushic Acid.*— This peculiar acid is the main constituent of the original juice, and also of the portion soluble in alcohol. The juice also contains a very small quantity of a volatile substance which passes into alcoholic solution, and is almost completely driven out during the drying of the acid at 105°–110° C.

Urushic acid is a pasty substance of somewhat dark colour, having the characteristic smell of the juice, readily soluble in benzene, ether, carbon bisulphide, and chloroform, less easily soluble in fusel oil and petroleum of high boiling point. It is quite insoluble in water. Its specific gravity, taken at 23° C., is 0·9851. The acid is not affected by a temperature of 160° C., but above 200° C. it decomposes slowly with carbonisation. When exposed to the air or in oxygen gas it neither dries up nor shows any sign of change as the original juice does, and in other respects it is a very stable body.

The acid, dried at 110° C., and analysed, gave the following results :—*

	I.	II.	Mean.	Theory for $C_{14}H_{18}O_2$ demands
Carbon, . . .	77·09	77·01	77·05	77·06
Hydrogen, . .	9·28	8·75	9·01	8·28
Oxygen, . . .	13·63	14·24	13·94	14·66
	100·00	100·00	100·00	100·00

The acid possesses very poisonous properties, and produces a most disagreeable itching sensation when applied to the skin. Although it does not act with equal severity upon all persons, the attack is worse when one comes in contact with it for the first time, subsequently the effect of the poison is very little felt. An immediate application of strong solution of acetate of lead to the inflamed part is the most effective remedy.

From the alcoholic solution of the acid many metallic salts can be produced, most of which are slightly soluble in alcohol, but almost insoluble in water.

Lead acetate gives a greyish flocculent precipitate — a very characteristic reaction of the acid. A quantity of this compound was prepared by precipitating an alcoholic solution of the acid with the lead salt. The precipitate, after being partially dried over a water-bath and in a dessicator, was analysed, and its composition found to be—

	Found.	Theory for $(C_{14}H_{17}O_2)_2Pb$ requires
Carbon, ...	52·08	52·40
Hydrogen, . . .	5·34	5·30
Oxygen, ...	10·13	10·01
Lead, ...	32·45	32·29
	100·00	100·00

This lead compound is a somewhat unstable body; when heated in an air-bath to 100° C. it gives off a peculiar odour, and turns darker in colour; at 110° to 115° C. it melts, and becomes a dark

* Analysed by Mr Hiraga.

brown mass; at about 130° C. it ignites spontaneously in the air, burning with a smoky flame, and leaving an oxide of lead.

Another salt of this acid which I examined was an iron compound. *Ferric chloride* gives a deep black voluminous precipitate, very slightly soluble in alcohol, and almost insoluble in water. Some of the alcoholic solution was precipitated with an insufficient amount of ferric chloride in order to see whether this fractional precipitation gave a salt of different composition. The compound obtained proved to be a salt of a very acid nature. Before analysis it was partially dried over a water-bath, and finally in a dessicator over sulphuric acid.

	I.	II.	Mean.	Theory requires for $(C_{14}H_{17}O_2)_3Fe$, $9(C_{14}H_{18}O_2) + 2H_2O$.
Carbon, . .	74·42	74·40	74·41	74·51
Hydrogen, . .	8·18	8·13	8·15	8·03
Iron, . . .	2·07	2·07	2·07	2·08
Oxygen, . .	15·33	15·40	15·37	15·38
	100·00	100·00	100·00	100·00

Another preparation of the iron salt was made with a larger quantity of ferric chloride than before. The compound again proved to be an acid salt, but of less complexity than the first. On analysis it gave the following result:—

	Found.	Theory for $(C_{14}H_{17}O_2)_3Fe$, $3(C_{14}H_{18}O_2)$ requires
Carbon, ...	74·56	74·06
Hydrogen, . . .	8·06	7·72
Iron, ...	4·29	4·11
Oxygen, ...	13·09	14·11
	100·00	100·00

These salts have very similar characteristics. They are light substances of a faint peculiar odour; at 120° C. they melt to a black mass with some decomposition, and at a somewhat higher temperature they ignite spontaneously, giving off dense smoke of a disagreeable odour. The *roiro* lacquer is produced by the formation of some of these iron compounds.

Experiments have shown that to prepare a good *roiro* lacquer, one must be careful to avoid adding too much iron salt to the juice;

for in that case the varnish will, in course of time, acquire a much browner shade (the oxidised iron urushiate having a reddish brown colour), losing at the same time in some measure its admirable qualities of resisting the action of strong chemical reagents. A small quantity of any soluble iron salt added to the juice will suffice for the preparation of the best roiro lacquer.

Free alkalies impart a very dark colour to the solution of urushic acid, which by transmitted light looks purplish blue, and by reflected light very dark brown. This viscid compound, if exposed to the air, rapidly blackens and dries up. It is a compound of an alkali metal with the acid, the normal salt of which will probably be represented by the formula $C_{14}H_{17}M'O_2$. The salt was not quite fit for analysis, as it seemed to suffer oxidation like some other salts of urushic acid during the processes of purification and drying.

Long-continued action of strong hydrochloric acid upon urushic acid produces a peculiar change in the latter; the resulting body has exactly the same composition as the original acid, but very different properties. When urushic acid was heated with a very large excess of hydrochloric acid for about three days, that lost by evaporation being replaced, it first swelled up to a soft sponge, gradually assumed a caoutchouc-like state, and finally hardened into a dark inadhesive mass. The substance, being cut into small pieces, was boiled with water, filtered, and dried over a water-bath till the last trace of hydrochloric acid retained in the pores of the substance was expelled. On cohobation with alcohol a small quantity of the substance dissolved, and this, when examined, showed the usual characteristics of unchanged urushic acid. The residue dried at 105° C., gave this result on analysis :—

	Found.	Mean obtained for Urushic Acid.
Carbon, . . .	77·07	77·05
Hydrogen, . .	8·77	9·01
Oxygen, . . .	14·16	13·94
	100·00	100·00

It appears from this that urushic acid suffers molecular transformation (polymerisation) under the influence of strong hydrochloric acid. β-urushic acid thus formed is a dark brownish solid body, with a faint peculiar odour, and soluble with difficulty in the usual solvents of urushic acid. Such being the case, an experiment was tried to ascertain whether urushic acid dries in an atmosphere charged with hydrochloric acid. A glass plate, very thinly coated with pure urushic acid, was placed upon a basin containing fuming hydrochloric acid under a bell jar, dried after standing two days. The urushic acid darkened in colour, and looked somewhat similar to the naturally hardened lacquer. When the β acid is heated to 100° C. it merely softens a little, and even at 130° it shows no sign of decomposition. It appears that the substance obtained by the decomposition of an alkali salt of urushic acid with hydrochloric acid is the same body as β-urushic acid.

Bromine acts powerfully upon urushic acid, evolving fumes of hydrobromic acid. To a solution of the acid in carbon bisulphide bromine was gradually added till it was in some excess; the whole being evaporated to dryness over a water-bath the mass was exhausted with strong alcohol, and the extract again evaporated, after which it yielded a dark semi-solid mass. This was tested for bromine by igniting it with pure lime. 0·7060 grammes of the substance gave 1·1510 grammes of silver bromide; or bromine was shown to be present in amount equal to 69·37 per cent., agreeing with a hexabromo substitution derivative of the acid, having the formula $C_{14}H_{12}Br_6O_2$, which requires 69·36 per cent. of bromine. At ordinary temperatures it is an almost solid body of a brownish colour, and soluble in most solvents of urushic acid. By using regulated quantities of bromine its lower substitution products might perhaps be obtained. Chlorine also gives a series of substitution products; but the compounds have not yet been fully examined.

The action of *nitric acid* upon urushic acid gives rise first to a series of nitro-substitution products, which appear to change afterwards into another acid containing more oxygen. The reaction is very energetic; the urushic acid first swells up to about thirty times its original bulk in the form of a yellowish sponge, which disappears gradually with the progress of the reaction. A quantity of this porous body was heated for half a day, treated with a large quantity of water, dissolved in alcohol, and precipitated with ferric chloride. The precipitate, after the usual purification and drying, was analysed, and the following results obtained :—

	Found.	Theory for $[C_{14}H_{15}(NO_2)_2O_2]_3Fe$ needs
Carbon, . . .	51·49	51·59
Hydrogen, . .	4·82	4·61
NO_2, . . .	28·16	28·25
Iron, . . .	9·77	9·81
Oxygen, . . .	5·76	5·74
	100·00	100·00

This is the ferric salt of *di-nitro-urushic acid.* The acid itself is a bright yellowish solid, readily soluble in the usual solvents of urushic acid, and gives characteristic reactions with many metallic salts : those of silver, lead, zinc, and manganese are light yellowish precipitates; those of copper and iron, greenish yellow; and those of soda and potash, light brownish. The acid itself and its metallic salts are to some extent soluble in water, and more so in alcohol. The higher nitro-substitution products, are likewise yellowish substances; their salts also seem to be characterised by their greater solubility in water and alcohol.

When the action of nitric acid upon the yellowish substance is continued for several days, it finally goes into solution with copious evolution of nitrous fumes. On evaporating the solution over a water-bath, and cooling it, a large number of small granular crystals are formed. The mother liquor, when treated with more of the strong nitric acid and evaporated, yielded several crops of similar crystals. These crystals were mixed, cleaned from the small quantity of brownish oily matter, and recrystallised from ether several times until quite pure. On analysis the following result was obtained :—

	I.	II.	III.	Mean.	Required by theory for $C_{13}H_{22}O_8$.
Carbon, . .	50·96	50·82	51·01	50·93	50·98
Hydrogen, . .	7·13	7·20	7·22	7·18	7·19
Oxygen, . .	41·91	41·98	41·77	41·89	41·83
	100·00	100·00	100·00	100·00	100·00

The substance is an acid which contains no nitrogen, and no water of crystallisation. At 134° C. it melts without decomposition to a yellowish liquid, and at 126° C. solidifies in a capillary tube.

It is readily soluble in alcohol and water, and less easily in ether. Its iron and lead salts are yellowish crystalline precipitates; that of barium of straw yellow, and of silver white. They are all slightly soluble in water. The alkali and calcium salts, which are also light yellow, are readily soluble in water and in alcohol. A quantity of the silver salt was prepared by decomposing silver acetate with aqueous solution of the acid. The ensuing precipitate was analysed with the following result:—

	I.	II.	Mean.	Theory for $C_{13}H_{18}Ag_4O_8$ needs
Carbon, . . .	21·20	21·19	21·20	21·25
Hydrogen, . .	2·39	2·59	2·49	2·45
Silver, . . .	58·86	58·86	58·86	58·85
Oxygen, . . .	17·55	17·36	17·45	17·45
	100·00	100·00	100·00	100·00

This silver salt suffers partial decomposition, blackening when exposed to sunlight. The barium salt of this acid was also prepared by exactly neutralising its aqueous solution with barium carbonate. The solution was evaporated to dryness, and the substance obtained analysed. By carefully and slowly evaporating the aqueous solution of either the silver or the barium salt, the substance can be got in minute hard crystals.

	Found.	Theory for $C_{13}H_{18}Ba_2O_8$ requires
Carbon, ...	27·02	27·08
Hydrogen, ...	3·09	3·13
Barium, ...	47·60	47·57
Oxygen, ...	22·29	22·22
	100·00	100·00

From the analyses of its salts the acid is evidently a new one, and tetrabasic, being represented by the formula $C_9H_{18}(COOH)_4$; but no name has yet been given to it.

The distillation of urushic acid with lime gives a small quantity of light hydrocarbon, which, however, appears to polymerise very easily during its purification by fractional distillation. The nature of this oil is being examined; but one of the lighter fractions analysed gave numbers which indicate a composition approaching that represented by $C_{14}H_{24}$, showing it to be probably one of the higher hydrocarbons of the terpene series. It absorbs oxygen from the air, and forms a resinous mass. It unites readily with bromine, and is blackened by concentrated sulphuric acid in the cold.

II. *Examination of the water extract, the Gum.*—Gum is a normal constituent of lacquer juice, and forms from 3 to 8 per cent. of the original liquid. Since gum is insoluble in alcohol, it is conveniently separated by treating that portion of the original which was insoluble in alcohol with boiling water, filtering, and evaporating on a water-bath till the weight becomes constant. In this way a friable, light-coloured, tasteless and inodorous substance is obtained. This is the anhydrous gum. On combustion it gave the following numbers :—0·5267 grammes of the substance gave 0·7823 grammes of carbonic acid (CO_2), 0·2834 grammes water (H_2O), and 0·0267 grammes ash. Analysis of the ash in a separate sample of the substance gave the following :—

Silica (SiO_2),	0·48	
Lime (CaO),	44·77	
Potash (K_2O),	13·68	
Iron oxide,	trace.	
Alumina (Al_2O_3),	7·85	
Magnesia (MgO),	5·79	
Soda (Na_2O),	1·33	
Carbonic acid (CO_2),	26·10	by difference.
	100·00	

If the metals in the ash be replaced by the equivalent amount of hydrogen, and the result calculated for carbon, hydrogen, and oxygen, the result will be—

	Found.	Arabic acid $C_{12}H_{22}O_{11}$.
Carbon,	42·47	42·11
Hydrogen,	6·40	6·43
Oxygen,	51·13	51·46
	100·00	100·00

The gum, when inverted, has the power of reducing Fehling's solution. 0·4747 grammes of the substance (ash deducted), after inversion with 10 per cent. hydrochloric acid, and precipitated, gave 0·8114 grammes of cupric oxide. If we suppose that after the hydration, one molecule of arabic acid ($C_{12}H_{22}O_{11}$) changes into two molecules of sugar ($C_6H_{12}O_6$), the molecular ratio which the product of inversion bears to cupric oxide will be exactly two-thirds of that of dextrose to cupric oxide, and consequently its cupric oxide reducing power or K will be 75. This, however, requires further confirmation. But whatever may be the nature of the sugar which is produced from this gum, its physical properties are identical with those of gum arabic. It is present in urushi juice in the form of an acid salt (probably of arabic acid), in combination chiefly with potash, lime, alumina and magnesia; and the point of difference which is of interest is the presence of an alumina salt, which has not hitherto been observed in other gums. A mixture of the gum and urushic acid with water in the proportion in which they exist in the juice *does not undergo any change* even when exposed to the conditions most favourable for the drying of the lacquer. Moreover, part of the gum can be extracted in an unchanged state from the perfectly hardened lacquer, and since it exists in the original juice in the form of aqueous solution, it probably serves to keep the constituents of the juice in a state of uniform distribution and intimate emulsion. It may also act as a binding material, and assist the adhering power of the lacquer when laid on any surface.

III. *The Nitrogenous Matter and its action upon Urushic Acid.*—That portion of the juice which remains insoluble in alcohol and boiling water consists essentially of a nitrogenous matter, the action of which upon urushic acid is the cause of the hardening of the lacquer. It forms from 2 to 8 per cent. of the original juice. The juice which contains most of it dries most quickly, but gives a varnish of inferior lustre. The substance, separated from the gum by the usual method of boiling water, has no action upon urushic acid, but the residue (after the separation of urushic acid) or its extract with cold water, shows its peculiar diastatic activity in an unimpaired degree. When such a solution is boiled, the albuminoid matter coagulates in the form of a white precipitate.

The substance, first dried on a water-bath, and then over sulphuric acid, gave on analysis, the following numbers :—

	I.	II.	Mean.
Carbon, . . .	59·52	59·72	59·62
Hydrogen, . . .	7·62	lost.	7·62
Nitrogen, . . .	5·48	...	5·48
Oxygen, . . .	26·18	...	26·08
Ash, ...	1·20	...	1·20
	100·00		100·00

In the ash traces of sulphur and phosphorus were detected.

The substance is slightly soluble in water, 10 per cent. sodium chloride solution, and in weak alkali solutions; but other liquids seem to have no solvent action upon it. It has no perceptible action upon sugar solution or gelatinised starch. It differs from the other albuminoids in containing a notably smaller amount of nitrogen (only one-third), whilst the numbers obtained for carbon, hydrogen, and oxygen for its composition very nearly agree with those of the other albuminoids. Active principles of malt (diastase), koji, and saliva do not possess the same property of exerting the peculiar action above mentioned upon urushic acid.

Two series of experiments were instituted to test the activity of the nitrogenous matter upon urushic acid, first at different temperatures, and secondly in different gaseous media. For this purpose a small quantity of Yoshino juice was put into a covered beaker and subjected to the regulated heat of the water-bath, the water lost by evaporation being replaced. The heated juice was next thinly coated on a glass plate, and left to dry in a box, the air of which was kept constantly moist by the falling in of drops of water. The time of heating in each experiment was from three and a half to four hours, and the temperature of the drying-box was 20° C.

1. At ordinary temperatures (20° C.) the sample dried after $3\frac{1}{2}$ hours in air, and the same under a bell jar containing moist oxygen gas dried after less than 2 hours.
2. The juice heated to 30° C., sample dried after 4 hours.
3. ,, ,, 40°–43° C., ,, ,, $4\frac{1}{2}$,,
4. ,, ,, 50° C., ,, time not known.
5. ,, ,, 55°–59° C., ,, after 24 hours;

The surface of the lacquer had a dull appearance.

6. The juice heated to 60°–63° C., sample did not dry.
7. " " 80° C., " "
8. " " 100° C., " "

Mr J. Takayama, working very carefully on a sample bought at Tokio, found the limit of activity of nitrogenous matter to be 70°–73° C., but with the Yoshino sample (which contains much less nitrogenous matter and water) he confirmed my former number of 60° C. as the limit. His method was to place the juice in a boat in a tube immersed in gradually heated water.

Next, glass plates coated with urushi juice were put under a bell jar containing an experimental gas, and left to dry at the temperature of the air, ranging between 13° and 15° C.

1. In dry air the sample did not dry.
2. " moist " " dried after 4 hours.
3. " dry oxygen " did not dry.
4. " moist " " dried after $2\frac{1}{2}$ hours.
5. " dry hydrogen " did not dry.
6. " moist " " dried imperfectly after $1\frac{1}{2}$ day.
7. " dry carbonic acid the sample did not dry.
8. " moist " " dried very slowly after 2 days.
9. " dry nitrogen " did not dry.
10. " moist " " dried imperfectly after $1\frac{1}{2}$ day.

The most legitimate inference to be drawn from all these experiments is that the combination of oxygen and moisture at the temperature of 20° C. is an essential condition for the display of the fullest activity of the diastatic matter, and consequently most favourable for the drying of the lacquer. With either the increase or decrease of temperature, the drying power decreases; at 0° to 2° C. it is temporarily suspended, and at from 60° to 70° C., the substance entirely loses its activity; this is then the point at which the coagulation of the albuminoid matter takes place—or, in other words, the diastatic action ceases. With other gases, however, I am inclined to think that some atmospheric air, which may have been present in them, might have favoured the conditions for drying; otherwise it would not have been possible. Mr J. Takayama has recently confirmed the view that lacquer juice never dries in an atmosphere of hydrogen or of carbonic acid, when kept in a eudiometer standing over mercury. These conclusions bear out the practical experiences of our lacquer men, viz., that lacquer dries most readily in the rainy season, and better in summer than in winter—a damp atmosphere at a temperature of 20° to 30° C. being usual during the rainy season.

The nitrogenous matter in the juice, if it be really possessed of a peculiar kind of diastatic action upon urushic acid, ought to be able to cause the change upon a comparatively large quantity of the acid. To study this property, and to find out the limit of the quantity of that substance within which the action can still take place upon the acid, certain experiments were made. Various mixtures of a known quantity of Hachioji juice with a weighed quantity of pure urushic acid were made; after each mixture had received the requisite quantity of water, it was thoroughly mixed in a mortar, and left to dry in a thin layer on glass plates in a moist chamber.

The practical limit within which the action can take place was found to be 1 of the nitrogenous matter to 413 of urushic acid.

Although a much less quantity of the diastatic matter can effect the drying of the acid after the lapse of many days, such length of time will unquestionably be considered inconvenient in practical working with the juice as a varnish. These experiments also show that the amount of gum in the juice can be brought down to a small percentage without bad effect. A large quantity of it, as it exists in bad juice, is always injurious, as it produces blisters upon the newly lacquered ware when it is brought into contact with water for any length of time. Knowing these facts, we are now able to prepare any good quality of the juice for varnish making, by mixing a regulated quantity of pure urushic acid with the natural juice.

The question still remains, How does the diastase act upon the urushic acid, or what is the change which urushic acid undergoes in drying? To solve this question, the states of the lacquer before and after drying have been examined and compared.

A quantity of the fresh juice (Yoshino sample) was rapidly heated on a water-bath, so as to coagulate the albuminoid, and put a stop to its further action upon the urushic acid. The heat was continued till all the water was expelled from the juice; the substance was then analysed, with the following result :—

	I.	II.	Mean.	Numbers calculated from the constituents of the juice.
Carbon, . . .	75·47	75·61	75·54	75·54
Hydrogen, . .	8·93	9·01	8·97	9·14
Nitrogen, . .	0·11	...	0·11	0·10
Ash, . . .	0·21	...	0·21	0·21
Oxygen, . . .	15·28	...	15·17	15·01
	100·00		100·00	100·00

The lacquer dried (naturally hardened) in the usual manner, and afterwards heated at 100° C. had the following composition:—

	I.	II.	Mean.
Carbon, ...	70·90	70·84	70·87
Hydrogen, . . .	8·55	7·90	8·225
Nitrogen, . . .	0·092	...	0·092
Ash, ...	0·032	...	0·032
Oxygen, ...	20·426	...	20·781
	100·000		100·000

The comparison of these two results indicates that the lacquer in hardening had taken up oxygen; and we see that, *cœteris paribus*, the amount of oxygen thus taken up is almost quite accounted for on the supposition that each molecule of urushic acid ($C_{14}H_{18}O_2$) in the juice has taken up one atom of oxygen, and changed into another body, $C_{14}H_{18}O_3$.

Further proof of this theory has been reached by the preparation of *oxy-urushic acid* ($C_{14}H_{18}O_3$), *which showed all the properties of a dried lacquer.* Urushic acid was repeatedly subjected to the action of strong chromic acid mixture containing some excess of sulphuric acid to prevent the precipitation of chromic oxide. The product, cohobated with strong alcohol to dissolve away the unattacked urushic acid, gave, on drying at 106° C., a brownish powder of the following composition:—

	First Preparation.		Second Preparation.	
	I.	II.	I.	II.
Carbon, ...	71·55	71·50	71·69	71·71
Hydrogen, . . .	8·32	8·13	7·60	7·72
Oxygen, . . .	20·13	20·37	20·71	20·57
	100·00	100·00	100·00	100·00

	Mean.	Theory for $C_{14}H_{18}O_3$ requires
Carbon, ...	71·61	71·79
Hydrogen, ...	7·94	7·69
Oxygen, ...	20·45	20·52
	100·00	100·00

This substance is very stable, and resists the action of strong mineral acids except hot fuming nitric acid, which gradually changes it to a yellowish body, and finally into the new acid previously mentioned, $C_9H_{18}(COOH)_4$. No solvent has yet been found for it. *The strength and durability of lacquer varnish are due to the presence of this oxy-urushic acid.* Many experiments on the hardening of lacquer were made by Mr J. Takayama, and they conclusively establish the fact that hardening is due to the oxidation of urushic acid, and not to its hydration.

Some drying oil is frequently added to the lacquer juice to make varnish. I have studied this point, to learn how far the introduction of the oil is admissible, without impairing the essential quality of the lacquer. It is ascertained that the addition of 10 to 15 per cent. of the drying oil to the juice does not hinder the hardening power of the lacquer, and 20 or 25 per cent. of the oil can be introduced without much bad effect. Such a mixture gives a varnish of greater transparency and spreading power than the pure juice itself, but its capability of withstanding strong chemical reagents is proportionally reduced. The results arrived at may be summoned up in the following statements :—

1. Lacquer juice consists essentially of four substances, viz., urushic acid, gum, water, and nitrogenous matter.

2. The main constituent, urushic acid, is a stable acid, capable of forming many well-defined salts and derivative compounds.

3. The gum is probably identical with gum arabic.

4. The nitrogenous matter has a composition allied to albumen, with much less nitrogen, and has a peculiar diastatic property.

5. The hardening of the juice is due to the oxidation of urushic acid ($C_{14}H_{18}O_2$) into oxy-urushic acid ($C_{14}H_{18}O_3$), which is effected by the aid of the nitrogenous matter in presence of oxygen and moisture.

6. The hardening can only take place within narrow limits of temperature, viz., between 0° to 2° C., on one side, and the temperature of the coagulation of the albuminoid (60° to 70° C.) on the other.

7. The gum is essential in keeping up the emulsion and uniform distribution of the constituents; but in the hardened lacquer it is injurious, causing blisters on newly lacquered ware when treated with water for a length of time.

8. Any quality can be conveniently given to the juice by the addition of pure urushic acid, which brings down the relative amounts of gum and nitrogenous matter. The lacquer becomes thus more transparent and gains in strength.

9. The mixture of 20 to 25 per cent. of drying oil with the juice does not much impair the essential quality of the lacquer.

4. On Atmospheric Electricity at Dodabetta. By Professor C. Michie Smith.

5. Recent Photographs of Stars, described by C. Piazzi Smyth, Astronomer-Royal for Scotland.

For many years past some little amount of isolated work *has* occasionally been accomplished in photographing certain of the brighter stars. But lately, stellar photography has gone forward with leaps and bounds; so that at a dozen different Observatories in Europe, America, South Africa, and Australia, so much is now being done in that line, that there is a speedy prospect of, in a manner, the whole sidereal heavens being photographed, and after a fashion that would not only have astonished Hipparchus, but been equally surprising to either Sir William Herschel, or Argelander or Struve up to within a very few years ago.

The reason of this sudden development of astronomical photography is twofold. *First*, a remarkable improvement, amounting even to a bursting of its bonds of the previous quarter of a century, which has taken place in ordinary photography; and *second*, the accompanying circumstance, that those new methods have been found most peculiarly suited to the special requirements of the Astronomer.

The new Photography of the portrait gallery consists in the replacement of inflammable collodions, the silver bath, with all its sicknesses, wet films, soft, slippery, contractile and perishable, together with sensitizations which each worker had to prepare painfully to his own hand, each time of using;—their entire replacement by dry plates, prepared by the thousand at large manufactories, ready to any one's hand, and with their bromo-iodised hard gelatine films, far more sensitive than the best wet collodion of the old silver bath preparation.

Now, this enormous improvement has suited the astronomers in several ways. They were never very fond of dealing with alcohol and ether at night, or manipulating all the other dangerous, or delicate and difficult experiments of chemical laboratories in the confined space of their revolving domes. And if they did occasionally prepare "wet-plates," they had to use them immediately, or lose them; while if the sky happily remained clear enough for the using,—the wet-plate would not remain long in its highest state of sensitiveness, or cleanliness either; for certain "oyster-shell" markings, as well as "fogging," would begin to form upon it, pin-holes would multiply, and the image of a brilliant and minute point of light would begin to spread chemically in the film, until pungent star-points became, as to size, more like apples and oranges.

But the new dry plates, after very easy purchase, can be kept waiting for an opportunity, through any length of time. They admit also of any length of exposure, without losing their sensitiveness, and without spreading the images of bright points so extravagantly as the wet films. And this ability of the dry-plates generally to stand long exposures is simply invaluable in photographing faint stars; for, contrary to the human eye, which can either see such an object at once, or never (for longer looking merely fatigues the eye, and at last deprives it of all power)—the photographic dry-plate goes on accumulating the effects of an at first invisible star, until by such accumulation a visible, or rather developable, mark is at length made; and if 5 minutes are not enough to produce that effect, a $\frac{1}{4}$ hour, $\frac{1}{2}$ hour, or even a whole hour may be tried.

To compass such an interval, the clock-work movement of any equatorial must of course be particularly good, and sedulously watched to keep the star-images always on one spot, and prevent their being drawn out into ellipses. But this correction being applied, then the only chemical operation left with the astronomer, is the developing of the latent image on the plate; which operation, however, may be delayed with these new plates to next day, or week, or month even, if agreeable.

Now the special examples of this new stellar photography which I have to lay before the meeting,—have been kindly sent to me by my friend Dr David Gill, Astronomer-Royal at the Cape of Good Hope: and as he is not present here, but is now on the other side of the world, I need have no compunction about alluding to him as a new rising star, of the first magnitude and richest promise, appearing just now above the Astronomical horizon; and by his singular genius, and surpassing success in whatever he undertakes, doing as much honour to his native city, the Granite Queen of the North, as to the Tercentenary of the Edinburgh University, where he received an Honorary Degree last year.

A professional photographer, with abundant supplies of apparatus and materials, was recently sent out to him, to act under his directions; and he has now accordingly begun, with that aid, the regular and systematic mapping of the whole Southern Sidereal heavens, seven degrees by seven degrees at a time; and the examples he has just sent, are merely the first essays. Yet they possess already a very considerable degree of perfection; and are specially to be commended for the neatness and roundness of all their stellar discs,—the long exposures notwithstanding.

The 1st of these interesting photographs represents, in chief, the three notable stars forming the belt of Orion, on a scale of 1 inch to 1 degree, and with an exposure of half an hour.

The 2nd represents the same subject, but with an exposure of one hour; and a great increase will be remarked in the number of smaller and exceedingly minute stars.

The 3rd represents, on the same scale though with a larger field, part of the Milky Way near that remarkable variable η Argûs.

While the 4th shows the instrument with which the views were obtained.

These photographs are evidently sharp enough to admit of being magnified several times linear, rendering the smaller stars more easily visible. Doubtless therefore, Dr Gill, who does everything well and on a continually rising ideal, will eventually have them magnified to that degree, or perhaps more; and will make his Camera views of the stars, everything that such short focussed views can ever become.

But I should warn the meeting that they never can rise up to the extraordinary importance of supplanting all the older forms of astronomy, as has been recently bruited about, with so much confidence, by some very well-intentioned persons; but who are not practically acquainted with either the *excelsior* requirements of intellectual astronomy on one side, or the limited capabilities of a photographic film, on the other.

As the art-science now stands, and with the class of instrument used on this occasion,—exceedingly pretty, *integrating* views of what can be seen, on a very small scale, of the really unfathomable depths of the starry heavens, may be obtained, and will have their own particular uses and approximate applications. But any one of these mere Camera views is totally unable to *differentiate* to the terrible extent required by the higher astronomy of the present day.

In double-star work for instance, and its most important attribute of being able to demonstrate a physical connection between one star and another, amenable to the calculations of Newtonian gravitational astronomy,—we ought to be enabled to divide a second of space into several parts with certainty. And for that purpose, such portion of space should be represented on a photograph by not less than $\frac{1}{50}$ of an inch. But that implies, in this case, a further magnifying of not less than 70 times linear. Or the making, out of one of the photographs on the table, 4900 others, each as large as itself, to represent properly that one very small portion of the sky. So that an atlas, to show the whole sky on the same scale, would require about 5 millions of them; and by no means every photograph that is taken is always a success, and worthy of being kept; while every one that is kept requires at least two companions as good as itself, to guard against accidental imitations of little stars by either pin-holes in the film, or specks in the glass plate.

And even if we should replace *that kind* of magnifying by the Achromatic compound microscope,—we are just as badly subject as ever to the inherent weakness of an originally small photograph, as distinguished from Nature herself further magnified, in this important truth; viz., that we do not, by simply magnifying a discoloured film, separate close stars; we merely enlarge their discs, or discous impressions. And at the rate of enlarging already indicated, such disc, or spurious photographic effect, in the case of any one of these three stars in the Belt of Orion,—would swell out into a huge circle, no less than 3·5 inches in diameter! Utterly covering, concealing, or swallowing up therefore any interesting stellar companion such star might have, though it should be 800 times as far off as the small angular distances which astronomers have to deal with.

While further still, though long exposure may bring out more stars than short exposure, with the same instrument,—it does not by any means enable a small telescope to compete with a large one in what *it* can show with any exposure. Photography of the stars therefore, though begun most meritoriously with small instruments, will have to be continued afterwards, in the accustomed ways of old, with larger ones. Larger ones possessing more light, and more magnifying power;—but with the inevitable accompaniment of smaller angular fields of view; and in that case there will ensue a great multiplication of the sensitive plates required. Wherefore in place of the telescopes of the future being, by photography, reduced to pocket size and minimum cost,—they will rather have to be made larger than ever, and worked more expensively.

Hence it is that so able a practical astronomer as Mr Ainslie Common, who has been performing such wonders of astronomical photography with his grand reflecting telescope of 3 feet diameter of aperture, is casting about now for the erection of another telescope of 7 or 8 feet in diameter, or considerably larger than Lord

Rosse's; infinitely more refined in its mounting, and requiring an almost uncountable number of photographic plates to represent everything it is capable of showing throughout the sky.

By all means too, I would say, let him be furnished with such an instrument by any one who can afford it, for he will use it to excellent purpose, and it will be a noble monument of Great Britain;—but do not insist on getting from Dr Gill, the work of so colossal an instrument, when you have only furnished him with a rather large Camera, of the portrait-taking order.

The next and final photograph I have to show, was received lately from my friend Colonel A. T. Fraser, R.E., in charge of the public works at Trichinopoly, south of Madras.

Though at first sight having nothing astronomical about it, it is surely, as he himself says by letter,—

"A very remarkable photograph. It represents an immense, an almost countless collection of natives at Combaconam in the Tanjore District, on the river Cauvery; where, *once in every* 12 *years* the Ganges of the North of India is said to flow into and fill a certain built tank in the town.

"For that day, the 28th of February on this particular 12 year occasion of 1885, the Ganges itself loses its efficacy, and bathing in this tank is equally meritorious. Consequently vast numbers save a long journey, and avail themselves of the opportunity. And yet it is well known that the supply of the tank percolates from the Cauvery River close by.

"Now why should I say that this photograph will be specially interesting to you?

"I asked a Brahmin, who in private tells me things now and then, what occasions the gathering? He replied it was the rising of the star 'Mukkum,' in Sanscrit, that brought such crowds on that particular day, and the rising only happens once in 12 years.

"So here you have hundreds of thousands of natives assembled to bathe in a tank in an out-of-the-way town, in consequence of the star 'Mukkum' having a peculiar position, that probably hardly any of them could define; nor could in fact any of the crowd give an intelligible reason for being in the picture, except a few from curiosity or obligation.

"I cannot, not having references at hand, find out what star is meant. According to Bentley, both the Ganges and the Euphrates symbolise the Ecliptic in Esoteric Astronomy.

"But apart from this, look at the photograph and see how closely it tallies with Isaiah xviii., literally translated,—'A people scattered and bald to a nation to be feared from this and onwards; people corded.' The people in the photograph have put aside their turbans for fear of losing them, and you see nearly every head is shorn and bald; and you may be able to make out the Brahmins by the piece of pack-thread slung across their shoulder and chest.

"Combaconam is an obscure town, principally inhabited by Brahmins, who are largely pensioned officials. It contains, however, a College at which the highest English education is given, and where the late Sir Alexander Grant was once Principal.

"What star I wonder is this Mukkum," continues the Colonel, "and why should it be important enough to draw such a mass of Hindoos on the 28th of February to N. Lat. 10° 45′, and East Longitude 79° 30′. Is not a multitude that can be incited by a motive of which we have no appreciation, literally 'to be feared.'

"It may be admitted that our Madras Astronomer, Mr Pogson, is as learned an Astronomer as any of the day, and yet I am certain there is nothing he could say about any one of the stars, which could collect hundreds of thousands of men to bathe at an obscure town on the Railway. Therefore natives must know what we do not."

In a subsequent letter dated May 4, the Colonel further writes:—

"I am now able to give you some information about the stars fixing the festival at Combaconam, having got a Brahmin the night before last to actually point them out.

"It appears that 'Mukkum,' which means they tell me in Sanscrit 'sacrifice,' is not a single star, but the four stars together, in the sign Leo, forming the four corners of a rhomboid. They were just overhead here about 7^h P.M.

"The very bright star close to them, I was told was 'Bramahaspiti,' the 'tutor of Brahma'—though I identify it with the Planet Jupiter.

"Each sacred town has what is termed its 'Stalla Purana, or Purana loci, and the festival of which I sent you the Panorama is described in one of these,—some cure having occurred from bathing, when the stars 'Mukkum' rose at some epochal date near 10^h A.M., and at the same instant Jupiter entered Leo.

"These Puranas have seldom been translated, and the authoritative copies, as of all the Hindoo books, are graven on slips of Palm leaf. The importance of what can be written, or found written, on Palm leaves is shown by the Photograph."

So far this most interesting letter writer, Colonel Fraser.

Having now looked into the *Nautical Almanac* on his day of the Photograph being taken, viz., February 28, 1885, there is this close approach of Jupiter to α Leonis, viz.:—

		H.	M.	S.			°	′
Jupiter	R.A. =	10	8	59	and	N. Decl.	+12	46
α Leonis	R.A. =	10	2	15	and	N. Decl.	+12	32.

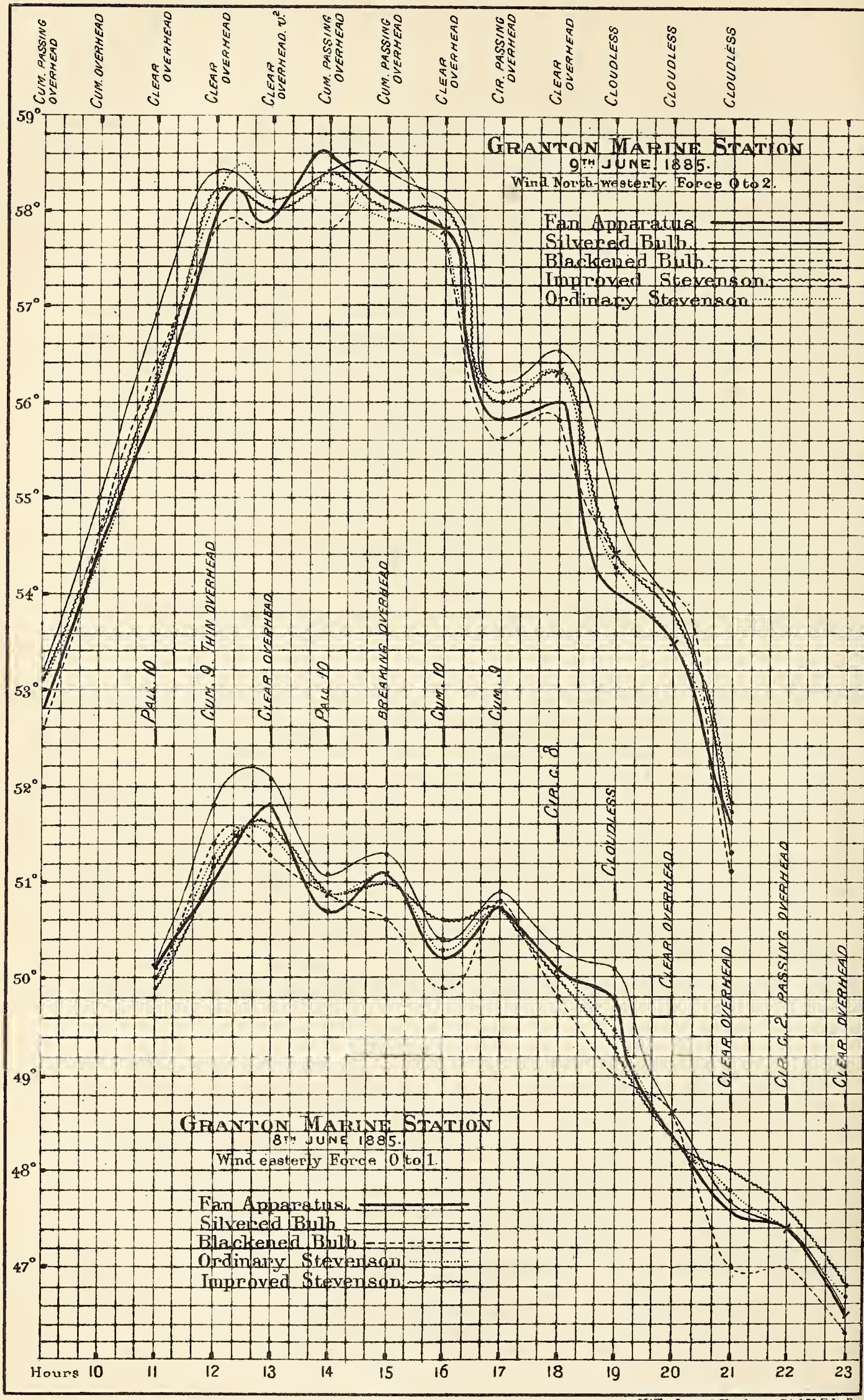
While 12 years and a few days previously, viz., on January 19, 1873, the positions were, after Jupiter had in the meantime wandered through the whole breadth of the heavens—

		H.	M.	S.			°	′
Jupiter	R.A.	10	8	43	and	N. Decl. =	+12	38
α Leonis	—	10	1	37	and	N. Decl. =	+12	35.

I shall inquire therefore of the Colonel what may have been the month and the day of the Festival being held in 1873, as well as at any other 12 year periods of which he can obtain exact information.

PRIVATE BUSINESS.

The following Candidates were balloted for, and declared duly elected Fellows of the Society:—Professor D'Arcy W. Thomson; Mr A. Y. Fraser; and Mr Alexander Scott.



McFarlane & Erskine, Lith^rs Edin^r

Monday, 15th June 1885.

ROBERT GRAY, Esq., Vice-President, in the Chair.

The following Communications were read:—

1. On Theories of the Formation of Coral Atolls and Barrier Reefs. By John Murray, Ph.D.

2. Observations on Recent Calcareous Formations of the Solomon Group, and their bearing on the Theory of Formation of Coral Islands. By H. B. Guppy, M.D., R.N. Communicated by John Murray, Ph.D.

3. Observations, Morphological and Physiological, on Pitchered Insectivorous Plants. By J. M. Macfarlane, D.Sc.

4. Preliminary Note on Observations with Aitken's Thermometer Screens. By H. N. Dickson, Esq. (Plate VIII.)

The following results of observations made with four of the thermometer screens, devised by Mr Aitken of Darroch, form the commencement of an investigation which has been begun at Granton Marine Station, and which is to be carried on there and at Ben Nevis Observatory during the summer and autumn, with the view of finding a more suitable screen for exposing thermometers for meteorological purposes, and, if possible, of determining the mean correction to be applied to the readings of thermometers exposed in the ordinary Stevenson screens. So far, the work has been entirely of a preliminary character, but some points have been brought to light which are of considerable interest.

Mr Aitken's screens were described in a paper read before the Society, on 2nd June last year, and published in the *Proceedings*, vol. xii. p. 661.

The screen used as a standard with which to compare the others consists of a rectangular wooden tube, into which the bulbs of two thermometers—wet and dry—are inserted from above, and through which a current of air is made to circulate by means of a suction fan. The air drawn in by the fan does not come into contact with much heated surface, and the circulation is sufficiently rapid to keep the walls of the tube at the temperature of the air, and to absorb any heat the thermometers may receive by radiation, without being so strong as to generate heat by friction.

The readings of this apparatus have been compared with those given by the ordinary Stevenson screen, and an improved form, having a double top, and the bottom closed with louvre-boards of the ordinary pattern. Besides these, the readings of thermometers without screens, simply protected from direct sunshine, have been taken. One of these has its bulb enclosed in a silver thimble, which reflects diffused radiations of all kinds. Under another shade two ordinary thermometers are placed side by side—the bulb of one of them having part of its surface blackened. The blackened bulb, of course, absorbs part of the heat radiated to it, and the arrangement is so constructed that the excess of the reading of the blackened bulb above that of the clean bulb, subtracted from the reading of the clean bulb, gives the true air-temperature.

The curves shown are drawn from hourly observations taken during twelve hours daily. Since the commencement of these observations the weather has not been of the character required to put the various screens to a severe test, there having been always more or less wind. The actual differences of temperature given, are therefore not nearly so great as those observed by Mr Aitken under more favourable conditions last summer; but the differences that do exist are of considerable interest.

The positions of the curves relatively to one another evidently depend to a very great extent on the state of the atmosphere with regard to cloud, and the influence of the clouds is regulated, not so much by their amount as by their position—the effect of a small amount of cumulus cloud situated directly above the instruments being very marked.

In the forenoon, as the temperature rises towards the daily maximum, the curves for the two Stevenson boxes are steeper than that for the fan apparatus; starting sometimes from a point below it, and after crossing it, gradually increasing their distance. This is obviously due to the gradual heating of the boxes, the effect being much more marked in strong sunshine than in dull cloudy weather. If the prevailing conditions persist during a maximum or minimum, the relative position of the curves remains unaltered; but if any change takes place with respect to clouds, the effect is at once noticeable. In the curves for June 9 (Plate VIII.), we have in the morning the various instruments reading very close together, the sky being covered with large quantities of cumulus cloud. After 11 hrs. we have a clear sky, and temperature rising steadily till noon, the gradual divergence of the curves being very well shown. Shortly after noon a maximum occurs—the sky remaining clear—and hence we find the positions of the curves, with respect to each other, unaltered. At 13 hrs. a minimum occurs, followed at 14 hrs. by another maximum; but in this case we have cumulus clouds passing overhead and checking the radiation of heat to the two Stevenson boxes. These boxes have now the effect of cooling the air circulating through them, and hence the curve for the fan apparatus crosses the others, and becomes the highest. The curves remain reversed till 16 hrs., when the sky was again clear, and then fall back to their original positions, the old form of Stevenson being the last to do so, as the double top keeps the improved form from being heated as easily as the other. At 17 hrs. the curves show a minimum point after a considerable fall of temperature. Although a small quantity of cloud was observed overhead at this hour, its effect is scarcely perceptible, as it was of a cirrus type, very high up. After 18 hrs. a steady fall of temperature sets in, continuing till 21 hrs., when observations were stopped. Whenever the radiation from the boxes may be considered to have fairly commenced, we find the curves for the old and improved Stevenson screens changing places, the former being now lower than the latter, as the double top and louvred bottom cause the improved form to lose heat less rapidly. Both, however, as the process of cooling goes on, gradually approach the curve for the standard apparatus. Throughout these observations the wind was north-westerly, varying in force from 0 to 2 (Beaufort Scale). The effect of varying wind force is only shown in the general form of the curves—their relative positions remaining almost unchanged. This shows that although in a dead calm the radiation effects are enormously increased, they still require to be taken into account in accurate measurements of temperature, even when the wind-force is considerable.

In the curves shown for 8th June one point is of especial interest, the same effect being produced as in one of the curves just discussed —but by almost opposite causes. In the forenoon the weather was dull and wet, the sky being overcast with a pallium of cumulus clouds. At 13 hrs. the clouds cleared away, the sun shining brightly. Observations were begun at 11 hrs., when the Stevenson screens read lower than the standard; the rain water drying off the louvre boards probably cooling them, and so reducing the temperature of the air passing over them. About 11·40 the curves cross and assume their usual positions. At 13 hrs. a maximum occurs, and the effect of the clear sky overhead and sunshine is at once seen by the standard crossing the others and giving the highest reading. At 14 hrs. we have the sky again overcast, and the lines rearrange themselves as before at a minimum point. At 15 hrs. another maximum comes in, the clouds breaking overhead and sun gleaming occasionally, and here again the standard rises—higher than the improved Stevenson, and coinciding with the old. After 18 hrs. the clouds cleared away almost entirely, but as the boxes had not been heated during the day to any considerable extent they give readings slightly lower than the standard, but gradually approach it as the temperature falls, and ultimately cross and take up their usual positions.

The readings of the thermometer with the silvered bulb are extremely good at first, the radiation effects being all reduced to a minimum; and the delicacy of the instrument remains almost unaffected. One great advantage of this instrument is that it can be much more carefully read than those in ordinary use, as the radiation from the body of the observer is almost without effect. But the silver becomes so much tarnished in less than a week as to be almost entirely ineffective, the readings being ultimately the highest throughout. Very great care is necessary in repolishing the thimbles, as they are liable to be scratched, which seriously impairs their reflective powers. It is intended to try experiments with nickel-plated thimbles, as it has been found that nickel stands exposure to the weather for a longer time without tarnishing.

The readings of the black bulb arrangement are on the whole very satisfactory. They are as a rule lower than those of the standard apparatus, sometimes so much so that one is led to suspect that the black bulb has too much of its surface covered. At other times curious points occur, which are not indicated by any of the other instruments, and of which the explanation is not obvious. As the readings are somewhat difficult to take accurately—the temperatures being liable to change before both thermometers can be read, and any error in the clean bulb is doubled by the process of reduction—these peculiarities probably arise from errors of observation, and it will be necessary to use the instruments for a considerable time before anything definite can be said. The chief objection to the instrument is that the black coating of the bulb is liable to be chipped; but as the adjustment of the amount of black surface does not appear to be very delicate, this will probably be easily got over.

The readings of wet and dry bulb hygrometers have been taken throughout in the fan apparatus and in the two Stevenson screens. The dew points, as calculated from these readings by means of Glaisher's Tables, present some interesting peculiarities—but as yet sufficient material has not been collected to enable any very definite conclusions to be drawn.

It was to be expected that the fan apparatus would give results more nearly approaching the truth than the others, as the operation of drawing the air through the wooden tube can scarcely affect the amount of moisture in that passing over the bulbs,—at least when the air is comparatively dry,—and the free circulation produced by the fan prevents the water evaporated from the wet bulb from remaining in its immediate vicinity, and so indicating a greater amount of moisture than is really present in the atmosphere. Again, the passage of a large quantity of air through the apparatus should enable us to get a better idea of the amount of moisture in the air around.

The dew points given by the fan apparatus are in all cases considerably below those given by the other instruments, being in one case more than 5° lower than the Stevenson. As a general rule, the curve of dew points for the improved Stevenson is the highest of the three, but it is in most cases an almost exact reproduction of that given by the fan apparatus. The curve for the ordinary Stevenson usually lies about midway between the two—on the whole nearer to the curve for the improved Stevenson than to that for the fan apparatus. On some days this curve resembles the others only in its general outline—the maxima and minima being greatly rounded off, and sometimes only hinted at. This effect is probably due to the thermometers being freely exposed underneath—evaporation and condensation of moisture from the grass neutralising the various changes.

It is intended to compare the dew points given by these screens during the hourly observations with those given by a direct hygrometer; the form to be used being that designed by Professor Chrystal. This consists of a copper box, nickel-plated, into which the bulb of a thermometer is inserted. By means of a double-tap arrangement communication can be kept up with two reservoirs, one of which is filled with warm water, and the other with water surrounded with ice or a mixture of snow and salt. The temperature of the water flowing through the box can thus be adjusted until a film of moisture has just begun to form on the plated surface, and the reading of the thermometer at once gives the dew point. With this instrument results differing from each other by not more than 0°·3 can easily be obtained.

A few experiments have been made with this instrument, but in circumstances under which the dew points given by the wet and dry bulb hygrometers approached each other more closely than usual, although still maintaining their usual order. The results are somewhat different from what was expected, but are perfectly consistent throughout. The direct hygrometer invariably gives the highest dew point, being always a little above the improved Stevenson. The mean of fifteen observations shows the dew points given by the improved Stevenson to be about 0°·7 lower than the direct hygrometer—those by the ordinary Stevenson about 1°—and those by the fan apparatus about 1°·5. These show a much closer agreement throughout than could have been expected; and the fact that the direct hygrometer is always highest tends to confirm the result arrived at by Mr Shaw of Cambridge, that the film of moisture begins to deposit on the silvered surface before the actual dew point has been reached.

A FOR BOY.

Monday, 6th July 1885.

Sheriff FORBES IRVINE, Vice-President, in the Chair.

The following Communications were read:—

1. Notes on the For Tribe of Central Africa. By Dr Robert W. Felkin, F.R.S.E., F.R.G.S., Fellow of the Anthropological Societies of London and Berlin, &c. (Plate IX.)

It may be within the recollection of the Fellows of the Society, that in December 1883 I had the honour of reading, in this room, a paper on the Madi Tribe of Central Africa.

I have now to lay before you a similar paper on the For Tribe, which, as in the former case, I have written from notes of my own observations when in the country, and from information supplied to me by people of the tribe. I am able on this occasion to introduce to your notice a For boy, who has been with me since 1880, when I was in Darfur. The boy was rescued from slavery by General Gordon in 1878, and he entered my service at Dara in 1879. I hope it will add to any interest you may take in my remarks to see the only representative of his tribe, who, as far as I know, has reached Europe.

The country of Darfur is bounded on the south by 9° 30′ N. lat.; on the north by the 16th degree N. lat.; on the east by about the 22° 30′ E. long.; and on the west by the 28th degree E. long.

Darfur, or Darfor, means the land of the Fors, who were once the owners and sole inhabitants of the whole province. They have, however, been driven back into the western part of the country, the remainder of which is now inhabited by various invaders, namely, the Homr Arabs in the north, the Bertis Turkruri in the east, in the south-east the Rezigat, while in the south the Baggara and the Turkruri are mingled. There has been no intermarriage between the Fors and the strangers, and the regular features and lighter colour of the latter at once proclaim their Arab origin.

The whole population of Darfur may be roughly estimated at from 3 to 5 millions, about half that number being Fors; but it is impossible to obtain exact information on this point.

It is not my intention to give any account of the political history of the country, as that may be found in a learned paper by the late Dr G. Nachtigal, entitled "Darfor, die neue Ægyptische Province," *Petermann's Mittheilungen*, 1875, p. 281. Some further information may be obtained in Dr Perron's *Voyage au Darfour*, which is the translation of an Arabic work by Mahommed Ibn Umar or Mohammed el Tunsi. His notes on the manners and customs of the people are wonderfully correct as far as they go.

Darfur was taken by the Egyptians in 1874, after the battle of Menowatzhi, when Zebehr Pasha conquered and killed king Brahim, but the province was not really subjugated until after my visit there, for Haroun held out in the Marah mountains till 1881, when he was killed by the Egyptian troops under Slatin Bey.

The Fors are pure negroes, and are the most northerly tribe in the eastern part of Central Africa. They form one of the three great negro Mohammedan kingdoms, the other two being Wadai and Bornu.

I was unable to spare the time for making detailed measurements of the For people. The average height of twenty-five men was 173·0; of fifteen women, 168·7. Pulse, 72; respirations, 19. Temperature in the axilla, 97°·2 Fahr.

The following measurements of my boy's head are given as better than nothing. The numbers correspond to Virchow's table:—

1.	Height,	155·2
2.	Greatest breadth from glabella backwards,	20·0
3.	Greatest breadth above ears,	14·2
4.	Length of face from root of nose to lower border of chin,	12·1
5.	Breadth of face from one foremost edge of cheek bone to the other,	11·6
6.	Breadth of face from one angle of lower jaw to the other,	10·4
7.	Greatest breadth between zygomata,	13·0
8.	Length of nose from root to junction of nose and upper lip,	5·3
9.	Height of head from chin to vertex,	22·6
4.	Height of head from meatus auditorius to vertex,	13·0
15.	Distance between two ears at top of meatus auditorius,	12·4
16.	Upper breadth of nose from one canthus to the other,	3·4
17.	Lower breadth of nose on cheeks,	4·4
18.	Length of nose from root to tip,	4·6
19.	Breadth of mouth,	5·9
20.	Distance from meatus auditorius to junction of nose and lip, middle line,	11·8

21.	Distance from meatus auditorius to root of nose, ...	11·2
22.	Distance from meatus auditorius to middle of upper lip, . .	13·7
23.	Distance from meatus auditorius to chin, lower edge middle line,	13·0
24.	Greatest circumference of head at glabella, ...	57·0
25.	Arc from tragus to tragus over top of head, . . .	35·0
39.	Arc from root of nose to inion, overhead, ...	39·0

TABLE OF PRINCIPAL INDICES.

Cephalic Index.

$$\text{Measure } \frac{\text{No. } 3 \times 100}{\text{No. } 2} = 71 \cdot 00$$

Nasal Index.

$$\text{Measure } \frac{\text{No. } 17 \times 100}{\text{No. } 8.} = 83 \cdot 01$$

Facial Index A.

$$\text{Measure } \frac{\text{No. } 4 \times 100}{\text{No. } 5.} = 104 \cdot 31$$

Facial Index B.

$$\text{Measure } \frac{\text{No. } 4 \times 100}{\text{No. } 6.} = 116 \cdot 34$$

Facial Indrx C.

$$\text{Measure } \frac{\text{No. } 4 \times 100}{\text{No. } 7.} = 93 \cdot 07$$

Colour of skin, Broca's Table No. 43–42.
Colour of eyes, Broca's Table No. 42 of the skin table, but darker.

Physical Powers.—I was not able to test the physical powers of the Fors, but both men and women are strong, and can march well. They carry loads from 70 to 80 lbs. weight with ease for fifteen miles a day, but they do not like the occupation, as oxen and asses are, as a rule, used as baggage animals.

Their sight, hearing, and smell are very good, but the sense of touch is not very acute, and their sensibility to pain is decidedly less than that of Europeans.

Reproduction.—Marriage takes place at about the age of 17. The women are prolific. I saw a good number of women with seven, eight, and nine children. Twins are common, and more especially welcome if females; a great feast is held after their birth, and the whole village rejoices. I never heard of a case of triplets.

Polygamy exists. Barrenness is common in the Gebel Marah district, where the men always make sure of a woman's fertility before marriage. In the other parts of the country it is not so common. Divorce does not take place in consequence of sterility. There are no restraints on population. Infanticide is unknown. If a girl should have a child before she is married, and its father will not marry her, he has to pay a fine of cows to the chief of the village. The child belongs to the mother's father, and when she subsequently marries it remains with him. If it should be a daughter, its grandfather is by no means displeased by the arrangement.

Hair.—The Fors have fairly good heads of hair, black in colour, and naturally frizzled in character. The men sometimes shave their heads, but will never plait their hair or otherwise ornament it. The women dress theirs with numerous small plaits, which are flatly pressed down on the top of the head, and then hang loosely as far as the shoulders. The hair is much greased with butter, scented by various substances. Some of the men have beards of which they are very proud; they do not shave them off, as they say it is wrong to make themselves look womanish. A man with a very long beard is very highly esteemed. The men shave the hair from the armpits, and from off the chest; the women pull out the hairs from under the arms by the roots. The hair on the pubes is not removed.

Colour.—The people are all very much of the same colour, No. 42 and 43 of Broca's table. They rub their bodies all over with butter or with castor oil. Small white patches, due to the absence of pigment, are occasionally met with, but are not nearly so common as in some other tribes; the natives attribute these patches to syphilis. One celebrated hunter was affected by this malady; it attacked the left part of his forehead, the bridge of his nose, and the upper part of his cheeks. It injured his power of smell, and he had in consequence to give up his place as chief hunter. The children are of a slightly lighter shade of colour.

Odour.—Their odour is rather offensive, although it is to a certain extent masked by castor oil, or by the various scents they use to perfume their bodies; still after a long march the smell from them is very noticeable.

Motions.—The Fors generally sleep upon the right side, with the right arm bent under the head as a pillow. When standing at ease, they balance themselves on one leg, leaning on a spear or staff, the other foot resting upon the knee. They are very good riders, and bestride their horses in the usual manner. They walk with a long, easy, swinging stride; the body is well balanced, the head slightly thrown back, and the arms are permitted to swing with easy grace. All their attitudes are unconstrained. They climb trees very well, swarming up them; no ropes or other aids are used in climbing. In moving heavy objects, such as the trunk of a tree, they make use of rollers and levers, and push, but rarely or never pull. They can move their scalps backwards and forwards. I never noticed them moving their ears, but found that they had great difficulty in opening one eye, the other being shut. They can extend each finger separately; they point at objects with one finger, often the middle one, but have no tricks of sleight of hand. Their joints are pliable, with the exception of their toes; in rope-making, however, they can grasp the strands with the great and second toes. They occupy the squatting position when following the calls of nature. The most common position for a woman to occupy in labour is that of standing, leaning against the hut wall. In isolated cases, a rope is suspended to the roof of the hut for the woman to support herself with (see *Labour*).

Clothing.—With the exception of a very few chiefs, who are rich and have come much in contact with the Arabs and adopted their costume, all the Fors are dressed alike. The men wear damoor cloth shirts, open at the neck, and extending to about the knee. They have large open sleeves, which they tuck up when at work. The women wear a loin cloth, and also a loose sheet, which is wrapped round the body and thrown over the shoulder, leaving the arms free. This is, however, dispensed with very frequently. Till puberty the boys and girls go naked, and then the girls wear a skirt only.

Tattooing.—The For men do not tattoo. A good number of women, however, make three vertical and two horizontal cuts on each cheek, which custom has evidently been introduced by the Arabs. In order to add to their beauty, the women also prick their lips with sharp-pointed thorns, and then rub in kohl to make them black. Kohl is also used round the eyes and on the eyebrows.

Personal Ornaments.—Some few ornaments have been introduced among the upper classes in Darfur from the Arabs. The men wear no bead ornaments, but a plain ear-ring is inserted into the top of each ear. They also wear rings, one of which is a wedding ring; unfortunately, I have forgotten upon which finger this is worn. The women wear a wooden stick about half an inch in length, or a small crystal through the left nostril. The septem of the nose and lips are never pierced, but ear-rings are almost universally worn. They also affect numberless necklaces and girdles made of various kinds of beads, and bracelets and anklets made of iron or brass, and more rarely still of silver. At festivals many of the women also wear tinkling bangles and small bells around their wrists, waists, and ankles, to please their lovers. Many women adorn their foreheads with three or four thin, round gold plates, having various patterns, and fastened to a band. Filigree ear-rings are also made of silver or gold, modelled after Arab patterns. Both men and women wear amulets and love tokens, which are suspended round the women's necks and fastened round the upper arm of the men. No ornaments are employed as badges of distinctive rank, nor have they tribal marks, save those worn in war (which see). The Fors never deform themselves, nor do they extract the incisor teeth, which is an almost universal custom among the tribes living farther south.

Customs.—The usual mode of salutation is by shaking of hands. To this is added kneeling on one knee, if the persons have not met for a long time. Women always kneel to men, and, rarely, a man kneels to a woman if she is a relation and they have not met for many weeks. Women always kneel to their husbands, except in private. Kissing is confined to mothers and their babies. When people pass one another in the streets they say "Kilonya." Members of a family meeting each other in the morning say "Konas kav kor," which is analogous to "I hope you have slept well." When friends or relations have been absent a long time, or been in any danger, and meet for the first time, they kneel down on both knees, put their arms round each other's shoulders, and then shake hands.

Rules of precedence in serving food are as follows:—Puggees, aged men, chiefs, younger men, youths.

Women are evidently considered inferior to men, whom they must respect and obey in all things. The aged women, however, as well as men, are treated with great respect and care; when beginning to bend with age they are not permitted to work in the fields any more, but are supported by their children.

The Fors are not particularly hospitable, and they are very suspicious of strangers. Should any appear in the village, they are closely questioned as to whence they come and what their business is; and if their answers are not satisfactory they are at once taken to the chief.

Both boys and girls are circumcised shortly before arriving at puberty. A feast is held on such occasions at which all the village takes part. If the children bear the operation bravely, they receive presents from their father.

The following is a rough description of the Fors' daily life:—They rise at dawn, and after washing, the man prays and then goes into the fields to work. The woman does household work and prepares the breakfast. When breakfast is over, the man returns to the fields, where he is soon followed by his wife, and they both work together till midday. Then the man rests while the woman prepares the dinner. After dinner, the man sits down and spins cotton, or makes mats or basketwork. When the woman has washed up, put the fire out, and fetched water, she joins her husband at his work, or else they severally go and join working groups, until the cool of the day, when they go again to their gardens and fields, and work until the sun has set. They never work in the huts, but in cool sheds provided for the purpose. No work takes place after supper, a few hours being then given to social intercourse, or occasionally to dancing. The very rich women and chiefs' wives spend most of the mornings in perfuming themselves, or bathing and dressing their hair. In the afternoons, they also spin and make light mats of grass, but all women, to whatever class they may belong, always do the cooking.

Huts.—Some of the huts in Darfur are the ordinary beehive grass huts, but by far the greater number are made with stone and mud walls; they are circular, and very large. The people build about two feet each day, and then leave the work to dry till the next day; they never build higher than they can reach, and no scaffolding is used. The roof is supported by five poles, one of them being in the centre, with cross bars placed on the top to which circular bundles of supple sticks have been fastened. The roofs are conical, and overhang the walls about three feet; the thatching is very neatly done. The entrance is small, and is made still smaller by a stone which is placed in it on the ground. The door is of wicker-work, made to slide backwards and forwards, and fastened behind by a bar and pins; a handle is placed in the middle of it, both inside and out, to move it with. There are two fireplaces—one chiefly for cooking, made with three stones; the other for the people to sit round, especially in the cold season, as the mornings are very chilly. There are no chimneys or windows. The young men in the village have one hut in common for sleeping, into which they are banished at puberty. Outside the hut are cooking places, store-houses, and cow seribas, all of which are enclosed by a fence, and beyond it extend the gardens.

Food.—Although the staple food of the Fors is dhurra, it must not be supposed that this is the only item in their bill of fare, for their larder is well stocked with fish, flesh, fowl, insects, vegetables, and fruit. Fish is very abundant in the lakes and the rivers of western Darfur. There are many different kinds, all of which are freely eaten by the natives with the exception of the eels, which it appears are only consumed by the blacksmiths (see below). Cows, sheep, goats, gazelles, hares (rare), rabbits, wild dogs (eaten by wandering beggars), buffaloes, various antelopes, elephants, rhinoceros, rats, and wild boars, form a plentiful and varied supply of animal food.

Fowls are reared in large numbers, and pigeons, guinea-fowl, parrots, storks, wild ducks, owls (eaten only by beggars in great want), and various small birds, are found in abundance. Ostriches are eaten sometimes, but only when other food is very scarce, as their flesh is supposed to induce a disease, the principal symptom of which is a very red and repulsive face. Locusts, water beetles, and grubs from trees, are considered luxuries, and form favourite entrées. The vegetables are tomatoes, bananas, cucumbers, water melons (used also for washing and drinking purposes when water is scarce), various marrows, and onions. The fruits are not very varied; dates, bananas, lemons, and a kind of cherry from which wine is made, are cultivated; and sugar-cane grows in great abundance in the west. Wheat is grown to a limited extent in the Gebel

Marah district, but, curiously enough, it is never eaten, but exported as an article of barter. Rice is also sparely grown in some parts of the country.

Dhurra and rice are ground, and then made into bread, as also a root which is considered poisonous until well boiled. In order to keep the bread, which is in the form of pancakes, it is broken up into small pieces, dried for a day or two in the sun, and then preserved in leathern sacks. Milk is much used as an article of diet; it is obtained from cows, sheep, goats, and camels. Very good butter, cheese, and curds are made. The butter is chiefly used for anointing the body and as pomade; for this purpose it is mixed with dried odoriferous plants. The flesh of goats and sheep is considered to be the best meat, and that of young kids the most strengthening. As a great luxury, a fat she-camel is sometimes killed; this, however, can only be indulged in by rich chiefs. Meat is not much used in hot weather, fowls being preferred then, and they are also considered the best food for invalids. Rice boiled for a long time in new cow's milk is one of the best and most expensive dishes. Cow's liver, raw, with Cayenne pepper, is eaten by rich people and by invalids. The brains of all animals are thought a great delicacy; marrow is also a tit-bit; the bones are cracked, and it is taken out with a chop-stick or knife. The blood of bullocks and of fatted he-goats is eaten after being well boiled, strongly flavoured with Cayenne pepper.

The poor buy meat at open-air sales; the rich kill their own cattle, and after drying the meat in the sun, store it away in huts. These are built like the dwelling huts, and are surrounded by thorn hedges; there are separate store-houses for meat and corn. The granaries are constructed as follows:—A circular framework is made of poles, and this is filled up by bundles of dried grass, bound securely to it by rope made of fibre. The roof is formed of thatch, shaped at the top like a pinnacle. A deep hole is dug inside the hut, and it is lined with mats or hides, and then filled with grain. The meat store-houses are narrower, higher, and stronger; the door is made of very strong wickerwork, and halfway down the roof a wicker-lattice provides for ventilation. Inside the hut are shelves made of sticks on which to support the small pieces of meat; the larger pieces are suspended from poles fixed in the roof.

People of small means, who have less corn to stow away, build miniature granaries within their dwelling huts; they are supported by stones, and the top is movable.

In times of scarcity the people resort to wild fruits, roots, and leaves; at all times the poor live chiefly on dhurra and wild fruits. When hard work has to be undertaken, mutton, dhurra, porridge and milk are preferred, as they are considered to form the most strengthening diet. Oil is only used for frying purposes. The chief spice is Cayenne pepper; it is taken with almost everything, and even the poorest person contrives to cultivate the plant. Various other spices have been introduced into the country by Arabs. Onions are much relished, and largely cultivated. The best salt is obtained from a salt lake near Gebel Marah; it is exceedingly expensive, and is used as money. The salt eaten by the poor is procured either from burnt grass or from salt beds. No sugar is used, but sugar-cane is largely chewed, and the people are very fond of it. Honey too, of which a large quantity is obtainable, is much relished. Earth is never eaten.

Fire.—Fire is obtained whenever it is required by friction, a round, soft, pencil-shaped piece of wood being rotated by the hands in a small hole cut in a flat piece of hard wood. I am not aware of any superstitions connected with the kindling of fire.

Cooking.—Cooking is performed as a rule by the women; even the richest women prepare their husband's food. The food for both men and women is cooked together; there are no professional cooks. Culinary operations are carried on either in the dwelling hut or in small huts erected for the purpose by the wealthy. Meat is preferred well cooked; it is roasted, boiled, stewed, and fried. It is preserved by drying in the sun or cured by smoke. This preserved meat is either eaten as it is or soaked before cooking. Meat is never salted. Roasting is managed as follows:—Two forked sticks are placed on either side of a bright fire; another is laid across them, from which the meat is suspended. In order to stew or boil the meat, flat stones are placed round the fire in groups of three, upon which large earthen jars are placed; for frying, shallow round pans are used. No pots are hung over the fire. Sometimes a whole or half a sheep is roasted at a time; a spit is put through it, and it is turned occasionally. Meat and bread are never baked in the ground, but vegetables are prepared for use as follows:—A hole is dug in the ground, and sometimes lined with flat stones; in this a fire is lit, and is subsequently removed to be replaced by the vegetables, which are wrapt in large leaves (Dameregy); they are then covered with earth and remain until cooked. These ovens are not permanent structures, but after being used they are filled up, new ones being constructed as occasion requires. Hot stones are not used in boiling. Bread is baked on large flat stones, supported over the fire. Vegetables are generally boiled in the same pot with the meat. Butter is used for frying. Dripping is collected, and after being scented with various herbs is used as pomade and for anointing the body. In the huts there is sometimes a permanent fireplace, enclosed on three sides by large flat stones and on the fourth by a lower one.

Cooking vessels are made of earthenware, the only exception being the iron pots which are used when travelling. Most of the vessels are round with flat bottoms, and without necks; they are always well washed after use and scrubbed with sand. Knives, and sticks bent at one end, are the only cooking utensils employed.

Corn is ground between two stones, mixed with water and baked in thin cakes, but the more usual plan of preparing it is to boil it into a thick porridge; it is served in a large pot, with meat and gravy round it. No yeast is employed.

If animals have been shot by a poisoned arrow, the flesh around the wound is cut out as soon as possible, and the entrails of such animals are thrown away. No pickles are made, and the only fruits preserved are the *kuma* and *cogna*, small fruits about the size of grapes; they are simply dried in the sun. They are either eaten in this condition, or soaked in water and softened, the water being also drunk.

Outside each village there is a public yard, in which all rubbish is deposited; it is subsequently used as manure.

Drinks.—No spirits are manufactured. Water and milk are used freely. Beer is made from dhurra, and wine from *kuma*. The beer is brewed as follows:—The dhurra is placed in a hole in the ground until it begins to sprout; it is then spread out in the sun to dry. then cleared of earth by shaking in a round sieve made of plaited grass, and afterwards ground between two stones, mixed with ordinary flour, and put into large jars, which are then filled up with water. After being well stirred, dry flour is scattered upon the top of the water, and the pots are covered with a lid made of basket-work. In a few days it begins to ferment; more water is then added, and it is well stirred and again left for several days. A little more water is then poured on it, and it is strained through a sieve made of damoor cloth. It is ready for use the next day, and will keep for a week; the longer it is kept the more intoxicating it is, and after a week it becomes sour and unfit for use; it is kept in jars in the huts. Each family brews for itself, but widows sometimes make it in large quantities and retail it. The utensils employed in the manufacture of beer are earthenware pots of various sizes, sieves made of plaited grass and others of damoor cloth, and sticks bent at one end, which are employed for stirring.

The wine is made as follows:—The fruit is either dried first for the best wine, which is intended to keep a long time, or it is used quite fresh. It is then well boiled, strained through damoor sieves, placed in small jars with tight-fitting lids, and put in a dark cool hut. It is ready for use after a few days, and is very intoxicating. Kogna fruit is sometimes soaked in water for a day or two, after which the water is drunk.

Meals.—As a general rule, three meals are partaken of in the day—breakfast, two hours after sunrise; dinner, an hour or so after the sun has reached its zenith; and supper, two hours after sunset. Breakfast and dinner are partaken of separately at home, but supper is eaten in a public yard, where the men and boys over 14 meet together for the purpose. A large fire is made in the yard soon after sunset, and social intercourse is enjoyed by its light until the supper is brought by the women. The latter and the children eat at home, often outside their huts together with their neighbours. Each person provides his own food for the public supper, and those who are not possessed of means for the provision of a good one must eat at home.

Breakfast consists of stiff porridge with milk, a little salt being sprinkled over it. All help themselves with their fingers out of the same dish.

For dinner they take either porridge or bread cakes broken up into small pieces, with chopped or minced meat and gravy round it.

Water is drunk at dinner out of a gourd, all drinking out of the same, and holding it between their wrists or between the left hand and the right wrist. It is a very general custom for the right hand alone to be used in eating; this practice was introduced by Arab fakirs hundreds of years ago.

Supper, like breakfast, consists of porridge and milk; roasted meat, stews, and vegetables are added to create variety. Water is almost invariably drunk with food; beer and wine are drunk between meals, the only exception being at great feasts, when they are immoderately consumed.

Feasts take place at births, weddings, and at the great yearly religious festival. At funerals there is a solemn meal, when laughter and jokes are unheard. A description of these will be given later on.

On occasions of rejoicing a man will call his friends together to drink with him. Friends are well looked after at meals, tit-bits often being presented to them. Meat is sometimes ready cut into small pieces before being placed on the dish; sometimes, however, it is served in joints; occasionally also a sheep is served entire. In this case one of the party, generally a young man, carves for everybody; otherwise each person helps himself. The older people always take food out of the dish first, for though visitors are requested to begin, they would be considered very rude if they did so before older persons than themselves; the same custom applies to drinking. Food is always taken with the fingers, and it is considered very unbecoming for all the fingers to be put into the mouth; the first and second and thumb are used. Young people are not supposed to talk before their elders unless they are spoken to; and if anything is needed at a repast, they are expected to make themselves generally useful. When no youths are present, the women are called to fetch or take anything away, but they are required to crawl on their knees when the men are engaged in eating. It is thought the height of impropriety for a woman to convey anything to her mouth when in the presence of her husband or of any grown-up man.

The Fors are considered by surrounding tribes to be very objectionable in their eating, as they like their food so "high." There are no traditions that cannibalism has ever prevailed in this country, and the Fors speak with the greatest contempt of the Niams-Niams on account of their cannibal propensities.

Tobacco is not smoked, but chewed and snuffed, and no other narcotics are used. The tobacco is indigenous, and very strong. It is carried about in small bundles, the leaves having been first dried and broken up small and mixed with fine wood-ashes, and it is rolled up in palm leaves. After a plug has been chewed it is stuck behind the ear till next wanted. Various roots and barks are chewed for medicinal purposes. Some of the Fors who have come into intimate connection with the Arabs have learnt to smoke, but they are looked down upon by their compatriots.

Religion, Fetishes, &c.—It is a very difficult matter, if not impossible, to give any account of the original religion of the Fors. Mohammedanism has been professed by them for hundreds of years; at the same time it is tempered by their original beliefs, and a great many of its tenets are totally ignored. For instance, they are so much addicted to drink that the decrees of Islam on this point remain altogether unregarded, although several of their kings have made great efforts to put down this vice.

In the following remarks about their religious beliefs it will be perfectly possible for the intelligent reader to recognise which of them have been assimilated from the teachings of Mohammedan fakirs.

"Kilma" is what seems to correspond to our idea of "soul." It is called "the power of the liver," for, believing that the liver is the seat of the soul, it is considered that an increase of a man's own soul may be obtained by partaking of an animal's liver. Whenever an animal is killed its liver is taken out and eaten, but the people are most careful not to touch it with their hands, as it is considered sacred; it is cut up in small pieces and eaten raw, the bits being conveyed to the mouth on the point of a knife or the sharp point of a stick. Any one who may accidentally touch the liver is strictly forbidden to partake of it, which prohibition is regarded as a great misfortune to him. Women are not allowed to eat liver, and are believed not to possess a "kilma."

When a man dies his kilma is supposed to go to Accra, and there he is told whether he has been good enough to go to Molu. Molu is the ancient native name for God. The name of Allah is used now by many of the people for God, but they have a very confused idea as to the difference between God (Allah) and the Shereef at Mecca. Some few of them go on pilgrimages to Mecca, and they say that this Allah is a very fat man, who lies on a white mat and never does anything, but receives those who come to him, and lets them kiss his hand. When a man starts on this pilgrimage he takes with him a small drum called Beedi, which he beats in all the villages he passes through. It has a very low, solemn sound, and is a signal to the villagers that he is going to see Allah, and that they may join him if they like. Perhaps a party of five or six is made up altogether, and the rest of the people are satisfied with crying out, "Aga be nasaba bani, zidzi ďomabani ye ka duo deba, dinzidisi dongab ani dinesidingtong suma karaky," the meaning of which is somewhat as follows:—"You are going to our master's house, give him my hand, and tell him that I am so weak and that his house is so far that I cannot go." The district of Khartoum, through which they must pass to get to Arabia, is called Urebiah, and Arabia itself Baribaru, or "the country beyond the water." When the pilgrims come back they are called Arch-barr, and are considered very holy; they never have their heads shaved, and are supposed never to do wrong. Their title must not be confused with Arch-barch, a term of honour sometimes bestowed on people in acknowledgment of bravery.

The dead are supposed only to stay in Accra about a day, when, if they have been good, they go to Molu, who lives in Jouel, "the sky," and are very happy there. If they have been wicked, they go to Uddu, the place of punishment, where they meet with all sorts of disagreeable things, and are finally burnt up. The people are very fond of singing a song which speaks of the fire in Uddu, rejoicing greatly because it has plenty of work to do in burning up wicked people. The oldest tradition, and one which is still firmly believed in the extreme west of Darfur, is that after death a man remains in the grave for two or three days; he then passes in a mysterious manner to a new country, where he becomes young again and marries. Women, however, are supposed to have no life beyond this one.

The ghosts of departed spirits are called "Malal"; they are said to appear to their friends most frequently during the first few nights after their decease, and to be clad from head to foot in white damoor cloth (this material forms their shroud), and they appear much taller than when in life. They are supposed to visit houses during the night, and to alter the position of different articles of furniture. Should any one be unable to find some article in the morning, they commonly say, "So and So's spirit paid us a visit last night," and thus account for its temporary disappearance. The ghosts are thought to hide, but not to steal things.

Great fear is felt of going into or near burial-places on dark nights, as the apparition of ghosts is dreaded. They think that if the grave has not been firmly built, and any air finds its way in, there will also be room for the spirit to find its way out. This spirit, however, is not the "kilma" which has gone to Accra, and which possesses no power of return.

The Fors have priests or fakirs, who go by the name of puggees. They are in no sense hereditary, and there is no ceremonial induction into their office. Any one may become a puggee if he chooses, but he must first be educated by a priest, in reading and writing, in the Koran, and in the For law ; for the Fors have a written law, which differs considerably from that found in the Koran. The date at which it was reduced to writing I was unable to ascertain, but it is certainly more than 300 years old. Some parents set apart their sons to be priests, and send them to be educated while still very young. The puggees are the teachers of all who wish to learn, but the instruction they give is very meagre; only a little reading and writing are taught, and a few prayers from the Koran. The schools are held in the evening after the work of the day is over, and are conducted by firelight. The puggees have a great deal of influence over the sultan and chiefs, who consult them much, and generally follow their advice. They take precedence over the chiefs, and nobody is allowed to eat with the sultan but the priests. Chiefs are sometimes priests too. There are three ranks of priests; they wear little white caps, the embroidery of which tells their status. Although each puggee is under no practical obligation to obey those of higher rank, still they do defer to their opinions, and are ready and willing to receive instruction from them. The difference in rank is caused by age and experience; those men too who have been a pilgrimage to Mecca are naturally more respected, and hold a higher rank than their fellows. The puggees appear to be sincere in their beliefs; they do not practise austerities or live secluded lives. They may marry, and have as many wives as they please. They do not as a rule do manual work themselves, their time being chiefly occupied in teaching, writing amulettes or charms, in attending the councils of the chiefs, and officiating at the various religious ceremonies. They do not pray so continuously as their Arab compeers, nor do they spend so much time in telling their beads. They advise the chiefs in points of law, and act themselves as judges, most matters being submitted to them for decision, but in cases where the penalty of death or mutilation is passed, the chief's consent is necessary before the sentence can be carried out. The puggee's wives and daughters are the only women who are taught a smattering of reading; even these women do not pray, but it is said that they will go to Jouel if they lead exemplary lives.

There appears to be no idolatry in Darfur, and the various powers of nature are not associated in any manner with various gods. The Fors used to believe that they alone worshipped a God at all, and this idea still lingers, especially in the west and among the very ignorant. The one God Molu, who lives in the sky, is believed in and worshipped. He is regarded as the Creator of men, and as Supreme Ruler of the world. Prosperity and adversity alike are believed to be the result of his ordaining; and when evil happens or death occurs the people console themselves and each other by saying that they could not help it, and that Molu willed it. The wind is thought to be Molu's breath, and it is considered very wrong to swear at it, even though it should unroof their huts or damage their corn fields. The thunder is supposed to be Molu speaking to some one, and is feared in consequence. They attach considerable importance to the rainbow, believing that Molu causes it to ascend from the water to the sky in order to prevent men thinking that there is no God, and to warn them that if they do not behave themselves they will be burnt up in Uddu with fire like the red of the rainbow. It seems to be rather a difficult thing to get to Jouel, otherwise heaven; most of the people seem rather to expect to go to the other place, and if they do so they will never leave it until the fire ends their existence; the length of time that this occupies depends upon the life they have led on earth. They believe that the puggees and their sons will certainly go to Jouel, and their wives and daughters also appear to have a pretty good chance, as also the Medchera, who are the puggees' pupils. In fact, all learned men are considered more likely to be rewarded in the next world than the ignorant. If a man has accidentally killed a puggee, he is supposed to inherit the priest's spirit, and will therefore go to Jouel. If a man is killed in battle, or if killed or murdered by a For, he will go to Jouel, and be provided with a white horse. If any one murders a man, the murderer inherits his spirit, and has to bear the consequences of the murdered man's actions in the next world. This is, however, not the case if one man kills another accidentally. The priests and those who have been taught by them are influenced by a strong desire to be received by Molu when they die, and are greatly afraid of the punishments meted out in Uddu. The unlearned people do not think much about an after life, and are far more influenced by the fear of having their hands cut off if they steal, or their lips if they are guilty of falsehood. There are still a few stone huts in existence, which were devoted to the worship of Molu before Mohammedanism was introduced, and the people still reverence them. Drunkenness is not considered to be a sin, nor is want of hospitality to strangers or unkindness to human beings thought a mortal sin, if I may use the expression; but ill-treatment of tame animals is said to be very wicked, as they have to suffer without being able to defend themselves or to retaliate. Animals, however, are not believed to have souls; when they die there is an end of them.

Animals are not held sacred, but there is one sacred bird; this bird is often seen sitting on the trees near water. When a puggee notices one of them in this position, he calls out to it "Te bate salewate" (?), at which the bird dives into the water, returns to its perch, and shakes the water from its wings. The priest runs underneath, in the hope of this water dropping upon him, as it is supposed to contain the spirit of Molu.

The Fors have another very strong belief, which has been unaffected by the Mohammedan religion, that a great spirit lives on the summit of Gebel Marah. They do not worship him, but they believe he has an innumerable army of spirit servants, zittan, who possess extraordinary powers. A limited number of magicians are supposed to stand in intimate relation to this great mountain spirit, and requests made to them are conveyed to him, and granted, if they be accompanied by a sufficiently large present to the magician. The spirits are supposed to reside in large trees; they protect cattle from robbers; and it is a curious fact that, with an exception mentioned later on, no For would dream of stealing another man's cattle, as he thinks he would be at once seized upon by the zittan, become insensible, and so remain until the owner of the cattle arrived on the scene. Any one can enlist the services of a zittan to protect his house, and more especially his milk-pots, and epilepsy in girls is said to be caused by them. The girls are supposed to have interfered with the milk-pots, or stolen the milk, in the absence of their mother. The same disease is believed to attack them as a result of misconduct under a tree inhabited by a zittan (see *Epilepsy*). The brides also have a wholesome dread of these trees, for if they pass under them without wearing an amulet they will be sterile.

The old custom of praying to Molu has become almost obsolete, and has been replaced to some extent by a few prayers from the Koran learnt from the puggees. The practice of regular prayer, however, is now limited to the educated classes, and the poor people do not pray at all. In the enclosures of the rich there is a small place surrounded by stones, and carpeted with sand, set apart for prayer. The father prays at one time, the sons at another. The regular prayer hours of Islam are unobserved, and bead-telling is only in vogue among the puggees, the chiefs, and a few of the rich people.

Warriors returning from war are not allowed to enter their village until they have seen a puggee, and he has offered a prayer.

No idea appears to prevail of the existence of an evil spirit tempting people to do wrong.

There is a very ancient belief prevalent that some men are possessed of the power of transforming themselves into wild beasts, *e.g.*, lions, jackals, hyenas, and that when in this condition they are able to traverse immense distances in a remarkably short time. They have also the power of divination, can restore lost cattle, tell fortunes, and perform various other miraculous feats. They are well versed in the medicinal properties of various roots, and the knowledge of these is committed to writing. One or two of these manuscripts which I saw were very old, but I was unable even to procure a copy of any one of them. All these powers are believed to be bestowed by the great mountain spirit, and they are not hereditary.

On the death of one of these men there is always a very lively competition for his manuscripts, the proceeds of which are handed over to his youngest son. These men are not bound together by any common interest, but are all deadly rivals, and use every means in their power to damage the repute of their opponents.

Social Relations, including Education of Children, &c.—Children are brought up very strictly. Disobedience is not permitted, and is very rarely seen. They are punished either by whipping or by being tied up without food or water for a given time. They are compelled to be very polite; they may not sit in the presence of their parents, nor may they speak when their elders are conversing, nor play about the hut. If they wish to amuse themselves, they must go to the village yard. They are just as respectful and well-behaved to women as to men, also to strangers.

As soon as they are old enough they are taught to make themselves useful—first, they must help their mother about the house and garden, and fetch water. They are then taught to spin, to dance, and to fight. A little later they are employed in tending the cattle and in helping their parents in the fields. There does not seem to be much systematic instruction given them in any of these things, but they are obliged nevertheless to perform their duties in a satisfactory manner.

With the exception of the schools for boys who are set apart for a higher education, the children do not receive much schooling. The puggees hold classes for an hour or two after supper, by the light of large fires, and in these the boys are taught a smattering of writing and reading, and to repeat various portions of the Koran. Those who are going to be educated for priests live in a puggee's village, where only puggees and their pupils reside. There are sometimes 200 or 300 of the latter, and no females are permitted there.

Treatment of Women.—Notwithstanding that the women associate with the men constantly in all their daily pursuits, they are by no means considered their equals, and are obliged to pay very great respect and absolute obedience to their husbands. They are not supposed to possess souls, and do not receive any education. Great consideration is shown towards women when they are old, as well as towards aged men. Widows have a large amount of sympathy shown them, their female friends going daily to lament with them after the death of their husbands. If good-looking, however, they usually marry again in a month or two's time. When women die they are buried without prayers. On the whole, the women make fairly good mothers, but indifferent wives; one cannot, however, say that the men make much better husbands.

Festivals.—The oldest festival which the Fors possess appears to be that of "sowing the seed." In the days when the sultan of Darfur lived in great pomp, it was carried out on a very large scale, and even now it still obtains and is observed by the chiefs of all the For districts. It is a kind of consecration ceremony, and is performed now in the following manner:—As soon as the ground is ready to receive the seed, a day is set apart for the ceremony, and messages are sent by the chiefs to all the surrounding villages, inviting the presence of the people to take part in it. They all assemble by midday, when beer is partaken of under the shade of trees. A small company of virgins, the most beautiful that can be found, are each provided with an ornamental wickerwork basket containing seed; these baskets are covered with fresh green leaves, and sometimes decorated with flowers. A procession is then formed; the virgins, carrying the baskets on their heads, lead the way; next come the musicians, and after them a group of unmarried young men and women dancing; then the chief, decked out in his best, generally riding on a horse, and accompanied by a few puggees (this only in recent times) and magicians. He is followed by the heads of the villages, and afterwards by the villagers themselves, and the rear of the cavalcade is formed by the women, carrying on their heads large pots of beer and all manner of provisions. They proceed some distance, and halt in a forest glade, in which a small piece of ground has been cleared and prepared for sowing. Here halt is made, a prayer is offered to Molu asking him to take care of the seed, and to supply them with plenty of rain, in order that they may have an abundant harvest. Each of the virgins then makes a hole in the ground and plants one seed. Then the chief plants a seed, after which all the people follow suit in order of their respective ranks, the virgins having first handed round their baskets, from which each person takes a seed. As soon as this ceremony is over the whole company separates into two parties, the men on the one side, the women on the other, of the glade. The people belonging to different villages group themselves together, the food is set out, and the midday meal takes place. The afternoon is spent in singing and dancing, and at sunset they return to the chief's village, where large fires are lit, and a convivial evening closes the day.

The next in importance of the For festivals is the great Mohammedan feast of Bairam, which lasts for eight or ten days. A large level piece of ground is enclosed by stones and strewed with sand. Within this enclosure the male portion of the population meet after breakfast, prayers are said for an hour or an hour and a half, and sometimes a short exhortation is delivered by one of the elder puggees. The rest of the day is spent in feasting, singing, and dancing, in which latter of course the men are joined by the women. During the days of this festival an entire holiday is taken by all the people, work in the fields ceases, and their time is wholly given up to prayer and feasting.

I have now to describe the proceedings which follow the birth of a child. A few hours after the child is born messages are sent round by the happy father to all his friends and relations living in the neighbourhood, inviting them to assemble in the village yard. A puggee is also invited to attend, and for this duty he receives a present. It is true that he generally makes a show of declining the gift, saying that it is his duty to come, but it would be considered bad form on the part of the father were he not to insist on its acceptance. Prayers of thanksgiving for the birth of the child are first said by the puggee and the grown-up men; these prayers last about half an hour. Afterwards the boys join the men, and a feast takes place; the father provides the guests with food, but it is considered a friendly and complimentary thing for each to bring a little offering of food. When the meal is over the old men are invited by the father to accompany him to his house to drink, while the younger men and boys, being joined by the fair sex, spend the night in dancing. Seven days after the child's birth the people assemble again outside the father's hut. The father and mother, who holds the child, stand in the doorway, and their nearest relations are grouped on either side of them. The puggee then arrives, and asks the father what the child's name is to be. He then reads a prayer, and afterwards calls out the name, and the ceremony is closed by another prayer. For the performance of this duty the puggee is not allowed to receive payment, and it can only be performed by the highest class of priests. The name given to the child on this occasion may never afterwards be altered. The rest of the day is spent in singing, telling tales, and then in dancing, the child being exhibited with much pride, and if it happens to be a daughter the father receives very hearty congratulations, the wish being always expressed that she may grow up to be very beautiful, and to be as supple as a bending branch, in order that his riches may be increased by an extraordinary large dowry.

Marriage Customs.—I have referred in another place to courtship and elopement; I will here describe the nuptial ceremonies.

Large stores of food and immense quantities of beer and wine are prepared for the marriage feast, and if a very poor man is about to be married he is allowed to select a cow and a few sheep from his richer friends' flocks, provided that he kills them where they are feeding, and subsequently explains why he does so. If the bride and bridegroom live in different villages, the wedding takes place in the bridegroom's village. The marriage ceremony is observed in the evening in the village yard. The fathers, brothers, and invited friends assemble together, but, strange to relate, the bride and bridegroom themselves are not present. Prayers are said, and then the priest, standing in the midst of the group, announces that the bride and bridegroom, giving their names, are hereby married, and calls upon the assembled company to bear witness to the fact. As soon as this is over, the man in the company who has the loudest voice calls out with all his might "Ku-ru-ru," in order that the bride and bridegroom, who are in adjacent but separate huts, may hear that their marriage is accomplished. Then food is served, the most of it being provided by the bridegroom's father; the bride's father, however, provides a small share. The boys are allowed to join in this feast, and when it is over the younger portion of the company dance all night long, the older people retiring to the house of the bridegroom's father to drink. More or less dancing takes place for several days, lasting, however, only two or three hours in the evenings. The drinking goes on until the beer and wine are finished, the visitors going away at night, if they live in the village, and returning early next morning. If they are from a distance, house-room is provided for them. Among the higher classes, singing and dancing women, of whom there is a small class in Darfur, are engaged to add to the enjoyment of the evening. Music is always provided.

During the following week the bride and bridegroom do not see one another; the bride is engaged in perfuming herself, dressing her hair, and in other mysteries into which I have not been initiated. The bridegroom is occupied in counting over and over the dowry which he will have to pay for his wife, and in receiving the visits of his young male friends, who help to wile away the weary time of waiting by songs and stories, expatiating on the charms and duties of wedded life, and expressing, in terms of rapturous eulogy, the captivating graces of his dusky bride.

On the sixth day after the wedding the bridegroom sends the dowry to his father-in-law, and if it be correct he receives a message to say that he may arrive to claim his bride next day. In the morning the bridegroom's unmarried friends take presents from him to the bride, such as one or two cows, a few loads of grain, ornaments, &c. In the afternoon the bridegroom is conducted to the bride's hut; she meets him at the door, and he presents her with the marriage ring, she making him in return a present of a love token and a ring. He then enters her hut with some of their chosen companions, and another feast is held outside provided by the bride's father. After this is over the father of the bride retires, and the bridegroom, leaving the bride, joins the company. Soon after, the bride is taken round the village, preceded by music and lighted by torch-bearers, and after having received the congratulations of everyone she retires to her hut with some dozen of her female friends. A few hours later the bridegroom is conducted thither by an equal number of his friends, who remain outside the hut, he alone entering. These young men then ask if they too may enter, and having gained permission they arrange for three or four engaged couples to keep watch over the bride and bridegroom for the night. This watching is kept up for several nights, and three or more may pass before the bride and bridegroom lose their patience and send their friends away. Then at last the marriage is consummated amidst the "Ku-ru-rus" of the assembled friends. The next morning the wife leads her husband and presents him to her parents; he looks them in the face and speaks to them for the first time since his engagement; he salutes them, and presents them, as also his wife's unmarried brothers and sisters, with a ring. He lives with his wife at his father-in-law's until his first child is born, when he is permitted to take his wife away and set up housekeeping on his own account. During the whole of this time the father-in-law has to pay all housekeeping expenses for the young couple, and the husband is entitled to three meals during each night. Amongst the poorer classes the whole of these festivities, which usually occupy twelve or fourteen days, are compressed into seven days, the bridegroom being led to the bride's hut on the evening of the marriage day.

Burial Customs.—Funerals take place within a few hours of death. The corpse is wrapped in a winding shroud of damoor cloth, and carried to the grave on a rude bier hastily constructed of wooden poles lashed together with rope. It is not used a second time, but is burnt. Graves are dug 6 or 8 feet deep and covered with stones, but the Arab method of burial is being rapidly introduced into the country. The graveyards are situated at some considerable distance from the villages.

When a woman dies her body is buried without much ceremony, but her friends accompany it to the grave uttering mournful cries. When a man dies, however, a priest is sent for, and his friends and relations collected. The priest recites some prayers, and the body is then conveyed to the grave, accompanied by the friends and by women wailing for the dead. The usual Moslem rites are performed, and the company then disperses, to meet again a little later in the outside village yard, where an hour is devoted to prayer, and where they then hold a solemn funeral feast. The food for this occasion is provided by the deceased's nearest kin, but contributions are also brought by friends, and if they should arrive too late the animals they give are reserved until two months later, for it is the custom to kill a cow or a goat every two months for two years after the death of a father. On such occasions the meat must not be taken into the hut where the man died, but eaten outside, and the whole of it consumed before nightfall. Any passers by are at liberty to partake of this meat. This custom is by no means universally carried out, for one reason, on account of the expense, but a man who thus honours his father is much respected. If it should be done by a husband in memory of his wife, it is considered to be a mark of extreme affection for her, and men will often do it for the sake of what people will say. No animals are offered as a sacrifice at funerals.

Superstitions.—The Fors are not particularly remarkable for their superstitious beliefs; other tribes I have visited are far more credulous. Some strange ideas, however, must be noticed.

The cry of the owl is believed to foretell a death. It is supposed to say:—"To-morrow a grave will open for some one." A gazelle crossing one's path is taken as a good omen. To knock one's left big toe against anything on going out in the morning is supposed to bring bad luck. It is also very unlucky to forget anything and to return for it, especially when going out hunting. It is a very lucky thing for any food to fall to the ground when eating. It must be picked up and swallowed with any earth that may adhere to it, for in the next world, should a man be accused of having starved his body, the earth will bear witness that he has fed it. There is a great objection to cutting anyone else's nails, for should the part cut off be lost and not given into its owner's hands, it will have to be made up to him somehow or other after death. If a person cuts his own nails he bears the consequences of his own acts. The nail parings are buried in the ground. If the sound of a drum is heard proceeding from Gebel Marah a national calamity is expected, or the defeat of an army, should the tribe happen to be at war at the time. It is supposed that an old woman who has always been faithful to her husband has power over fire, and that should a village take fire her presence will stop the flames. Such women are, however, few and far between. When several deaths occur about the same time in one family, it is thought to be due to falsehood or perjury on the part of one of its members. It is very unlucky for a bride to pass under a large tree or to cross a broad road unless she wears an amulet to protect her from the zittan.

Cups made of rhinoceros horn are supposed to detect poison in water, beer, or wine, the fluid changing colour; to give one of these cups to a friend is the highest honour that can be paid to him.

(I think this idea must have been derived from the Arabs.) Twins are supposed to be very lucky, especially girls; they are believed to bring good fortune to the whole village.

Crimes.—Wilful homicide is considered a great crime. The murderer is followed by the friends of the deceased, then tried by the chief, and the invariable sentence is death; neither he nor his friends can by any possible means evade the immediate execution of the sentence. There is no definite executioner, and, with the exception of the puggee (who may never shed blood), any bystander may be called upon to carry out the rigour of the law. Should the person whom the chief orders to undertake the office of executioner refuse to do so, even if a relation or friend of the criminal, he is compelled to pay a fine of two cows. The usual method of execution is as follows:—The murderer's hands are tied behind his back, he is made to kneel down, and is then struck on the back of the neck with a heavy knobbed stick. Another less common plan is to call on a party of men to pick him up and drop him head foremost on the ground, and to repeat this until his skull is completely smashed. This method is called "breaking the water melon," as that fruit is broken by being thrown upon the ground. If an aggravated murder has been committed, or the murderer has killed more than one man, or has tried to escape from or fight with his pursuers, he is slowly beaten to death. The criminal's friends are obliged to bury him at once, at a considerable distance from the village and cemetery; no prayers may be said at his grave, nor may the grave be marked in any way. If a man kills another accidentally he is tried by the chief, and has to give a full account of the circumstances which ended so disastrously. If he has no witnesses to confirm his story, he is required to take an oath on the *Koran*, or on one of the ancient religious books of the Fors; he is then kept for a week in prison, and if none of his relations die in the meantime, he is declared innocent and set at liberty. He is then expected to call together the friends and relations of the deceased man, and to express his sorrow for what has happened, after which he is treated in a friendly way by them, but on no account will they eat out of the same dish with him. Suicide is unknown in Darfur.

If a man wounds another in hunting or in the games no notice is taken of it; if on other occasions, a fine must be paid. If two men quarrel and fight, they are not punished, unless either is hurt on the head, in which case both of them incur a fine. If a rape should be committed upon a very young girl, a circumstance of extreme rarity, the whole of the offender's cattle are confiscated. If a man runs away with a girl, both his and her parents have to pay a fine to the chief. Seduction in our sense of the word is unknown. If a woman is caught in the act of adultery her husband is allowed to kill the man and beat the woman. It is very common for a married woman to fall in love with another man and ask him to kill her husband; if this gets found out, as is usually the case, both the guilty parties are executed. If a man sets fire to another man's hut, he has to pay all damages; he also gets a good beating, and must pay a fine to the chief, as the fire is so liable to spread through the village. If a person steals, he receives a thorough beating for the first two or three offences; but if repeated, one of his hands is cut off, the arm being made fast to a log of wood and the wrist-joint divided. If a person insults a puggee, or in any way injures him, he must pay a fine both to the chief and to the injured priest. Lying is held to be a great crime; even the youngest children are severely beaten for it, and any one over fifteen or sixteen who is an habitual liar suffers the loss of one lip as a penalty.

When several of a family die, it is supposed to be the result of lying on the part of the father, or rather a denial of an accusation of lying while placing the hand on the *Kitab*, the falsehood having been really committed. On such occasions the priest says—"If you are not speaking the truth may God turn against you," and then if deaths in the family soon follow they are thought to be God's judgment. To obtain His mercy a white pigeon is brought to the puggee by the man, accompanied by his accuser; the priest kills the pigeon, puts some of the blood on both accused and accuser, and then the pigeon is carefully put away and not eaten. This seems to be the nearest approach to sacrifice that obtains in Darfur.

On the whole, Darfur is singularly free from crime, adultery and inciting to murder in order to get rid of a jealous husband being the most heinous offences.

Morals.—The words used to express right and wrong are those which denote also good and bad; namely *Tulai*, good, and *Gettee*, bad. A good man is one who is truthful and honest, brave, and kind to animals, who bears pain with fortitude, and is loyal to his neighbours and his sultan; the bad man is the reverse of all this.

The Fors are rather wanting in vivacity, and are somewhat sluggish in action. They are, however, very quick tempered, and even passionate and brutal when excited by drink. They are very avaricious and little given to hospitality, except from interested motives. They are not very cleanly. They are very intemperate, and drunkenness is not considered either sinful or degrading.

The women are associated with the men in all their occupations, save in war; but their presence does not appear to have exercised any softening influence upon the character of the men.

The men are not much given to jealousy, unless with very good cause, and therefore the women do not avoid the society of men, and girls and even married women think nothing of passing the night with men who please them. They wear bells on their ankles and bangles round their necks and waists, and perfume themselves extensively in the hope of attracting lovers. Before marriage the young men and women are most lax, and indeed a father would be held up to public ridicule, if not well beaten, if he attempted to preserve his daughter's chastity. Indeed, excessive ugliness or very bad health could alone secure to a girl her virginity.

At markets, at feasts, and at dances, the young people have as much freedom as they could possibly desire; the men visit their sweethearts at night, or the girls go to them, and it is not considered immoral. If, however, a father has any strong objection to any particular suitor for his daughter's hand, he may forbid him to visit her, and give him a thrashing if he catches him in her hut. Adultery is considered a purely personal injury, and no sympathy is shown by outsiders to a man who is not brave enough to kill the rival in his wife's affections. Should he ask for help, the only reply would be—"You cannot be a good husband or your wife would be satisfied with you." A police of eunuchs was once instituted to put down this open immorality, but it totally failed and was soon given up. The chiefs and rich men have all fairly large harems, and usually have one or two eunuchs, who are slaves, to look after their women. But notwithstanding this precaution, the women do pretty much as they please, for either young men are dressed up as women and smuggled into the harems, or the women steal out at night to carry on their intrigues.

It is not considered right to rob strangers, but the chiefs wink at this offence, and the stranger runs but a poor chance of obtaining justice. Cowardice is regarded as a very grave delinquency, and if a man ran away during a battle his wife would be entitled to a divorce, and no one would marry either his daughters or sisters.

The virtuous side of the For character may be summed up in three words: they are industrious, brave, and remarkably truthful.

Slavery.—The Fors are not large slaveholders, and they do not themselves make slave raids; but they are permitted to capture slaves in war. The chiefs and the very rich people occasionally buy slaves from the Arabs, who are constantly passing through the country with their slave caravans, but it cannot be said that a slave population exists. A good number of eunuchs, who are also slaves, are employed by the chiefs. They are treated as confidential servants, and often attain great wealth and influence. Some of the most influential of them marry, in order that they may appear to have a family. The few slaves who are found in Darfur are well treated; as a rule they are permitted to marry amongst themselves, but some are treated as concubines. It must be remembered that a good number of the Fors have been enslaved themselves by their Arab conquerors.

Marital Relations.—I have described the marriage ceremonies in another place. The woman enters into the man's family circle after marriage. In a first marriage, when the contracting parties are still young, they are compelled to remain in the bride's father's seriba until the first child is born. When a man marries a second or third wife this custom is limited to a week or two. A man may have as many wives as he can afford to buy and keep, but as they are very jealous of one another, they are provided with separate huts in different parts of the village, or even sometimes in separate villages. It is this custom, combined with the large harems of the chiefs, which induces the very lax morals everywhere met with. The first wife married is the chief wife; her children take precedence over the children of others. A man is expected to visit his wives in regular rotation, but the chief wife enjoys the society of her husband for a fortnight, whilst the others must be content with only a week at a time. Concubinage is permitted, but seldom occurs, only a very few slaves being held as concubines. Polyandry is not permitted. There is no class of prostitutes. A man may not marry his near relations, and it is considered better that he should marry out of his own village. But many of the young people become engaged at a very early age when thrown together in tending the cattle. A mutual understanding exists between the young people, and it is only when other young men begin to pay marked attention to the girl that her accepted lover goes to her father and asks his permission to marry her. Such permission is usually given, and they exchange presents before their assembled friends; if they met with a refusal they would probably elope, and then the parents on both sides would have to pay a heavy fine.

The presents mutually given are kept as great treasures, and if any evil befall the separated lovers, they console themselves by saying (pointing to the charm)—"Never mind, I am engaged to so-and-so." The engagement lasts generally for a year or two, and during this time the young man is not allowed to speak to or to visit his intended's parents; should he meet them in the road, he must try to avoid them; he may however visit his *fiancée* at nights as often as he chooses. On arriving at puberty every girl has a separate hut built for herself. From what has been said, it is obvious that the relation of husband and wife in Darfur is not of a very satisfactory character.

Mythology.—Although songs and stories are handed down by tradition in Darfur, the people have no bards or story tellers by profession.

The following are specimens of their stories or fables :—

"Upon a certain day, many years ago, some boys were in the fields watching a herd of cattle. A thunderstorm, accompanied by much rain, came on, and the boys drove the cattle home, but in their haste they lost a cow belonging to an Arch-Barr. The cow happened to be a valuable one, so as soon as the rain ceased the Arch-Barr set off to seek for it, and during his search he was obliged to cross a very broad swamp. As is usual after a shower of rain, all the frogs in this swamp were singing (croaking). The Arch-Barr waded through the swamp, when one of the frogs called out—'Arch-Barr you've gone too far, your cow is on this side of the swamp;' so, thanking the frog, he retraced his steps, but had no sooner returned than another frog called out to him—'Arch-Barr your cow is not there, it is just by me;' but when he reached that frog he discovered that he had been misled again. This went on for some time until the poor man got quite tired with wading backwards and forwards across the swamp, and the frogs laughed so much at his expense that they had not strength to call out to him any more. Seeing that he had been made a fool of, he tried to kill one of the frogs with a stick; but this angered them, and they cried out that they would kill him, at which he was so frightened that he ran away. On his way he met another frog who told him the real whereabouts of his cow, and he drove it home at last in triumph; but his jubilation was short-lived, for one of the frogs hopped after him to the village and told his friends how they had made a fool of him. Everybody laughed at him and gave him the name of Sandara (the frog), which nickname clung to him to his dying day." It is said, too, that his sweetheart lived on the other side of the swamp, and each night when he went to see her he was laughed at by the frogs and insulted with many rude remarks.

"Once upon a time an elephant and a camel were great friends, and they agreed that they would plant a large field with dhurra; this they did, and then they got a hare to watch and take care of it until the time of harvest arrived. The dhurra was then gathered, thrashed, and winnowed, and two great heaps were formed—one of grain and one of husks and stalks. When they began to divide the grain they had a dispute, and it waxed so hot that their friendship vanished and they decided to fight for the biggest share; so each went away to collect an army. The elephant gathered together all the large animals into his army, while the camel enlisted the services of the small animals. Now the captain of the camel's army, although so small, was very wise and cunning, and he said to the camel—'Unless we cheat the big animals we shall not be powerful enough to beat them.' So he told the camel to lie down on the ground, and all the little animals covered him up with a heap of dhurra stalks, with the exception of one knee, and told him to lie perfectly quiet and still. They then all ran away, and hid themselves at a little distance to watch for their big enemies. At last the elephant and his army arrived on the scene, and were much surprised to find no one to fight with. However, one of them, with eyes sharper than the rest, noticed the camel's knee, and said—'What is this?' and went up and gave it a good bite, at which the camel roared out with pain, and this so frightened the elephant's army that they turned tail and ran away. The camel's army then left their hiding-places and pursued the fugitives, coming up at last with the elephant, who was quite alone and unprotected, and whom they killed, and then devoured. By this means the camel obtained all the corn for himself; he thanked his army very much, and paid them well for the great service they had rendered him. Little people can beat big ones if they are only sharp enough."

"One winter day a hyena climbed up a tree to gather some leaves for food. After he had collected a great many, he saw below him a little lamb who had wandered from her mother and was all alone. At this he came down so quickly that he lost all his leaves. When the lamb saw him she was very frightened, and said—'Hyena, what do you want?' he answered—'I want to eat you up.' The lamb knew it would be of no good to run away as she would then very soon be caught, so she thought of the following plan to save her life. She said to the hyena—'There is a pool of water a little way from here; before you eat me you must go and get your mouth full of water,' and the hyena went, and the lamb went off as fast as her legs could carry her towards the village. After she had proceeded some little distance on her way, up came the hyena with his mouth full of water. 'Now you can't eat me,' she said, 'because your mouth is full of water.' 'Oh yes,' said he, and in so saying the water was of course spilt. Then replied the lamb—'Now you certainly can't eat me, because you have no water in your mouth,' so he turned and ran away to get some more. On his return he found the lamb just entering the village, and when he followed her, she turned and said—'Now you can neither eat me with your mouth full or empty, for I am safe,' and with this she jumped into the seriba, and the dogs came and drove the hyena away. So the lamb was saved by her cunning, and the hyena was very angry because he had lost so much time and also his leaves, for when he came to the place where he had left them the wind had blown them all away."

The following story of the rabbit and the hawk (?) is rather long, but as it contains a good many different ideas I think it is worth repeating :—

"A rabbit and a hawk once had a cow as common property ; they used to take it in turn to watch this cow while grazing. The rabbit is a very deceitful animal, and, liking milk very much, on the days when he had charge of the cow he milked it and drank the milk before driving the cow home. The hawk was honest, and on the days when he drove it home there was always plenty of milk for both. Not content with obtaining most of the milk every other day, the rabbit thought of a plan to deceive the hawk still more, so said to him—'It is not good for you to drink the thin milk, but it is good for me, so if you will make a hole at the bottom of your milking pot, I will place mine under it ; then the thin milk will flow into mine, and you will keep the thick milk.' The hawk agreed to this, but of course all the milk ran into the rabbit's bowl, and the hawk retained the froth alone, which vanished when he put it on the fire to boil. The hawk could not understand this, and so went to ask the rabbit for an explanation. The latter said—'Oh you silly bird, you must stop up the hole in your pot, and put some water in it before you place it on the fire to boil, and then you will get good milk.' Next day the hawk did so, but found the milk very poor, so went to the rabbit for a taste of his milk. He said it was in his hut and he would go and fetch it, but he brought out a bowl of water to which he had added a few drops of milk. Thus the hawk was deceived again, and was very angry with the cow for giving such poor milk, on which the rabbit suggested that he should drive her to new pastures a long way off, as that might improve her milk. The hawk consented to the rabbit taking the cow, on condition that his son should accompany him. After proceeding for some distance, the rabbit made up his mind that, as he could deceive the hawk no longer, it would be best to kill the cow, so he killed the hawk's son and the cow, which he devoured. He then went home and told the hawk that he had left the cow with his son, and that they would return in a few days, but he was very much afraid of the hawk finding out what had happened, and thought of the following plan to escape from his vengeance :—Far, far up in the sky, so far as to be invisible to mortal eyes, there is a place where the animals meet to dance and sing and to amuse themselves, and to this place the birds carry the four-footed animals. The rabbit therefore proposed to the hawk that they should go up and amuse themselves until the cow returned, and to this plan he consented, only stipulating that they should first dress themselves nicely, and perfume themselves well, in order to be received with joy and to find mates quickly amidst the merrymakers above, and he asked the rabbit to prepare him a nice scent. The latter, however, prepared him a kind that smelt exactly like the 'kurkinja' (a small animal that lives in holes in the ground, and whose smell is very much disliked by the Fors). This scent the hawk placed upon some glowing embers, and fluttered about in the smoke until he was thoroughly perfumed. He then took the rabbit on his back and flew up to the animal's paradise. After they had been there some little time and had become acquainted with the denizens of the country, the rabbit requested permission to sing a song. On this being accorded him he procured a drum, and began to sing—'Oh! the hawk stinks like a kurkinja! Oh! the hawk stinks like a kurkinja!' at which everyone laughed, and cried out—'Yes, yes, he does.' This much enraged the hawk, who flew away. As soon as the rabbit had made sure that he had really gone, he asked his new friends to make a long rope and to let him down to earth again. This they did, and he told them that directly he shook the rope they were to let it go. But he mistook his distance and shook it too soon, by which he got a good fall, and coming in contact with a thorn bush a thorn went right through one of his ears. The rabbit was very angry at this, but the thorn bush said—'Never mind,' and gave him some gum, whereat he went away. He soon found a bird sitting on a nest of eggs, and gave her the gum, which she ate; his anger was aroused again, and to appease him she gave him an egg. He then soon came up to a group of boys taking care of some sheep, and gave them the egg to look at, which they dropped down and broke. Once more he was very angry and demanded a sheep, which he got; and this he drove before him until he came to a village where the people had many cattle. He showed them the sheep and they killed and ate it, he partaking of the meal. After they had finished, and all had washed their hands, he told them that he must have a cow in exchange for his sheep. This they refused, but he made such a noise that at last they made him a present of a big fat bull, which he took into the forest near by. He killed and ate it and afterwards stuffed the skin, and came back to the village and asked them if they would exchange it for a camel. They consented, and he mounted his camel and rode with them to the place where the stuffed bull lay. He told them to beat the bull and it would wake up, and then rode off and vanished in the distance. When the villagers found out how they had been treated they were very incensed against the rabbit, but he took care never to come that way again."

This story is told to show how deceitful the rabbit is, and to warn people that if their path is crossed by one they must be very cautious during the whole of that day, or they will probably be deceived by some one.

War.—A class of regular soldiers exists in Darfur, and they are called dalimars. They are in the service of the chiefs, and any strong young man may enlist in their ranks, but they receive no regular pay. They are liable to be called on for service at any time, and they then receive proper rations of food, and at the close of a war they get presents of damoor cloth and grain. They all possess land just as others do, and in times of peace cultivate it and support themselves and their families. All the dalimars of a district reside at the chief's headquarters. They are divided into two classes; the one is composed of well-to-do men, the other of common soldiers. The former live in separate huts with their families, in an enclosure on one side of the chief's quarters, and are treated by him with much respect and consideration. Notwithstanding this they do not seem to be very contented, and the puggees often have to bring their influence to bear on them to settle disputes between them and their chief. The lower class soldiers live in long sheds on the other side of the chief's enclosure, and a strong grass wall divides the two classes. A similar one forms an enclosure all round the chief's village, and outside this again a strong hedge protects the place from attack by men or intrusion of beasts. Between the two walls are gardens, but the principal gardens and the fields are outside the seriba.

An under chief lives in a hut at the door of each division, and is responsible for the gate being properly guarded, as watch is kept there night and day. No one can go and speak to the chief without first having his business ascertained by the under chief. The lower dalimars are very badly treated by the upper class dalimars; most of them drink to excess, and a good many chew tobacco. The dalimars are exercised in throwing spears, &c., outside the village, on ground set apart for the purpose. A young man may become a soldier when about 15, but boys are allowed to go and live with the dalimars long before this age if they have friends among them, and their parents have no objection to their following that calling when they grow up. A sub-chief is responsible for the whereabouts of all the dalimars, and they have to leave their names with the gatekeeper whenever they go out of the seriba. These gatekeepers have a remarkable power of remembering names and faces, and are able to give the chief the names of all absentees, who sometimes may number a hundred or two. Although the dalimars form the nucleus of an army, they by no means represent the entire force of fighting men, for every man capable of bearing arms is required to fight when necessary. The dalimars are employed very much as a police force in time of peace; should war break out, they are sent round to all the villages to collect those who intend to fight, and to tell them to assemble on a given day at the head chief's seriba. When all are collected the march begins, and definite positions are occupied during the march by the various constituents of the army. The chief leads the procession; on his left hand is the second chief at the head of the rich dalimars; on his right, the third chief at the head of the lower class dalimars. To the left of the rich dalimars march the villagers, led by their respective headmen. The chiefs and the headmen often ride on horseback, but they do not like fighting on their horses (this does not apply to the cavalry). The distinctive dress when at war is a white girdle of damoor cloth wound round the waist. The chief does not wear his unless walking, but uses it as a saddle-cloth. If a man distinguishes himself greatly by bravery in battle he is often made a chief, and such chiefs are more respected than the hereditary chiefs. The minor rewards are by election to be sub-chiefs or headmen of groups of villages. There is no punishment for cowardice, as the disgrace is in itself a sufficient penalty; the news of it soon spreads, and is made the subject of sarcastic songs at the village feasts. The Fors believe that if they are very brave in battle they will have a white horse to ride upon in the next world. Duels are common in battles, and are often resorted to in order to regain the favour of the sultan.

As soon as the army nears the enemy's country the order of marching is slightly altered. A vanguard and a rearguard and right and left wings and centre are formed; skirmishers are also sent out (Sandanger) in couples to look out for the foe. The attack is often delivered from various points in order to throw the enemy into confusion. They choose their camps if possible near a river or by wells, and seribas are formed for their protection. The people encamp in exactly the same positions they occupy when at home, so that there is no difficulty in finding a given man when wanted. Fires are allowed in camp, unless they are very near the enemy, in which case they are forbidden to talk loud or to sing. All sleep on the ground, their girdles (mulpa) being spread beneath them. In marching they are not obliged to keep step. The arrangements as to scouting and the various divisions of the army are made by the heads of the villages in consultation with the sub-chiefs. The only baggage carried is the food, which is taken by each man in a skin bag carried on the back, being hung round the neck by a cord. Camp followers are not allowed. The war songs are numerous and spirited, and are sung in camp, on the march, and sometimes during the fight itself. The particular cry in danger is "Ku-ru-ru." When in camp, war dances are sometimes performed for the purpose of cheering the sultan or chief. They advance in rows, each man holding a spear aloft with his right hand and trailing another in his left. On approaching the chief they kneel down on one knee singing all the time an inspiriting song, and on rising they touch the ground with the tips of their spears. They then move off, and are followed by successive rows, who go through the same manœuvre. The same thing is done by the dalimars to the heads of the villagers and by the villagers to their own headmen. Camp life appears to possess great charms for the people, and for the time being they appear to be much drawn together, and to avoid quarrelling.

There used to be about 3000 cavalry, with headquarters at El Fascher; but their number is now much reduced.

During a war the women are sent to places of security, and do not accompany the men.

The Fors do not like to encounter their enemies if the latter are on a height above them. In such a case they do not stop to throw spears while advancing, but go rapidly forward and try to dislodge the hostile ranks from their position. One of their favourite means of warfare is to surprise their enemy by getting round them through a wood or a valley, or in some such way to take them unawares. When about a mile from the foe the army is often divided, the smaller portion making a direct advance, while the others form a circuit and take the enemy in the rear, the latter being meanwhile deceived by those who are attacking them from the front pretending to run away. The enemy is also very often attacked at night, the army advancing very quietly and throwing a spear with a light tied on to it so as to strike one of the enemy's huts. Sometimes they approach the hostile camp just before dawn, and lie down under the seriba until the people begin to get up, when they rush in and easily gain a victory. At other times they fire the seriba at different points, and when the whole is ablaze and the enemy run out the latter are impeded by rows of spears firmly planted in the ground slanting towards the seriba. They are careful to prevent the enemy attacking their villages during their absence by means of scouts, who are very clever. In retreat they keep together, and halt at the sound of the drum. Alliances are frequently made with other tribes for mutual defensive purposes. The villages are all surrounded by a strong hedge composed of stakes and thorn bushes, 7 or 8 feet high and 12 broad, with flat tops. In the Gebel Marah district earthworks are also employed as a means of defence. If the Fors are being attacked by an enemy they often light fires in their village in order to deceive their foes, and then retire to a short distance, returning as soon as the enemy are well inside the village; by this means they hem them in and prevent their escape. The wars in which the Fors engage are generally of short duration, one or two battles being usually sufficient to settle their disputes. Prisoners taken in war are sometimes kept for a long time; they are chained and confined in strong huts and are compelled to work, but they may be ransomed or exchanged. Unless they misbehave themselves they are well treated, but any one trying to escape is killed. After conquering another tribe the Fors do not stay and govern the country, but after collecting together all that is movable they burn the villages and retire; the main object in war is to kill or capture the opposing chief.

Weapons.—The weapons used by the Fors are spears, bows and arrows, throwing knives, swords, a few guns, clubs, shields, stones, and two machines for throwing large stones and javelins. Bows and arrows are not very much used; the bows are very strong, about 4 feet long, and are strung with the sinews of animals; the arrows have very varied barbed heads, and are made so that the head shall remain in the wound when the arrow is withdrawn; they have no feathers, but are notched for the string, and are ornamented with bits of iron wound round them. Six spears make a complete set, five of which are light, so as to be easily thrown; the other is much heavier, and is used in hand-to-hand combat. There are many different shapes in use, some plain and others barbed. Shields are made of bulls' hide; they are oval and convex, and from 3 to 5 feet long. A wooden rib runs down the centre inside, in the middle of which there is a wooden handle, which is grasped by the hand. Most of the swords in use are imported; they are straight, two-edged, and used for both cutting and thrusting. The throwing knives are curiously curved, and are thrown with unerring aim, as are also stones, the latter being much used, especially from heights such as occur in the Marah district; they are also thrown with a split stick. The machines for throwing heavy stones, and the catapults for javelins are well and dexterously made. I do not know when they were introduced into the country, but they have been there for hundreds of years if tradition be correct.

Government.—The Fors have had a long hereditary line of despotic sultans, the last of whom, Haroun, was killed by the Egyptian troops in 1881, after I visited Darfur. Until this time the sultans lived in great state, and the Arab tribes who had encroached upon their country had been compelled to pay them taxes in order to enjoy their protection. Wherever the sultan lived his residence was called El Fascher, and it is only since the Egyptians conquered the country that El Fascher has become a definite spot. Darfur was divided into five large provinces, severally ruled by a high dignitary of state, and each of these provinces were subdivided into small districts under the management of *shartays* or local governors. All these rulers are hereditary, but the succession goes to the youngest son, who also inherits the chief's private property. The local government is carried on by each chief independently, but they are all responsible to the sultan for maintaining order in their respective districts. The people are not allowed to appeal from the chief's decision to the sultan, and their only means of redress under oppression is to rise against their chief, which action is usually followed by the sultan's interference, who either compels the people to submit, or removes the chief, as the case may be. The chiefs are compelled to pay certain taxes to the sultan, which they must present in person. No one is allowed to speak to the sultan directly, but only by means of a go-between.

Laws.—Any person may occupy as much unappropriated land as he pleases without paying for it. Encroachments on land are prevented by thorn hedges, broad paths, or ridges of earth, which are employed as boundaries. Game is not preserved; it may be killed whenever found. If a man dies without heirs, or leaves the country without giving up his land to a successor, it may be reoccupied by any one who chooses. Land is either left to daughters or to the youngest son, that is, if they are still infants, for their support until they are married; it is subsequently equally divided amongst them. The elder sons are supposed to be able to occupy land for themselves. As a rule, a father leaves nearly all his personal property to his youngest son. If he should die without any special orders to this effect, the first wife's children draw lots for the property, and thus divide the cattle, grain, &c., between them. Smaller parts of the property, however, are in the hands of the other wives, for their own support and that of their children, and these goods and cattle are divided amongst their children on the father's death. There is no provision made for the widows, as they mostly marry soon after their husband's death. When a man is thought to be dying he sends for two puggees to hear his will, and they are charged with the carrying of it out. If a man dies without a puggee being present, except in war, he is thought to die like a dog.

The chiefs and puggees are the judges. Persons who are waiting for trial are chained and kept in a hut by themselves. Strangers are never put to death except for murder. Suspicious-looking strangers entering a village are confined in a hut until they can give a good account of themselves. Failing this, they are escorted by two men outside the village and sent away. For other laws, see the paragraph on *Crimes*.

Hunting.—During the dry season the people devote much of their time to hunting. While spinning their cotton in the village yard the hunting parties are planned and arranged, chiefly by the young men. Their leader, generally the best and most experienced hunter, is called the *ageet;* he settles the district to be hunted in, and lets the people in the neighbouring villages know when the hunt is to take place. At the given time the several parties meet there, each led by their *ageets*, and blowing their horns, to hasten those who are late. When all have arrived at the place of meeting the chief ageet takes the supreme direction, and arranges everything connected with the hunt. After it is over they reassemble at this place, and the *ageet* tells them where the next hunt is to take place. These hunting parties are not at all identical with war parties. There are no rewards given to successful hunters; each man hunts for himself, and retains his own spoil; if a man has more game than he wants, he gives to his friends or sells the remainder. If several shoot at the same animal, it is divided between them. Very few serious quarrels occur while hunting. There are no laws for the preservation of game, and they shoot everything that comes in their way; the whole country is free for all to hunt in, even should the hunters belong to a neighbouring tribe. The skin and horns of an animal belong to its slayer. The meat is preserved by drying it in the sun or smoking it over the fire. The hunting weapons are used for war too, but not as tools. They use spears, and bows and arrows. They can hit birds on the wing. Dogs are trained to hunt. The Fors very often fire the forest, and then place themselves in a favourable spot, so that the frightened animals may fall an easy prey to their spears. Guinea fowl are driven into nets; snares made of string are used for catching birds. Game is carried home in the hand or on the shoulder, or on a pole carried between two or four people. Should the animal be very large it is cut up on the spot and taken home in pieces, none being left to waste. Sometimes small hunting parties are made up of horsemen, who go long distances in search of game; the horses are used for hunting the wild boar and for running down ostriches. All other animals are attacked on foot. Should the chief *ageet* of a district die, the best known hunter is appointed in his place.

The wound of a poisoned animal is cut out immediately.

Boys go hunting by themselves; they catch birds, mice, rats, guinea fowl, and hares. Guinea fowl and a kind of partridge seem to be the only animals taken alive and kept. Their eggs are also taken and hatched by fowls.

Traps.—The Fors resort to various means of trapping game.

A stout post is placed in the ground on either side of a path frequented by animals going to drink; a cross bar is fixed at the top, on which a slip noose is fastened which hangs almost to the ground; into this the animal runs and is secured.

Small holes are dug in the ground and covered with twigs and grass. Around them slip knots are arranged, their ends being made fast to a heavy log of wood or the trunk of a tree. The animal, walking over these holes, gets its feet entangled, and while trying to shake them loose tightens the noose and makes sure its captivity. Sometimes large animals drag the block of wood with them, thus leaving a trail for the hunters to follow up.

A trap for lions is constructed as follows:—A large hole is dug in the ground and covered with mats, which are again covered by earth. A tall pole is placed in the middle of the hole with some meat suspended at the top; when the lion attempts to jump up to the bait, it of course falls into the hole.

A tall pole is fixed in the ground with a bait at the top; around it are placed spear heads firmly embedded in the ground, with their points upwards. The animal jumps to get the bait, and falling back impales itself on the spear points.

A stone house is built, with one end open. A swinging door is arranged to close it when an animal has entered for the bait which is placed at the opposite end.

A basket trap is employed for birds. One edge is supported by a stick, so arranged that when the birds enter the basket imprisons them.

The roof of a big hut is sometimes lightly supported by stakes, to one or two of which a rope is tied. A man conceals himself at some distance from the hut, holding the ends of the ropes in his hand, and when animals enter the hut for the bait which is placed there, he pulls the ropes and the roof falls over them. This contrivance is sometimes placed over a small stream where animals come to drink.

Nets are also used for trapping birds.

Fishing.—Although the For women do not take part in the hunting, they join in fishing; in fact, the whole population in the western part of Darfur fish, and consider it fine sport. They fish with the rod and line, with baited hook; they spear the fish, and they catch them in wickerwork traps. Fish are also netted, but this method is rarely employed except by the blacksmiths, who always fish by themselves. Small pieces of the bark of a bitter tree are sometimes thrown into the water; the fish eat them and are poisoned. Dams are also constructed in the river, from which the water is subsequently drained and the fish caught by hand. When caught, the fish are cut open, and then smoked on a stand over a fire or dried in the sun. The harpoons are made with movable heads, to which a line is attached; they are usually barbed. As soon as the fish is struck the head becomes loose and the fish is played by the line attached to the head; this same remark applies to the hand spears. Bows and arrows are used by the boys for shooting fish; the arrow has a line attached to it, but the heads are not loose. Fish are not preserved alive.

Trade.—Men devote themselves entirely to no trade save war, with the exception of the blacksmiths, and in war alone are the services of the women dispensed with. All other employments are followed by men and women alike.

The following articles are manufactured:—Damoor cloth, shirts of damoor, caps of damoor, leathern sandals, water skins, leather bags for carrying grain, earthenware, string, mats, basketwork, rough spinning wheels and looms, shields, spears, bows and arrows, bracelets and rings, and iron implements used in cultivation. A few of the Fors are very expert in the manufacture of filigree work, and in ivory turning.

Damoor cloth, wheat, and dhurra are employed as the principal articles of barter, but almost everything is used for exchange as occasion serves. All the Fors are very industrious, in fact they are the most industrious tribe I have ever visited. It is quite a pleasure on entering one of their villages to see the whole population, men and women, young and old, engaged in some useful occupation. Work is paid for with dhurra, food, and drink. The people consider it to be an honour to work for the chief without pay, but he provides them with food and drink.

The blacksmiths are the only class of special workers who do nothing but follow their own trade. They are a class quite apart, live in their own villages, enjoying a very bad reputation, and being looked down upon by the rest of the community. They are great drunkards, and are continually quarrelling and fighting, and the dalimars have to be constantly employed in keeping order in their villages. They are the only men who take apprentices.

Strangers and very poor people are sometimes employed by the rich, and are paid in dhurra and cloth, besides receiving their food.

Exchange of goods is carried on with several of the surrounding tribes, and with the Arabs. Markets are held once or twice a week at convenient places near several villages. There is a free exchange of food, cattle, tools, arms, ornaments, &c. Beer is also sold, and disputes and fighting in the market are of common occurrence. A few dalimars are usually sent there to keep order, and they levy a small toll on the villagers. Any one may engage in trade, and most people have something to sell. Credit is sometimes given to people living in the neighbourhood; should they not pay, the dalimars are sent to exact the debt, and the debtor must also pay them for their services. All people have a right of way so long as they behave themselves. There is no hongo. People go in companies to the markets, but each trades on his own account; this applies also to fishing and hunting expeditions. Goods are carried in skin bags or in mats upon their heads or backs. Camels, donkeys, and oxen are also used as beasts of burden. There are no porters proper, but sometimes men are hired to carry things. There are no boats, nor is there any river navigation.

Ancient tools, weapons, knives, and ornaments are sometimes found on the sites of deserted villages.

The Fors are not at all wasteful; dry bread, for instance, is kept after being dried in the sun, and when needed for use it is chopped up fine and eaten with water. Remnants of food are not thrown away, but given to the dogs. Meat and fish are cured and stored, as also dhurra and dried vegetables.

People are rich or poor according to the number of cows they possess. A poor man often becomes rich by working hard, and thereby accumulating presents of cattle.

Money—Exchangeable Values.—A good bull is worth fifteen sheep, and some favourite bulls are sold for not less than thirty sheep. A cow is worth fifteen young goats; a he-goat, three sheep. A sheep values six hoes, eight or nine common spears, or three good spears, or one damoor cloth.

Wedding dowries depend much upon arrangements made between the parents, and also very much upon the class of the contracting parties and the beauty of the bride.

No beads or cowries are used as money, the standard money being damoor cloth, but in the large towns imported cloth and Maria Theresa dollars are used. Forty small pieces of damoor cloth, a foot long and 4 inches broad, equal in value one white cloth, two of which equal a dollar, a small blue cloth being used to represent half a dollar. The standard white cloth is called a *tob;* the blue cloth, *faradieh;* and the smallest pieces of cloth, *rubieh.* The prices at Dara, when I was there, were as follows:—An ox, from 3 to 6 dollars; a sheep, three-quarters of a dollar; a goat, half a dollar; a good riding camel, 50 to 70 dollars; a pack camel, 25 to 30 dollars. A horse cost 50 or 60, though some horses and hygeenes (riding camels) fetch as much as 300 or 400 dollars.

The taxes then paid to the Egyptian Government were in tobs or grain, and the inhabitants were obliged to provide camels and oxen for transport, but for these they were paid at a fixed rate in *tobs.*

Weights and Measures.—The standard measures are two sizes of wooden vessels, the largest of which holds about a peck of grain; the other is half this size. Small adansonia fruit-shells are also used; they vary in capacity. Strangers who come to the country to buy must use these measures.

Damoor cloth is measured by the length of the arm, from the tip of the middle finger to the elbow, or to the axilla. If the whole arm is used, three fingers'-breadth more cloth is added, to make this measure double the length of the fore-arm and hand, which latter is the standard measure for cloth. Cloth is also measured on the ground, either by placing one foot before the other or by strides. When cutting out cloth and measuring its breadth, the span of the hand is used, from the thumb to the end of the middle finger, but people with large hands must use the span of the thumb and the first finger. Short distances are measured by strides, and long ones by the sun and a day's journey. Land is not measured. Weights are not used. Two handful of dhurra are considered a meal for one person, and this quantity is supposed to be contained by an adansonia fruit-shell. Counting is performed with ease. Tallies are not used, but for counting high numbers beads on a string or marks on the ground are made use of.

Communication.—The roads in the northern and north-eastern parts of Darfur are simply paths which lead through the open country. In the south, paths between villages are worn by use. No roads are made. Very deep swamps are sometimes rendered passable by grass, stones, and branches of trees sunk into them. The only bridges that are formed are those made by felling trees and placing them across small deep rivers. Ferries do not exist. Wells are kept up in the caravan roads and in the north-east part of Darfur; where water is very scarce, adansonia reservoirs are constructed, which are filled by the neighbouring villagers during the rains, the passing caravans having to pay a tax for the water they use. The pack-saddles which are used for donkeys and oxen are simply pads made of platted grass, and fastened round the animals by a rope or leathern thong. The goods are then slung on each side of the animal. The camel- and riding-saddles are exactly like those used by the Arabs.

Pastoral Life.—The Fors are in no sense nomadic, but reside in settled habitations.

No store of hay or any other fodder for animals is kept for winter use. They are all fed on grass in the fields all the year round, whether it is green or dry. Horses and he-goats are allowed corn. In colour the cows are either all black, all white, white and black mixed, red and white, grey, grey and white, dark red, almost black. These and the grey variety are considered the best breeds. All the cattle have beautiful horns; the bulls' horns are generally much straighter than the cows'; if they grow too long they are cut to prevent them breaking off. The cattle are not used for draught purposes, but they are ridden and employed as beasts of burden. They are eaten as well as milked.

The horses are white, grey, or dark brown. Many of them are splendid creatures; they are well-proportioned, and have perfect action. They are very well framed, and some of them are so swift that they can run down an ostrich with ease. The people feed them with great care, as if they get too much corn they become ungovernable. The dark brown horses are nicknamed "dongolwies;" the white and the grey are called "kuruks."

The sheep are large, have very short wool, and fine long tails. The rams have long twisted horns. The wool is only used to stuff saddles. Their milk is used for food.

The goats are very fine animals, with splendid horns; they are black, white, grey, or black and white mixed. Their milk is used, and considered the most nourishing milk obtainable. The goat's hair is not made use of, but the skins of goats and sheep are employed as mats, and also made into bags to carry water or babies in. Sometimes they are used as loin-cloths.

Camels are made to serve as baggage and riding animals; they are also eaten, and their milk is used. They have only one hump; some of them are very vicious. They cannot live in the south-western part of Darfur. Their skins are used for mats, for *extempore* beds, for sandals, and to make ropes.

Two breeds of dogs are found in the country. The best are fawn-coloured, and have smooth skin, short hair, long legs, long curly tails, and erect ears. They are used for hunting and as watch-dogs. They are much attached to their masters. Hydrophobia is not known. The other is a mongrel breed, miserable curs, white or black and white; they act as scavengers, and serve no other useful purpose. There are cats similar to our own, but somewhat larger, with long tails and long silky hair.

Fowls are kept and eaten; their eggs are not often used as food, but usually kept for hatching. Cocks are sometimes encouraged to fight; but if this becomes known to the dalimars the perpetrators of the cruelty are made to pay a fine in damoor cloth. Gelding is not practised.

A trade exists in horses, camels, cows, sheep, and goats. Horses and hygeenes are the most valuable. There are no special cattle markets, but in the ordinary markets a space is set apart for the cattle. Donkeys and horses are trained by being made to carry heavy weights, stones, or sand. If a cow is wild its legs are hobbled, and it is not milked for several days.

An epidemic disease called *rutpoia* sometimes attacks the cattle; it occurs in the hot season, and is very serious and usually fatal. The animals when attacked are either killed or at once isolated; the only cure tried is smoking the animals.

The bits, saddles, and stirrups employed are copied from the Arabs. The cattle are guided by a nose-ring, to which a line is attached. There are no carts. Horses are either hobbled or picketed by a rope tied round their necks, and fastened to a stick buried in the ground or to a stump.

Butter is made as follows:—The evening and morning milk are mixed, and then set aside for an hour or two, after which the milk is shaken in skins until the butter is formed. Butter-milk is much preferred to fresh milk. Cheese is made in the following way:—As soon as the milk becomes sour and the curds form, it is strained through a palm-leaf sieve; a little salt is then added, and the curds are tightly wrapped in damoor cloth, upon which a heavy weight is placed. This cheese does not keep long, but the Fors prefer it mity. Butter is often bought, but the cheese is always made at home, the reason for this being that butter can be washed, but not cheese. The women make both butter and cheese, as also the beer. The cattle are milked before breakfast, after which the boys and girls drive them to their pastures, from which they do not return till about sunset; they are milked again in the evening. Women usually milk the animals, but there is no reason why men should not do so if necessary. Cows, sheep, and goats are herded together. During the dry season the men sometimes drive the cattle to a considerable distance, and stay away for several days at a time. When on these expeditions they do not use tents, but form a simple seriba, to which they return at night; they sleep on the ground on skins.

All the cattle of the village are herded together. Every family must send a boy or a girl to help to take care of them, or if they have no children they must hire help. The children all unite to protect the cattle, and if danger is apprehended men go with them to act as a guard; this duty is performed in regular rotation. Wild animals rarely attack the cattle in the daytime, and if they should do so they are usually scared away by the children shouting. The boys are all armed with spears and bows and arrows, which they know well how to use effectively. Most people have a private shed for their cattle, but in some villages there is a public seriba as well.

All animals are killed by having their throats cut, except camels, which are speared in the neck. Wood alone is used as fuel, the dung being used for manure. Animals are never branded or marked, but are each known by name.

Agriculture.—The whole population are agriculturists. Each member of a family has a plot of land which they can call their own, but notwithstanding this division the land is cultivated by the whole family together. After the ground has been cleared it is hoed with iron hoes having wooden handles. Manure is sometimes mixed with the soil. Sowing is performed at the beginning of the rains. The men make holes in the ground for the seed with stakes, the women, who carry the seed in small baskets or adansonia fruit-shells, drop them in the holes, the children following and covering them with earth. A great deal of attention is paid to the growing crops. Children watch them to scare away the birds; they are carefully weeded, the weeds being collected into heaps and subsequently used as manure. Every one helps at the harvest; the corn is reaped by small knives, and put into baskets which the reapers carry with them; it is carried home in these baskets and stacked near the house to dry. When dry it is spread upon the ground which has been beaten hard for the purpose, and thrashed and winnowed by the women. The men measure the grain and store it away in the granaries, which have been previously described. Wheat, tobacco, and onions require to be watered, and this is done by irrigation. Most of the fields are at some distance from the village. If a man wishes to enlarge his possessions he chooses any uncultivated ground near; he cuts down the shrubs, which he makes use of to form a seriba round the land, and generally pastures his cattle there for the first year. Hedges are not built as a protection from wind. The Fors have no idea of leaving the ground fallow or of improving it by a rotation of crops.

Games and Amusements.—One of the most favourite games played by people who have horses very much resembles polo, and is played as follows:—A flat field is chosen for the purpose, and a large square formed by a ridge of earth. At each corner of the square inside, a goal is placed, formed of two stones or posts. Four companies of horsemen are formed in equal number, and, if possible, the horses in each company are of the same colour. Each man is armed with a long hooked stick, and two large balls are used. Two men throw these balls in the air three times, and then throw them in the direction of two companies of horsemen, who try to drive them back through the lines of horsemen defending the other goals. The latter endeavour to prevent this, and at the same time to drive the balls through their enemy's goals. Should the ball be thrown outside the boundary, the horsemen may not follow it, but it is thrown in again by the umpires. When both balls have been sent through a goal, the game is finished and commences anew. Much agility is displayed by both men and horses. Sometimes several villages combine to get up a match, which is followed by a supper and a carouse. The game is called *puknun.*

A game called *dadarn* is played by boys. A large heap of stones is divided equally amongst all the players, who sit in a circle. They place the stones on the ground before them, then throw one into the air, pick up another, and catch the falling stone. They then put one of the two stones in a separate place, and repeat the manœuvre until all their stones have been removed, or they fail to catch one. If they have used all their stones, they are allowed to help themselves from their neighbour on the right hand, and then from the neighbour on the left until all are finished. If a boy loses all his stones three times, he has to pay a forfeit; either he must dance or must pinch the tips of each of his fingers, or roar like a lion, or run a certain distance and back again. After this, all the other players give him a few stones that he may commence again.

Another game for boys is played as follows:—A large number of holes are made in the ground in a circle, in the middle of which there is a large hole with four other holes round it. The players are provided with a number of small stones, and they move round the outer circle in turns, dropping a stone into each hole, but taking one up whenever an equal number is found. The boy who has the most stones then puts them into the hole in the centre of the ring, and each of the other players forfeits a stone to him. The four boys who have the next largest number of stones place them in the four holes round the central one, and the best player gives them each a stone. Then the five most successful players play against each other until one remains victor. He has to stand up in the middle and sing, turning round as if on a pivot, while the other boys dance round the outer circle of holes. This game is called *aringari.*

Hide and seek is played, and they call out *kee lu.* It is played by boys and girls together. Sometimes two parties are formed, each having a piece of ground marked off by a circle of stones. The one party hides and the others look for them. When found, the hiders run back to try to get into their ground before the seekers catch them. If any are caught they go to the victors' party.

Another very favourite game is played as follows :—Two parties are formed on either side of the village yard; the leader on the one side has a short stick, which he rubs backwards and forwards between his hands. He stands a short distance in front of his party calling out "kiri kirine daw." One of the opposite party then tries to catch the stick, running across the yard on his tip toes and holding his breath. If he succeeds in so doing, and says "Dang doga pute kora kite" without once taking his breath, he is at liberty to take back the stick to his own side, but if he fails he is detained as a prisoner. When a party has lost several of its members in this way, it cannot gain possession of the stick until each of the prisoners have been redeemed by a successful run. Then a run may be made for the stick, and if it is taken, the opposite side take their turn in running. The opposing parties do all in their power to make the runners laugh, so as to compel them to take breath. They laugh, shout, cut capers, and make sarcastic or joking remarks. This game is played by both boys and girls; the girls are more successful in holding their breath than the boys.

The most famous game among the boys is that of mimic warfare. The company separates into two armies; they then mark off a neutral zone, which must be so broad that the best throwers are not able to throw a stone across it. The captains then order the opposing armies to retreat and gather stones; they then advance on each other, singing and throwing stones as they go until they reach their respective boundaries, beyond which they may not proceed until the whole of their stones are expended. Then, at a given signal, they charge each other with sticks, holding them as if they were spears, but they may not throw them. Many of them fall down as if dead, and the arrangement is, that the side on which most fall should be considered the bravest, and that the others should then retreat, being pursued by the conquerors, who capture a number of prisoners. These they bring back in triumph, with dancing and singing, and forming a circle around them they compel them to dance for the amusement of their conquerors. Then they chase them and let them go.

Another mimic war is carried on in the water. The players divide into two parties and swim against each other, trying to drive their opponents out of the water. Those who are driven out arm themselves with grass and mud, which they throw against their adversaries in the water. These dive to get out of the way, and at the same time try to prevent their enemies regaining the water. When both sides are tired, two captains are chosen to end the play by single combat. If one of these is driven out of the water, or beyond a certain point, the other remains victor; should neither succeed in expelling his opponent, the game is considered drawn.

Sometimes the boys make an artificial ostrich. A long stick is fastened to their backs, having a cross stick fastened just above their heads; upon this framework a piece of damoor cloth is arranged, and this represents the bird, which is then hunted by the other boys and girls.

They also make artificial ghosts in a similar way. Two sticks are tied to the boy's arm, over which a damoor cloth is placed; this he holds over his head, and bends about in all manner of directions. By the light of the fire this has a very grotesque appearance, and spreads consternation among the children.

Another game is played as follows :—A row of boys and girls sit with their legs stretched out, while another boy, beginning at one end of the line, repeats a sentence, singing one word for each leg that he passes. When he comes to the end of his sentence, he touches a leg, whose owner must draw it up; he goes on until one of the players has both legs drawn up, and the latter must then go away and hide. The sentence is then repeated, until all the children save one have gone to hide, when the last boy left must go and try to find them. The boy who touched the legs has to remain as a "touch post" on the ground, to which each child that is found runs, but if caught by the seeker before touching him, he has to aid in finding his companions. One of the sentences which they sing is as follows:—"Kamal dolge-jam kune-bort-plo diu-tier tilgam."

The For children have a good many more games of this description, including a tug of war and leap frog.

Medicine.—When ill the Fors are fairly well looked after, and some of the old women are considered to be good nurses, and are often sent for in illness. Except in cases of small-pox, the patients are treated in the ordinary huts. At times, however, they partition off a part of the hut for the patient's separate use.

Although a good deal of belief exists in the power of charms and amulets, the Fors have also a very decided knowledge of the medicinal properties of many barks, roots, and leaves. They are gathered and stored in horns or jars, and decoctions are made from them when required. Some books exist as to the method of employing these drugs, and the way in which they are to be prepared and partaken of is definitely laid down. Most of them are given in a decoction, but some roots are chewed.

Phthisis is well known. It occurs chiefly among the inhabitants of the Marah mountains. It is called *korlo-koro*, and many people die from it. Headache is treated by allowing butter to run into the nostrils, the patient being placed in a recumbent position. It is said to "grease the brain." I have noticed this custom among the Arabs too, so it may have been introduced by them. Toothache is very rare, and I never saw caries in Darfur, although I must note that my boy has had three teeth affected by it since his stay in England. Pains are treated by rubbing or by cupping if very severe; small iron knives and cows' horns are used in the operation. Ague is not very common, and occurs mostly in hunters who have crossed the Bahr-el-Arab in search of game. It is treated by decoctions made from roots, which act as very powerful diaphoretics. Sometimes the attacks are very severe, and the people seem to be afraid of it. Guinea worm is also very frequently met with in hunters who have been in the Darfertit district. The tumour caused by the worm is poulticed with leaves soaked in water, and tied over the part by a damoor rag. As soon as the worm makes its appearance, it is carefully drawn out and wound round a stick, a little each day.

All fevers are treated by heat. Large fires are made in the huts near to the patient's bed, who either rubs himself with castor oil, or is rubbed and kneaded well by his friends. Warm decoctions of leaves are given him to drink.

There is one drug celebrated far and near. It is said to make women sterile, and in men it causes the testicles to atrophy. It is often given out of spite. I saw two men—one about 40, the other an Arab about 25—who said they had had this drug given them, and certainly their testicles were very small; but I confess I was dubious, though most strongly assured of the power of the drug. An antidote is known by a very few of the magicians, and is very dear. Syphilis is treated by a decoction made of twelve parts of a root to one of pepper, and boiled over the fire for about six hours, water being added occasionally. A small gourdful is taken twice a day, and the patient may eat nothing salt or sour for six days, and must drink as little fluid as possible; then for six days he must eat only bread, and perhaps a little fowl, but no salt; for the next week he may eat a little meat, and then return to ordinary diet. The medicine is taken for twenty days. Slatin Bey told me he had seen twenty or thirty cases thus treated and cured (?). I saw a good number of people suffering from secondary and tertiary symptoms. Necrosis of the skull bones is apparently common. The people say that this disease was introduced by the Arabs from the north many years ago. Persons afflicted by it do not try to communicate it with the hope of curing themselves, as is the case in some neighbouring districts, Kordofan for instance. Inoculation is not practised. A peculiarly virulent form of gonorrhœa, accompanied by cystitis, is very common; the Fors are very noted for this disease. Leprosy and elephantiasis are far from uncommon; the former is said to be hereditary. Ulcers of the leg are not so general in Darfur as among the tribes farther south. Ophthalmia is very rife, but is invariably cured by the application of a lotion made from the root of a shrub. Epilepsy is frequent; girls are more prone to it than boys, in whom it is rare. It is thought to be caused by the afflicted person committing some fault, such as pilfering food, or going into a hut which is under the protection of the Zittan (see above), or committing some offence under a tree in which a Zittan is thought to live. The aura is said to be a peculiar smell which they attribute to the Zittans, and which is usually smelt under trees where they are supposed to reside. When girls suffer from this disease, they hardly ever find husbands, and in consequence lead immoral lives. The priests try to cure them with charms and amulets. The internal medicine which alone is used for epilepsy is as follows:—A puggee writes a few prayers upon a board, the writing is then washed off with water, which is then drunk by the patient. Epileptics are not systematically ill-treated, but their fathers cannot be said to have much affection for them, as they cannot expect any dowry for them. Although I made many inquiries on the subject, no single case of idiocy or mania came under my notice, and the people said that they were very rare. Small-pox is very common. Persons who suffer from this disease are kept strictly isolated; an old woman is deputed to nurse them. She gives a diet of porridge and milk, keeps the hut very warm, pricks the pustules as soon as they are well formed with a thorn, and anoints the patient's body with castor oil.

Wounds heal very rapidly; they are dressed with a pulp made from various roots and barks. Arms are sometimes amputated for disease, but the legs never. The Fors also remove parts of the tongue affected by epithelioma. Splints well padded with cotton wool and fastened by strips of damoor cloth are used for broken bones. A few of the magicians are very celebrated for their dexterity in removing cataracts; they travel round the country, and enjoy a wide reputation, and for successful operations receive very considerable remuneration. Deformities are very rarely seen.

I never saw an albino. They are said to be very exceptional. They are called abortions, as the people believe that they were born before their time. They are mostly beggars, and much despised, as they are said to be very cowardly, silly, and cry whenever they are pinched. They are also said to have little power of smell.

Labour.—As before mentioned, married women have huts of their own, and as a husband does not live with his wife during the later months of pregnancy, she has only to send her children away to her friends to be free from observation. A few of her female friends attend her during delivery. A group of women usually stand outside the enclosure uttering cries to encourage her, but all men are kept at a distance, and it is considered very bad manners for a man or lad to go near a compound in which a woman is in labour; the woman either leans against a wall of the hut with feet apart or in rare cases supports herself from a rope attached to the rafter. Her friends meanwhile keep up the fire, supply her with beer, and from time to time rub her abdomen, and as the child is born they receive it and cut the cord with a knife (rarely, a sharp stone). The cord is never tied, and if it bleeds it is held between the teeth. Cases of difficult labour appear to be rare, and no inquiries could elicit any information of measures taken to aid delivery. Should it be impossible, the woman and child die, for abdominal section is not practised either before or after the death of the woman. The child is washed after birth and rubbed with oil, and then wrapped in damoor cloth. The woman does not bathe but is washed, and she then lies down near the fire; the child is put to the breast as soon as the mother has been made comfortable. The woman is perfectly secluded for a week after the birth of the child.

For some days before a woman expects her labour she abstains from meat, and during the week afterwards she is fed on thin porridge, and eats no meat until the feast is celebrated at which the child receives its name. No superstitious practices take place at the birth of a child.

Ironwork.—Brown hæmatite iron is to be found in great abundance, and used to a large extent, but no flux is employed. The smelting furnaces are about 6 feet high; they are conical, and have at the bottom a number of holes to which the draught from the bellows is led through clay pipes. The bellows are made of clay pots covered with soft skins into which a hollow stick is fastened. Each man works two of them, one with each hand. The ironstone is broken up into fragments about as large as walnuts, and these are placed in the furnace with charcoal in alternate layers. The iron is purified and shaped by long-continued hammering; stone hammers and anvils are alone used. The work turned out is of a very good quality.

Basketwork.—Various kinds of baskets are made, some of open wickerwork but others so closely woven as to hold water. The shapes are oval and round; some are made with lids. The bottom of the basket, which is always flat, is first made and the sides are worked up from it. Dhurra stalks, palm leaves, and the bark of trees are used for basket making. The baskets are never painted; they vary in colour according to the kind of material used. Good and pliant mats are also made, and some of the patterns are very nice. Trays and open baskets are constructed for food, and it is protected by ornamented covers of tasteful and fanciful patterns, and invariably round.

Tanning.—As soon as animals have been skinned, the skins are scraped and then put into water in which *okun* (the bark of a tree) has been mixed. After several days they are taken out, scraped again with iron knives, and afterwards pegged out under the shade of a tree or under a shed made for the purpose; they are then rubbed and beaten with flat stones. At times they are also rubbed with butter.

Pottery.—The jars and pots constructed by the Fors are of fairly good quality. They are chiefly made by the women, and no potters' wheel is used. After the clay has been freed from stones and lumps it is beaten with heavy stones, and water is added to bring it to a proper consistence. A ball of this dough is then made, large enough to form the bottom of a jar, which is then moulded by a series of stone or solid clay-blocks being pressed into the soft clay; rings of clay are then added to form the sides of the jar and it is smoothed by the hands. Sometimes they ornament the pots; plait, cross lines, and herring bone patterns are alone used, and are formed by a sharp-pointed stick.

The pottery is burnt in a large hole dug in the ground in which the pots are placed, and which is then covered by a framework of wood strewn with earth. Over this a large fire is made and kept up for a day or two. Small images of men and cattle are made in clay as toys.

Dyeing.—I was unable to gain any information on this point, but I know that red, black, blue, and dirty green dyes are made. The black is called *dego* and is procured from the bark of a tree named *pedan.* The red is known as *pucki* from a plant called *klutu.*

Music.—The Fors are very fond of music, and have several musical instruments, which they play with more or less proficiency. They have drums of various sizes—some so large as to form a good load for a man, others of smaller calibre. Each village has a collection of drums in common, apart from those possessed by individuals. The drums, which are broader at one end than the other, are made of hard wood, hollowed out by knives. They are covered at the ends by parchment, and the two coverings are laced together by thongs, which can be tightened at will. They are played with sticks and fingers.

There are two varieties of flutes, made from reeds or hard wood. One kind is blown from the side, and has six notes, producing low tones; it is about 18 to 20 inches long. The other flute is much larger; a plug is placed at one end, leaving only a small aperture, through which the instrument is blown. The flutes are held as in Europe.

Trumpets are made from the horns of bulls, sheep, goats, and antelopes, and from elephant's tusks. Signals are sometimes given by them, but mostly by drums. There are two kinds of harps. One shaped somewhat like a lyre; the half of a large gourd is taken and two holes made in it, into which are fitted two upright sticks, which diverge a little from each other. They are united near the top by a cross bar, from which six strings made of sinews are carried down, and passed through small holes made in the gourd, on the inside of which they are fastened to small pieces of wood. The gourd is then covered by a skin. This harp is rested on the knee and played with both hands. The other one is much larger and heavier, and rests upon the ground when played on. It is constructed like a mandolin and has twelve strings, all of which are made of the sinews of animals. Another kind of musical instrument is a small bow, strung with horse-hair; one end of this bow is placed in the mouth against the teeth, and the music is produced by striking the hair with a switch. Gourds filled with small stones are used as rattles. Bells are made, the clappers of which are continuous with the handle and do not move, but the bells strike against them. I will mention one more instrument resembling our hurdy-gurdy. An elongated drum has a large number of holes bored in its side, through which pointed sticks of varying lengths are driven. A crooked stick passes through the centre of the drum, and when turned it causes the pointed sticks to vibrate, producing strains of music marvellous. The only real orchestras to be found in Darfur are those composed of flutes, rattles, and sometimes small drums, which discourse really harmonious melodies. There are no professional musicians, although they have some women who make a livelihood by singing and dancing. They attend feasts, marriages, &c. The For songs are very numerous, and are usually accompanied by music. Solo songs are sung, and songs in chorus; sometimes both are combined. The Fors can apparently pick up very readily foreign airs, and are not slow in learning to play European instruments. I often heard the Dara band perform, and although they had only been a very short time under instruction their performances were highly creditable.

Writing.—The only writing in Darfur is in the Arabic character. Few people use it, but it must have been introduced centuries ago, as all the books of For law, and those giving instruction in the preparation of drugs and charms, are written in the For language in Arabic characters. I was unable to obtain any specimen of it, much as I tried to do so. The art of drawing is unknown.

Astronomy.—The Fors' knowledge of astronomy is very rudimental. The months are lunar, but there are no ceremonies connected with seeing the new moon for the first time. The day is divided by the heights of the sun. They have names for only a very few stars.

Arithmetic.—The Fors count as far as hundreds, but have no word for a thousand. They use strings of beads for counting, as also small stones. As far as I could make out, fingers and toes are not used for the purpose. I inquired particularly about this. The Arabic notation is in vogue amongst the educated people. They are only capable of making the simplest calculations, and this is done mentally.

A Short Vocabulary of the For Language.

Antelope	Munu.
Arm	Donah.
Arrow	Korr.
Axe	Bo.
Bedstead	Pidi.
Beer	Kera.
Beads, White	Badiana.
,, Red	Marigana.
Beard	Furu.
Bow	Napar'.
Boy	Kwatin.
Brother	Bein.
Brook	Kura Soruba.
Cat	Bis.
Calf of leg	Toringdolgoin.
Child	Kwa.
Chin	Karu or Asa.
Cloth	Guri.
Clouds	Kuttu.
Cow	Uh.
Chief	Sagal.
Crocodile	Taubareh.

Dog	Assă.
Drum	Kisu.
Ear	Dilo.
Earth	Du.
Elephant	Engri.
Eye	Nui.
Father	Babă.
Face	Kumi.
Fire	Utŏ.
Fence	Giabl.
Fish	Pun.
Fishhook	Nyamdam.
Finger	Toringa.
Flute	Morli.
Foot	Tar.
Forest	Kuruma.
Forehead	Eri Muji.
Fowl	Doga.
Gazelle	Pra.
Girl	Kwann.
Goat	Diu.
Grass	Dei.
Hand	Donahsor.
,, Palm of	Donahdiu.
Hair of head	Gabbu nilu.
Harp	Kurbe.
Heaven	Jouel.
Hell	Uddu.
Hippopotamus	Lieu.
Horse	Murta.
Hoe	Bouten.
House	Joug.
Iron	Doura.
Ivory	Engridagi.
King	Abbakuri.
Knife	Sagin.
Lake	Birga.
Leg	Tar.
Leopard	Giara.
Lion	Muru.
Man	Duo.
Millet	Kam.
Moon	Duāl.
Mother	Ama.
Mouth	Udŏ.
Monkey	Karou.
Mouse	Moui.
Moustache	Dulenge.
Mountain	Pugŏ.
Morning	Losari.
Night	Lodikoin.

Nail finger	Karu.
Nose	Dormi.
Neck	Ku-i.
Ox	Nu.
Rat	Gummul.
Rain	Kwi.
River	Bow.
Rope	Bord.
Sandal	Dowla.
Serpent	Num.
Sister	Dadă.
Shield	Kerbi.
Sun	Dule.
Star	Uri.
Sheep	Urī.
Spear	Kori.
Sword	Sarr.
Tobacco	Tabă.
Tooth	Dagi.
Thigh	Dinil.
Tongue	Dali.
Tree	Kuru.
Wood (timber)	Eir.
,, fire	Eira.
Water	Koro.
Well	Trohr.
Wheat	Karu.
Woman	Dunyan.
Bad	Tulabă.
Big	Apah.
Black	Diko.
Clean	Tay.
Dirty	Kusay.
Fat	Dai.
Good	Tulai.
Little	Itng.
No	Kei-elba.
Red	Puka.
White	Puta.
Yes	Woi.
1.	Dik.
2.	Go.
3.	Is.
4.	Ungal.
5.	Ors.
6.	Sundi.
7.	Servi.
8.	Tuman.
9.	Tisi.
10.	Wei.
11.	Weni

2. On Bisulphide of Carbon Prisms. By Dr Daniel Draper. Communicated by Professor Piazzi Smyth.

New York Meteorological Observatory,
May 27th, 1885.

C. Piazzi Smyth,
Astronomer Royal of Scotland.

Dear Sir,—I take pleasure in answering your kind note of May 9th, in regard to the experiments made by my brother Dr Henry Draper, on bisulphide of carbon prisms.

In this letter I shall only refer to those portions of my brother's experiments, which did not appear in sufficient detail in the paper published in the *American Journal of Science*, by Professor George F. Barker of the University of Pennsylvania.

My brother was led to perform these experiments with bisulphide of carbon prisms, with the stirrer, and uniform temperature bar, on account of the trouble he had experienced while working upon "Oxygen in the Sun" in his old laboratory, in getting coincidences between the solar spectrum, and the spectra of various other substances with the electric spark. He found that sometimes the lines of the overlapping spectra would coincide, and at other times there would be discrepancies, although the experiments appeared to have been made in exactly the same manner each time.

On continuing these experiments on oxygen in his new laboratory he found that the discrepancies were much greater than before. This led him to suspect that the lack of coincidence was due to temperature.

At about this time Mr Lewis M. Rutherfurd told my brother of his experience, in shaking the bisulphide of carbon prisms just before using them, and the surprising results they gave, and also the short time of their continuance to give good results.

My brother and I, in talking this subject over, decided to see if some simple plan could not be devised to keep the fluid in the prism continually stirred, or shaken by some small steady motor power. To try this device brother Henry borrowed from our brother-in-law, Dr Mytton Maury, his Edison electric pen, which consists of a very small magneto-electric engine, mounted on the upper end of a (stylus) or light tube, through which a needle point is caused to move very rapidly up and down, and having power enough to prick holes in this legal cap paper. On attaching a propeller or stirrer to it, it was found that there was sufficient power to keep the propeller in motion, and obtain the results that are mentioned in Professor Barker's paper.

To prevent the dangerous escape of the bisulphide of carbon vapour from the prism, which you justly fear, a mercurial stuffing box was employed. . . . . In the neck of the bisulphide prism bottle, a little below the upper edge, is a cork, that has through its centre a small glass tube; through this passes a steel wire or shaft having attached to its lower end the propeller, half an inch in diameter. On the upper end of the shaft is fastened a small glass cap with its opening downwards, so as to dip below the surface of the mercury, in the upper portion of the neck of the bottle above the cork. On the top of this cap is fastened a pulley to receive motion from the Edison electric motor (just described) by means of a thread or small belt. It was found that, even when the propeller was caused to revolve very fast, there was not the slightest leakage of the vapour of the bisulphide of carbon. . . . .

The controlling of the temperature inside of the prism box is accomplished by the use of two thermostat bars that were made under my direction for brother Henry. They are on the same principle as those that I invented many years ago for the taking of observations on temperature at the New York Observatory. Each bar consists of a strip of vulcanite a foot long, one inch wide, and $\frac{1}{10}$ of an inch thick, riveted to a similar strip of brass only $\frac{2}{100}$ of an inch thick. The rivets are in two rows set one inch apart. One end of the bar is fastened firmly to a block, while the other end is free to move with the changes of temperature. The vulcanite expanding more than the brass, causes the thermostat bar to bend towards the brass side, on an increase of temperature; but if it falls, the bar bends the reverse way. On the loose end of the bar is an adjusting screw (with a platinum point for electric contacts), so that it can be set for any temperature. We used two of these bars so as to have very quick action. If there is the slightest fall of temperature in the prism box, the platinum points of the bars come in contact, causing the current of the battery to pass through the electro-magnet, and open the valve of the gas lamp to give more heat in the metal pipe of the prism box. If it becomes too warm in the box, the reverse action takes place; the current is broken, and the heat is shut off.

Just before my brother's death, it was decided to make a slight change in the heating part of the apparatus, because on one occasion, as we were watching it, we found that the sudden action of the electro-magnet on the valve of the gas lamp in shutting off the heat had caused the light to become extinguished. On the cooling of the inside of the box the electro-magnet opened the valve, and allowed the gas to escape into the room, making it very dangerous. It was then decided to change this portion of the apparatus. It was thought that it would be safer to have the electro-magnet control a damper in the hot air pipe, than the lever of the gas lamp. . . . . It was also decided to have the hot air pipe in the prism box make several turns around its inside, so as to dispense with the double box and cotton filling, and have a more even distribution of heat throughout the box.

What you so kindly say of my brother's early death is too painfully true. It awakens reminiscences that cannot, and should not be forgotten. If some twenty years ago you could have looked into the laboratory at Hastings, you would have witnessed the interesting sight of my father John William Draper, and his three sons all discussing together the best plan to be followed in the building of my brother Henry's observatory, and then after its construction father would often leave his work on the *Intellectual Development of Europe*, and go to the observatory to deliberate what observations should be made, and how they should be carried on, Father was a born astronomer, scientist, and historian. When only eight years of age he attempted to make a Gregorian telescope like the one he saw his father using.

But how strange is death. Brother Henry, in the prime of life, followed father to the grave in ten short months.—I am, very truly yours,

DANIEL DRAPER.

3. Vital Relations of Micro-Organisms to Tissue Elements. By G. Sims Woodhead, M.D., and Arthur W. Hare, M.B. Communicated by Professor Turner.

In entering upon the consideration of a subject so important, one cannot but feel surprised at the very general obscurity which envelops a question upon which so large a mass of accurate detail has been collected. In looking for the cause of this unsatisfactory state of affairs, it would appear to be due to a lack of appreciation by one set of workers, of the methods pursued by another, and this in two directions. In the first place, the student of normal cell life relegates aberrant vital processes entirely to the domain of pure pathology; whilst the pathologist, relying mainly on organs as a whole for his views on function, normal and abnormal, is apt to ignore the value of the study of the cell processes as carried on under normal conditions. How without the aid of such study are we to explain inherited variability in cells? How without its aid can we interpret aright the numerous processes which, minute or almost imperceptible in the unit, in the aggregate, constitute a disease? Conversely, how is the student of cell life to make a complete analysis of normal vital phenomena if he fails to contemplate the striking analogies presented in morbid conditions? Mr Geddes, in a paper on the cell theory, read before this Society in 1883, attempted to remove this reproach on the one hand, whilst on the other there are already signs of a growing recognition among pathologists of the claims upon their attention of those fundamental vital phenomena of cells so fully expounded by Goodsir and Virchow.

For our present purposes it will be necessary to quote merely a definition of pathological changes in cells as "those variations which happen not to be conducive to success in the struggle for existence." Taking the theory that "variation and disease in the cell are closely allied," to start from, it will be curious to observe how the cycle in cell life, or parts of it, may be traced in those processes which are initiated through the action upon them of micro-organisms.

That such a "variation" theory of disease is now largely held is evidenced by the definitions quoted in our paper, as given by various modern pathologists.

These may be shortly summed up in such a phrase as "vital processes under abnormal external conditions."

In the present paper are considered those external abnormal conditions supplied by the presence of micro-organisms.

The subject must be approached from two points of view—(1) the nature and function of the altering agent, represented by the micro-organisms; and (2) the nature of the alterations and reactions set up in the elements acted upon, represented by the tissue changes.

It has now been proved experimentally that micro-organisms act upon complex nitrogenous bodies, as do several classes higher in the organic scale, *e.g.*, animals and insectivorous plants, by a process very nearly allied to true digestion. Their function from a chemical point of view, as Frankland and others have pointed out, is analytical and not synthetical, and by this difference they are at once widely separated from the majority of the more specialised members of the vegetable kingdom.

In carrying on their analytical functions the same sequence occurs as in the digestion of albuminoid matters in the animal digestive apparatus, and experiment shows that their action upon an insoluble albumen, such as fibrin, produces a soluble globulin and other bye-products identical with those evolved in tryptic digestion. Further, Pasteur has recently expressed the opinion, basing his view on numerous analogies, that perfect digestion in animals cannot take place without the presence of micro-organisms; and Duclaux states that the process of caseation in tubercle is due to, or at least advances *pari passu* with, the production of a ferment which acts upon milk in the same way as pancreatic juice or trypsin. We may consider then, that it is after the production of these ferments, and after they have exerted their digestive action upon the tissues, that micro-organisms can obtain food material in an assimilable form, which they can utilise in their growth and development.

The same soluble products of the ordinary processes of digestion are equally well adapted for the nutrition of the animal. Digestion, then, from this point of view, is a process of fermentation, in which the ferment-producers do not utilise the whole of the material on which they act, but set free a very large proportion of elaborated food material which may be applied to the use of the organisation in which the process is carrried on. It would appear that this same law governs the processes set up by micro-organisms in the tissues of their host in several of the specific infective diseases, and that the products of the fermentation set up, are applied, at least in part, to the nutritive purposes of the organisms themselves, and, in part, to prepare living or only partially devitalised tissues for further assimilative processes on the part of these micro-organisms. But beyond this, in some cases, a product is elaborated which, acting as an antiseptic, destroys the vitality of the organism which produced it.

The existence of these special products is now generally acknowledged. They are not necessarily accompanied in their distribution by the organism which produced them on account of their greater diffusibility. The organism will, however, usually be found at some point whence absorption of its products might occur. In those cases where it is not found in such a position, and where typical traces of its action may be met with, we have abundant evidence that, owing to the exhaustion of the material necessary for its nutrition, it has ceased to exist, but its progeny have migrated to, and are found in, the less altered tissues in the immediate neighbourhood, prepared for their reception by the products of the primary fermentative process.

Up to this point the paper deals with the subject of the organised irritant agent; we must next turn to the reactions brought about in the cell elements of the invaded tissues, and we shall find that these reactionary changes have a definite relation to the nature of the irritant and the conditions under which it is applied. Under normal and constant conditions we might anticipate that the cells of any part of one of the higher organisms would continue to be reproduced at a fixed rate, to perform their function and die, a regular proportion of young, functionally active and dying cells, being maintained throughout. We know, however, that such a cycle, if left alone goes on for a certain period only, and that there comes a time at which the reproduction is not equal to the removal, and that consequently organic death takes place, and the species dies out if the process is not again commenced *ab ovo*. But there are conditions in which the regular cycle is interfered with. The external conditions or moulding forces may be so altered that the reaction of the tissue to these forces manifests itself in a form which varies somewhat from that observed under normal conditions.

The constant presence of micro-organisms upon the free surfaces, and within the cavities of the body, gives rise to the question, Why are they not normally present in the tissues? Here we may adopt Lister's theory of standard vitality, based on the absence of micro-organisms from the healthy urethra and from a wound healing by first intention. Unless this standard vitality of cell elements be in some way impaired, all the conditions are unfavourable to the growth of micro-organisms. The circumstances in which we have depression of tissue vitality include, in addition to general organic depressants, such structural features as the formation of cavities, pouches, and wounds, in which there may be accumulation of secretions or other effete products, the structure, function, and arrangement of the epithelium covering a free surface, the position of the surface and its relations, first, to the external world, and second, to the deeper tissues, especially to the lymphatics, the number, size, and relation of these lymphatics, the tissues in which they occur, and the relations of the lymphatics to the small veins. Several instances might be quoted from the paper in illustration of the bearing of these several factors on the invasion of the tissues by micro-organisms. According to certain differences in the character and distribution of these invasions, it is possible to form a general classification of the action of the organisms which give rise to them.

(1) This action may be purely local, and accurately confined to one area, beyond which neither the micro-organisms nor their products have any effect. (2) There may be a purely local action in the first instance, but this localisation is only temporary. The invasion goes on in stages, point after point being attacked. The spores developed at one point are transported to others, and so the process goes on intermittently, as in actinomycosis. (3) The organism may be limited to a definite tract, but its products may be diffused throughout the whole of the invaded organisation, as in certain cases of septicæmia. (4) There is no limitation to the sphere of activity of the micro-organism, which, with its irritant products may penetrate to all parts of the tissues, and so give rise to a general disease, as in the case of the organisms which give rise to the specific fevers.

In all these cases several factors must be taken into account in considering the changes which result from the presence, during their life history, of micro-organisms in the tissues. They may act (*a*) merely as mechanical irritants, as do particles of coal or stone in coal miner's or stone mason's lung. (*b*) By the evolution of an irritant digestive product or "ptomäine," which may act generally or locally. (*c*) In the third place, it may be suggested that in certain cases there is, in addition to the preceding factors, a subtle physico-chemical or molecular reaction between the micro-organisms and the cells, which may give rise to changes, local or general, and which might be compared to the action of the sperm cell on the germ cell or ovum. It is in connection with these points, and with regard to the varied degrees in which the infective process occurs in various species of parasitic organisms, that we wish specially to speak, for recent work of numerous observers upon these questions appears capable of throwing a clearer light upon the matter than has previously been the case.

The five following types of tissue reaction may be taken as illustrative of the principal pathological processes of micro-organismal origin. (1) Septicæmia, in which there is an absorption of septic products from an external or localised internal source, but no absorption of the organisms which give rise to them. Diffusion of products. (2) Specific infective fevers. No localised source after period of incubation. General diffusion of both organisms and products. (3) Abscess formation. Micro-organisms in area strictly localised by "pyogenic membrane." Rapid death of that area. (4) Tubercle. Micro-organisms localised. Slower death and caseation of area in which they occur. Slight tendency to fibrous tissue formation. (5) Actinomycosis. Localisation of micro-organism. Little tendency to death of proliferated cells. Greater tendency to fibrous tissue formation.

Without attempting to enter fully into the description of the process involved in tissue reaction in each of the classes above named, we may briefly summarise the many features, and illustrate them by one or two examples. Amongst the chief forms in which cell activity exhibits itself during various stages of the life cycle, are, according to Mr Geddes, (1) the amœboid stage, where nutritive activity is well marked, but where formative activity is not yet distinctly manifested. (2) The plasmodial stage, where there is excessive nutrition or excessive stimulation, and where there is latent formative tendency, which comes into play on the removal of excessive stimulation. (3) The encysted stage, where the formative activity is a more prominent feature than the nutritive. In normal tissues under normal conditions, the metabolic processes balance one another. Under the influence of irritation, this balance is lost; there is first, excessive nutritive activity, corresponding to the amœboid stage, in which the process of aggregation is well marked, as instanced by cloudy swelling of the cells of various organs during the early stages of specific infective fevers. If the irritation is continued, this is followed by greatly increased nutritive activity, or rather digestive power, which is found in the plasmodial stage. In both these forms, if the irritant be excessive, complete aggregation, followed by disintegration, takes place; while, if irritation be not excessive, formative activity is evolved, and we have a tissue formation corresponding to the encysted stage of the cell. In our paper we have attempted to illustrate these processes by a description of the phenomena observed on a septic granulating surface, in an abscess, in actinomycosis, and in tubercle.

From Marshall Ward's recent researches on the mode of reproduction in certain cellular organisms, it appears that it is possible for a parasitic fungus to reproduce its like without the direct aid of a sexual process, the necessary stimulus to multiplication being supplied by the highly organised proteids, derived from the tissues of its host, which in their turn are also stimulated into proliferation. Applying this to the case of cells in an animal, it would appear that the stimulus applied by the presence of micro-organisms, or their chemical products, acts in a manner comparable to the action of the male element upon the ovum in setting up segmentation. There is thus a reappearance of excessive reproductive activity without the process being re-initiated *ab ovo*. Cell proliferation may be set up by effete products or other chemical irritants, or even by mechanical irritants, as pointed out by Charles and Francis Darwin in connection with their researches on insectivorous plants, and the results, though varying greatly in degree, are absolutely one in kind. Apply any irritant to a surface, or a tissue, and the result is a tendency to proliferation of the cells. This appears to be the case especially in

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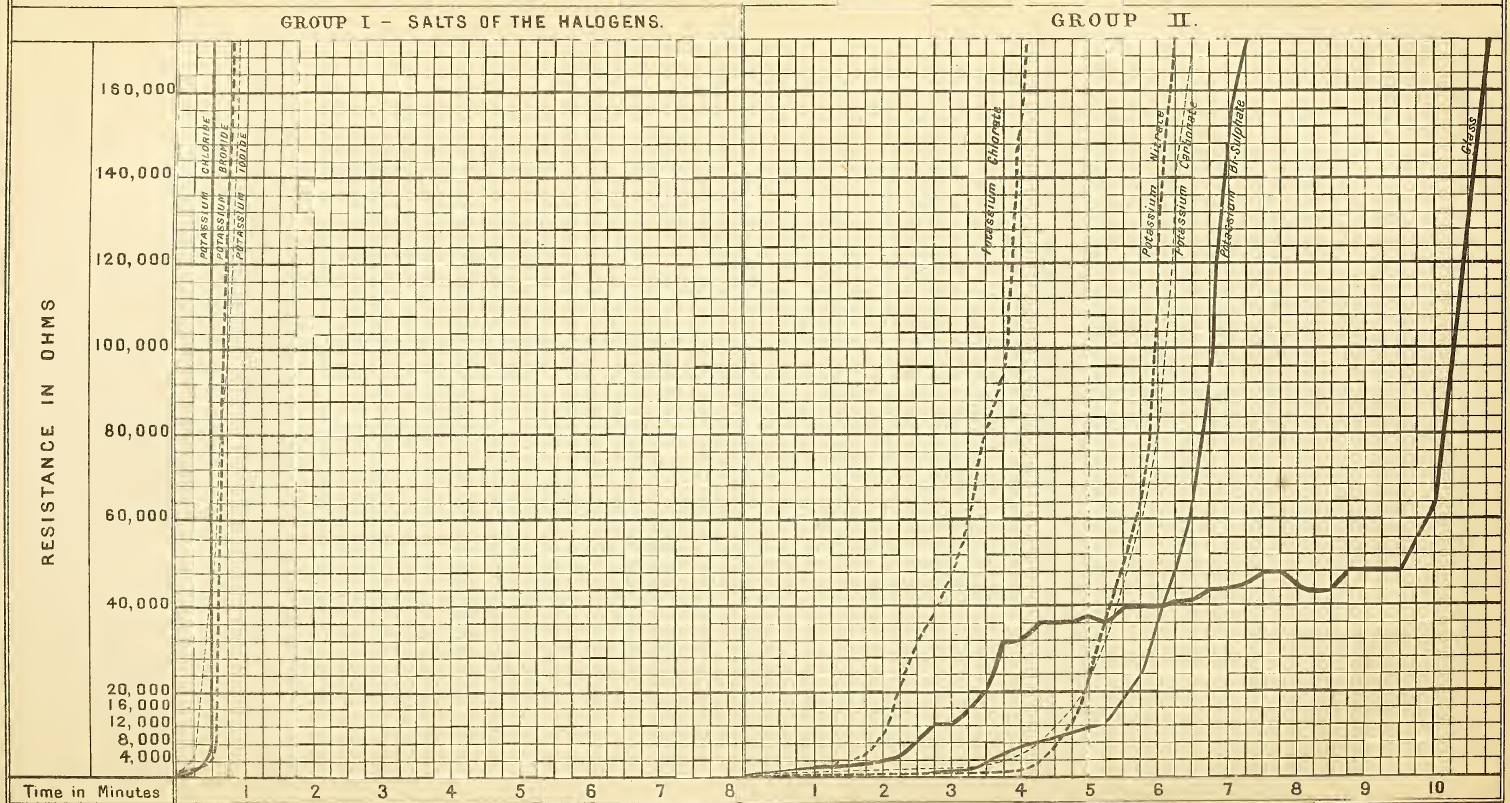
CURVES INDICATING THE TIME CHANGES OF RESISTANCE (IN OHMS) OF FUSED SALTS AND GLASS DURING RECRYSTALLIZATION ON COOLING FROM TEMPERATURES GIVEN.



The highest temperature in case of each Salt at commencement was measured by a Siemen's Pyrometer, being the average of many observations—the Salts were all purposely raised to these temperatures for a few moments.

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the connective tissue group, where the increase in the number of cells is extremely marked. With this increased cell formation there is apparently a taking up of the irritant material by the cells, and if one cell is not sufficient for the task a number combine to form plasmodia or giant cells. That the taking up of these products, or the micro-organisms themselves, further lowers the vitality of the cell, may be inferred from the fact that as soon as the cell becomes filled with the irritant particles it dies, and with its contained material, acts as an irritant to other cells. The chemical products then may be looked upon as the prime movers in bringing about a proliferation of the cells with which they come in contact; by this proliferation the cells appear to attempt to get rid of the irritant material by which their resisting power is greatly diminished.

Edinburgh is now thoroughly equipped for bacterological investigations, as there are complete apparatus and very complete arrangements for carrying on such investigations in several of the departments. A part of the pathological laboratory has been adapted for such work; and in the surgical department Professor Chiene has established a complete bacterological laboratory. There is a similar laboratory in the department of practice of physic. In all these laboratories useful work is at present going forward, under the guidance of the several professors, and there is every prospect that the Edinburgh School may contribute additions to the science of mycology not unworthy of her high reputation in other branches of science.

In conclusion, we desire to express our sense of indebtedness to Professors Greenfield and Chiene for suggestions and encouragement whilst carrying on in their laboratories the work upon which this paper is based.

4. The Resistance during Recrystallisation of fused Salts of the Halogens compared with some others and Glass. By Thomas Andrews, F.R.S.E., F.C.S., Wortley, near Sheffield. (Plate X.)

The electrical resistance manifested relatively by certain fused salts is peculiar. The following communication contains the result of observations on time changes of resistances noticed during the cooling and resolidification of two typical groups of fused salts and also of molten glass.

The salts (analytically pure) employed were—

Group I.—Potassium chloride, potassium iodide, potassium bromide (three salts of the halogens).

Group II.—Potassium carbonate, potassium nitrate, potassium chlorate, potassium bisulphate and glass.

The glass used in the observations was a powdered sample showing the following composition :—

Analysis of the Glass employed.

The sample, dried at 212° Fahr., gave the following results :—

Silica.	Alumina.	Peroxide of Iron.	Oxide of Manganese.	Magnesia.	Lime.	Potash and traces of Soda.	Carbonic Acid.	Total.
72·35	1·00	0·40	0·65	0·77	7·76	15·31	traces.	98·24
The sample contained no lead, copper, or barium.								

The fusions were made in a platinum crucible, using a Fletcher's Bunsen burner, either with or without blast as required. The galvanometer employed was an astatic one (the R. of which at 20° C. was 521 ohms) of known constants, and which, to ensure accuracy, was carefully calibrated during the investigation. With the salts in fusion and raised to the high temperatures given, it was found that when a Daniell's element (zinc in cold saturated solution of zinc sulphate, copper in concentrated sulphate of copper with crystals) was placed in circuit (using two platinum wires as electrodes), the resistance of the fusing salts or glass varied of course very greatly with the temperature. On allowing cooling to commence, the conductivity in the case of the salts (Group I.), almost immediately ceased, although the temperature would only be just below their fusing points. It will be seen, however, from Table A. that the current from the Daniell's continued to pass, in the case of the other salts and glass, for a considerable time.

Owing to the difficulty of obtaining a steady and gradual rise of temperature in melting the salts and powdered glass, the reverse method of taking the time change resistances during gradual cooling from the highest temperature to recrystallisation was adopted. A weighed portion (300 grains) of each salt, &c., contained in the platinum crucible was first melted and raised to the high temperature given (consistent with the nature of the substance), which was measured by a special arrangement with a Siemen's pyrometer. The ends of two strong platinum wires (0·063 inch diam.), connected with the Daniell's element, remained deeply immersed in the salt from commencement, at equal distances apart in each case ($\frac{1}{4}$ inch); the galvanometer and resistance coils were also in circuit. The resistance was then taken at the highest temperature, the source of heat instantly removed, and the fused salt or glass allowed gradually to cool. The time changes of the deflections of the galvanometer were then recorded every 15 seconds (the resistance, values, &c., of which were known from the calibration of the galvanometer), until final solidification of the salt or glass ensued, and the current from the Daniell's ceased to pass.

This method afforded an indication of the nature of the resistance of both groups of the fusing salts and glass through considerable ranges of temperature, during the varying molecular changes incident to recrystallisation on cooling.

The curves of the resistances thus obtained are given in Table A.

Remarks on Table A.

Potassium Carbonate.—This salt allowed a feeble current to pass until 8 minutes from commencement, at a comparatively low temperature.

Potassium nitrate and Potassium chlorate.—A very faint current continued to pass (through higher resistances) after the above measurements were taken, until the salts were quite cold.

Potassium chloride, Potassium iodide, and Potassium bromide.—The resistance of these fused salts was observed many times with the above results, after a very short time from the commencement of cooling in each experiment, the resistance almost instantly increased to an enormous extent, allowing only the feeblest current from the Daniell's to pass, although the salt was still at a high temperature, the KCl quite a bright red, and the KI still showing distinctly red. The property of bad conductivity during such high temperature appears peculiar to these salts. In the case of KBr, when at 845° C., there was a free passage of the current, but

TABLE A.

TIME CHANGES OF RESISTANCE OF FUSED SALTS AND GLASS DURING RECRYSTALLISATION ON COOLING FROM TEMPERATURES GIVEN.

Time from commencement of cooling.		Group I.—Salts of the Halogens.			Group II.				
		Potas. Chloride.	Potas. Iodide.	Potas. Bromide.	Potas. Carbonate.	Potas. Nitrate.	Potas. Chlorate.	Potas. Bisulphate.	Glass.
		Highest Temp. 845° C.	Highest Temp. 695° C.	Highest Temp. 699° C.	Highest Temp. 845° C.	Highest Temp. 694° C.	Highest Temp. 422° C.	Highest Temp. 400° C.	Highest Temp. 845° C.
Min.	Sec.	Resistance in Ohms.	Resistance in Ohms.	Resistance in Ohms.	Resistance in Ohms.	Resistance in Ohms.	Resistance in Ohms.	Resistance in Ohms.	Resistance in Ohms
	0	20	353	585	10	10	70	10	67
	15	123	5,390	1,141	52	80	353	52	108
	30	8,000	38,805	5,920	327	134	492	108	134
	45	...	95,574	154,830	550	160	705	160	215
1	0	...	266,948	zero	585	187	1,160	215	327
	15	...	...	...	705	201	1,930	270	550
	30	...	533,896	...	890	215	3,410	298	1,025
	45	...	...	...	1,085	270	6,200	327	2,020
2	0	...	...	...	1,230	353	10,730	406	3,850
	15	...	...	...	960	406	20,755	830	4,750
	30	...	...	...	1,160	521	31,406	1,025	8,870
	45	...	...	...	1,370	615	38,805	1,290	11,500
3	0	...	...	...	1,760	765	48,234	1,600	12,500
	15	...	...	...	2,310	925	59,136	2,210	16,506
	30	...	...	...	3,130	1,122	80,043	3,130	20,755
	45	...	...	...	4,550	1,440	95,574	4,730	31,406
4	0	...	...	...	6,200	2,020	154,830	6,800	31,406
	15	...	...	...	8,870	3,850	210,889	8,400	35,675
	30	...	...	...	12,500	7,930	266,948	9,450	35,675
	45	...	...	...	16,506	14,389	A feeble current	10,730	35,675
5	0	...	...	...	23,967	23,967	continued till	11,500	37,240
	15	...	...	...	35,675	38,805	galvanometer	13,428	35,675
	30	...	...	...	48,234	50,997	at 8 minutes	18,632	38,179
	45	...	...	...	59,136	64,512	reached zero.	23,967	38,805
6	0	...	...	...	80,043	125,202	...	38,805	38,805
	15	...	...	...	139,347	170,313	...	48,234	40,966
	30	...	...	...	170,313	170,313	...	64,512	40,966
	45	...	...	...	210,889	170,313	...	95,574	43,128
7	0	...	...	...	A feeble current	210,889	...	154,830	43,128
	15	...	...	...	continued till	210,889	...	170,313	45,681
	30	...	...	...	galvanometer	210,889	...	210,889	48,234
	45	...	...	...	at 8 minutes	266,948	...	210,889	48,234
8	0	...	...	...	reached zero.	A feeble current	...	266,948	45,681
	15	...	...	...	...	continued till	...	A feeble current	43,128
	30	...	...	...	...	galvanometer	...	continued till	43,128
	45	...	...	...	...	at 10 minutes	...	galvanometer	48,234
9	0	...	...	...	...	reached zero.	...	at 9 min. 15	48,234
	15	...	...	...	...	...	...	sec. reached	48,234
	30	...	...	...	...	...	...	zero.	48,234
	45	...	...	...	...	...	...	...	...
10	0	...	...	...	...	...	...	...	64,512
	15	...	...	...	...	...	...	...	95,574
	30	...	...	...	...	...	...	...	125,202
	45	...	...	...	...	...	...	...	154,830
11	0	...	...	...	...	...	...	...	...

on reducing the temperature to about 676° C. (the salt being apparently in a red hot semi-pasty condition), the flow of the current was almost stopped, the R. of the salt was then about 154,830 ohms. With a temperature somewhat below the last named, the salt entirely ceased to conduct.

As all the experiments in this memoir were conducted under similar conditions, the comparative results are interesting, and afford a further indication of the generally non-conducting character of these salts of the halogen group, below their fusing points (KCl fusing point 734° C., KI fusing point 634° C., KBr fusing point 699° C.), the reverse being the case with the other salts and glass employed. The author has not made any observations on the fluorides.

5. Notice of a Second Specimen of Sowerby's Whale (*Mesoplodon bidens*), from Shetland. By Professor W. Turner, M.B., LL.D., F.R.S.

The Shetland seas are frequented by several species of Ziphioid whales. Since the year 1870 I have come into possession of, and placed in the Anatomical Museum of the University of Edinburgh, the skull of *Ziphius cavirostris*,* the skull and a large part of the skeleton of *Hyperoodon rostratus*, and the skull and almost complete skeleton of *Mesoplodon bidens*.† They were all captured on the north-east side of the mainland of Shetland.

On the 2nd June of this year I was told by one of my students, Mr Charles Anderson, that a small whale had been taken a few days previously at Voxter Voe, Delting. This voe is about 13 miles from Urafirth Voe, where in April 1881 the specimen of *Mesoplodon bidens*, above referred to, had been captured by his brother, Mr Thomas Anderson of Hillswick. Mr Charles Anderson informed me that, from the description which his brother had written to him of the Voxter Voe specimen, it was also, he believed, a Sowerby's whale. I telegraphed, therefore, to Mr Thomas Inkster of Brae, near Voxter Voe, to secure the animal for me as little injured as

* Described and figured by me in *Trans. Roy. Soc. Edin.*, May 20, 1872, vol. xxvi.

† Described by me to Royal Society, Edinburgh, Jan. 30, 1882. See *Proceedings* of that date, also *Jour. of Anat. and Phys.*, April 1882.

possible. On the 15th June it arrived at the University, and proved to be a fine specimen of an adult male *Mesoplodon bidens.*

The whale had been flensed, eviscerated, and cut into blocks before being despatched to me; all the skin had been removed except that of the tail and flippers. The thoracic and abdominal viscera had been removed *en masse,* and accompanied the divided carcass. From the extent to which the animal had been cut up, my notes on the soft parts are necessarily very fragmentary; and as the specimen reached me in the hot weather in June, more than a fortnight after the death of the whale, the viscera could only be examined in a very general way.

When the various blocks were put together in their proper position, the length from the tip of the lower jaw to the mid-point of the tail was 15 feet 8 inches. The shape of the tail and flipper closely corresponded with the Ziphioid which Burmeister has named *Epiodon patachonicum* or *australe* (*Ziphius cavirostris*). The tail was dark slate grey, almost black on both surfaces. The flipper on both surfaces had the colour of a well-blackened boot. A pair of mandibular teeth projected for one inch beyond the gum, but no rudimentary denticles were seen. The blow-hole was transverse, and on the surface of the head was not divided into two nostrils. The position and form of the tongue, the relation of the larynx to the nares, and the branching of the trachea and bronchi, were examined.

The stomach was seen to consist of ten compartments, viz., a proximal cavity, which freely communicated with the œsophagus; eight globular or saccular compartments, which varied in size from a moderately sized orange to about three times that magnitude. The first saccular compartment communicated with the hinder end of the proximal cavity, and the various saccular compartments communicated in succession with each other, whilst the last one opened into the tenth compartment of the stomach.

The tenth or distal compartment was in size and shape not unlike a large human stomach; it showed an indication of a division into two parts by a projecting fold of mucous membrane which passed across it; it communicated with the duodenum. A large duct opened into the duodenum which was traced to the pancreas, and probably represented the combined pancreatic and biliary duct. The compartments of the stomach, from one to seven inclusive, contained a brownish mucus,—the eighth and ninth contained a bile-stained fluid, with a number of opaque crystalline lenses and hard white calcareous bodies, which looked not unlike the otoliths of fish. The tenth compartment contained several ounces of a bile-stained fluid, but no other contents.

The liver, heart, lungs, pelvic bones and penis, hyoid apparatus, and other bones of the skeleton were examined. A dissection was made of the extensor and flexor muscles of the flippers, and of the vessels and nerves of these limbs. [It is intended to publish a more detailed account of the visceral anatomy in the *Journal of Anatomy and Physiology*, October, 1885.]

6. Preliminary Report on the Cephalopoda collected by H.M.S. "Challenger." Part II. The Decapoda. By William E. Hoyle, M.A. (Oxon.), M.R.C.S.

It is rather remarkable that the Decapoda should have yielded fewer new forms than the Octopoda, although judging by the number of genera contained in them, the former is a much more extensive group than the latter, and is furthermore represented by a larger number in the "Challenger" collection, as the following synopsis* will show :—

Genera.	Previously known species.	New species.
Sepiola (Rondelet), Leach,	1	...
Rossia, Owen,	3	...
Promachoteuthis, Hoyle,	...	1
Sepioteuthis, Blainville,	1	...
Loligo, Lamarck,	2	5
Sepia, Linné,	1	10
Spirula, Lamarck,	1	...
Ommastrephes, d'Orbigny,	1	...
Todarodes, Steenstrup,	1	...
Bathyteuthis, Hoyle,	...	1
Enoploteuthis, d'Orbigny	1	...

* In this synopsis several forms to which Professor Steenstrup had given MS. names are reckoned as new, and a number of immature forms are not included.

Genera.	Previously known species.	New species.
Teleoteuthis, Verrill (= *Onychia*, Leseur),	1	...
Mastigoteuthis, Verrill, . . .	1	...
Histiopsis, Hoyle, . . .	...	1
Calliteuthis, Verrill, . . .	1	...
Cranchia, Leach, . . .	1	...
Taonius, Steenstrup, . . .	1	1
Nautilus, Linné, . . .	1	...

As usually happens the largest genera received the most additions, *e.g.*, *Sepia* and *Loligo*; while the new genera are each represented only by a single specimen.

All the Sepias obtained by the Expedition were got between Stations 163 and 232,—that is to say, during the cruise from the eastern coast of Australia, through the Malay Archipelago to Japan; and when this is taken in connection with the fact that of some fifty previously known species, no less than thirty come from the same area, it becomes obvious that this Indo-Pacific region is the metropolis of the genus. It is further remarkable that most of the new Loligos come from the same region.

One of the most curious of the new forms is a small creature from the Southern Ocean, which has been called *Bathyteuthis abyssicola* (fig. 2);* it measures about 5 cm. in length, excluding the tentacles; the body is subcylindrical, tapering to a blunt point behind, where are situated two small rounded fins. The head is broad, with prominent eyes, and there is a very large oral membrane provided with suckers. The arms are very short, the longest not quite reaching 1 cm., and the suckers are minute and arranged biserially; the tentacles about equal the body in length, and have no clubs, but gradually taper to a point armed with numerous very small suckers like those of many *Sepiæ*. The funnel is provided with a valve, and the pen resembles that of *Ommastrephes* (see p. 308 *postea*).

The structure of this form seems to adapt it for life at great depths, and to justify the belief that it really came from the depth reached

* This seems to be at all events congeneric with a form which Professor Verrill has recently dredged in the North Atlantic, and named *Benthoteuthis megalops* (*Trans. Connect. Acad.*, vol. vi. part 2, page 402, pl. xliv. fig. 1).

by the dredge (1600 fathoms); the small fins are in marked contrast to those of pelagic species, while the small suckers and delicate tentacles are equally little fitted for raptorial purposes; but, on the other hand, the large circumoral lip would seem well suited for collecting nutritive matters from an oozy bottom.

A new genus has also been erected for the reception of another interesting Decapod, *Promachoteuthis megaptera* (*vide postea*), and a third for a specimen nearly allied to the genus *Histioteuthis*, which was obtained in the South Atlantic (Station 333); the web is very small in comparison with that of this genus, not extending quite half-way to the tips of the arms. In the present state of our knowledge it seems impossible to refer this form to any type hitherto described, and it has therefore been erected into a new genus under the name *Histiopsis atlantica.*

Among the Challenger Collection is also one mutilated individual of *Taonius hyperboreus*, Stp., a species hitherto known only from examples in the Copenhagen Museum;* there are also two medium sized specimens and a small one, which appear to be referable to the same genus. It is remarkable that many of the most interesting specimens are mere fragments; among others may be mentioned part of a tentacle of *Mastigoteuthis Agassizii*, Verrill, which was found adhering to the dredge rope, and numerous pieces of a long gelatinous pen, taken from the stomach of a shark; these latter seem to resemble nothing hitherto known so nearly as the pen of *Chiroteuthis lacertosa*, Verrill,† though, if this determination be correct, that species must sometimes attain a length of several feet.

I append definitions of the new species contained in the collection:—

MYOPSIDÆ.

PROMACHOTEUTHIS, Hoyle.

Promachoteuthis, Hoyle, Narr. Chall. Exp., vol. i. part 2, p. 270, fig. 109, 1885.

The *Body* is short, rounded, with large broad *fins*, situated

* The specimen which Verrill figures (*Trans. Connect. Acad.*, vol. v. p. 302, pl. xxvii. figs. 1, 2, 1882) is certainly not *Taonius hyperboreus*, Stp. I have elsewhere adduced arguments for believing it to be *Taonius pavo* (Les.), (*Proc. Roy. Phys. Soc. Edin.*, vol. viii. p. 319, 1885).

† *Loc. cit.*, p. 408, pl. lvi. figs. 1 *a*, *a'*, *a''*, 1881.

posteriorly. The *mantle* is free behind, as in *Rossia.* The *siphon* is short and slender and with everted margin; valve?

The *Head* is small and narrow; *eyes* not prominent.

The *Arms* are long and conical, with two series of pedunculate spherical *suckers.* The *tentacles* exactly resemble the arms at their origin; the *club* is absent?

The *Gladius* has not been removed from the single example.

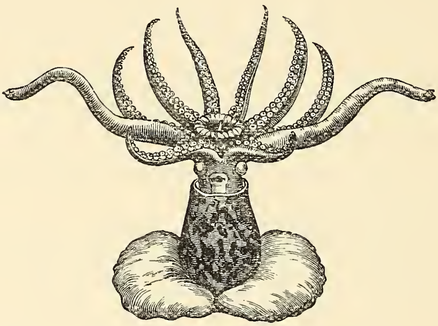


Fig. 1.—*Promachoteuthis megaptera,* Hoyle.

Promachoteuthis megaptera, Hoyle.

Promachoteuthis megaptera, Hoyle, *loc. cit.;* also *Ann. and Mag. Nat. Hist.,* ser. 5, vol. xvi. p. 182, 1885.

The *Body* is short, barrel-shaped, rounded behind; the *fin* is large, transversely elliptical, and extending beyond the end of the body posteriorly; each half is wider than long. The *mantle-margin* is transversely truncated. The *mantle-connective* consists of a linear ridge on either side, fitting into an almond-shaped depression at either side of the base of the *siphon,* which is short, slender, and has the distal margin, everted like the neck of a flask; the specimen was so small and indifferently preserved that it was not opened to ascertain whether a valve was present.

The *Head* is very small and narrow, almost the whole of its sides being occupied by the *eyes,* which are not prominent, but covered with a transparent membrane, and with a distinct pore in front of and below each.

The *Arms* are unequal, the fourth being the shortest (considerably so on the right side); the first, second, and third are subequal; they are on an average about the same length as the body, smoothly conical, and taper evenly to fine points. The *suckers* are in two series throughout, pedunculate, spherical, with a lateral aperture directed inwards; the *horny ring* is smooth and surrounded by a few large papillæ. The *hectocotylus* is not developed. There is no trace of an *umbrella*. The *buccal membrane* is well developed and has the usual seven points, but they are not very well marked nor provided with suckers; the membrane is not connected with the arms by ligaments. There seems to be only one *lip*, which is thick and papillate.

The *Tentacles* arise directly between the third and fourth arms, exactly resembling them at their origin, and obviously being part of one series with them; the *stem* is swollen at first and somewhat more than one-third up the arms narrows rather suddenly to about half its previous diameter. The *club* is wanting.

The *Surface* is smooth.

The *Colour* is a dull purplish madder, paler on the fins (especially their under surface) and on the arms and tentacles.

The *Gladius* has not been extracted.

Hab. North Pacific, east of Japan (Station 237), 1875 fathoms. One specimen, sex ?

Loligo, Lamarck.

Loligo ellipsura, Hoyle.

Loligo ellipsura, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xvi. p. 182, 1885.

The *Body* is elongated, widest anteriorly, and tapering gradually to an acute point behind. The *fin* is comparatively short, only one third the length of the body, elliptical, slightly broader than long. The *mantle-margin* passes almost straight across the back, except where a long narrow median process juts out over the head; it is slightly sinuate ventrally. The *siphon* is short and blunt.

The *Head* is short and very nearly as broad as the body; it has the usual auricular crest and preocular pore.

The *Arms* are unequal, the order of length being 3, 4, 2, 1, and about one-third the length of the body; the first has a distinct web on its dorso-median angle, and the third a still broader web on its outer aspect, passing back nearly as far as the eye, where it becomes connected with another passing up the dorso-lateral aspect of the fourth. The *suckers* are in two series, pedunculate, oblique, notched distally, and somewhat larger on the lateral than on the other arms. The *horny rings* bear from five to seven large pointed teeth in their distal portion, but are smooth proximally. The *hectocotylus* is not present. The *buccal membrane* has the usual seven points, each of which carries two or three small suckers. The *outer lip* is thick and marked with radial grooves; the *inner* was not seen.

The *Tentacle* is slender, approximately cylindrical, and about two-thirds the length of the body; its terminal fourth is occupied by the *club*, which is but little expanded, and has a delicate protective membrane along either side of the inner surface and a well-marked web externally. The large median *suckers* are about ten in number, and about twice as large as the alternating lateral; the proximal are about twenty, and gradually increasing; the distal occupy nearly one half the club, and are in four series diminishing. The *horny rings* of the largest suckers have about twenty-four distant square pointed teeth, much longer on the distal margin; the lateral ones have about half as many similar teeth on the outer margin, and the terminal suckers are armed in the same way.

The *Surface* has been almost entirely denuded of skin.

The *Colour* appears to have been pale buff with purple chromatophores.

The *Gladius* has not been extracted.

Hab. Off Sandy Point, South America (Station 313), 55 fathoms. One specimen, apparently ♀.

Loligo galatheæ, Steenstrup, MS.

Loligo galatheæ, Steenstrup, MS.
,, ,, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5 vol. xvi. p. 183, 1885.

The *Body* is about three times as long as broad, cylindrical anteriorly, and pointed behind. The *fin* is rather less than half the length of the body,* about as long as broad, and with rounded lateral angles. The *mantle-margin* curves out rapidly to a triangular process in the dorsal median line, for the rest is almost transverse, except where it forms two obtuse angled processes, one at either side of the ventral emargination.

* With respect to this and one or two other points in the description it must be remembered that the specimens are immature.

The *Head* is comparatively broad and with prominent rounded *eyes.* The *siphon* is moderately large and of the usual form.

The *Arms* are unequal, the order of length being 3, 4, 2, 1, and not quite one third as long as the body. The dorsal have a distinct keel on the upper margin, the second are keeled on the ventro-lateral aspect, the third are stout and flattened and have a broad web on the outer aspect, which unites with the web running up the dorso-lateral aspect of the ventral arms. The *suckers* are in two series throughout, with short peduncles, and not very oblique; their horny rings bear nearly twenty distant blunt teeth. The *hectocotylus* is not developed. The *umbrella* is absent. The *buccal membrane* has the usual seven points, each of which bears a few suckers. The *outer lip* is thin, the *inner* thin and papillate.

The *Tentacles* are comparatively short, being not quite so long as the body; the *stems* are subtriangular. The *club* occupies more than one-third of the length, and has a protective membrane at either side of the suckers and a distinct web on the outer aspect. The large central *suckers* are eight to ten in number, and nearly twice the diameter of the lateral ones; the proximal group consists of about ten, while the distal portion bears four series of diminishing suckers. The *horny ring* bears long, distant, bluntly pointed teeth, about twenty-four in the largest suckers, proportionally fewer in the smaller, which are much larger in the distal and external portions of the ring respectively.

The *Surface* is smooth.

The *Colour* is pale yellowish, spotted with brownish-purple and red chromatophores.

The *Gladius* has not been removed.

Hab. Philippine Islands (Station 203), 20 fathoms. Two specimens, juv.

Loligo kobiensis, Hoyle.

Loligo kobiensis, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xvi. p. 184, 1885.

The *Body* is elongated, cylindrical in the anterior moiety, then tapering posteriorly, and terminating in a blunt point. The *fin* is more than half the length of the body, trapezoidal, with rounded lateral angles; the extreme breadth is less than the length and is situated anteriorly to the middle of the fin. The *mantle-margin* presents a triangular process in the mid-dorsal line and is deeply sinuate ventrally. The *siphon* is short and bluntly conical.

The *Head* is short and not so broad as the body; the *eyes* are comparatively small and have a bracket-shaped auricular crest behind and a minute pore in front of them.

The *Arms* are unequal, the order of length being 3, 4, 2, 1, and, on the average, rather more than one-third the length of the body; the first are the most slender, and have the dorso-median angle raised into a prominent keel; the second have only a faintly-marked angle ventro-laterally; the third have a broad web externally, passing over at the base into one which extends up the dorsal aspect of the ventral arms. The *suckers* are arranged in two series, pedunculate, very oblique, and rather larger on the lateral than on the other arms; the *horny ring* has about nine short, close-set, square-cut teeth on its distal side, and is smooth on the proximal. The *hectocotylus* was not observed. The *buccal membrane* has five points, each of which bears two or three small suckers, the two ventral points are rounded off; just within the ventral margin is a small papilla surrounded by two elevated rings, probably for the reception of spermatophores. Both the *outer* and *inner lips* are folded.

The *Tentacle* is faintly three-sided and shorter than the body, one-third of its length being taken up by the *club*, which is expanded and triangular in section; there is a protective membrane on either side and a web externally; in the centre are eight large *suckers*, three times the diameter of the lateral ones; at the proximal end are about nine suckers, gradually increasing in size, and at the distal end more than twenty rows arranged in four series, gradually diminishing. The largest suckers are scarcely at all oblique, and have the margin cut up by radial grooves into a number of small papillæ, an arrangement also found on the outer margin of the lateral suckers, but not in the terminal ones. The *horny rings* of the largest suckers are smooth; those of the lateral bear about twelve long distant teeth on their outer margin; those of the terminal suckers are similarly armed.

The *Surface* is smooth.

The *Colour* is pinkish yellow, with purplish chromatophores.

The *Gladius* has not been extracted.

Hab. Off Kobi, Japan, 8 fathoms; one specimen, ♀ South of Japan (Station 233c), 11 fathoms; two specimens, juv. Also (?) Inland Sea, Japan; two specimens, juv.

Loligo edulis, Hoyle.

Loligo edulis, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xvi. p. 186, 1885.

The *Body* is moderately stout, being about three times as long as broad, cylindrical in its anterior third, and tapering gradually to a bluntish point. The *fin* occupies a little more than half the length of the body, is rhomboidal, not quite so broad as long, and broadest anteriorly to the middle; the lateral angles are rounded. The *mantle-margin* has a slight projection in the median dorsal line and a broad shallow sinuate excavation ventrally. The *siphon* is of moderate length and bluntly pointed.

The *Head* is small, with prominent rounded *eyes*, and bears the usual auricular crest and preocular pore.

The *Arms* are unequal, the order of length being 3, 4, 2, 1, and about half as long as the body. The first are very slender and bear a distinct keel on the dorsal aspect; the second are thicker and triangular, and have a broad keel almost expanding into a web on the lateral aspect; the third are the stoutest, flattened from above downwards, and distinctly keeled externally; the fourth are intermediate between the third and second, triangular, and with a broadish web extending the whole way up the dorso-lateral aspect. They all have a web up each side of the inner face. The *suckers* are in two series, very oblique, and with slender conical peduncles, their size varying with that of the arms on which they are situated; the *horny ring* bears eight long square-cut teeth on its distal margin. The *hectocotylus* is developed as usual on the left ventral arm, which bears proximally ten rows of suckers, then a minute sucker with an exaggerated peduncle, and beyond this two series of long conical papillæ. The *buccal membrane* has the usual seven angles produced into long lappets, each of which bears about eight suckers in two rows; the *outer lip* is moderately thick, the *inner* much thicker and marked with deep radial grooves.

The *Tentacles* are about as long as the body, with flattened *stems*; about one-third their length is occupied by the *club*, which is only slightly expanded, has a protective membrane on either side, but a dorsal web is present only at the extremity. The central *suckers* are about sixteen in number and about one-third larger than the laterals; the proximal are about ten, the distal are closely packed in four series. The *horny rings* of the largest are provided with about twenty larger teeth, with which smaller ones alternate somewhat regularly; the lateral bear about ten distant acute teeth on the outer margin, while the proximal and distal groups are similarly armed on the distal margin.

The *Surface* is smooth.

The *Colour* is a dull yellow with purplish chromatophores.

The *Gladius* is of the usual form, the narrow anterior portion being less than one-fourth of the total length.

Hab. Japan; purchased in the market, Yokohama. One specimen, ♂.

Loligo japonica, Steenstrup, MS.

Loligo japonica, Steenstrup, MS.
,, ,, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xvi. p. 187, 1885.

The *Body* is only moderately elongated, being about three times as long as broad, and bluntly pointed behind. The *fin* is a little more than half the length of the body, about as long as broad, rhomboidal, rounded laterally, and very slightly notched at the anterior angles. The *mantle-margin* curves gradually forward to a projecting point in the dorsal median line, and is deeply emarginate ventrally. The *siphon* is short and of the usual form.

The *Head* is comparatively large and rounded; the *eyes* are swollen and prominent.

The *Arms* are unequal, the order of length being 3, 4, 2, 1, and on an average about half as long as the body; the first are very small, slender, and rounded; the second have a prominent ventro-lateral angle, not amounting to a keel; the third have a distinct web on the outer aspect of the distal portion, which is continued backwards as a faint ridge which joins the web lying along the dorso-lateral edge of the fourth. The *suckers* are in two series, and vary in size in accordance with the arms on which they are situated; they are subglobular and oblique. The *horny ring* bears about ten broad, close-set, square-cut teeth. The *hectocotylus* is present on the left ventral arm; the distal suckers of the ventral series only are modified into conical papillæ, some of which bear a minute sucker at their tips.* The *umbrella* is absent; the *buccal membrane* is well developed, has the usual seven points, each of which bears a few small suckers (occasionally only one). The *outer lip* is thick, thicker than the *inner;* both are cut up into papillæ along the edge.

The *Tentacles* are as long as the head and body together, and have very slender, almost cylindrical *stems;* the *club* occupies about one fourth of the whole length, and is but slightly expanded. The large central *suckers* are about eight in number and fully twice the diameter of the lateral ones; proximally to them are about half a dozen suckers of different sizes, and beyond them a large number of diminishing ones arranged in four series and occupying nearly half the length of the club. The *horny ring* in the largest suckers bears about twenty-five square teeth; in the lateral suckers it bears more than twenty close-set acutely-pointed teeth, and in the distal ones about the same number of similar character.

The *Surface* is smooth.

The *Colour* is pale, with purplish chromatophores.

The *Gladius* is of quite typical form, expanded behind, and about six times as long as broad; the narrow anterior extremity occupies less than one-third the total length.

Hab. Japan; purchased in the market at Yokohama. One specimen, ♀.

Sepia, Linné.

Sepia esculenta, Hoyle.

Sepia esculenta, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xvi. p. 188, 1885.

The *Body* is broad, stout, and semielliptical posteriorly. The *fins* are about one fourth of the body in breadth and commence within 6 millim. of the anterior margin, and end within 5 millim. of each other; the *mantle-margin* is produced far over the head dorsally, and evenly truncated below. The *siphon* just reaches the gap between the ventral arms.

The *Head* is broad and the *eyes* laterally prominent.

* The description of the hectocotylus is taken from a specimen in the Copenhagen Museum.

The *Arms* are subequal, the order of length being 4, 1, 2, 3, and nearly half as long as the body; they are all more or less compressed, especially the ventral ones; they have a distinct web along the outer margin, and a rather broad membrane runs up either side of the sucker-bearing face. The *suckers* are in four series throughout, not very obliquely set; they are large and spheroidal, and have meridional markings on the outer surface; the *horny ring* is smooth and surrounded by a narrow papillate area. In the *hectocotylized* arm of the male the first four rows of suckers are normal, then come two rows of gradually diminishing suckers, succeeded by four rows of minute ones, after which they again regain their normal dimensions. The *umbrella* is narrow, widest between the second and third arms, where it reaches up to the fifth row of suckers The *buccal membrane* has the usual seven points in the male; in the female the two ventral are rounded off; the *spermatic cushion* is exceedingly well developed, and has four deep transverse grooves. The *outer lip* is thin and longitudinally corrugated; the *inner* is thick and bears numerous very long papillæ.

The *Tentacles* are absent.

The *Surface* is smooth throughout.

The *Colour* is dull grey, mottled with black above, yellowish below.

The *Shell* is elliptical in *outline*, somewhat broader behind (especially in the female); the *chitinous margin* is narrow and does not form a complete ridge across the shell below the spine; it forms two slightly expanded wings behind, and extends but a little distance over the *dorsal surface*, which is marked with coarse rugosities disposed in curved lines parallel to the anterior margin; a distinct but low rib runs down the centre. The *ventral surface* is elevated on either side of a deep median groove; the *last loculus* covers about one-fifth of the surface, and is bounded posteriorly by two slightly wavy lines, meeting at an acute angle; the *striated area* is long, and the angle between the striæ widens posteriorly. The *inner cone* is very well developed; the *limbs* arise one-fifth the length of the shell forward, and gradually become more elevated until they enclose a deep conical cavity. The *spine* is strong, pointed, and somewhat curved laterally in the female example.

Hab. Japan; purchased in the market at Yokohama. Two specimens, 1 ♂, 1 ♀

Sepia elliptica, Hoyle.

Sepia elliptica, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xvi. p. 189, 1885.

The *Body* is ovoid, broadest one-third from the anterior margin, pointed behind. The *fins* are one-third the width of the body, broadest in the middle, extending the whole length of the body, and approaching within 2 millim. of each other posteriorly. The *mantle-margin* not very prominent over the head dorsally. The *mantle-connective* is rather short and deep, but otherwise normal. The *siphon* is conical, reaching within 1 millim. of or quite up to the space between the ventral arms.

The *Head* is very short and broad, the *eyes* prominent.

The *Arms* are subequal, the order of length being 4, 3, 2, 1; they are nearly half the length of the body, and taper evenly to fine points; there is a distinct but narrow ridge along the fourth and a delicate web along each side of the oral aspect of the arms. The *suckers* are in four series throughout, and of moderate size, marked with inconstant meridional grooves, and there is a large notch proximally and distally in the rim. The *horny ring* has for the most part no distinct teeth, but is marked in the distal half with shallow irregular notches, which are occasionally more regular. A papillary area surrounds the horny ring. The *hectocotylus* is developed in about the middle third of the left ventral arm; beyond the eighth row of suckers the two ventral series are continued of the normal size, but the two dorsal are each represented by five minute suckers, gradually diminishing to the middle one and then increasing again; beyond this the arm exhibits no peculiarities. The *umbrella* is widest between the two lateral arms, where it extends as far as the sixth row of suckers. The *buccal membrane* bears the usual seven distinct points in the male, whilst in the female the ventral pair are lost in the thick swollen *spermatic cushion;* this is subdivided by four or five deep grooves into as many transverse ridges. The *outer lip* is thin; the *inner* bears about half a dozen rows of distinct hemispheroidal papillæ.

The *Tentacles* are about as long as the mantle; the *stem* is indistinctly three-sided; the *club* is long and wide, and bears eight series of minute equal suckers; there is a *protective membrane* on either side and a broad *fin* on the dorso-internal aspect. The *horny ring* is small and has a smooth margin.

The *Surface* is smooth.

The *Colour* is a dull grey dorsally, pale yellowish below.

The *Shell* is broad, subelliptical in *outline*, the anterior extremity bounded by two straight lines, which form obtuse rounded-off angles with each other and the sides of the shell; the posterior is rounded gradually off. The *dorsal surface* has a faint ridge passing to each of the three angles just mentioned, and is covered with curved rows of tubercles parallel to the anterior margin. The *ventral surface* is but little elevated; the *last loculus* occupies one-third of it, and is bounded behind by a broadly open curve with three or four irregular sinuations in it. The *striated area* is hollowed posteriorly, and is marked by grooves corresponding to the sinuations just mentioned. The *inner cone* arises about half-way along the striated area, curves evenly outwards, and then rises into a distinct ridge, forming a wall separate from the margin of the shell; its ventral surface is marked by a number of striæ pointing in the direction of the *spine*, which is of medium length and strength, and curved gently upwards.

Hab. South of Papua (Station 188), 28 fathoms; four specimens, 1 ♂, 3 ♀. Also Station 190, 49 fathoms; four specimens, 1 ♂, 3 ♀.

Sepia Smithi,* Hoyle.

Sepia Smithi, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xvi. p. 190, 1885.

The *Body* is of medium breadth, widest one-third back, curving evenly to a pointed posterior extremity. The *fin* is nearly one-third the breadth of the body, extending from the anterior margin of the mantle to within four millim. of its fellow at the posterior extremity. The *mantle-margin* projects to a considerable extent over the head dorsally, and is slightly emarginate ventrally. The *siphon* is long, reaching up to the interspace between the ventral arms.

The *Head* is of medium breadth and the *eyes* prominent.

The *Arms* are subequal, their order of length being 4, 3, 2, 1; they are a little more than half as long as the body; the dorsal are

* Called after Mr Edgar A. Smith, F.Z.S., of the British Museum.

the smallest and subconical, the ventral wide and with a narrow web on the outer aspect; they all taper gradually to fine points. The *suckers* are in four series throughout, pedunculate, oblique, and notched proximally and distally, and with meridional grooves on the margin; the *horny ring* has about twenty blunt triangular teeth on the distal semicircumference, and is surrounded by a broad papillate area. The *hectocotylus* is not present. The *umbrella* is but slightly developed, reaching in its greatest extent (between the third and fourth arms) only to the fourth row of suckers. The *buccal membrane* has the usual seven points, but there is no *spermatic cushion.* The *outer lip* is moderately thick and longitudinally ribbed; the *inner* is provided with many rows of elevated rounded papillæ.

The *Tentacles* are about as long as the mantle, and have stout three-sided *stems*; the *club* occupies about one-fourth of the whole length, and extends fully half round the stem; a protective membrane is found at either side of the suckers and a web along the dorso-median aspect of the club. The *suckers* are very numerous, minute and closely packed; the *horny ring* has about eight or ten stout distant teeth on the distal margin.

The *Surface* is for the most part smooth, but there are about five elongated elevations down each side of the body near the origin of the fin, and a few minute papillæ on the dorsal surface.

The *Colour* is a dull purplish grey above, pale ochre below.

The *Shell* is roughly elliptical in *outline;* the anterior extremity is bounded by two straight lines forming a blunt rounded angle; the sides curve evenly outwards (the greatest breadth being a little anterior to the middle) and form a bluntish point behind. The *chitinous margin* is narrow and vanishes in the median ventral line behind. The *dorsal surface* is rough, with granules arranged in rows parallel to the anterior margin; three slightly elevated tracts diverge from the spine to the three anterior angles. The *ventral surface* is little elevated; the *last loculus* occupies one fourth of the length, and is emarginate, being bounded behind by a more or less evenly curved line; the *striated area* is excavated, so that the whole shell is thin; the *inner cone* is well developed, with a thickened rounded margin, and encloses a deep pit; the limbs extend half-way along the striated area. The *spine* is long, tapering, and curves gently upwards.

Hab. South of Papua (Station 188), 28 fathoms. Four specimens, ♀.

Sepia sulcata, Hoyle.

Sepia sulcata, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xvi. p. 192, 1885.

The *Body* is cylindrical in its anterior fourth, then tapering gradually backwards, and pointed behind. The *fins* are one-fifth the breadth of the body, commence 2 millim. from the anterior margin of the mantle, and approach within 5 millim. of each other posteriorly; the *mantle-margin* reaches far over the head dorsally, and is evenly truncated below. The *siphon* does not extend up to the interbrachial space.

The *Head* is broad and the *eyes* very prominent; in the only specimen it is much retracted into the mantle.

The *Arms* are subequal, the order of length being 4, 3, 2, 1; they are one-third the length of the mantle, and taper gradually to slender points; the first are thin and rounded, the fourth flattened, each has a distinct ridge on the outer side, which in the fourth expands to a broad membrane. The *suckers* are in two series in the first and second arms, but with a tendency to form four series in the others, more especially in the distal portions; they are pedunculate and very oblique, and the margin is marked with meridional grooves and has a deep distal notch; the *horny ring* is small, smooth, and surrounded by a papillate area. The *hectocotylus* is present along three-fourths of the left ventral arm in the form of a groove with convex bottom, bounded on either side by a narrow fillet; on either margin of the groove is a row of minute suckers, which are larger and more distinct, and even form two series on the ventral aspect; the tip of the arm bears two series of small suckers. The *umbrella* is better developed than usual, its greatest extent (between the lateral arms) being up to the eighth row of suckers. The *buccal membrane* has the usual seven points, but not very strongly marked; the *outer lip* is smooth and thin, the *inner* papillate.

The *Tentacle* is as long as the head and body together, with a slender and somewhat flattened stem; the *club* is short and rather broad, and has a protective membrane on either side of the suckers, and a broad web on the dorsal aspect, extending for a distance equal to half its length down the stem ; there are from six to eight rows of very minute *suckers*, subequal, and with smooth *horny rings*.

The *Surface* is smooth, except that on one side of the ventral surface are three slightly raised linear ridges, apparently due to contraction, and a few minute papillæ on the dorsal surface posteriorly.

The *Colour* is, on the whole, pale yellowish below, purplish above.

The *Shell* is hemielliptical in *outline* anteriorly, tapering to a point behind. The *chitinous margin* is rather broad, widest about two-thirds back ; it covers all except the median third of the *dorsal surface*, which is finely rugose where free, and has a slightly elevated median portion and a faint linear ridge in the middle line posteriorly, about 3 millim. long, and terminating 2 millim. from the base of the spine. The *ventral surface* is but little elevated ; the *last loculus* occupies more than one-third of it, and its posterior boundary is almost semicircular, inflected in the centre. The *inner cone* is evanescent ; its limbs are chitinous and form a ventral margin to the terminal cone. A *spine* is present, but, as it had been broken off, its length and form cannot be determined.

Hab. Off the Ki Islands (Station 192), 140 fathoms. One specimen, ♂.

Sepia andreanoides, Hoyle.

Sepia andreanoides, Hoyle, *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xvi, p. 193, 1885.

The *Body* is very long, broadest one-third of the way back, pointed and acuminate behind. The fins are narrow, commence 3 millim. behind the anterior margin, and terminate 5 millim. from the posterior end of the body, and, each approaching within 3 millim. of its fellow, end slightly on the dorsal aspect of the body. The *mantle-margin* extends well over the head dorsally, and is very slightly emarginate ventrally. The *siphon* extends rather further forward than the middle of the eyes, but not up to the space between the ventral arms.

The *Head* is decidedly narrower than the body and somewhat elongated ; the *eyes* being distended and laterally prominent.

The *Arms* are subequal, the order of length being 1, 2, 3, 4, or 1, 4, 3, 2 ; they are two-fifths the length of the body, elongated, conical (except the fourth pair, which are flattened), and taper to very slender tips. The *suckers* seem to be normally in four series, but in some cases the arms are so compressed that they seem to be in only two, especially at the proximal extremities of the first and second arms; they are globular, slightly oblique, with a small aperture and smooth *horny ring*. The *hectocotylus* occupies the distal half of the left ventral arm; the suckers are normal up to the twelfth row, after which the arm widens and has a median groove from which about twelve shallow grooves pass outwards on either side, separating raised portions, each of which bears a minute sucker on the dorsal side of the groove. The *umbrella* is present only between the second and third and third and fourth arms up to the fourth row of suckers. The *buccal membrane* is well developed and has the usual seven points; in the female there is a deeply grooved *spermatic cushion*. The *outer lip* is thin and smooth, the *inner* thick and papillate.

The *Tentacles* are somewhat longer than the head and body, very slender and somewhat flattened. The *club* is flattened and expanded; along its outer margin is a very narrow membrane, and along the median edge, at some distance from the cupules, is a broad web, marked on the dorsal aspect with fine parallel shallow oblique grooves; along one margin it bears three or four series of small pedunculated *suckers*, whose *horny rings* bear very numerous and acute teeth.

The *Surface* is smooth.

The *Colour* is a dull purplish grey above, ochre with purple chromatophores below.

The *Shell* has a narrow elongated oval *outline*, somewhat pointed in front and tapering gradually backwards; the *chitinous margin* extends about one-third across the *dorsal surface*, which shows the boundary lines of the loculi clearly as brown striæ, and is very minutely roughened; the *ventral surface* is elevated, so that the shell is thick in proportion to its breadth, a narrow groove runs down the centre; the *last loculus* occupies one-fourth of the surface, and is bounded posteriorly by a shallow open curve. The *posterior extremity* is a very flattened irregular cone, to the apex of which the spine is attached; the *inner cone* is very shallow and its opening is some 4 millim. from the margin or the outer cone. The *spine* is long, straight, and points directly backward.

Hab. Japan; purchased in the market at Yokohama. Three specimens, 1 ♂, 2 ♀.

Sepia kiensis, Hoyle.

Sepia kiensis, Hoyle, *Ann. and Mag. Nat. Hist.* ser. 5, vol. xvi. p. 194, 1885.

The *Body* is narrow, widest anteriorly, and tapering gradually backwards: the *fin* is narrow, less than one quarter the breadth of the body, widening a little behind; it commences 1 millim. from the anterior margin and extends to within 2 millim. of its fellow behind. The *mantle-margin* is prominent dorsally and slightly emarginate ventrally. The *siphon* does not quite extend to the bases of the arms.

The *Head* is broad, and the *eyes* rounded and prominent.

The *Arms* are subequal, the order of length being 4, 3, 2, 1; they are very short, about one-third the length of the body; the first and second are conical, the third flatter, with a slight ridge externally, and the fourth broad and flat with a distinct crest. The *suckers* are in four series throughout, small, spheroidal, and not very oblique; the *horny ring* is smooth. The *hectocotylus* is not developed. The *umbrella* is evanescent, extending at most only up to the second row of suckers: the *buccal membrane* has five points and is rounded dorsally; the *spermatic cushion* is but slightly developed. The *outer lip* is thin and grooved longitudinally, the *inner* thicker and papillate.

The *Tentacle* is as long as the head and body; the *stem* being slender and indistinctly three-sided. The *club* is very slightly expanded; a protective membrane, grooved obliquely on the dorsal aspect, is situated on the outer margin, and there is a web on the internal side. The *suckers* are in four or five series, which are slightly larger towards the inner margin; the *horny ring* presents a few acute teeth.

The *Surface* is smooth throughout.

The *Colour* is a dull reddish grey above, yellowish below.

The *Shell* is a very elongate oval in *outline;* the *chitinous margin* is very narrow and extends only slightly over the *dorsal surface*, which is finely granular and marked by the divisions between the loculi: the *ventral surface* is somewhat elevated and marked by a distinct but not very deep median groove ; the *last loculus* extends over more than one-third the shell, and is bounded posteriorly by an almost semicircular line ; the *striæ* are very close ; the limbs of the *inner cone* arise about midway along the shell, pass backwards as low, narrow, smooth fillets, and unite behind without forming any deep cavity ; the *posterior extremity* is curved towards the ventral aspect and ends in a narrow blunt cone, to the apex of which is attached the straight somewhat dorsally directed spine.

Hab. Off the Ki Islands, south of New Guinea (Station 192), 140 fathoms. One specimen, ♀.

Sepia kobiensis, Hoyle.

Sepia kobiensis, Hoyle, *Ann. and Mag. Nat. Hist.* ser. 5, vol. xvi. p. 195, 1885.

The *Body* is long and narrow, widest near the anterior margin, and tapers gradually backwards. The *fin* is very narrow, only one-eighth of the body ; it commences 3 millim. from the margin of the body, and posteriorly passes on to the ventral surface and terminates 2 millim. from its fellow and 4 millim. from the extremity of the body. The *mantle-margin* has a narrow projection over the head, and is evenly truncated ventrally. The *siphon* is short, not reaching half-way to the space between the ventral arms.

The *Head* is of medium breadth, and the *eyes* prominent laterally.

The *Arms* are subequal, the order of length being 2, 4, 3, 1, and less than one-third the length of the body ; the first two pairs are subconical and slender, the third broader and with a web running up the ventral aspect, the fourth wider and with a distinct ridge along the outer edge ; they all taper to very fine points. Many of the *suckers* are deficient, but they seem to have stood in four series throughout ; they are spheroidal and very oblique, the distal margin of many has a deep notch : the *horny ring* is smooth in most cases, but occasionally possesses a few angular teeth. The *hectocotylus* is not developed. The *umbrella* is but little developed, its greatest extent being on the ventro-lateral aspect, where it reaches the fourth row of suckers. The *buccal membrane* has the usual seven points, the two ventral being the least distinct (as usual in female specimens) ; the *spermatic cushion* is small. The *outer lip* is narrow, the *inner* thick and papillate.

The *Tentacle* is shorter than the body and slender; the *stem* has three sides, the inner being slightly hollow, with a slender fillet along the middle. The *club* is slightly expanded with a distinct protective membrane; the inner side of the club is deeply grooved, and internally to the groove is a rather broad fin. The *suckers* are in about five series, near the inner margin are three rather larger than the rest, which gradually diminish towards the outer margin. The *horny rings* of the larger suckers have about twenty fine teeth on the distal semicircumference, the smaller have fewer in proportion.

The *Surface* is smooth all over.

The *Colour* is a dark purplish grey above, paler below.

The *Shell* is a very elongated oval in outline; the *chitinous margin* is very narrow and extends one-third over the *dorsal surface*, which is smooth and evenly convex, with the exception of a slight ridge along the middle line: the *ventral surface* is elevated, so that the shell is thick, with a shallow median groove becoming evanescent posteriorly, the *last loculus* occupies one-third of the surface, and is bounded by a slightly curved line with a cusp where the median groove meets it: the *inner cone* is formed by two limbs, which arise half-way along the shell and form a rounded fillet slightly more elevated posteriorly, where they bound a shallow depression: outside them the margin of the shell expands into a subcircular plate, from the centre of which the *spine* projects backwards; no information can be given as to its form or length, as it has been broken off close to the base.

Hab. Kobi, Japan, 8 fathoms. One specimen, ♀.

Sepia papuensis, Hoyle.

Sepia papuensis, Hoyle, *Ann. and Mag. Nat. Hist.* ser. 5, vol. xvi. p. 197, 1885.

The *Body* is elongated, broadest about one-third back, pointed behind: the *fins* extend the whole length of the body and are one-third of its breadth, a little wider behind; they extend to within 1 millim. of the anterior margin, but are separated by about 5 millim. posteriorly: the *mantle-margin* projects far over the head dorsally, and is slightly emarginate ventrally. The *siphon* is conical, reaching two-thirds up to the gap between the ventral arms.

The *Head* is short and broad ; the *eyes* prominent.

The *Arms* are subequal, their order of length being 4, 3, 1, 2 ; they are about one-fourth as long as the body and taper to fine points : the dorsal are conical with a very slight ridge up the outer aspect, the third pair have a similar ridge; the ventral are flattened and bear a distinct crest. The *suckers* are in four series throughout and of moderate size, set obliquely on short peduncles, with meridional grooves on the outside : the *horny ring* bears twenty to twenty-five long, square-cut, irregular teeth in its distal semicircumference, and outside it is an area covered with close-set papillæ. The *hectocotylus* is not developed. The *umbrella* is slight, reaching only as high as the sixth row of suckers between the third and fourth arms, where it is widest; as usual it is entirely absent between the two ventral arms. The *buccal membrane* has the usual seven points. The *spermatic cushion* is not developed · the *outer lip* is smooth, except for a few ridges due to contraction ; the *inner* bears numerous small papillæ.

The *Tentacles* are about as long as the body, the *stem* being three-sided : the *club* is short, flattened, and expanded, with a protective membrane on either side and a broad web down the back, reaching along the stem for a distance equal to half the length of the club ; it bears six larger *suckers* in the central line, a series of smaller ones on either side, and some very minute ones along each margin : at the top are fifteen to twenty in four series.

The *horny ring* of the large suckers has twenty-five to thirty teeth in its distal semicircle ; those of the smaller about ten.

The *Surface* is smooth, except for a few irregular inconstant papillæ on one side of the ventral surface and below the eye.

The *Colour* is a pale yellowish grey, darker above.

The *Shell* is oval in *outline*, broadest anteriorly to the middle, tapering somewhat rapidly in front and ending in a semicircle; posteriorly it tapers gently, and, then rounding off, ends in two almost straight lines, which meet at a right angle at the base of the spine. The *chitinous margin* extends but slightly over the *dorsal surface*, which shows two grooves diverging as they pass forwards, separating three ribs, and is covered with rounded papillæ arranged in curves parallel to the anterior margin. The *ventral surface* has a rather deep and broad median groove : the *last loculus* occupies one-third of its extent, and is bounded posteriorly by a wavy line with three parts; the *striated area* is hollowed, so that this part of the shell is thin: the *inner cone* commences by two limbs, which arise half-way along the striated area, curve outwards and unite below the posterior apex with a broad chitinous band passing from one side of the shell to the other and forming a rather deep *outer cone:* the *spine* is short (but has been broken off); it bends slightly upwards and has a narrow longitudinal keel on its ventral surface.

Hab. South of Papua (Station 188), in 28 fathoms. Two specimens, ♀.

Sepia cultrata, Steenstrup MS.

Sepia cultrata, Steenstrup MS.
,, ,, Hoyle, *Ann. and Mag. Nat. Hist.* ser. 5, vol. xvi. p. 198, 1885.

The *Body* is elongated, broadest about the middle of its length. The *fins* are rather narrow, about one-fourth the breadth of the body, commencing 2 millim. from the anterior edge of the body and approaching within 5 millim. of each other posteriorly; the left is somewhat broader than the right. The *mantle-margin* extends far over the head dorsally and is not emarginate but slightly undulating ventrally. The *siphon* is short, terminating far short of the depression between the ventral arms.

The *Head* is broad, and the *eyes* very prominent.

The *Arms* are subequal, the order of length being 4, 3, 1, 2; they are one-fourth the length of the body, all are flattened and taper evenly to fine points. The *suckers* are in four series, except in the right dorsal arm, where they appear to be in two, probably owing to its state of extreme compression; they are of medium size, many are deeply notched proximally and distally, and provided with fine meridional grooves on the margin: the *horny ring* is smooth and surrounded by a papillary area. The *hectocotylus* is not developed. The *umbrella* is small, widest between the lateral arms, where it reaches up to the sixth or seventh row of suckers. The *buccal membrane* has five distinct points, the ventral edge being thickened and forming a large folded *spermatic cushion;* it bears no suckers. The *outer lip* is thick, and marked with fine longitudinal grooves; the *inner* is papillate.

The *Tentacles* are as long as the mantle, with a three-sided flattened *stem*, much broader proximally than distally. The *club* is slightly expanded, with a narrow protective membrane below, a broad one above, and a distinct web outwardly. There are five or six series of *suckers*, slightly larger in the middle than at the margins, on very long slender peduncles : the *horny ring* is smooth.

The *Surface* bears a number of small irregularly scattered papillæ, and four or five elongated warts near the origin of the fins on the dorsum, and some folds in the skin on the ventral surface; probably these are due to contraction.

The *Colour* is a dull grey with a bluish shade above inclining to yellow below.

The *Shell* has an elongate oval *outline*, broadest one-third of the way back and rounded off at both ends. The *chitinous margin* is narrow anteriorly, then broader, evanescent posteriorly, a deep calcareous ridge forming the posterior extremity of the shell; it extends very little over the *dorsal surface*, which bears only faint indications of a median ridge, and is beset with fine granules disposed in rows parallel to the anterior margin. The *ventral surface* is elevated so as to give the shell a more than average thickness: the *last loculus* occupies one-third the surface and is bounded by a transverse hemielliptical curve : the *striated area* is excavated, but slightly convex in the middle line. The *inner cone* consists only of the slightly elevated limbs, which run along three-quarters of the striated area and unite with each other as a flattened fillet posteriorly. The *spine* has lost its extreme point, but is strong, and has raised a knife-like ridge developed upon its ventral aspect.*

Hab. Off south-east coast of Australia (Station 163), depth 2200 fathoms. One specimen, ♀.

METASEPIA, subgen. nov.

Sepia (*Metasepia*) *Pfefferi*†, Hoyle.

Sepia (*Metasepia*) *Pfefferi*, Hoyle, *Ann. and Mag. Nat. Hist.* ser. 5, vol. xvi. p. 199, 1885.

The *Body* is short and stout, broadest about the middle of its length, very thick (dorso-ventrally), and bluntly rounded behind.

* Whence the specific name.

† Named after Dr Georg Pfeffer of the Hamburg Museum.

The *fins* are one-fourth as broad as the body, and placed much nearer the dorsal than the ventral surface; they commence 2 to 3 millim. from the anterior margin and are connected by a narrow fillet behind; a slightly raised ridge passes down the ventro-lateral aspect of the body, similar to that seen in many specimens of *Octopus* and *Eledone* (possibly due to contraction). The *mantle-margin* projects very slightly dorsally, and is a trifle emarginate opposite the funnel: the *connective cartilages* are deeper than in most species of *Sepia*, but there is no distinct knob as in *Sepiella*. The *siphon* reaches up to the depression between the ventral arms.

The *Head* is broad, and the *eyes* prominent.

The *Arms* are subequal, in order of length 3, 4, 2, 1; they are rather more than half as long as the body and distinctly three-sided, having a ridge on the outer side of each, broadest on the ventral ones; they taper evenly to very fine points; the inner surface of each is roughly papillate and has hemispherical depressions into which the suckers are retracted. The *suckers* are in four series throughout, almost hemispherical, not very oblique, and marked with meridional grooves: the *horny ring* bears irregular square teeth. The *hectocotylus* is not developed. The *umbrella* is larger than usual in the genus, reaching on an average about one-third up the arms: the *buccal membrane* has seven not very prominent points, and there is a *spermatic cushion* as usual: the *outer lip* is very thin, the *inner* thick and papillate.

The *Tentacle* is about as long as the body, stout, indistinctly three-sided, and tapering. The *club* is short and but little expanded, with a narrow protective membrane on its outer side; the sucker-bearing area is, as it were, undermined on its inner aspect by a deep groove or fissure, and internally to this again is a broad fin which reaches down the tentacle for a distance exceeding half the length of the club. There are three *suckers* much longer than the rest, whereof the middle one is the largest and the proximal the next, placed on stout peduncles arising in deep depressions; towards the outer side of the club is a series of about four medium-sized suckers, and beyond these again one or two series of minute ones. The *horny rings* appear smooth under a powerful lens.

The *Surface* is smooth in general, but there are a few irregular papillæ in the ventro-lateral region.

The *Colour* is a dull grey, with indications of annular markings on the back.

The *Shell* has a rhomboidal *outline*, with rounded anterior and lateral angles ; the *chitinous margin* is narrow, widest behind, where it forms a flat, acute-angled plate, the posterior extremity of the shell ; it covers entirely, however, the *dorsal surface*, which is slightly raised mesially and marked by a number of faint striæ radiating from the posterior end. The *ventral surface* is much elevated on either side of a median groove ; the *last loculus* occupies one-sixth of the surface, is bounded by a wavy line, and deeply emarginate in the middle. The *inner cone* is represented only by a narrow rib reaching half-way along each posterior side of the shell and meeting its fellow in a rounded angle behind, from which a number of radiating calcareous streaks pass outwards into the horny termination.

Hab. South of Papua (Station 188), 28 fathoms. One specimen, ♀.

ŒGOPSIDÆ.

Histiopsis, Hoyle.

Histiopsis, Hoyle, 1885. Narr. Chall. Exp. vol. i. p. 273 (*nomen tantum*).

Resembles *Calliteuthis*, Verrill, in the shape of the body and fin and in the pigment spots scattered over it, but has a web extending for some distance between the dorsal, dorso-lateral, and lateral arms : the suckers are in two series. The siphon has a suspensory ligament and a valve. The gladius has not been removed.

Histiopsis atlantica, Hoyle, (*loc. cit.*).

Histiopsis atlantica, Hoyle, *Ann. Mag. Nat. Hist.* ser. 5, vol. xvi. p. 201, 1885.

The *Body* is short, conical ; acuminate and curving gently downwards posteriorly. The *fin* is about one-third the length of the body, and considerably broader than long ; each half is roughly semicircular, and narrows in to its insertion both in front and behind. The *mantle-margin* is in general transverse, but projects slightly as a blunt rounded angle in the dorsal median line. The *mantle-connective* consists of a groove with a narrow fillet in the mid-dorsal line fitting into a corresponding median cartilaginous surface on the back of the neck, and of a long linear ridge extending up to the margin, which fits into a shorter groove on the base of the *siphon;* this is broad, short, and conical, has a thick suspensory ligament, through the skin of which two muscles may be distinguished, and a distinct valve.

The *Head* is as large as the body, rounded at the sides and flattened above and below. The *eyes* appear to have been enormous, one is distended and protrudes from its orbit, whilst the other is shrivelled. There is no auricular crest nor preocular pore, but behind each eye is a white papilla.

The *Arms* are about equal in length to the head and body together; the dorsal are the shortest, the other three pairs subequals, the order of length being 3, 4, 2, 1; they are quadrilateral, with rounded angles externally, with two slightly raised ridges internally, on which the suckers are situated; they taper gradually to very slender tips; the third pair have a delicate narrow web along the third quarter of their outer aspect. The *suckers* are in two series throughout; they are small and distant along the proximal third (the webbed portion) of the arms, then larger and closer, and finally minute and very closely set towards the tips; they are set transversely on short conical peduncles, spheroidal with a swollen band round the face. The *horny ring* is smooth proximally, distally it bears about five close-set, broad, bluntly rounded teeth. No trace of a *hectocotylus* could be found. The *umbrella* is found only between the dorsal, dorso-lateral, and lateral arms; it takes origin from the sucker-bearing ridge and extends about one-third up the arm. The *buccal membrane* is broad and somewhat contracted over the mouth; it has the usual seven points, but they are very blunt and indistinct; it is united by three ligaments with the web between the dorsal and dorso-lateral arms, by a ligament with the inner side of each ventro-lateral arm on its ventral aspect and by another to the inner surface of each ventral arm, there being altogether seven ligaments. The membrane bears no suckers; its inner surface is much creased and folded. The *outer lip* is very thin and smooth, and hidden between the creased integument of the buccal membrane and the *inner lip*, which is thick and marked with irregular radial grooves.

The *Tentacles* have been removed; the stumps which remain are not half the length of the arms; they are quadrangular and flattened from above downwards.

The *Surface* bears a large number of papillæ, slightly elevated, resembling those of *Calliteuthis;* they are arranged most thickly on the ventral aspect of the head and body, but also on the dorsal, and extend up the outer aspect of the arms, three series on the ventral arms, two on each of the others. Near the tip of each dorsal arm is a series of four or five black, elongate, egg-shaped swellings, gradually diminishing in size, and forming apparently an extreme development of the papillæ above mentioned. The second pair of arms appears to have been similarly provided; the third has been so stripped of integument towards the tips that it is impossible to ascertain their original condition. In the fourth the warts at the tip are quite similar to those lower down the arm.

The *Colour* is a dull purplish madder, paler above than below, the papillæ are a deep black, with a white centre, usually situated towards the anterior margin. The *buccal membrane*, both sides of the umbrella, and the inner surfaces of the arms, so far as this extends, are a deep purple.

The *Gladius* has not yet been extracted from the solitary individual.

Hab. South Atlantic (Station 333), 2025 fathoms. One specimen, sex ?

Bathyteuthis, Hoyle.

Bathyteuthis, Hoyle, Narr. Chall. Exp., vol. i. p. 272, May 1885.
Benthoteuthis, Verrill, Trans. Connect. Acad., vol. vi. p. 401, July 1885.

Body long, cylindrical, tapering but slightly behind; *fins* sub-terminal, small and rounded; *mantle-connective* an elongated linear ridge fitting into a similar shorter groove on the base of the siphon, which is provided with a valve, but has no dorsal bridles.

Head large, very broad, with prominent eyes.

Arms very short, slender and conical; suckers very minute and in two series. *Buccal membrane* large, with seven points, each bearing one or two suckers.

Tentacles long, slender, without clubs, but with numerous minute suckers.

Gladius, resembling that of *Ommastrephes* in front, but expanded in the posterior third.

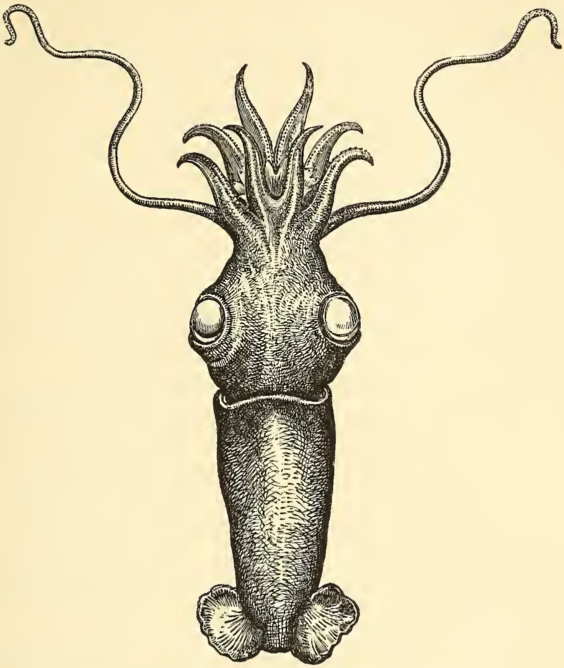


Fig. 2.—*Bathyeuthis abyssicola*, Hoyle.

Bathyteuthis abyssicola, Hoyle.

Bathyteuthis abyssicola, Hoyle, Narr. Chall. Exp., vol. i. p. 272, fig. 108, 1885.

The *Body* is subcylindrical, somewhat narrowing towards and bluntly rounded at the posterior extremity. The *fins* are small, separate; each is somewhat rectangular in shape, with rounded angles, and attached to the body by one angle.

The *mantle-margin* is almost transverse, but projects slightly in the dorsal median line, and forms a shallow sinus behind each eye and the siphon. The *mantle-connective* consists of a long linear ridge, extending quite to the margin, and fitting into a similar but somewhat shorter and broader groove on the base of the *siphon*, which is short, tapering, and bluntly pointed, fits into a shallow depression below the head, but has no dorsal bridles.

The *Head* is much broader than the body, being distended laterally by the enormous eyes which look outwards and forwards, and have bright, prominent, glistening lenses.

The *Arms* are unequal, the order of length being 4, 3, 2, 1, and about one-fourth the length of the body: they are all conical and taper to slender points; each has a distinct angle along the outer side, which expands to a distinct web in the fourth pair; there is also a very narrow delicate web along each side of the sucker bearing face. The *suckers* are very minute, pedunculate, and are arranged in two rows, almost embedded in the arm: they are spheroidal, and have a smooth horny ring, surrounded by two or three rows of conical papillæ. The *hectocotylus* was not present. The *buccal membrane* is very large, has the usual seven points, connected by ligaments with the arms; each joint bears one or two suckers.

The *Tentacles* are almost equal in length to the head and body together; the *stem* is very slender, cylindrical, and grooved along the inner aspect; they taper away rapidly towards the extremity, no *club* being formed: the *suckers* cover only the distal eighth of the tentacle in its inner aspect; they are smaller than those of the sessile arms, and almost imperceptible to the naked eye; they are urn-shaped, and have a smooth horny ring, surrounded by about two rows of very small papillæ.

The *Surface* is covered with minute wrinkles, probably due to the action of the spirit.

The *Colour* is a very deep purplish brown.

The *Gladius* was unfortunately somewhat damaged; for the anterior two-thirds it resembles that of an *Ommastrephes*, but posteriorly it expands into a broad blade, resembling that of *Loligo;* it was impossible to ascertain whether it forms a terminal cone.

Hab. Southern Ocean (Station 147), 1600 fathoms. One specimen, sex ?

7. Some Stereoscopic Photographs, &c., were exhibited by the Astronomer Royal for Scotland.

Monday, 20th July 1885.

DAVID MILNE-HOME, Esq., LL.D., Vice-President, in the Chair.

The following Communications were read :—

1. On Patella. Part II. By Dr Harvey Gibson.

2. On the Unifilar Knots with Ten Crossings. By the Rev. T. P. Kirkman, F.R.S.* Communicated by Professor Tait.

3. Census of Ten-fold Knottiness. By Professor Tait.

4. On the Thermal Effects produced, in Solids and in Liquids, by sudden large Changes of Pressure. By Messrs H. G. Creelman, B.A., and J. Crocket. Communicated by Professor Tait.

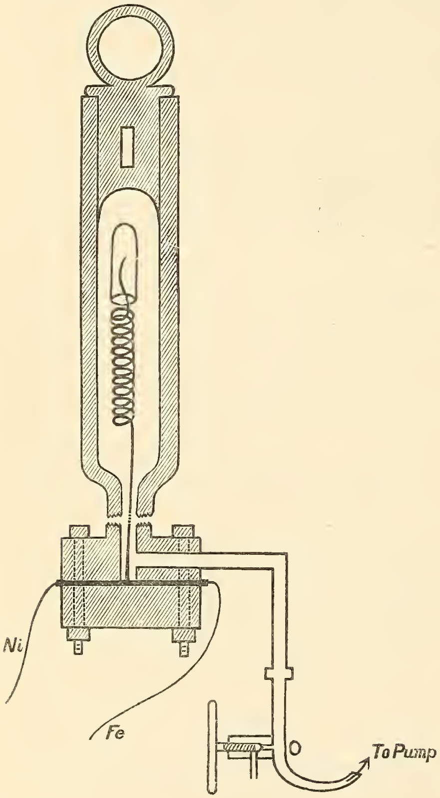
In several papers communicated to the Society within recent years the thermal effect of compressing water has been dealt with by various observers. The present paper gives the results of experiments of a similar kind to ascertain the thermal effects of compressing certain solids and liquids. These experiments were conducted in the University of Edinburgh, under the superintendence of Professor Tait.

Pressure was applied by forcing water by means of a powerful force pump into a strong steel tube, called the "small gun" (shown in section in the accompanying figure). Within this, a thermo-electric junction of nickel and iron wires was placed, most of the wire within the gun being in the form of a coil, so that the junction could be drawn up and pushed down as required. The wires passed out of the gun between two well-oiled leather discs, which could be tightly screwed together between a steel plate and a similar one forming the lower part of the gun. The nickel wire formed, with an iron wire, another junction, called the "outer junction," which was kept in water at a uniform temperature. The two iron wires were connected with a Thomson's dead-beat galvanometer (resistance

* A Supplement to this paper will be printed after the Proceedings for July 20.

1·5 ohms at 10° C.). When the wires were reversed the deflections differed by about 1 per cent. The upper orifice of the gun was closed with a steel plug, of the form shown in the diagram, and secured by a slot passing through plug and gun. At the lower orifice was a tap to allow of a sudden release of pressure. The gauge for measuring the pressure has been already described, and a figure of it will be found in the "Challenger" Commission Report.

In experimenting on solids our method was simply to fix tightly a piece of the substance two centimetres long by one square cm. in section on the inner junction. In the case of viscous solutions and liquids heavier than water, we arranged a small test tube within the coil, so that the inner junction dipped down into the tube, and was surrounded on all sides by the liquid. For liquids lighter than water we inverted the tube as shown in the figure, and having filled the gun with water, sucked out the air with a narrow U tube, and then admitted the liquid to be tested by a pipette.



A pressure of three tons on the square inch could be applied almost instantaneously by two strokes of the pump handle; the deflection of the galvanometer was simultaneously taken, and when the spot of light had steadied, the pressure was let off instantaneously, the deflection of the galvanometer being observed. The data for converting these deflections into degrees centigrade were obtained from experiments made from time to time to determine the deflection arising from known changes of temperature of the outer junction. The galvanometer was delicate enough to enable us to measure differences of temperature amounting to less than ·01 degree centigrade, and yet not so sensitive as to be seriously affected by the traffic in the street without. Each result recorded below is the mean of at least five experiments; in the case of pressures of about two tons each result is usually the mean of ten. 22·5 divisions of the pressure gauge correspond to a pressure of one ton on the square inch, or about 150 atmospheres.

Each day, with the exception of those on which we found the exact value of galvanometer readings by observing the result of known changes of temperature of the outer junction, it was our habit to take a series of observations for water alone, by means of which we could verify the previously ascertained equivalent of galvanometer readings.

It was generally observed that the fall of temperature on relaxation of pressure was greater than the corresponding rise on applying pressure, owing to some extent to the fact that pressure could be more suddenly relieved than applied. In the case of water, we observed, as the mean result of many experiments, that the two differed in the proportion of about 14 to 13. Thus, on applying a pressure of two tons on the square inch, we obtained a deflection of 1·3, equivalent to 0°·31 C.; while on releasing pressure the deflection was 1·4, equivalent to 0°·33 C. This at a temperature of 16° C., at which, by Sir W. Thomson's formula, the rise of temperature should be 0°·35 C.

Some reduction thus seems necessary of the results given in the tables below, though not in the same proportion, since convection currents present in the considerably large quantity of water which filled the gun, would be wanting in the solids and the comparatively small quantities of liquids used.

To furnish an idea of the general agreement in the results, we give the full data from one experiment, taken at random; namely, the effect produced in vulcanite by changes of pressure to the extent of about two tons on the square inch.

Effect on applying Pressure.		Effect on relieving Pressure.	
Change of Pressure.	Deflection Positive.	Change of Pressure.	Deflection Negative.
48	2·9	45	2·7
47	2·8	44	2·6
44	2·6	41	2·5
41	2·5	37	2·2
44	2·7	41	2·5
47	2·7	43	2·5
43	2·5	39	2·3
45	2·6	41	2·5
48	2·8	43	2·6
45·2	2·68	41·6	2·5

Thus taking the mean of nine experiments, and having found, in the manner referred to above, that 4·8 divisions on the galvanometer scale are equivalent to 1° C., we deduce the rise of temperature on applying $\frac{45 \cdot 2}{22 \cdot 5}$ tons on the square inch, to be 0°·56 C., and the fall on relieving $\frac{41 \cdot 6}{22 \cdot 5}$ tons to be 0°·52 C. Hence we can deduce the rise or fall per ton, as shown in the table under *Vulcanite.*

Cork.—A parallelepiped, two centimetres long and one square centimetre in section, was cut from a piece as homogeneous as could be obtained. A reference to the following table will show that, for this substance, the fall of temperature on relieving pressure is considerably less than the rise on application of pressure. This result had been given by Professor Tait in a Note in the *Proceedings* (May 16, 1881), and it was to some extent with a view to the discovery of like anomalies that the present investigation was undertaken. But no other of the substances which we have tested showed this peculiarity. Each of the following results is the mean of six experiments :—

Temp. in Degrees Centigrade.	Thermal Effect on applying Pressure.				Thermal Effect on relieving Pressure.			
	Pressure.	Deflection.	Temp. Raised.	Rise per Ton.	Pressure.	Deflection.	Temp. Lowered.	Fall per Ton.
15°	22·3	3·6	0°·75	0°·75	23·2	2·5	0°·53	0°·51
15°·3	45·2	6·2	1°·3	0°·65	44·5	4·3	0°·9	0°·45
15°·6	65·6	8·2	1°·71	0°·59	59·5	5·4	1°·12	0°·42

Vulcanite.—The first specimen employed was a parallelepiped, two centimetres long and one square centimetre in section. The following is a table of the results :—

Temp. in Degrees Centigrade.	Thermal Effect on applying Pressure.				Thermal Effect on relieving Pressure.			
	Pressure.	Deflection.	Temp. Raised.	Rise per Ton.	Pressure.	Deflection.	Temp. Lowered.	Fall per Ton.
16°	26	1·66	0°·35	0°·30	22·4	1·4	0°·3	0°·30
16°·3	45·2	2·68	0°·56	0°·28	41·6	2·5	0°·52	0°·28
16°·6	67	4·0	0°·83	0°·28	61	3·7	0°·79	0°·28

We also tested the vulcanite used to protect the "Challenger" Expedition thermometers. The specimen employed was a cube of one centimetre. The following table shows slightly greater results than were obtained with the first specimen :—

Temp. in Degrees Centigrade.	Thermal Effect on applying Pressure.				Thermal Effect on relieving Pressure.			
	Pressure.	Deflection.	Temp. Raised.	Rise per Ton.	Pressure.	Deflection.	Temp. Lowered.	Fall per Ton.
16°·6	25	1·6	0°·37	0°·33	22·5	1·4	0°·33	0°·33
16°	45·6	2·72	0°·63	0°·31	45	2·86	0°·66	0°·33
16°·3	66	3·6	0°·83	0°·28	55	3·4	0°·79	0°·32

Glass.—The specimen employed was a cylinder of common lead glass, two centimetres long and one in diameter. The bore into which the junction fitted was filled with powdered glass, so that as little water as possible might intervene between the junction and the glass. The following is a table of the results :—

Temp. in Degrees Centigrade.	Thermal Effect on applying Pressure.				Thermal Effect on relieving Pressure.			
	Pressure.	Deflection.	Temp. Raised.	Rise per Ton.	Pressure.	Deflection.	Temp. Lowered.	Fall per Ton.
14°·6	24	0·6	0°·13	0°·12	24	0·64	0°·13	0°·12
15°	49	1·35	0°·28	0°·13	47	1°·45	0°·3	0°·14
	66·4	1·87	0°·39	0°·13	65·2	1·97	0°·41	0°·14
	58·4	1·66	0°·34	0°·13	58·6	1·74	0°·36	0°·14

The following tables give results for other substances treated in the same way as cork and vulcanite :—

Pure India-rubber.

Temp. in Degrees Centigrade.	Thermal Effect on applying Pressure.				Thermal Effect on relieving Pressure.			
	Pressure.	Deflection.	Temp. Raised.	Rise per Ton.	Pressure.	Deflection.	Temp. Lowered.	Fall per Ton.
14°·6	29	5·1	0°·95	0°·74	22·3	4·3	0°·8	0°·79
	46	7·7	1°·42	0°·70	38	7·2	1°·33	0°·79
	64	10·9	2°·0	0°·70	49·4	9·6	1°·8	0°·80

Vulcanised India-rubber.

16°	26	3·55	0°·72	0°·64	19·2	2·85	0°·6	0°·70
	45·4	6·3	1°·3	0°·64	38·7	5·6	1°·16	0°·67
	66	8·9	1°·8	0°·61	56	7·9	1°·6	0°·64

Gutta-percha.

16°	22·5	3·0	0°·65	0°·65	22·5	3·1	0°·67	0°·67
	46·6	5·66	1°·23	0°·60	46·6	6·08	1°·32	0°·64
	66	7·8	1°·7	0°·58	66	8·9	1°·9	0°·63

Beeswax.

15°	23·4	3·94	0°·86	0°·83	23	3·86	0°·84	0°·83
	47	7·6	1°·65	0°·79	43·6	7·8	1°·7	0°·86
	66·4	10·6	2°·3	0°·78	60·6	10·9	2°·4	0°·89

Solid Paraffin.

14°	25	3·94	0°·61	0°·56	24·4	4·0	0°·62	0°·57
	45	7·2	1°·12	0°·56	45	7·6	1°·18	0°·59
	67	10·4	1°·62	0°·54	65	11·26	1°·76	0°·61

Marine Glue.

Temp. in Degrees Centigrade.	Thermal Effect on applying Pressure.				Thermal Effect on relieving Pressure.			
	Pressure.	Deflection.	Temp. Raised.	Rise per Ton.	Pressure.	Deflection.	Temp. Lowered	Fall per Ton.
15°·5	33·6	4·76	1°·36	0°·91	30·8	4·7	1°·34	0°·98
	47·4	6·24	1°·78	0°·85	45	6·26	1°·79	0°·90
	66	8·4	2°·4	0°·82	45·7	6·45	1°·84	0°·91

Turning our attention, in the next place, to colloids, we examined common glue in three forms—(1) the brittle form in which it is usually sold; (2) as a dry jelly; and (3) as a viscous liquid, which poured with difficulty. The following table shows the results :—

Glue (Brittle).

Temp. in Degrees Centigrade.	Thermal Effect on applying Pressure.				Thermal Effect on relieving Pressure.			
	Pressure.	Deflection.	Temp. Raised.	Rise per Ton.	Pressure.	Deflection.	Temp. Lowered.	Fall per Ton.
18°	24·4	1·8	0°·42	0°·39	22·5	1·8	0°·42	0°·42
	45·2	2·94	0°·68	0°·34	44·5	3·44	0°·8	0°·40
	46·6	3·24	0°·75	0°·36	45	3·66	0°·84	0°·42
	67·4	4·5	1°·05	0°·35	67	5·3	1°·22	0°·41

Glue (Jelly).

16°	24·4	1·67	0°·36	0°·33	24·1	1·67	0°·36	0°·33
	45	3·1	0°·68	0°·34	44	3·3	0°·72	0°·36
	65	4·8	1°·04	0°·36	64	5·1	1°·11	0°·39

Glue (Viscous Solution).

17°	23	1·02	0°·24	0°·23	23·1	1·06	0°·25	0°·24
	45·7	1·91	0°·44	0°·22	45	2·17	0°·50	0°·25
	67·6	2·9	0°·67	0°·22	67·3	3·36	0°·78	0°·26

We also examined gelatine in the form of a dry jelly, isinglass as a jelly wet to the touch, and gum arabic as a viscous solution. The following were the results obtained :—

Gelatine.

Temp. in Degrees Centigrade.	Thermal Effect on applying Pressure.				Thermal Effect on relieving Pressure.			
	Pressure.	Deflection.	Temp. Raised.	Rise per Ton.	Pressure.	Deflection.	Temp. Lowered.	Fall per Ton.
15°	24·4	1·34	0°·29	0°·27	24·1	1·26	0°·27	0°·25
	47	2·5	0°·54	0°·26	47	2·7	0°·58	0°·28
	67	3·4	0°·74	0°·25	63	3·6	0°·78	0°·28

Isinglass.

14°·3	21·4	1·0	0°·21	0°·22	22	1·0	0°·21	0°·22
	48	2·04	0°·43	0°·21	48	2·24	0°·47	0°·22
	67·5	3·0	0°·65	0°·22	66	3·0	0°·65	0°·22

Gum Arabic.

17°·3	24·2	1·81	0°·39	0°·36	24·2	1·88	0°·41	0°·38
	45·7	3·27	0°·71	0°·35	44·6	3·5	0°·76	0°·38
	66·9	4·69	1°·02	0°·35	66·1	5·25	1°·14	0°·39

Chloroform (Specific Gravity, 1·497).

15°·5	23·3	6·25	1°·49	1°·44	22·5	6·1	1°·45	1°·45
17°	46	11·46	2°·73	1°·34	45	12·2	2°·90	1°·45
	66	16·2	3°·85	1°·31	69	19	4°·52	1°·47

The following liquids, lighter than water, were examined in the manner already explained :—

Paraffin Oil.

Temp. in Degrees Centigrade.	Thermal Effect on applying Pressure.				Thermal Effect on relieving Pressure.			
	Pressure.	Deflection.	Temp. Raised.	Rise per Ton.	Pressure.	Deflection.	Temp. Lowered.	Fall per Ton.
18°	24·3	6·4	1°·49	1°·39	23·7	6·37	1°·46	1°·39
16°	44·3	10·5	2°·44	1°·22	45	10·8	2°·51	1°·25
19°	45·7	11·7	2°·74	1°·34	44	12·2	2°·84	1°·45

Florence Oil.

19°·3	23·5	5·66	1°·3	1°·26	23	5·58	1°·29	1°·26
20°·8	47·2	11·02	2°·62	1°·24	47·2	11·8	2°·81	1°·34
21°	63	14·6	3°·48	1°·24	67·1	16·8	4°·0	1°·34

Linseed Oil.

19°·5	22·5	5·0	1°·19	1°·19	22·3	5·1	1°·21	1°·21
16°·6	45	8·0	1°·90	0°·95	45	8·2	1°·95	0°·96
	68	11·9	2°·83	0°·94	68·5	12·35	2°·94	0°·96

Castor Oil.

	27	3·9	0°·93	0°·78	25·6	3·75	0°·89	0°·78
	49	6·4	1°·52	0°·69	47	6·6	1°·57	0°·75

Sulphuric Ether.

21°	23·3	7·9	1°·9	1°·8	22·5	8·0	1°·9	1°·9
	46·2	15·04	3°·58	1°·74	45	15·44	3°·67	1°·83
	70	22	5°·2	1°·67	66·5	21·5	5°·1	1°·73

5. On a Method of Measuring the Resistance of Electrolytes without endeavouring to prevent Polarisation. By Mr W. Peddie.

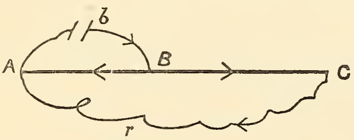
In the case of a metallic conductor the resistance may be got at once by means of Ohm's Law. But when the conductor, the resistance of which is to be determined, is an electrolyte, the electromotive force acting along the circuit is only partly employed in producing the current. So that we obtain the equation

$$E = Rx + P,$$

where E is the electromotive force, R the resistance, x the current, and P the reverse electromotive force of polarisation. Since, for a considerable stretch of values of the current, P seems to be proportional to it, we may write

$$E = (R + p)x,$$

where p is a constant for the given values of x. That is to say, if the ordinary method of measuring resistance could be used, what would be measured is the actual resistance *plus* an unknown quantity. Hence, in most methods of experimenting, alternating currents, or non-polarisable electrodes, are used so as to prevent polarisation. In Horsford's method, p is eliminated by giving R different values, while x remains constant. The difficulty here consists in the fact that polarisation may not be the same in both cases, for the nature of the solution at the electrodes may be different because of the liberated ions. The object of this paper is to describe a method of measuring the resistance which is free from this objection. The annexed diagram will show the arrangement. ABC represents an electrolytic conductor, with one pole of a battery (b) joined to an electrode at B,



while the other is joined to an electrode at A, which in turn is joined to a similar electrode at C by a metallic conductor of resistance r. The current may be supposed to flow in the directions indicated by the arrow-heads. Let A, B, C represent the potentials at these points, and let x be the current flowing from B to A, and y be the current flowing from B to C, while R is the resistance between A and B, and $R + \rho$ is that between B and C. We have then

$$B - A = (R + p)x,$$
$$B - C = (R + p + \rho)y,$$
$$C - A = ry.$$

Hence we obtain

$$R + p = \frac{\rho + r}{\frac{x}{y} - 1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Now, placing the battery between B and C, we get similarly

$$R + p + \rho = \frac{r - \rho}{\frac{x'}{y'} - 1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

when x' and y' are the currents corresponding to x and y in the previous arrangement. From (1) and (2) we get

$$\rho = r \frac{xy' - yx'}{xx' - yy'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Hence the difference between the resistances of the two parts of the electrolyte may be calculated in terms of a known resistance and of known currents. In this form of the experiments, however, it is assumed that polarisation is proportional to the current density. Also there is the objection that heating is going on, usually to different extents, in the two parts, because of the currents being different. Both these sources of error vanish if x' is equal to y', and then equation (3) reduces to

$$\rho = r .$$

I have as yet made only a very rough series of experiments with the view of testing the steadiness of the currents, but it seems to indicate that the method will be successful. The form in which the experiments were conducted is that to which equation (3) applies. In addition to the errors above indicated as affecting the results, there were causes tending to produce large variations arising from the roughness of the apparatus set up provisionally. Three cylindrical glass cups were connected in series by two glass tubes inserted near their lower edge. The electrolyte (a 5 per cent. aqueous solution of sulphuric acid) was poured into this arrangement, and the electrodes (platinum) dipped into it through the open ends of the cups. The cups were of large volume, so that the resistance of the portion of liquid between the electrodes and the extremities of the tubes could be neglected. The lengths of the tubes were 9·2 and 8·5 centimetres respectively, and their diameter was ·65 centimetre. The metal wire used to connect the extreme electrodes had a resistance of ·95 ohms. A battery of four Bunsen cells was found necessary to produce a current. The following figures show the readings, on a tangent galvanometer, of the deflections produced by the currents $x'+y'$ and y' respectively:—

22°·8	23°·1	22°·9	22°·9	23°·1	23°.1
13°·1	13°·1	12°·8	13°·0	12°·9	13°·1

This series of readings is one of the most unsteady obtained, and it was found on testing that most of the variations might be due to alteration of the electromotive force of the battery employed, or to alteration of contact at the various junctions of the circuit. The next set of figures are values of the ratios $\frac{x}{y}$ and $\frac{x'}{y'}$ respectively.

1·25	1·19	1·245	1·19
0·811	0·840	0·846	0·87

The value of the specific resistance deduced from these observations agrees very closely with previous determinations by other methods.

Evidently the method may be used to investigate the laws of variation of polarisation with current density. For we have as above

$$ry = (\mathrm{R}+\rho)x - \mathrm{R}y + p_1 - p_2 \,.$$

And we may put generally

$$p = \mathrm{P} + \frac{1}{a} f(\gamma)\,,$$

where $f(\gamma)$ is some function of the current γ, P is the E. M. F. required to decompose the electrolyte, and a is the area of the electrode. Hence, if $x=y$, we get

$$r = \rho + \left(\frac{1}{a} - \frac{1}{a'}\right) f(\gamma)\,.$$

So if $a=a'$ we get $r=\rho$. If now we make $a'k=a$ and adjust the currents to equality by altering ρ, we have

$$r = \rho' + \frac{1-k}{a} f(\gamma)\,,$$

where ρ' is known in terms of ρ, so that $f(\gamma)$ is determinate.

Again, either of equations (1) or (2) may be used to find the value of p, which is the electromotive force of polarisation produced by unit current.

6. Note on the Contraction of the Auricles of the Pig's Heart. By J. MacFadyean, M.B., B.Sc., M.R.C.V.S., and G. Sims Woodhead, M.D.

It is a familiar fact that the heart of cold-blooded vertebrates may continue to beat for a long period—even for days—after its removal from the body, but it is not so well known that contractions may occur in the heart of the higher vertebrates for a considerable time after death. On this latter point, however, there are many observations on record. Harvey noted that rhythmical contractions continued in the heart of the pigeon for some time after death, and, further, that after it had ceased to beat, it recovered its vigour, and both auricles and ventricles pulsated on the application of a stimulus, such as the tip of the finger wetted with saliva.*

Lewes also quotes from Donders, that "Harless observed it (the heart) beating in the body of a decapitated murderer one hour after execution. Margo found the right auricle beating two hours and a half after the execution, although not a trace of irritability could be detected in the other parts of the heart. Dietrich, Gerlach, and Herz found that both ventricles contracted if one was irritated forty minutes after death." The same author further quotes, from Emil Rousseau, the case of a woman whose heart had these rhythmic movements seven-and-twenty hours after she had been guillotined. Landois† points out that numerous observations have been made by Pannum, Valentin, and others during recent years on the excised heart of rabbits, dogs, &c., and that even so early as 300 B.C. movements in an excised heart had been recorded by Cleanthes.

Our attention was specially drawn to this subject by the behaviour of a pig's heart which was obtained at the Edinburgh Abattoir for some inoculation experiments in connection with pig typhoid. At 10.25 A.M. the animal was killed in the way commonly practised by butchers, viz., by first stunning it by a blow on the cranium with a heavy mallet, and then by cutting across the great vessels at the root of the neck. It was allowed to bleed for a few minutes until apparently dead. The thorax was then opened, and

* *Physiology of Common Life*, by G. H. Lewes, vol. i. p. 334.

† *A Text-book of Human Physiology*, Landois and Stirling, vol. i. p. 96.

the heart and lungs were cut out together. While this was being done, the heart was observed to give a few pulsations, which led the butcher to remark that the animal was not quite dead. A string was then firmly tied round the great vessels at the base of the heart, which was next separated from the lungs by cutting the vessels on the distal side of the ligature. The heart on being laid aside on a table began to pulsate slowly but rhythmically, the contractions taking place in both auricles and ventricles. After a few minutes spent in examining the remaining viscera of the animal, and of others killed at the same time, the heart and portions of other organs were wrapped up together, and carried to the University New Buildings, the Abattoir being left at 10·35.

At 10.50, when the parcel was opened in the Pathological Laboratory, it was observed that spontaneous contractions were still occurring at intervals in the auricles of the heart. On stimulating the right auricle by slight scratching with a pin, a contraction of that cavity was easily obtained, and this was immediately followed by contraction of the left auricle. Stimulation of the left auricle produced a contraction of that cavity, but did not affect the right auricle. These experiments were repeated several times, and always with the same result.

Both auricles continued to beat spontaneously till 11.12, the contraction occurring first in the right, and this being followed immediately by a contraction of the left.

After 11.16 contractions of the left auricle were obtainable only by direct stimulation, the right auricle, however, continued to beat till 11.19.

At 11.28 fibrillary twitchings were obtained on slightly stimulating the posterior part of the right auricle, where it was still moist, and by increasing the stimulus, stronger contractions resulted.

At 11.33 the same results were obtained on stimulating the left auricle.

At 11.28, and again at 11.40, stimulation produced only fibrillary contraction.

At 11.44, on stimulating strongly the upper and inner part of the right auricle, a strong contraction resulted, with a peculiar tetanic appearance of the muscle along the line of stimulation. This part, as compared with the other parts, which had previously failed to respond on stimulation, had more blood beneath it in the cavity of the auricle, and it was also still moist on its outer surface.

Between 11.47 A.M. and 1.25 P.M. the left auricle was stimulated seventeen times, a contraction following each stimulus. In one instance, at 12.43, two strong contractions followed a single stimulus.

At 1.28, on slightly distending the right auricle by squeezing blood into and from the ventricle, contraction was obtained on stimulating any point, each contraction being circumscribed. At 1.38 contractions were fainter, and not obtainable at every point.

At 1.40, after fully distending the auricle, a very marked contraction followed, and extended along the whole inner border of the auricle.

At 1.50 a similar but less extensive contraction was obtained in the same way.

At 1.5 stimulation of the distended auricle produced a double contraction along its border, and strong but circumscribed contractions at several other points.

At 2.1 the empty auricle was stimulated, but without response. On distending the cavity, contractions at several points were obtained on stimulation.

At 2.6 the auricle was distended, and on stimulation some feeble contractions were obtainable, but only at a few points. The heart was immersed in water at 100° Fahr. for about one minute. On stimulation there was no response. The organ was next immersed in cold water (about 50° Fahr.), but no contractions could be obtained.

Summary.—Spontaneous contractions in left auricle for 47 minutes. Contractions could be induced in it on stimulation of right 4 minutes after this. It responded to direct stimulation for exactly 3 hours from the time the animal was killed. The right auricle continued to beat spontaneously for 54 minutes. It responded to stimulation for 3 hours and 41 minutes.

In another heart obtained at the same time, which was not otherwise examined, fibrillary contraction of the muscular wall of the right ventricle, near the auriculo-ventricular groove, was observed half an hour after death.

It seemed to us that this long continued contractility of the mammalian heart should have a most important bearing upon the question of resuscitation, after death from hæmorrhage, chloroform poisoning, and other forms of syncope, and we determined to make a series of experiments with the view of clearing up some points still under discussion. As yet we have had opportunity of making but one of these experiments, but we hope ere long to be able to communicate further observations. Immediately after we had formed this resolution an opportunity presented itself, but before we had made the necessary arrangements as to recording apparatus. The observation is of the roughest kind, but appears to us to be of sufficient importance to put on record.

An animal condemned for pig typhoid was killed as in the other case. It was noticed that the animal "bled" very slowly.

The heart was removed as rapidly as possible, and whilst all the cavities were still beating. In the meantime defibrinated sheep's blood, mixed with 2 parts of $\frac{3}{4}$ per cent. salt solution had been raised to a temperature of 99° Fahr.

A cannula (too small) was tied into one of the pulmonary veins, and connected by about 9 inches of elastic tubing with a similar cannula in the pulmonary artery. A third cannula was tied into the inferior vena cava, and another was fastened into the aorta. The superior vena cava was firmly ligatured at a distance of about three-quarters of an inch from the auricle. All these tubes were first filled with the blood mixture, as was also a "Higginson's" syringe, which was fitted on to the cannula in the inferior vena cava. These operations occupied 20 minutes, and by the time they were completed the ventricles had ceased to contract, and the auricles were beating very intermittently and feebly.

Warm blood solution was now pumped slowly and steadily into the right ventricle, and the heart was suspended in the same fluid. This was almost immediately followed by a full and regular contraction of both auricles, the beats being, as far as we could determine with the eye, quite synchronous. This went on regularly from 12.40 to 12.55, when the right auricle suddenly ceased to beat at all regularly, and only a few irregular contractions could be obtained on stimulating with the point of a needle. Whilst the auricle was contracting, the lower part of the superior vena cava (that part below the ligature) was also contracting regularly and firmly. This beat did not merge into that of the auricle, but was perfectly independent of it, and the cava continued to beat for at least two minutes after the auricular beat had ceased. Whilst the examination and stimulation of the right auricle and superior cava were going on, the heart had been withdrawn from the blood, and the distension had not been kept up.

At 1.30, on examining the left auricle, it also was found to have stopped contracting. It was stimulated with the point of a needle, but there was still no contraction. On removing the connecting tube from the pulmonary vein and immersing the heart, and pumping in blood solution until the left auricle was moderately distended, there were several distinct contractions which were repeated on touching the wall with the point of a needle. Similar contractions were obtained at 1.23, 1.24, and 1.26, on applying the point of a needle.

1.23, on stimulating the left auricle with the needle, slight fibrillar contractions were observed. On distending the cavity the contraction was more distinctly marked.

1.40, after distension, on stimulating with needle, several very strong wavy contractions were observed.

1.52, dead; not even a fibrillar twitching.

An attempt was made to induce contraction in the right auricle by distending, after the left auricle had been distended and had contracted, but without any effect; not even a fibrillar contraction after 12.55.

Summary.—The right auricle beat regularly for 35 minutes after the animal commenced to bleed to death, and 15 minutes after the heart was placed in blood. Irregular contractions continued for not more than a minute after this. Contraction of the superior vena cava continued for two minutes later. The left auricle beat regularly for about 55 minutes from commencement of the bleeding, and 35 minutes after the heart was placed in blood. More or less regular contractions could be *induced* for at least 25 minutes longer.

It will be seen, on comparison of the two cases, that contractions ceased much sooner in the heart specially prepared. It should be noted in this connection that there were two points of difference. (1) In the first case, tension was maintained in the cavities of the heart by the ligature which was applied whilst some blood remained in the organ; whilst in the second case the tension was kept up, irregularly and intermittently, by means of the "Higginson" syringe, and by stopping the outflow of the fluid at the various points in turn. (2) Whilst both pigs were diseased, the lesions were more pronounced in the viscera of the second animal, and the vitality of the tissues might be expected to be somewhat lower.

The points to be specially noted in the second case are—(*a*) that, contrary to what is usually observed, movements were arrested in the right auricle before those in the left had ceased; (*b*) that the contraction of the superior vena cava was quite independent of that of the auricle, a contraction occurring before each contraction of the auricle.

The latter observation coincides with those quoted from Haller and Nysten by Landois, *loc. cit.*, p. 69:—"Independent rhythmical contractions of the venæ cavæ and pulmonary veins are often noticed after the heart has ceased to beat."

Stirling also notes that such contractions can be observed in the veins of the rabbit after the heart is cut out of the body.

The contraction of the superior vena cava was so distinct and forcible that it suggested to us the idea that it might, under certain conditions, be sufficient to produce a distinct sound which might be referred to the orifice.

It is interesting to note, in connection with this contraction, that we were able to trace striped muscular fibre in the wall of the superior vena cava at least $1\frac{1}{4}$ inch from the orifice.

7. On the Heats of Combination of Zinc and Iodine in Presence of Water, as determined by the Measurement of the Electromotive Force of the Zinc-Iodine Cell. By A. P. Laurie, Esq., B.A., B.Sc.

During the spring of 1882 Mr Burton and I communicated some preliminary experiments on a new method of measuring the heats of combination of the metals with the halogens.*

In this paper I propose to show the result of the application of

* *Proceedings of R.S.E.*, 1881–82.

the method to the study of the heats of combination of iodine and zinc in presence of water.

The heats of combination are in each case obtained from the electromotive force of either the zinc-iodine cell, or of the zinc-cuprous iodide cell.

The zinc-iodine cell consists of a zinc rod and a platinum wire dipped in a water solution of iodine and iodide of zinc.

The zinc-cuprous iodide cell consists of a zinc rod, and a copper wire coated with cuprous iodide, dipped in a solution of iodide of zinc.

When a current passes through a given zinc-iodine cell, various changes take place requiring either the production or absorption of heat. In the first place, there is the combination of the zinc and iodine, producing heat; in the second place, there is the solution of the zinc iodide formed, producing heat. On the other hand, the disintegration of the zinc, the decomposition of the iodine molecule, and the removal of the free iodine from its solution in zinc iodide, absorb heat.

If now a series of cells are made up differing only in the strength of the zinc iodide solution, the heat of solution of the zinc iodide formed in the cell during the passage of a current will vary with the strength of the iodide of zinc solution, and that probably in a way familiar to chemists from the behaviour of sulphuric acid when added in larger and larger quantities to water.

On the other hand, the heat of combination of the zinc and iodine, and the heat absorbed in decomposing the iodine molecule and disintegrating the zinc, will probably remain the same. We shall, in fact, find that the infinitely small quantity of zinc iodide dissolved on passing a current has a definite heat of solution determined by the amount of zinc iodide already dissolved in the water contained in the cell.

Further, if a series of cells are made up differing only in the amount of free iodine dissolved in a given iodide of zinc solution, we shall find the heat absorbed in removing the iodine from its solution in zinc iodide diminish as the amount of free iodine present is increased.

It is also probable that the heat of solution of a constant quantity of iodine will vary with variations in the strength of the iodide of zinc.

Having thus stated what takes place in the cell, the question next to be decided is, Whether the heat given out by these reactions correspond exactly with the electromotive force of the cell?

Sir William Thomson, in publishing his formula connecting the electromotive force of a cell with the heat set free by the reactions taking place, assumed that this correspondence existed. Recent experiments have shown, however, that this is not a true assumption in many cases, and Helmholtz has recently treated the subject from a new point of view.*

The following is, as I understand it, the outcome of his work on chemical combination, in so far as it applies to finding the connection between the heats of combination and the electromotive force of the cell.

In general, when an infinitely small current de passes through a cell at a given absolute temperature θ, a certain amount of heat, dQ, must be supplied to or removed from the cell to keep its temperature constant, apart from the heat developed by the electric resistance of the liquid.

If the electromotive force of the cell corresponds exactly to the heat given out by the reaction taking place in the cell, then no heat need be added or removed.

Now the measurement of this cooling or heating of the cell would be difficult in practice, but, applying the second law of thermodynamics, Helmholtz obtains the following formula, showing that a measure of dQ can be obtained from the variations in electromotive force due to temperature—

$$\theta \frac{dp}{d\theta} de = \mathrm{J} d\mathrm{Q},$$

where dp is the variation in electromotive force due to temperature.

It is necessary, then, in practice to measure the electromotive force of the cell experimented upon at different temperatures and find the variation, if any, of the electromotive force.

In a cell of one volt, electromotive force at 300° ab. temp., a variation of ·0001 volt per deg. cent. would mean a correction of ·03 volt, or 3 per cent. to be applied before determining the heat of combination from the electromotive force.

* *Die Thermodynamik Chemischer Vorgänger. Wissenschaftliche Abhandlungen*, Von Hermann Helmholtz, Zweiter Band.

The heat of combination can seldom be obtained with much accuracy from books on thermal chemistry, the conditions under which the reactions have been performed in the calorimeter differing considerably from the conditions in the cell.

For example, three numbers are given by Naumann as representing the heat of combination of zinc and iodine in presence of water—

1st, The heat of combination of zinc and iodine in water, 60540 calorics.

2nd, The heat of solution of zinc iodide in water, 11310 calorics.

3rd, The heat of combination of zinc and iodine obtained by subtracting the second from the first, 49230 calorics.

Now the first and second numbers are obviously average results, the zinc iodide formed dissolving in pure water at the beginning of the reaction, but in a strong zinc iodide solution towards the end.

If care has been taken to use the same quantities of water and zinc iodide in both experiments, no doubt the third number represents fairly well the heat of combination of zinc and iodine.

The above criticism applies to Thomson's book, though more details are usually given by him. It is consequently impossible to compare with exactness these numbers with those obtained by measuring the heats of combination in the iodine cell.

In the following experiments on the zinc-iodine and zinc-cuprous iodide cell, I have used Professor Tait's Thomson electrometer to measure the electromotive forces obtained. Alder Wright recommends a high resistance galvanometer for the purpose, which is certainly more delicate, but not more reliable than this particular instrument.

About 50 divisions of the scale correspond to one volt, and it is possible to read to half a division.

As a standard of electromotive force a Daniell cell was used, made up according to the directions given by Alder Wright,* but specially constructed to make diffusion of the two liquids practically impossible. This cell has, according to Wright, an electromotive force of 1·107 volts.

* *Electrician*, Feb. 18, 1882. In recent papers Wright states the electromotive force of a Dan. cell differing in some details at 1·112 volts.

To check this cell, I used two Latimer Clerk cells, one made up two years ago, the other made up quite recently. Taking Lord Raleigh's recent determination of the electromotive force of this cell (1·454 volts), the three cells agreed with each other within the errors of experiment.

The electrometer was connected to a vocker so constructed that the zero of the instrument, the deflection due to the cell to be measured, and the deflection due to the Daniell cell, could be noted one after the other. This was always done, and the numbers given at the end are always the mean of several readings. The Daniell did not alter at all from week to week.

When very small variations in electromotive force had to be measured, two or three cells were placed in series, and in some cases cells were connected to the electrometer through similarly constructed cells, especially to note the effects of temperature. No correction has been made for the new determination of the B.A. unit, as this affects both the electromotive force and the zinc dissolved by unit current. Consequently the error introduced in calculating from electromotive force to heat of combination is very slight.*

With the above apparatus the following experiments were made :—

1. Experiments to find the effect on the electromotive force of the cell of varying the nature of the zinc.

2. Experiments to find the effect on the electromotive force of the cell of varying the temperature of the cell.

3. Experiments to find the effect of varying the strength of the iodide of zinc solution. For these the cuprous iodide cell was used, as simplifying the changes taking place in the cell.

4. Experiments on varying the strength of the free iodine present.

5. Experiments on varying the strength of the iodide of zinc solution in the iodine cell.

(1) In making measurements with the electrometer, the surface condition of the metals used is evidently of great importance, as so little current is drawn from the cell. If wet zinc is exposed to the air it becomes coated with a film of hydrate, which perceptibly lowers the electromotive force of the cell.

* See Alder Wright's recent papers in the *Phil. Mag.* for 1885.

I could find no difference between the deflections given by zinc electro-deposited from pure zinc, zinc "free from arsenic," zinc cleaned with sand-paper, zinc corroded by the iodine solution, and zinc with a freshly-broken crystalline surface. Probably, if two or three cells in series had been used, slight differences in electromotive force would have appeared, as is shown by Alder Wright's results with modifications of the Daniell cell.* It is well known that when a crystalline metal is treated with a weak acid the crystalline structure is brought out by the dissolving of the crystals, which have been cut through in smoothing the surface of the metal, and there is, therefore, probably a slight difference of electromotive force between a smooth-filed zinc surface and a broken crystalline zinc surface. This difference, however, is too small to be shown on the electrometer with one cell.

(2) Two iodine cells in series, containing a dilute solution of iodine and of iodide of zinc, were raised from 10° C. to 50° C. No variation of electromotive force could be detected, showing that the electromotive force does not vary ·0001 in 1° C.

Consequently the correction, if any, to be applied before calculating the heat of combination from the electromotive force is less than 2 per cent.

One iodine cell, made up with a saturated solution of iodide of zinc, was raised from 17° C. to 70° C. No variation of electromotive force could be detected.

(3) A series of measurements of the electromotive force of the zinc-cuprous iodide cell, with varying strengths of iodide of zinc, were made. The amount of zinc iodide in each solution used was estimated by determining volumetrically the amount of combined iodine.

The temperature of the room during the experiments varied a little above and below 20° C.

The results of the observations are given in the table (*a*) at the end of the paper.

The lowest number given is that obtained in a saturated zinc iodide solution; the highest is that obtained with only distilled water in the cell.

In every case zinc corroded in iodine solution, and then washed, was used. Some very minute traces of zinc iodide were therefore

* *Phil. Mag.*, Jan. 1885.

possibly present in the distilled water, but probably this number should not be taken as being a trustworthy statement of the heat of solution of the first few molecules of iodide of zinc, as the reactions in the cell are very complicated in this case. The next number obtained for a solution of ·003 grms. ZnI_2 in 1 grm. of water is probably safer as a starting-point for a curve.

Evidently the determination of the heat of solution of the first traces of a salt is difficult even by this method, though a much nearer approximation can be obtained than that possible in the calorimeter.

It was noticed, in the case of the stronger solutions, that on first placing the zinc rod, damp with distilled water, in the solution, the electromotive force of the cell was 2 or 3 per cent. too high, quickly falling to a constant value. This was no doubt due to the temporary dilution of a layer of liquid next the zinc, and the effect disappeared on drying the zinc with filter paper.

On looking at the table, it is noticeable that the electromotive force begins to fall off more rapidly again as the solution approaches concentration. This is possibly due to the more concentrated solution containing, as is well known, an excess of zinc, and being in fact no longer zinc iodide. This part of the table requires, however, further investigation.

(4) The variations in the electromotive force, caused by gradually increasing the amount of free iodine in a cell containing a constant amount of zinc iodide, are given in the table (*b*).

The free iodine present was estimated with standard hyposulphite solution in the usual way.

This table requires no particular remark.

(5) Three determinations of the variation of the electromotive force of the zinc iodine cell were made, due to varying the strength of the iodide of zinc, one in an iodine solution in distilled water, one in a zinc iodide solution of medium strength, and one in a saturated iodide of zinc solution. The results are to be found in the table (*c*).*

If these numbers are subtracted from those obtained for corresponding solutions in the cuprous iodide cell, the numbers obtained show that the curve for the zinc iodine cell is slightly different, rising a

* Very similar results have been obtained for sulphates and chlorides by Alder Wright, *Phil. Mag.*, 1884.

little higher for distilled water, and not falling quite so low for saturated iodide of zinc.

On comparing these numbers with those already mentioned as given by Naumann, we find that the number (expressed in volts) which he gives for the heat of combination of zinc and iodine is 1·085 volts. The electromotive force of an iodine cell with about ·04 grm. of free iodine, in saturated iodide of zinc solution, is 1·082 volts. Naumann gives the heat of solution of zinc iodide in water as ·162 volts. The average number obtained from the curve is ·110 volts. The number given by Naumann is higher, because it does not represent the average heat of solution up to a saturated solution of zinc iodide.

In conclusion, I think these experiments are sufficient to show that we have here a method peculiarly suitable for the determination of the heat of solution of salts, as it is possible to study the behaviour of the salt under any required constant conditions.

For instance, the heat of solution of zinc iodide in water containing other salts in solution could be evidently determined with great accuracy by this method. It seems probable that another advantage of the method is that no heat requires to be absorbed in varying the salt from a solid to a liquid state. I have not found any indication that the heat required for this change, in the case of zinc iodide, is at all considerable.

Table (*a*).—*Variations in Electromotive Force caused by varying the Zinc Iodide in solution as measured in the Zinc-Cuprous Iodide Cell.*

Electromotive Force in Volts.	Grms. of ZnI_2 in 1 grm. of Water.
·390	3·870
·419	3·640
·454	2·490
·488	1·860
·545	·537
·607	·236
·637	·118
·656	·059
·696	·029
·771	·003
·894	D.W.

TABLE (*b*).—*Variations in Electromotive Force caused by varying the amount of Iodine dissolved in a solution containing* ·33 *grms. of* ZnI_2 *in* 1 *grm. of water.*

Electromotive Force in Volts.	Grms. of Iodine in 1 c.c.
1·287	·309
1·271	·155
1·271	·077
1·268	·037
1·259	·018
1·238	·005
1·221	·0006

TABLE (*c*).—*Variations in Electromotive Force caused by varying the strength of the Iodide of Zinc in a cell containing* ·014 *grms. of Iodine in* 1 *c.c.*

Electromotive Force in Volts.	Grms. of ZnI_2 in 1 grm. of water.
1·075	3·870
1·303	·118
1·594	D.W.*

On subtracting these from the cuprous iodide members, we get

·686
·667
·719

* Iodine calculated to ·014 grams.

8. On Expressions for the Areas of Rectilineal Figures. By A. H. Anglin, M.A., LL.B., &c.

I. *When the straight lines forming the sides of the figure are referred to two given straight lines at right angles in the plane of the figure*—without reference to the co-ordinates of its angular points.

1. Take OX and OY, two straight lines at right angles to one another in the plane of the figure, as axes of reference; and let the straight lines forming the triangle ABC (fig. 1) meet them in the points A_1, A_2, A_3 and in B_1, B_2, B_3 respectively, the distances from O of the former being in descending, and of the latter in ascending order of magnitude.

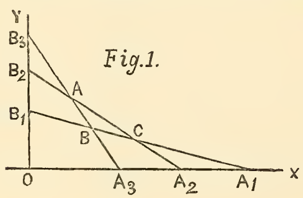


Fig.1.

With the usual notation, let the equations to the sides of the triangle ABC be

$$y = m_1x + c_1, \quad y = m_2x + c_2 \text{ and } y = m_3x + c_3.$$

Then, since twice the area of any triangle ABC is

$$\frac{a^2}{\cot \mathrm{B} + \cot \mathrm{C}},$$

we have

$$2\Delta \mathrm{AB_2B_3} = \frac{(\mathrm{B_2B_3})^2}{\cot \mathrm{B_2} + \cot \mathrm{B_3}} = \frac{(c_3 - c_2)^2}{m_2 - m_3},$$

with similar expressions for the triangles $\mathrm{BB_3B_1}$ and $\mathrm{CB_1B_2}$.

But $$\mathrm{ABC} = \mathrm{AB_3B_2} + \mathrm{CB_1B_2} - \mathrm{BB_1B_3},$$

$$\therefore 2\Delta \mathrm{ABC} = \frac{(c_2 - c_3)^2}{m_2 - m_3} + \frac{(c_3 - c_1)^2}{m_3 - m_1} + \frac{(c_1 - c_2)^2}{m_1 - m_2}.$$

Again, by reference to the triangles formed by OX and the sides of ABC produced, since

$$2\Delta \mathrm{AA_2A_3} = \frac{(\mathrm{OA_2} - \mathrm{OA_3})^2}{\cot \mathrm{A_2} + \cot \mathrm{A_3}} = \frac{(m_2c_3 - m_3c_2)^2}{m_2m_3(m_2 - m_3)},$$

with similar expressions for the triangles $\mathrm{BA_3A_1}$ and $\mathrm{CA_1A_2}$, w have also

$$2\Delta \mathrm{ABC}$$
$$= \frac{(m_2c_3 - m_3c_2)^2}{m_2m_3(m_2 - m_3)} + \frac{(m_3c_1 - m_1c_3)^2}{m_3m_1(m_3 - m_1)} + \frac{(m_1c_2 - m_2c_1)^2}{m_1m_2(m_1 - m_2)}.$$

And each of these expressions for 2ΔABC may be shown to be equal to

$$\frac{\{c_1(m_3 - m_2) + c_2(m_1 - m_3) + c_3(m_2 - m_1)\}^2}{(m_3 - m_2)(m_1 - m_3)(m_2 - m_1)}.$$

We may further observe, that if the equations to the sides of ABC be given in the form $ax + by\ c = 0$, the corresponding expressions for twice the area of the triangle are respectively

$$\frac{(b_3c_2 - b_2c_3)^2}{b_2b_3(a_3b_2 - a_2b_3)} + \frac{(b_1c_3 - b_3c_1)^2}{b_3b_1(a_1b_3 - a_3b_1)} + \frac{(b_2c_1 - b_1c_2)^2}{b_1b_2(a_2b_1 - a_1b_2)},$$

and $$\frac{(c_3a_2 - c_2a_3)^2}{a_2a_3(a_3b_2 - a_2b_3)} + \frac{(c_1a_3 - c_3a_1)^2}{a_3a_1(a_1b_3 - a_3b_1)} + \frac{(c_2a_1 - c_1a_2)^2}{a_1a_2(a_2b_1 - a_1b_2)},$$

each of which expressions may be shown to be equal to

$$\frac{\{c_1(a_2b_3 - a_3b_2) + c_2(a_3b_1 - a_1b_3) + c_3(a_1b_2 - a_2b_1\}^2}{(a_2b_3 - a_3b_2)(a_3b_1 - a_1b_3)(a_1b_2 - a_2b_1)}.$$

2. We shall now deduce corresponding expressions for the area of a quadrilateral, and generally for the area of a rectilineal figure of any number of sides.

The triangle ABC is formed by three lines which we call 1, 2, 3. Denoting the area of the triangle formed by any two lines (1, 2) and either axis, by (12), we have seen that

$$\Delta(\mathrm{ABC}) = (12) + (33) + (31),$$

where (12) stands for either

$$\frac{(c_1 - c_2)^2}{2(m_1 - m_2)} \text{ or } \frac{(m_1c_2 - m_2c_1)^2}{2m_1m_2(m_1 - m_2)},$$

with similar expressions for (23) and (31).

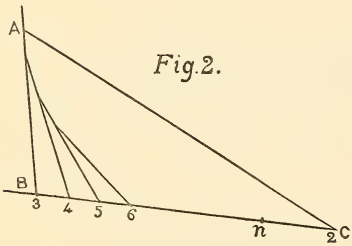


Fig. 2.

Now (fig. 2), let a fourth line be drawn cutting the sides 3 and 1 of the triangle, and so intercepting a quadrilateral formed by the lines 1, 2, 3, 4 in order opposite to that of the hands of a clock. Then

$$\begin{aligned}&\text{Area of quadrilateral } (1234)\\ &= \Delta(123 - \Delta(143)\\ &= (12) + (23) + (31) - (14) - (43) - (31)\\ &= (12) + (23) + (34) + (41);\end{aligned}$$

that is, consists of the four triangles formed by either axis, and the lines of the figure taken two at a time in order round the figure from 1 to 1 in the same direction as before stated.

Again, let a fifth line be drawn cutting the sides 4 and 1 of the quadrilateral, and thus intercepting a pentagon formed by the lines 1, 2, 3, 4, 5 in order as before. Then

$$\begin{aligned}&\text{Area of pentagon } (12345)\\ &= \text{quadrilateral } (1234) - \Delta(154)\\ &= (12) + (23) + (34) + (45) + (51),\end{aligned}$$

which consists of the five triangles formed in the same way as above.

So if a hexagon, heptagon, &c., be constructed in like manner, the line drawn necessary to complete any figure always intersecting the last drawn side of the preceding figure and the line 1, we shall have corresponding expressions for the areas of the figures formed in exactly the same way, and consisting of a series of terms denoting the areas of the triangles formed by either axis and the lines 1, 2, 3, 4, &c., taken two at a time in order all round the figure, each line or number occurring twice; so that if the area of a polygor of $n-1$ sides be

$$(12)+(23)+(34)+(45)+\ldots+(n-2, n-1)+(n+1, 1),$$

drawing an nth line so as to cut the $(n-1)$th line and the line 1, the area of the polygon of n sides so formed will be equal to

$$\text{Area of polygon of } n-1 \text{ sides} - \Delta(1, n, n-1),$$

that is,

$$(12)+(23)+(34)+(45)+\ldots+(n-1, n)+(n1),$$

in which each number from 1 to n, and so each c and m in the equations to the sides, occurs twice, thus showing the truth of the law for a figure of any number of sides.

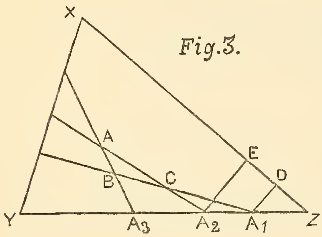
As an algebraical result we may note:—We have seen that the sum of three expressions, involving any three suffixes, of which $\frac{(c_1-c_2)^2}{m_1-m_2}$ is a type, is equal to the sum of three expressions involving the same suffixes, of which $\frac{(m_1c_2-m_2c_1)^2}{m_1m_2(m_1-m_2)}$ is a type, each sum being equal to the same expression of the form $\frac{A^2}{B}$. It follows also from the preceding results, that the sums of 4, 5, 6, . . . , n expressions (selected as indicated above), of the first type are equal to the sums of the corresponding number of expressions of the second type, each sum denoting twice the area of the polygon of the corresponding number of sides—the truth of which may also be shown algebraically, and without reference to the areas of figures. For, completing the series of terms in any case by replacing those terms which cancelled, the expression for the area of a figure will consist of a series of three-termed expressions, each of which denotes the area of a triangle, and is of the form $\frac{A^2}{B}$,—the quadrilateral having two such expressions, the pentagon having three, &c., and the figure of n sides having $n-2$; and such an expression, as we have seen, is obtained whether it is composed of terms of the first or second type.

The same remarks will apply to the pair of expressions

$$\frac{(b_1c_2-b_2c_1)^2}{b_1b_2(a_1b_2-a_2b_1)} \text{ and } \frac{(c_1a_2-c_2a_1)^2}{a_1a_2(a_1b_2-a_2b_1)}.$$

II. *When the straight lines forming the sides of the figures are referred to three given intersecting straight lines in the plane of the figure.*

The method employed is uniform with the first method.



1. Let XYZ (fig. 3), the triangle formed by the three given straight lines, be taken as the triangle of reference, the position of any point being determined by its distances (α, β, γ) from the sides.

With the usual notation, let the equations to the sides of the triangle ABC, whose area we seek, be

$$l_1\alpha+m_1\beta+n_1\gamma=0, \quad l_2\alpha+m_2\beta+n_2\gamma=0, \quad l_3\alpha+m_3\beta+n_3\gamma=0,$$

and suppose the sides when produced to meet YZ $(\alpha=0)$ in the points A_1, A_2, A_3. Then

$$\Delta ABC=\Delta AA_2A_3+\Delta CA_1A_2-\Delta BA_1A_3.$$

Now $2\Delta CA_1A_2=A_1A_2\times$ the α of the point C, that is, of the point of intersection of the lines $l_1\alpha+m_1\beta+n_1\gamma=0$ and $l_2\alpha+m_2\beta+n_2\gamma=0$, which is given by

$$\frac{\alpha}{m_1n_2-m_2n_1}=\frac{\beta}{n_1l_2-n_2l_1}=\frac{\gamma}{l_1m_2-l_2m_1}=\frac{2\Delta}{\begin{vmatrix} a, & b, & c \\ l_1, & m_1, & n_1 \\ l_2, & m_2, & n_2 \end{vmatrix}},$$

Δ denoting the area of the triangle of reference, and a, b, c its sides.

And, A_1D, A_2E being perpendiculars on XZ,

$$A_1A_2 = ZA_2 - ZA_1 = \frac{A_2E - A_1D}{\sin Z}$$

$$= \frac{2\Delta}{\sin Z}\left(\frac{n_2}{bn_2 - cm_2} - \frac{n_1}{bn_1 - cm_1}\right)$$

$$= \frac{abc(m_2n_1 - m_1n_2)}{(bn_1 - cm_1)(bn_2 - cm_2)},$$

since A_1D is the β of the point of intersection of the lines $\alpha = 0$ and $l_1\alpha + m_1\beta + n_1\gamma = 0$, A_2E being obtained in like manner.

Thus $$\Delta CA_1A_2 = \frac{abc\Delta \times (\quad)(m_1n_2 - m_2n_1)^2}{-\begin{vmatrix} a, & b, & c \\ l_1 & m_1 & n_1 \\ l_2 & m_2 & n_2 \end{vmatrix}(bn_1 - cm_1)(bn_2 - cm_2)},$$

which is the corresponding expression to $\frac{(c_1 - c_2)^2}{m_1 - m_2}$ in Case I. Similar expressions holding for the triangles AA_2A_3 and BA_3A_1, we shall get

$$\Delta ABC = (23) + (12) + (31),$$

which may be shown to be equal to the expression

$$\frac{\Delta abc\{l_1(m_2n_3 - m_3n_2) + l_2(m_3n_1 - m_1n_3) + l_3(m_1n_2 - m_2n_1)\}^2}{\begin{vmatrix} a, & b, & c \\ l_2 & m_2 & n_2 \\ l_3 & m_3 & n_3 \end{vmatrix}\begin{vmatrix} a, & b, & c \\ l_3 & m_3 & n_3 \\ l_1 & m_1 & n_1 \end{vmatrix}\begin{vmatrix} a, & b, & c \\ l_1 & m_1 & n_1 \\ l_2 & m_2 & n_2 \end{vmatrix}} \quad (A)$$

We may observe (as possessing an algebraical interest), that by considering in like manner the triangles intercepted by the other sides ZX ($\beta = 0$) and XY ($\gamma = 0$) of the triangle of reference, we shall obtain two other expressions for the area of the triangle ABC in the form $(12) + (23) + (31)$, namely, those in which (12) denotes respectively

$$\frac{k(n_1l_2 - n_2l_1)^2}{(cl_1 - an_1)(cl_2 - an_2)} \text{ and } \frac{k(l_1m_2 - l_2m_1)^2}{(am_1 - bl_1)(am_2 - bl_2)},$$

in which k stands for the common factor $\frac{\Delta abc}{-\begin{vmatrix} a, & b, & c \\ l_1 & m_1 & n_1 \\ l_2 & m_2 & n_2 \end{vmatrix}}$,

with similar expressions for (23) and (31); and thus the sum of three similar terms involving the same letters, of which *any one* of the above three expressions for (12) is a type, is the same, that sum denoting the area of the triangle ABC and being equal to the expression (A).

Further we may notice that if the sides of the triangle ABC be given by equations of the form $lx + my + nz = 0$, where x, y, z denote the *areal* co-ordinates of a point, corresponding results will be obtained by writing la, mb, nc, for l, m, n respectively; or, which comes to the same thing, by putting $a = b = c = 1$ in any expression denoting an area.

Thus, in areal co-ordinates, the value of (12) is

$$\frac{\Delta(m_1n_2 - m_2n_1)^2}{(m_1 - n_1)(m_2 - n_2)\begin{vmatrix} l_1 & m_1 & n_1 \\ l_2 & m_2 & n_2 \\ 1, & 1, & 1 \end{vmatrix}},$$

and the area of triangle ABC is

$$\frac{\Delta\begin{vmatrix} l_1 & m_1 & n_1 \\ l_2 & m_2 & n_2 \\ l_3 & m_3 & n_3 \end{vmatrix}^2}{\begin{vmatrix} l_2 & m_2 & n_2 \\ l_3 & m_3 & n_3 \\ 1, & 1, & 1 \end{vmatrix}\begin{vmatrix} l_3 & m_3 & n_3 \\ l_1 & m_1 & n_1 \\ 1, & 1, & 1 \end{vmatrix}\begin{vmatrix} l_1 & m_1 & n_1 \\ l_2 & m_2 & n_2 \\ 1, & 1, & 1 \end{vmatrix}}.$$

2. The area of a quadrilateral, and generally of a figure of n sides, may be deduced in the same manner as in Case I. We thus get, Δ_n denoting the area of a figure of n sides,

$$\Delta_n = (12) + (23) + (34) + (45) + \ldots + (n - 1, n) + (n1),$$

in which (12) denotes any one of the three expressions obtained above as its value, with similar corresponding expressions for the other $n - 1$ terms of the series.

And we may notice, as an algebraical result, in addition to that already stated for the case of three expressions, that the sums of 4, 5, 6, . . . , n expressions (selected and having signs as indicated above), of which any one of the above three expressions for (12) is a type, are equal to the sums of the corresponding number of expressions of each of the other types, each sum denoting the area of the polygon of the corresponding number of sides—the truth of which may also be shown, as in Case I., without reference to the areas of figures. For, completing the series of terms in any instance, the expression for the area of a figure will consist of a series of symmetrical expressions similar to (*A*); and such an expression, as we have seen, is obtained whether it be composed of terms of the first, second, or third type.

III. *When the straight lines forming the sides of the figures are referred to a given point in the plane of the figure.*

1. Let O (fig. 1) be the given point; and suppose, for the present, OX to be a fixed straight line through O. We shall adopt a method uniform with the foregoing methods.

With the usual notation, let the equations to the sides of the triangle ABC be

$$x \cos \alpha_1 + y \sin \alpha_1 - p_1 = 0,\ (\alpha_2, p_2) = 0,\ (\alpha_3, p_3) = 0,$$

where α_1, α_2, α_3 are in descending order of magnitude. Then

$$2\Delta CA_1A_2 = \frac{(A_1A_2)^2}{\cot A_1 + \cot A_2} = \frac{(p_1 \sec \alpha_1 - p_2 \sec \alpha_2)^2}{\tan \alpha_1 - \tan \alpha_2}$$

$$= \frac{(p_1 \cos \alpha_2 - p_2 \cos \alpha_1)^2}{\cos \alpha_1 \cos \alpha_2 \sin (\alpha_1 - \alpha_2)},$$

with similar expressions for the triangles BA_3A_1 and AA_2A_3.

Also, by reference to the triangles intercepted by OY, we shall get

$$2\Delta CB_1B_2 = \frac{(B_1B_2)^2}{\cot B_1 + \cot B_2} = \frac{(p_1 \operatorname{cosec} \alpha_1 - p_2 \operatorname{cosec} \alpha_2)^2}{\cot \alpha_2 - \cot \alpha_1}$$

$$= \frac{(p_1 \sin \alpha_2 - p_2 \sin \alpha_1)^2}{\sin \alpha_1 \sin \alpha_2 \sin (\alpha_1 - \alpha_2)},$$

similar expressions holding for the triangles BB_3B_1 and AB_2B_3.

Thus, denoting either of the two expressions obtained by (12), we have

$$2\Delta ABC = (12) - (13) + (23);$$

and each of these expressions for $2\Delta ABC$ may be shown to be equal to

$$\frac{\{p_1 \sin (\alpha_2 - \alpha_3) + p_2 \sin (\alpha_3 - \alpha_1) + p_3 \sin (\alpha_1 - \alpha_2)\}^2}{\sin (\alpha_2 - \alpha_3) \sin (\alpha_3 - \alpha_1) \sin (\alpha_1 - \alpha_2)}.$$

The corresponding expression for a figure of n sides is

$$(12)+(23)+(34)+(45)+\ldots+(n-1,\ n)+(n1),$$

the terms of which may be of either form of expression above obtained for (12). And, as an algebraical result, it may be shown, as in Case I., that the sum of n expressions in the form of this series is the same, whether the terms of the series be of the form

$$\frac{(p_1 \sec \alpha_1 - p_2 \sec \alpha_2)^2}{\tan \alpha_1 - \tan \alpha_2} \text{ or } \frac{(p_1 \operatorname{cosec} \alpha_1 - p_2 \operatorname{cosec} \alpha_2)^2}{\cot \alpha_2 - \cot \alpha_1}.$$

2. We can now obtain a very interesting form of expression for the area of a figure involving the distances of its sides from the given point, and without reference to the lines OX and OY.

Since $\alpha_2 - \alpha_3$ is the angle between the perpendiculars on the lines 2, 3 it is equal to the angle between the lines themselves, that is the $\angle A$ of the triangle ABC. The expression for 2ΔABC thus becomes

$$\frac{(p_1 \sin \mathrm{A} - p_2 \sin \mathrm{B} + p_3 \sin \mathrm{C})^2}{\sin \mathrm{A} \sin \mathrm{B} \sin \mathrm{C}},$$

which may also be appropriately written with $\widehat{23}$, $\widehat{31}$, $\widehat{12}$ for A, B, C respectively.

When the point O is *within* the triangle, the expression for twice its area is $(p_1 \sin \mathrm{A} + p_2 \sin \mathrm{B} + p_3 \sin \mathrm{C})^2 \div \sin \mathrm{A} \sin \mathrm{B} \sin \mathrm{C}$; and we observe that the necessary change in the sign of p, when the point is outside the figure, is made by the same rule as when the area is given in the form $p_1 a + p_2 b + p_3 c$ (a, b, c being the sides), and can be seen by inspection.

In the case of a quadrilateral we have

$$2 \text{ Area} = (12) + (23) + (34) + (41).$$

Using for (12), &c., the form of expression

$$\frac{(p_1 \operatorname{cosec} \alpha_1 - p_2 \operatorname{cosec} \alpha_2)^2}{\cot \alpha_2 - \cot \alpha_1},$$

expanding and collecting the terms in p^2, we find the expression involving p_1^2 (which consists of the difference of two terms), is

$$\frac{p_1^2 \operatorname{cosec}^2 \alpha_1 (\cot \alpha_4 - \cot \alpha_2)}{(\cot \alpha_2 - \cot \alpha_1)(\cot \alpha_4 - \cot \alpha_1)},$$

that is,

$$\frac{p_1^2 \sin (\alpha_2 - \alpha_4)}{\sin (\alpha_1 - \alpha_2) \sin (\alpha_1 - \alpha_4)},$$

which on completing, so as to have the denominator which is common to all the terms, is

$$\frac{p_1^2 \sin(2, 3, 4)}{\sin(1, 2, 3, 4)},$$

where $\sin(2, 3, 4)$ denotes the product of the sines of $\alpha_2 - \alpha_3$, $\alpha_2 - \alpha_4$, and $\alpha_4 - \alpha_3$, that is, the product of the sines of the angles of the figure formed by the lines 2, 3, 4; while the denominator denotes the product of the sines of the angles of the quadrilateral. Similar expressions holding for the coefficients of p_2^2, p_3^2, and p_4^2, we have

$$2\text{ Area} = \frac{\Sigma p_1^2 \sin(2, 3, 4)}{\sin(1, 2, 3, 4)} - 2\Sigma\frac{p_1 p_2}{\sin(1, 2)},$$

each summation consisting of 4 terms.

And generally, for a figure of n sides, we shall get in like manner

$$2\text{ Area}(1, 2, 3, \ldots n)$$

$$= \frac{\Sigma p_1^2 \sin(2, 3, 4, \ldots n)}{\sin(1, 2, 3, 4, \ldots n)} - 2\Sigma\frac{p_1 p_2}{\sin(1, 2)},$$

each summation consisting of n terms, the figure $(2, 3, 4, \ldots n)$ being formed by the sides $3, 4, \ldots n-1$ and the sides $2, n$ produced.

With regard to the signs of the terms in these series, we observe, in respect of the angles $\alpha_1, \alpha_2, \alpha_3, \ldots \alpha_n$ (see fig. 2), that α_1 is the greatest and α_3 the least; also $\alpha_4, \alpha_5, \ldots \alpha_n$ are in ascending order of magnitude, while α_2 may be $\gtrsim$ or $\angle$ any of these latter angles. Thus the actual coefficients of $p_3^2, p_4^2, \ldots p_n^2$ are all negative, that of p_2^2 is positive, while the coefficient of p_1^2 is positive or negative according as the last drawn line of any figure makes with BC an angle $\gtrsim$ or $\angle$C. But the figure $(1, 3, 4, \ldots n)$ has re-entrant angles at the points (4, 5), (5, 6), &c., so that the expression $\sin(1, 3, 4, \ldots n)$, the apparent coefficient of p_2^2, is negative. Also if p_n make with BC an angle $\gtrsim$C the figure $(2, 3, 4, \ldots n)$ has re-entrant angles at the points (34), (45), &c., so that the expression $\sin(2, 3, 4, \ldots n)$ is also negative. With regard to the signs of the products, they are all positive except those of $p_1 p_2$ and $p_2 p_3$, that is, except those in which p_2 occur.

Hence, the expression for twice the area of figure (1, 2, 3, . . . n) may be written

$$2\Sigma\frac{p_1 p_2}{\sin(1, 2)} - \frac{\Sigma p_1{}^2 \sin(2, 3, 4, \ldots n)}{\sin(1, 2, 3, 4, \ldots n)},$$

where all the terms in Σp^2 are positive, while all those in the first series are positive except those in $p_1 p_2$ and $p_2 p_3$. In the corresponding expression, when the point O is within the figure, all the signs in both series are positive; and we observe that the necessary change of sign, for an external point, is made according to the rule stated above (in this particular instance by writing $-p_2$ for p_2), the truth of which is evident on inspection of the figure.

3. Lastly, we may deduce the results for *regular* polygons.

Denoting the angle of a regular polygon of n sides by $\pi - \theta$, so that $\theta = \frac{2\pi}{n}$, we have

$$\begin{aligned}\sin(2, 3, 4, \ldots n) &= (\sin\theta)^{n-2} \sin 2\theta \\ &= 2 \sin^{n-1}\theta \cos\theta .\end{aligned}$$

Thus the expression for the area of the polygon becomes

$$\operatorname{cosec}\theta . \Sigma p_1 p_2 - \cot\theta . \Sigma p_1{}^2 ,$$

the signs of the terms in each series being the same as before.

If the point O be the centre of the figure, all the p's are equal to one another, each being equal to r the radius of the inscribed circle of the polygon; and thus the area becomes

$$\begin{aligned} & nr^2(\operatorname{cosec}\theta - \cot\theta) \\ &= nr^2 \tan\frac{\theta}{2} \\ &= nr^2 \tan\frac{\pi}{n} ,\end{aligned}$$

the usual expression for the area of a regular polygon of n sides in terms of the radius of the inscribed circle.

Note.—In the case of an equilateral triangle and a square, the above expression for area reduces to particular forms: in the former case to $\frac{1}{3}\sqrt{3}(p_1 \pm p_2 + p_3)^2$, and in the latter to $(p_1 + p_3)(p_4 \pm p_2)$, according as the point O is within or without the line 2, the truth of which is obvious on inspection of the figures.

9. On Pitchered Insectivorous Plants. Part II. By J. M. Macfarlane, D.Sc.

10. Note on the Salinity of the Tay Estuary and of St Andrews Bay. By Hugh Robert Mill, B.Sc., F.C.S.

In January I read a paper on the salinity of the Firth of Forth,* in which the law governing the distribution of salt in that estuary was pointed out. It appeared that in the eastern or seaward part of the Firth the change in mean salinity per mile was very slight, and the tidal range was small, while both decreased gradually as the sea was approached. On the other hand, the riverward half of the Firth showed a rapid alteration in density along its length, and a correspondingly great range between high and low tide.

The estuary of the Tay is shorter, narrower, and shallower than that of the Forth, and the river is much larger, of great volume, and more rapid. It might then be expected that the condition of the seaward part of the Firth of Tay would resemble that of the riverward portion of the Forth in its main characteristics, while the sea around the mouth of the estuary would be perceptibly freshened.

A slight dip in the salinity curve at the Isle of May was referred to in the paper cited above,† and the suggestion was thrown out that this might be due to the diluting action of the fresh water of the Tay. This hypothesis has been confirmed by observations made during the first week of June 1885.

The Scottish Marine Station's yacht "Medusa" went from Granton to the Tay on June 2nd, when water samples were collected at regular intervals both from the surface and the bottom. These were afterwards examined, the density determined as described previously,‡ and reduced to 15°·56 C. to admit of comparison with other observations. The result of this day's work is shown in Table I.

Table I.

Position,	Off Inchkeith.	Off Elie.	Off Crail.	St Andrews Bay.	Tay Fairway Buoy.
Tide,	$1\frac{1}{2}$ hr. ebb.	4 hrs. ebb.	l. w.	1 hr. fld.	$1\frac{3}{4}$ hr. flood.
Surface density,	1·02488	1·02547	1·02537	1·02505	1·02435

* *Proc. Roy. Soc. Edin.*, xiii. pp 29–64.

† *Ibid.*, p. 53.

‡ *Ibid.*, p. 35.

Table I.—*continued.*

Position,	Tay Lightship.	Lady Buoy.	Off Tayport.		Off Dundee.
Tide,	$1\frac{3}{4}$ hr. flood	2 hrs. fld.	$2\frac{1}{2}$ hrs. fld.	$5\frac{1}{2}$ hrs. fld.	h.w.
Surface density,	1·01991	1·01760	1·01282	1·01734	1·01394
Bottom density,	1·02381 (10 fm.)	...	...	...	1·01457

This indicates the increase of salinity from Inchkeith to off Elie, and then its increasingly rapid decrease to the mouth of the Firth of Forth, across St Andrews Bay, and up the Tay as far as Dundee. The tide being on the ebb to Crail, increases the apparent rate of freshening very slightly, while its flowing reduces it to a greater degree in the latter part of the journey.

While returning from the Tay to Anstruther, the following series of observations was obtained (Table II.). The course was out of the river and eastward until about 7 miles beyond the Fairway Buoy; S.W. until the North Carr Rock at the entrance to the Firth of Forth was sighted about $1\frac{1}{2}$ mile off, then northwards near the shore until close on Abertay Sands, and finally southward, keeping about a mile off shore until arrival at Anstruther. All this area was freshened more or less by the Tay, taking as a standard of average salinity the usual state of the water between St Abb's Head and the Isle of May. Off St Andrews the water was slightly salter at low than at high tide, a fact which may be accounted for by the drying of the Abertay sandbanks, about half ebb, leading the brackish flow of the river further east than at high tide.

Table II.

Position,	Tayport.	Lady Buoy.	Abertay Lightship.	Fairway Buoy.	7 miles E. of Fairway.
Tide,	$1\frac{1}{2}$ hr. fld.	2 hrs. fld.	$2\frac{3}{4}$ hrs. fld.	3 hrs. fld.	4 hrs. fld.
Surface density,	1·02184	1·02325	1·02379	1·02424	1·02486
Bottom density,	...	...	1·02514	...	1·02543

Position,	$1\frac{1}{2}$ mile N.E. of N. Carr.	Bet. N. Carr and Kingsbarns.	$1\frac{1}{2}$ mile off St Andrews.	S. end of Abertay Sands.
Tide,	5 hrs. flood.	h. w.	1 hr. ebb.	$1\frac{3}{4}$ hr. ebb.
Surface density,	1·02491	1·02468	1·02490	1·02468
Bottom density,	...	...	1·02516	1·02511
Position,	Off St Andrews.	Off Kingsbarns.	Off N. Carr.	Off Anstruther.
Tide,	$4\frac{1}{2}$ hrs. ebb.	$5\frac{1}{2}$ hrs. ebb.	l. w.	1 hr. fld.
Surface density,	1·02510	1·02484	1·02512	1·02539

These observations, while insufficient to trace out the form of the brackish area beyond the mouth of the Firth of Tay, show that St Andrews Bay is affected with the fresher water, and that the Firth of Forth to a few miles west of the May Island is also slightly freshened. Both these effects must be subject to variations from the direction of the wind and the amount of flood in the river. Until further examination is made, speculation on the subject of the general variation of salinity along the coast had better be postponed; but it is certain that if such work could be carried out valuable results would be obtained.

The following are the densities of the water samples collected in the estuary of the Tay (Table III.):—

TABLE III.

Position,	Perth	Newburgh.	
Date,	May 27	May 26	May 26
Tide,	h. w.	h. w.	l. w
Depth,	2 fm.	2 fm.	...
Surface density,	...	0·99931	0·99910
Bottom density,	0·99920	0·99934	...

Position,	The Kirk (5 miles below Newburgh.				Bet. Birkhall Bank and Tay Bridge.
Date,	May 26	May 26	June 3	June 3	June 3
Tide,	$2\frac{1}{2}$ hrs. ebb.	$1\frac{1}{2}$ hr. fld.	$3\frac{1}{2}$ hrs. fld.	h. w.	2 hours fld.
Depth,	3 fm.	5 fm.	$3\frac{1}{2}$ fm.	...	$4\frac{3}{4}$ fm.
Surface density,	1·00491	0·99910	1·00140	1·00286	1·00395
Bottom density,	1·00807	0·99940	1·00122	...	1·00492

Position,	Off Dundee.					
Date,	May 26	May 26	June 2	June 3	June 3	June 3
Tide,	4 hrs. ebb.	l. w.	h. w.	$4\frac{1}{2}$ hrs. ebb.	$1\frac{1}{2}$ hr. fld.	1 hr. ebb.
Depth,	...	3 fm.	...	...	4 fm.	...
Surface density,	1·00874	1·00413	1·01394	1·01358	1·00909	1·01500
Bottom density,	...	1·00413	1·01457	...	...	...

Position,	Off Tayport.				
Date,	June 2	June 2	June 3	June 3	June 4
Tide,	$2\frac{1}{2}$ hrs. fld.	$5\frac{1}{2}$ hrs. fld.	5 hrs. ebb.	1 hr. fld.	$1\frac{1}{2}$ hr. fld.
Depth,	...	...	9 fm.	...	...
Surface density,	1·01282	1·01734	1·01459	1·01813	1·02184
Bottom density,	...	...	...	...	...

Position,	Abertay Lightship.		
Date,	June 2	June 3	June 4
Tide,	$1\frac{3}{4}$ hr. fld.	l. w.	$2\frac{3}{4}$ hrs. fld.
Depth,	9 fm.	6 fm.	10 fm.
Surface density,	1·01991	1·01919	1·02379
Bottom density,	1·02381	1·02183	1·02514

This table shows that, as on the Forth, but in a more pronounced manner, the effects of tide and of flooding in the river are very considerable in the upper part of the estuary; so much so that the observations recorded above are of almost no use in determining the normal salinity of the Firth of Tay at any point. The serial densities observed on each day when plotted in a curve, show a state of matters very similar to that existing in the Forth. From Newburgh to the Abertay Lightship corresponds in regard to surface salinity with the stretch of the Forth from Alloa to Queensferry, but the closer proximity to the open sea produces its effect in raising the salinity of the bottom water about the mouth of the Tay.

It appears that in the Tay, while the salt sea water runs up along the bottom so as to produce a very marked difference in the density of the bottom and surface water at the Lightship, it is rapidly mixed as it passes on, no doubt on account of the shallowness of the channel and the strength of the current.

The position of the highest point to which brackish water extends in the Tay at high water is effected by the amount of tidal rise and of flooding in the river. In summer it is said to be always undrinkable at high water at Newburgh; while some fishermen say that the salt can be tasted at Perth during very dry summer weather and at high spring tides.

Although not connected with the salinity, the colour of the water when looked down into on a clear day may be noted. At Newburgh it is a clear amber-brown, which lower down becomes a little muddy, and as the salt manifests itself a green tint is added, so that at Tayport it is an exquisite olive-green, a colour which prevails with a lessening of the brown ingredient right across St Andrews Bay. This contrasts with the pale muddy green of the upper reaches of the Firth of Forth, which gives place to a deeper and more transparent blue-green tint as the Isle of May is approached. The effect is very much that which would be produced if a green liquid (*e.g.*, solution of dark transparent cupric chloride) were diluted gradually with water for the Forth, and with a brownish-yellow liquid (*e.g.*, very dilute ferric chloride solution) for the Tay.

11. Concluding Address by David Milne Home, Vice-President.

At this, the concluding meeting of the Session, some observations and information are expected from the Chairman for the night, and which I now, at the request of the Council, proceed to offer.

During the past Session there have been sixteen ordinary meetings of the Society for the reading of papers, which may be classed under the following heads:—22 in Natural Philosophy, 11 in Chemistry, 10 in Mathematics, 7 in Physiology, 6 in Meteorology, 4 in Zoology, 3 in Mineralogy, 3 in Geology, 1 in Anthropology, 1 in Astronomy, and 1 in Mechanics.

The total number of papers is 72, being two more than the average of the last two years.

It will be observed, that all these papers are on branches of *Physical Science.* There have been none of a *literary character*—though literature is one of the objects which our Society was intended to encourage—and though Lord Moncreiff, till lately our President, has more than once, from this Chair, expressed a wish and a hope that there would be contributions to our meetings under that head also.

But this object, I fear, it is difficult to accomplish. The discoveries and speculations of a scientific nature are now so important and so urgent, that they crowd in upon every Society which will admit them; whilst, on the other hand, speculations in mental philosophy come before the public more readily, and perhaps more suitably, through the columns of innumerable magazines, journals, reviews, and newspapers, published monthly, weekly, or daily.

I see from looking at some of the addresses delivered from this Chair at the close of a Session, that it has occasionally been the practice to express an opinion regarding the merits of the papers read. I shrink from following that practice, first, because of not having heard any of the papers; and, more particularly, because I frankly avow my incompetence to form an opinion on three-fourths of the papers, judging from their titles. But in our Society there is some guarantee that any papers by Fellows of our Society shall not be unworthy of it, because we admit no person to become a

Fellow who is not recommended and vouched for by trustworthy persons, as having a taste for and a knowledge of either scientific or literary subjects; and having been myself on many occasions a member of Council, before which applications for admission come, I know that this rule is honestly acted on.

I do not find that this rule keeps back any whom we would desire to welcome within our walls. During the past Session the number of Fellows admitted was twenty-five, whereas the average number during the four previous years was twenty.

I am sorry to say, however, that during the past year an unusual number of deaths among our members has occurred—one in the Honorary class, thirteen in the Ordinary class.

The *Honorary* Fellow deceased was *Professor von Siebold*, who died last spring at the age of eighty-one. For the last thirty years of his life he was Professor of Zoology and Comparative Anatomy in the University of Munich. He is said to have written altogether 130 scientific papers, several of which were so appreciated in this country, that they were translated into English by Professor Huxley and Mr Dallas. *Von Siebold* was a corresponding member of the French Institute, and a honorary member of the Royal Society of London.

Of the deceased Fellows in our *Ordinary* class, the first name to be mentioned is that of *Sir Alexander Grant*, the distinguished Principal of Edinburgh University, who died on 1st December 1884. He was the representative of a branch of the Seafield family, and inherited a baronetcy which had been conferred in the year 1688.

Though eminently qualified to take part in the business of our Society, especially in the department of literature, Sir Alexander Grant's other important duties too much engrossed his attention, to allow him to do more than deliver an address at the commencement of one of our Sessions, and to give several obituary notices.

At Oxford University, as a student, he distinguished himself by his attainments in classics, philosophy, and general literature, and whilst resident there, he brought out the edition of Aristotle's Ethics, with English notes, which at once stamped him as an eminent scholar and a man of intellectual power. His first appointment to a post of duty was that of Inspector of Schools at Madras. A few years afterwards he was elected to the higher position of Professor of History in Elphinstone College. Subsequently he was promoted to be Vice-Chancellor of Elgin College, Bombay, which last position he held for four years, till 1868, when he was chosen to be Principal of Edinburgh University.

In all these positions Sir Alexander threw himself earnestly and enthusiastically into the work which these positions implied, and at the same time by his genial spirit he gained the hearty co-operation of all with whom he came in contact. To the academic interests of the students of our University he especially devoted himself, not only by opening almost every winter session with an address full of encouragement and good advice, but by aiding them in organising for themselves a Representative Council and a Students' Union.

The immense efforts made by Sir Alexander Grant during the last year of his life, to celebrate suitably the Tercentenary of our University, were probably the cause of the failure of health which supervened when these labours were over. The compilation and publication during the previous winter of two volumes on the History of the University; the arrangements for bringing to Edinburgh in the spring of 1884, from all parts of the world, men of academic renown, and the organisation necessary for providing suitable hospitality to these distinguished strangers; whilst these things acted as a stimulus at the time, they left Sir Alexander, when the celebration was over, in a state of prostration, from which, notwithstanding a holiday taken during the summer in Derbyshire, he never recovered.

I might say much more, especially in reference to what our distinguished associate did for the extension of our University Buildings. But this is not the opportunity, nor am I the person, to enlarge on this subject. I have no doubt there will be laid before us, by some one of our number (who knows better than I do his character, and his deeds of usefulness), a fuller and better biographical account than I can venture on.

It was only a becoming tribute of general esteem and respect, that the civic authorities of Edinburgh resolved that there should be a public funeral. It was attended not only by all the professors and students of our University, but by representatives from every scientific and literary society in Edinburgh.

The next deceased Fellow whose name I mention, is the *Rev.*

Dr Lindsay Alexander. He died at his residence in the parish of Inveresk on 20th December 1884.

He was for a time one of our Vice-Presidents; and he frequently attended our meetings, and took an interest in our discussions. But I am not aware that he contributed any paper beyond an address at the opening of one of our Sessions, and several obituary notices.

Born in Leith, and obtaining his earliest education at our High School, he subsequently went to St Andrews University to attend Dr Chalmers' Lectures on Moral Philosophy. At the early age of nineteen he became Professor of Classics and Mathematics in one of the Theological Training Colleges of the English Congregationalists. After holding that position for four years, he occupied in Liverpool a chapel as a lay preacher; and he thereafter resolved to follow that profession for life.

With that view he went to Germany to attend theological lectures, and on his return to Edinburgh received an appointment as minister of the Independent Congregation then meeting in Argyll Square; after which he became minister of the handsome building in George IV. Bridge, called the Church of St Augustine, erected at a cost of £15,000, and where he continued for about twenty years, till he resigned from failing health.

He was deeply reverenced by the members of his congregation, and much respected by persons of other denominations, who frequently went to listen to his discourses; two of whom were, I know, Dean Ramsay and his brother Admiral Ramsay, who were always with him on terms of social intercourse.

Dr Lindsay Alexander was a man of a tolerant and liberal spirit. I remember when, some years ago, it was proposed to give a testimonial to the Rev. Mr Beveridge, the parish minister of Inveresk, on his completing the fiftieth year of his ministry there, Dr Alexander not only joined in the subscription, but went to the public meeting where the testimonial was presented, and spoke in commendation of Mr Beveridge.

Dr Lindsay Alexander was distinguished for his scholastic knowledge. His acquaintance with theological works was so great, that he was appointed to the Theological Hall of the Congregational body, first as Professor of Systematic Theology, and afterwards as

Principal of the College. He was also a member of the committee for revising the authorised version of the Old Testament.

He published several treatises, chiefly theological. He contributed articles to the eighth edition of the *Encyclopædia Britannica* on "Moral Philosophy" and "Scripture Theology." The collection of hymns now used in the Augustine Church was entirely composed by him.

In these circumstances, it was natural that Dr Alexander should receive many public testimonials of the esteem in which he was held. In February 1876, on the completion of the fortieth year of his ministry, the congregation of his church presented to him an address, from which I quote these words, "to express their grateful recognition of his profound learning, and of the fearless fidelity and true Christian love with which he had discharged the duties of his sacred office." Since his death, as I see from to-day's newspapers, a marble bust was placed last Saturday in the corridor of Augustine Chapel, bearing Dr Lindsay Alexander's name, as "the honoured minister of this Church for forty-three years; eminent as a theologian, preacher, and scholar."

Professor Fleeming Jenkin, who died suddenly only a few weeks ago, was Professor of Engineering in Edinburgh University, being the first who occupied that chair. He was skilled in various branches of engineering, especially in electricity with reference to its mechanical applications. For several years he worked in connection with Sir William Thomson of Glasgow University in the manufacture and laying down of several great submarine telegraph lines. During the last two years of his life he is said to have occupied himself in endeavouring to invent a system of electrical locomotion, to which he proposed to give the name of "*Telpherage*."

In the year 1877 he gave two lectures before the Edinburgh Philosophical Institution on "Sanitary Houses," which created so much interest that they led to the formation of the Edinburgh Sanitary Protection Association, the first of its kind, and the usefulness of which has been so generally acknowledged that it has led to the formation of similar associations elsewhere.

Professor Jenkin was the author of numerous important papers, which appeared in magazines and reviews—one on Magnetism and Electricity (published in 1883), so much appreciated that it was translated into German and Italian.

Professor Jenkin began his education at a school in Jedburgh, from which he passed to the Edinburgh Academy. Subsequently he visited Germany, France, and Italy, staying in each country long enough to master the language. He took his M.A. degree at Genoa University, after which he proceeded to Marseilles, where he began the practical work of life in the employment of a Locomotive Steam-engine Company. Thereafter he returned to England, and, becoming an associate of the Institute of Civil Engineers, soon advanced into more extended and profitable employment.

Thomas C. Archer, Director of the Museum of Science and Art, died on 17th February last, very suddenly, in a hotel in London, whilst speaking to his daughter, though then apparently in his usual health.

He had been in charge of our Museum since the year 1860, having been appointed on the death of Professor George Wilson, who was then Director of that Institution.

Mr Archer directed his whole time and thought to the procuring of objects of interest for the Museum, not only by purchases at the expense of Government, but even by occasionally obtaining temporary loans for exhibition of valuable objects from individuals to whom they belonged.

He went frequently to the Continent in search of specimens, and in 1876 he was sent as Joint British Commissioner to the Philadelphia Exhibition of Arts and Industry. He had great business tact, and, in particular, never omitted any favourable opportunity of pressing the Government for additional grants to extend or enlarge the buildings, to accommodate the stores he collected, and of which he generally contrived to show a supply in boxes unpacked, to prove the necessity of more space for his treasures.

I am not aware that he ever took any part in the business of our Society.

Professor Morrison Watson, who died on the 25th March last, at the early age of thirty-nine, began his short life of usefulness by receiving his educational training in Edinburgh. He took a degree in our University as Doctor of Medicine, receiving for his thesis a gold medal. He became Fellow of the Royal College of Physicians, a Fellow of our Royal Society, and subsequently a Fellow of the Zoological Society of London. For some years he was Demonstrator of Anatomy in Edinburgh University, under Professor Goodsir and Professor Turner. In 1874, on the amalgamation of the Manchester Medical School and Owens College, he was elected there Professor of Anatomy. Whilst holding that appointment he wrote valuable papers on zoological subjects, the last being an elaborate memoir of above 200 quarto pages on the *Penguin*, from notes taken during the voyage of the "Challenger."

Professor Morrison Watson's career of usefulness was cut short in a strikingly impressive manner. Whilst delivering a lecture to his students he suddenly became speechless and unconscious, owing, as was afterwards discovered, to the rupture of a blood-vessel in the head. So precarious was his condition, that for three weeks he could not be moved from the college. He was then carried to a convalescent hospital adjoining the college, but he survived there only a few days.

General Sir James Alexander, K.C.B., of Westerton (Stirlingshire), who died a few weeks ago, occasionally attended our meetings, but I am not aware that he contributed any papers.

As an officer in a Scotch regiment, he saw much active service in foreign lands, viz., New Zealand, at the Cape of Good Hope, and also in Egypt.

When in Egypt, he became interested in the great buildings and obelisks of antiquity; and when he returned home, endeavoured to bring about some arrangement for transporting to this country Cleopatra's Needle. Having heard that the late Captain Donaldson Boswell, R.N., of Wardie, had entertained the same idea, and had submitted to the Admiralty a report showing how the transport of the obelisk might be accomplished, Sir James applied to me to assist him in procuring access to these plans, my brother, Sir Alexander Milne, being then at the Admiralty. These plans having been obtained, Sir James went with them back to Egypt, and satisfied himself of the possibility of removing the prostrate obelisk. Having received from the Khedive permission to construct a huge box, to contain and float the obelisk, he returned to England, and applied first to the Admiralty, and then to the Treasury, for the necessary funds, which he estimated would amount to £10,000. His applications in these quarters having been peremptorily refused, he next appealed to a wealthy personal friend, Dr Erasmus Wilson of London, who eventually agreed to give the money. Sir James then went back to Egypt to superintend the removal, which was entirely successful, notwithstanding that in the course of the voyage, a heavy gale having come on, the cable which dragged the barge containing the obelisk broke, and there was much difficulty in recovering it. It finally reached the Thames, and the obelisk now stands on the Thames Embankment.

Another object of public interest which next occupied Sir James was a fortification with heavy guns to be erected on Inchkeith, for the protection of Leith and Edinburgh against enemy's ships. He was at great trouble to get petitions from the Magistrates of Edinburgh and Leith, and from the towns on the shores of the Firth of Forth, to the Government, urging the erection of these defences. He at length succeeded, and had the pleasure of seeing the fortifications erected and mounted with guns.

He next engaged in endeavouring to procure a similar protection for Greenock and Glasgow, by fortifications at the entrance of the Firth of Clyde. He did not live long enough to see the erection of these fortifications, but before he died he knew that his proposal had been adopted by Government, and that it only remained to fix on the spot where the fortification should be erected.

Out of respect for the memory of an old personal friend, and a Fellow of our Society, I have thought it right to mention these details regarding Sir James Alexander, as a tribute due to one who did useful work for his country at home, after serving his country as a brave soldier abroad.

These obituary notices of life and work apply to only six of the thirteen Fellows who have died during the past year. Had there been more time for inquiry, perhaps others might have been found also deserving some special notice.

But even from those few to whom I have been enabled to refer, on account of their services to science and to the public interests, may I not venture to infer that the prestige of our Society has not deteriorated, and that, as the past year has shown an unusual accession of new members and a greater amount of business, we may hope for a continuance of prosperity and usefulness?

APPENDIX.

1. Demonstration of Theorems A, B, C, &c., page 484 of *Transactions*, Royal Society of Edinburgh, vol. xxxii. By Rev. T. P. Kirkman, M.A., F.R.S.

1. In the circle of an unifilar knot every crossing a is read twice, once in an odd and once in an even place; and the thread is supposed to pass under and over itself alternately at successive crossings

Every contiguous duad of the circle is a different edge of the knot. Let every mid-edge round the circle be dotted on the right.

Let $$128 \ldots a213 \ldots 5, \quad . \quad . \quad . \qquad \text{(A)}$$

of $2n$ terms 1, 2, &c., where 51 is a contiguous duad, be the circle of an unifilar $_n$N of n crossings. We see that 1 and 2 are the crossings of a 2-gon; for no mesh of $_n$N but a 2-gon can have two summits joined by two different edges of the mesh. (A) is the circle of any unifilar which has the duads 12 and 21.

Let us write the above thus, omitting only the crossing 1, and simply reversing one of the sequences between 1 and 1—

$$28 \ldots a25 \ldots 3, \quad . \quad . \quad . \qquad \text{(B)}$$

where 32 is a contiguous duad. What does this mean, when in the projection of $_n$N the 2-gon is shrunk up to a point 2, the edges 12 and 21 disappearing?

It is the circle of an unifilar $_{n-1}$M of $n-1$ crossings, which has every duad of (A) except 12 and 21; for it has 51 and 13 because it has 52 and 23, 2 and 1 being now the same point.

2. In (A) as we walk from 1 to 2, and later from 2 to 1, we make the circuit of the 2-gon 12 in the same direction round it; therefore our two dots will be both inside or both outside of it. This 12 is an *even* 2-gon; and every even 2-gon mn of an unifilar is known by a glance at the circle, by its exhibition of mn and nm.

3. We have demonstrated the following

Theorem A.—Every unifilar knot $_n$N of n crossings, which has an even 2-gon, can be reduced to an unifilar ${}_{n-1}$M of $n-1$ crossings by shrinking up that 2-gon to a point.

4. Let the sequence of $2n$ terms

$$128\ldots a123\ldots 5 \quad . \quad . \quad . \quad \text{(C)}$$

be the circle of an unifilar ${}_n$P of n crossings.

This ${}_n$P has an *odd* 2-gon 12; for since we pass over both its threads from 1 to 2, it must have one dot within and one without it. Any unifilar that has an odd 2-gon is represented by (C). We now write this, omitting the duads 12 and no other, and simply reversing 3 . . . 5—one sequence between 2 and 1;

$$28\ldots a15\ldots 3 \quad . \quad . \quad . \quad \text{(D)}.$$

What means this, when from the projection of ${}_n$P we have deleted the two edges, and consequently the two crossings of the 2-gon 12?

5. The edges of the crossings 1 and 2 in (C) are 12, 1a, 12, 15 and 21, 28, 21, 23. These make angles 212 and 51a vertically opposite, and 121 and 823 vertically opposite, where 51a and 823 are angles of the $(4+r)$-gon F′ laid bare by deletion of the 2-gon 12. The points 1 and 2 of these angles are merely bends or creases at the mid-points of the edges 5a and 83 of the $(2+r)$-gon F. Effacing the creases 1 and 2, (D) becomes

$$8\ldots a5\ldots 3, \quad . \quad . \quad . \quad \text{(E)};$$

which contains every crossing of (C) but 1 and 2, and every duad of (C) except 12, 1a, 15, 23, 28, and has besides the new edges 83 and 5a of the $(2+r)$-gon F. This (E) is the circle of an unifilar ${}_{n-2}$Q of $n-2$ crossings. We have thus proved

Theorem B.—If any unifilar knot ${}_n$P of n crossings has an odd 2-gon, the knot is reduced to an unifilar ${}_{n-2}$Q of $n-2$ crossings by the deletion of the two edges, and consequently of the two crossings of that 2-gon.

6. Let

$$\begin{array}{l} ..\, d765r\ldots p567s \\ ..\, d765r\ldots p765s \quad . \quad . \quad . \quad \text{(F)} \end{array}$$

be two circles of two unifilars of n crossings. In both of them 56 and 67 are contiguous 2-gons, having a common crossing 6—that is, both knots have a double 2-gon (a plural flap) 567. Let the first 7 in each be in an even place; then the second 7 is in an odd place, art. 1. Let the thread cross over itself in the even places. In both circles (F) then the thread, passing under itself at *d*, 6, and *r*, goes onwards till it passes over itself at *p*, 6, and *s*, proceeding till it comes under itself again at *d*. Let now the double flap 765 in the projection of each circle be shrunk to a point 7, the four edges of its two 2-gonal loops 65 and 67 disappearing. These circles thus become the two unifilars of $n-2$ crossings,

$$\begin{array}{l} \ldots d7r \ldots p7s \ldots \\ \ldots d7r \ldots p7s \ldots \end{array} \qquad . \qquad . \qquad (G),$$

which of course differ exactly as do the circles (F) in the portions omitted. The thread in each goes under at *d*, over at 7, under at *r*, and so on its course till it passes over at *p*, under at 7, over at *s* . . . and finally comes again under at *d*, as before the shrinking. And this is true whatever be the crossings *d*, *r*, *p*, *s*, in 2-gons or not, and whether these four be or not crossings in like meshes on the knots. Thus is proved

Theorem C.—If any unifilar knot ${}_nR$ of n crossings has a double flap, the two contiguous terminal 2-gons of a $(2+i)$-ple flap, $(i \gtreqless 0)$, it is reduced, by the shrinking up of the two 2-gons to a point, to an unifilar S of $n-2$ crossings.

7. Returning to the even 2-gon 12 of art. 1, it is plain that at its crossings it is covertical with two meshes whose edges, meeting at 1 and at 2, will be dotted both of each pair inside or outside its mesh, according as the 2-gon 12 has its dots both outside or both inside of it. And it is equally plain that every crossing *r* of a knot has two covertical angles about it so evenly dotted, and another covertical pair which have both one, and only one, dot inside those angles about *r*. We may call the latter pair the *odd* angles, and the former the *even* angles about *r*.

In the unifilar ${}_{n-1}M$ whose circle is (B), art. 1, we can reverse the process by which ${}_{n-1}M$ is obtained from ${}_nN$, *i.e.*, we can, by restoring in the projection of ${}_{n-1}M$ the deleted 2-gon 12, construct upon it ${}_nN$. In the circle (A) *a*28 and 315 are even angles about the crossings 2 and 1. In (B), the circle of ${}_{n-1}M$, we read along 32 and next along 28, dotting both on the right, and later along *a*2 and 25, dotting both on the right; *i.e.*, *a*28 and 325 are even coverticals about 2.

By making these two covertical with a 2-gon we construct ${}_n$N, whose circle is (A), and thus demonstrate

Theorem AA.—If at any crossing r of an unifilar knot of $n-1$ crossings we make the two even angles of r covertical with a 2-gon, thus adding an edge to each collateral of the 2-gon, we construct an unifilar of n crossings by one of its even 2-gons.

This is the constructing converse of the Theorem A, art. 3.

8. Let

$$v \ldots fcdr \ldots bam \ldots s$$

be the circle of an unifilar of k crossings, in which cd and ba are edges of the mesh H, both dotted inside H at their mid-points α in cd and β in ba. The circle is read

$$v \ldots fc(\alpha)dr \ldots b(\beta)am \ldots s,$$

say from c above to d below with the dot (α) on the right in H, till we come to the crossing b, and proceed from b below to a above past the dot (β) on the right in the same H. In H draw the 2-gon pq from p between (α) and d to q between b and (β). We now read from c above, not to d but to p below, having the dot (α) on our right in H; then crossing the upper edge pq of the 2-gon, we proceed along the lower pq to q, planting a dot (ϵ) inside the 2-gon on that pq; at q, again crossing the upper pq, we proceed to a past (β) on our right in H, next to m, &c., completing the smaller circle

$$v \ldots fcpqam \ldots s,$$

which contains neither the upper edge of the 2-gon pq, nor any of the crossings $dr \ldots b$. We have constructed a bifilar knot of $k+2$ crossings, and demonstrated

Theorem D.—If in any mesh H of an unifilar knot ${}_n$T we connect by a 2-gon two mid-edges that are dotted either both inside or both outside of H, we complete a bifilar ${}_{n+2}$U.

Observe that the dotting of art. 1 may be done either on the right or on the left of every edge.

9. If in the unifilar ${}_{n-2}$Q of art. 5 we replace in the $(2+r)$-gonal face F the 2-gon 12 effaced from ${}_n$P, art. 4, we reconstruct the unifilar ${}_n$P. It follows that of the mid-points 1 and 2 of that face F on ${}_{n-2}$Q one, and only one, is dotted inside F. For if otherwise

we should construct (Theo. D) by the 2-gon 12, not $_nP$ unifilar, but a bifilar $_nU$. Thus we have proof of

Theorem BB.—If in the projection of any $(2+r)$-gonal mesh F of an unifilar of $n-2$ crossings we connect by a 2-gon the mid-points of two edges of which one, and only one, is dotted (art. 2) inside F, we construct an unifilar of n crossings by one of its odd 2-gons.

This is the constructing converse of Theorem B, art. 5, and is true when $r \gtreqless 0$.

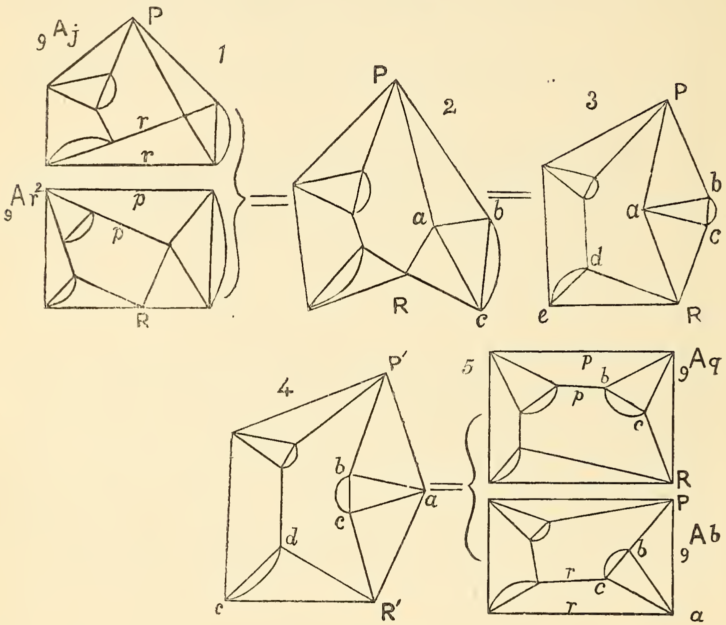
10. The constructing converse of Theorem C is

Theorem CC.—If in any unifilar knot of $n-2$ crossings we make, at any projected crossing r, either pair of opposed angles covertical with a double flap, adding two edges to each of the other pair of opposed meshes about r, we construct an unifilar of n crossings by one of its plural flaps.

No base which has a plural flap, not fixed, can be operated upon by Theorem AA or BB, unless the operation abolishes the plural flap. And every flap, single or plural, is fixed, if its deletion lays bare a section through two edges only. Such a fixed flap cannot compete for the lead, nor hinder an operation by AA or BB, which does not abolish the fixture. Every construction is by a leading flap (*vide* my paper, xvii.), and the leader has the most 2-gons.

2. On the Twists of Listing and Tait. By the Rev. Thomas P. Kirkman, M.A., F.R.S.

In the figure 1 following, the knot $_9Aj$ has a triangular section Prr cutting away on each side of it a $(3+r)$-gonal mesh, and $_9Ar^2$ has such a section Rpp, through one crossing only. Make in these knots creases at rr that approach to meet at R in 2, and creases pp that meet at P in 2. In 3, 2 is prepared for a rotation through two right angles about the fixed axis PR, through the crossing P and the crease-kiss R, or, as a more learned man would say, through the decussation P and the plicatorial osculation R—taking 2 for $_9Aj$: exchange here P and R if 2 is $_9Ar^2$. In 4 the rotation is effected, undoing the crossing P of 3, which has become a kiss P′ in 4, while the kiss R of 3 has become the crossing R′ in 4, if 3 is $_9Aj$: exchange here P and R, if 3 is $_9Ar^2$. In 5 the crease-kiss is undone, and ${}_9Aj$ has been twisted into ${}_9Aq$, as ${}_9Ar^2$ has into ${}_9Ab$, both by the twist of Tait, which is above analysed. In Tait's twist the part rotated is not the same figure between P and R after rotation as before.



There may, of course, be any number of crossings in the rotating part about PR.

If here we consider P and R as both crossings, 3 and 4 are two unsolids of ten crossings, complementaries of each other about PR.

When the knot to be twisted is such that the rotated part is the same after rotation as before, 3 has no complementary, and the result is simply one pair of convertibles, viz., K on the left instead of ${}_9Aj$, turned into K′ on the right instead of ${}_9Aqj$, and not two pairs as here, ${}_9Aj$ turned into ${}_9Aq$ and ${}_9Ar^2$ into ${}_9Ab$.

If, in the above process, we have only two summits *a* and *b* between P and R in 3, making the 2-gon *ab* collateral with the triangles *ab*P and *ab*R, we have the simplest possible case of twisting; and in this the rotation makes no change, 4 and 3 being as projections identical.

This is the twist of Listing, who found it in his study of knots of seven crossings, under what seems to me the needless disguise of gracefully flowing curves. It was sharp wit in Listing so to observe it; it was still more acute in Tait to detect under a more complete disguise the manœuvre of his twist of greater complexity.

The figures 3 and 4, considered as unsolids of ten crossings, are the complementary pair C71 and C74. If we had these two before we had obtained ${}_9Aj$, ${}_9Aq$, ${}_9Ar^2$, and ${}_9Ab$, all of which are subsolids to be regularly constructed by their leading flaps, we could, without the minute comparisons of that process, at once draw these subsolids—the first pair by unkissing at R and P′, the second by unkissing at P and R′. And if we had all the unsolids of ten crossings, having each a linear section PR, which cuts away on both hands a $(3+r)$-gonal mesh, we could with the same ease draw every knot of nine crossings that has a triangular section P*rr*. All we have to do is to take first every complementary pair of 10-fold unsolids, and by unkissing, as just shown, write down from it two couples of 9-fold convertibles; next to take every unsolid 10-fold without complementary, which has a linear section PR, above described, of which the two crossings P and R are not identical, and by unkissing first at P and then at R, to obtain from each such unsolid one couple of convertibles. The remaining unsolids in which those crossings P and R are identical will give, by unkissing at either in each, every 9-fold not already found which has a linear section P*rr*; where the words just used, "remaining unsolids," include every unsolid before handled as having a section PR with P and R unlike, to be handled again once, twice, &c., according as it has one, two, &c., different linear sections PR with P and R alike. And every 9-fold so got from P and R alike is a 9-fold having a triangular section at which it can be twisted into its reflected image. It will sometimes happen that amongst our couples obtained of convertibles, AB, BC, &c., the couple CC will be found. This means that the knot C has two different sections, P*rr* and S*tt*, at which it can be twisted into itself, besides one or more at which it can be twisted into B or B′ of the couples BC and B′C. For the truth is, that the number of different crossings P in the linear sections PR on all the knots of n crossings is exactly the number of different triangular sections P*rr*, above described, on all the knots of $n-1$ crossings. We shall obtain repetitions of some nine-folds, but no vain repetition; for when the unkissing is finished we shall have grouped all the convertibles in twos, threes, sixes, &c., without ever attempting to perform a twist, as well as have given an accurate account of the number of different triangular sections on the grouped ones and on the uniques, without ever trying to count these sections, or to distinguish them by their symmetry.

In all that precedes, no distinction is made or supposed between unifilar and plurifil knots; nor do I know any reason why unifilars only should be considered.

The crossing P in fig. 1 may stand for any tessarace in the projection of any knot, or of any n-acron whatever, through which lies the triangular section P*rr* there described. The twisting can take place in them all, no matter what the faces and the other $n-1$ summits may be, and the groups can be formed of which every figure can be so twisted into one or more of the others.

The question here presents itself—Will it be profitable, supposing that the census of all the knots of n crossings is wanted, to employ the method of unkissing above opened? I am of opinion that it will.

Let the subsolids (which have no linear section PR) be divided into S_n, all that have no triangular section P*rr* cutting away on both hands a $(3+r)$-gonal mesh, and T_n, all those which admit one or more such sections P*rr*, and let U_n comprise all the unsolids, which have each one or more linear sections PR, cutting away on each hand a $(3+r)$-gonal mesh.

Suppose that S_n and U_n are found, and that the subsolids T_n, in general more numerous than S_n, are wanting. If we can obtain U_{n+1}, we shall readily get by the simple process of unkissing, not only the missing T_n, but every pair of convertibles possible out of T_n and the unsolids U_n that admit a triangular section P*rr*, and every fact required for our table of uniques and grouped convertibles.

I believe that even when U_{n+1} is more numerous than T_n, it can be more easily found than T_n, which comprises only subsolids to be obtained by the minute and often many comparisons that determine the leading flap; whereas U_{n+1} is rapidly put together without minute comparisons by laying 2 upon $n-1$, 3 upon $n-2$, &c., by the simplest marginal sections *ffc* only.

The reader, having before him in the plates of vol. xxxii. *Trans. R.S.E.* nearly all the knots unifilar or not of fewer than ten crossings, can amuse himself by considering the question above proposed. He can begin with $S_5 = {}_5B + {}_5C$. Compounds like ${}_6E$ are rejected all through. But the student will not be able to confine his attention to unifilars only.

Observe that in the linear sections PR neither P nor R can be a non-terminal crossing of a plural flap. Also, if in PR R is a crossing of the 2-gon RR′, PR and PR′ are for our purpose the same linear section, because we get the same n-fold knot whether we unkiss at R or at R′ upon the $(n+1)$-fold. Hence it follows that Prr and P$r'r'$ are the same triangular section when rRr and r'Rr' are covertical angles at the crossing R.

It is not difficult to give simple rules whereby S_n is found without error or repetition from S_{n-1} and S_{n-2} by the leading flap of each knot of S_n. But a definition of a fixed flap must be made and stuck to.

I conclude with two useful little theorems.

a. On every unsolid unifilar V in U_{n+1} each of its linear sections PR (P and R unlike) lies through four angles at P and R, which are all odd or all even.

b. The couples of n-folds obtained by unkissing on V, or on V and its complementary, are all unifilars or not, according as these angles (in a) are odd or not.

My objection to the twistings, that they put a twist upon the tape, has been answered by Tait. In the case of Listing's twist, I have satisfied myself that his answer is sufficient. It appears to me that it ought to be formally demonstrated as sufficient in all cases.

After all, as it is certainly not on record who invented kissing, it may come to be forgotten who invented unkissing.

P.S. Nov. 7.—I have learned how to form readily all the unifilars only of U_{n+1}, required for unifilar couples, by operating on unifilars only of n and of fewer crossings. I shall soon present to Professor Tait the requisite unifilars in U_{12}, and thus I hope to save him much time and trouble in grouping the unifilar convertibles of eleven crossings.

PROCEEDINGS

OF THE

ROYAL SOCIETY OF EDINBURGH.

VOL. XIII. 1885-86. No. 121.

THE 103RD SESSION.

GENERAL STATUTORY MEETING.

Monday, 23rd November 1885.

The following Council were elected :—

President.

THOMAS STEVENSON, M.INST.C.E.

Vice-Presidents.

ROBERT GRAY, Esq.
A. FORBES IRVINE, Esq. of Drum.
DAVID MILNE HOME, Esq. of Milne-Graden.
JOHN MURRAY, Esq.
Professor DOUGLAS MACLAGAN.
The Hon. Lord MACLAREN.

General Secretary—Professor TAIT.

Secretaries to Ordinary Meetings.

Professor TURNER, F.R.S.
Professor CRUM BROWN, F.R.S.

Treasurer—ADAM GILLIES SMITH, Esq., C.A.

Curator of Library and Museum—ALEXANDER BUCHAN, Esq., M.A.

Ordinary Members of Council.

Rev. Professor FLINT, D.D.
Professor T. R. FRASER, M.D.
Professor CHIENE.
J. Y. BUCHANAN, Esq., M.A.
Professor CHRYSTAL.
Professor DICKSON.
Professor SHIELD NICHOLSON.
T. B. SPRAGUE, Esq., M.A.
Professor BUTCHER.
Professor M'KENDRICK.
THOMAS MUIR, Esq., LL.D.
Professor M'INTOSH.

By a Resolution of the Society (19th January 1880), the following Hon. Vice-Presidents, having filled the office of President, are also Members of the Council :—

HIS GRACE THE DUKE OF ARGYLL, K.T., D.C.L.
SIR WILLIAM THOMSON, LL.D., D.C.L., F.R.S., Foreign Associate of Institute of France.
THE RIGHT HON. LORD MONCREIFF of Tulliebole, LL.D.

Monday, 7th December 1885.

JOHN MURRAY, Esq., Ph.D., Vice-President, in the Chair.

Two instantaneous Photographs—one of the explosion of Hellgate, and the other of the "Genista" yacht—were exhibited by the Astronomer-Royal for Scotland. The thanks of the Society were accorded to the Astronomer-Royal.

The following Communications were read:—

1. On the Motion of a Liquid within an Ellipsoidal Hollow. By Sir William Thomson.

I have only recently noticed the propositions regarding fluid motion within an ellipsoidal hollow which form the subject of the present communication, and which, though obvious enough and remarkably interesting, do not seem to have been previously discovered.

Preliminary.

I shall use the expression *homogeneous* rotation, or homogeneous molecular rotation, to designate the condition of a fluid in respect to rotation, when throughout it the amounts of its molecular rotation are the same and the axial lines parallel. This designation clearly includes the case of a rotating solid: but it is applicable of course to the more complex case of a fluid, in which irrotational motion is superimposed upon homogeneous rotation as of a solid. To illustrate the complex motion thus signified, consider the following three examples, of which (1) and (2) are included in (3):—

(1) Let a liquid kept in the shape of a figure of revolution, by a rigid containing vessel, be given in a state of homogeneous rotation round the axis of the figure. Let an impulsive rotation round a line perpendicular to this axis be given to the containing vessel. The instantaneous motion of the liquid, at the instant when the impulse is completed, consists of an irrotational motion superimposed on the given homogeneous rotational motion. The molecular rotation of the liquid does not generally remain homo-

geneous after the first instant. But I find it does continue homogeneous, however the containing vessel be moved, provided the shape be ellipsoidal; that is to say (for the present limited case), an ellipsoid of revolution whether prolate or oblate. The possible incident of the containing vessel being brought again to rest in any position after any motion round any succession of diameters perpendicular * to the figure of revolution is of course included.

(2) Given a rigid solid, with a hollow space of any shape not a figure of revolution, within it, full of liquid: solid and liquid all rotating homogeneously. Let the given rotation of the solid be impulsively brought to rest or to any other rotation, whether rotation with changed angular velocity round the same axis, or rotation round another axis. The instantaneous motion of the liquid, at the instant of the completion of the impulse, will be the resultant of the given homogeneous rotation, with an irrotational motion superimposed upon it; this irrotational motion of the liquid being the same as the motion which would be generated from rest by giving to the solid (whether impulsively or gradually) an angular velocity the same as that which, compounded with the first given angular velocity, produced the second angular velocity to which we supposed the first angular velocity of the solid to be suddenly changed.

In this second example, as in the first, the molecular rotation does not generally continue to be homogeneous in the altered condition in which the solid and liquid do not rotate as if all solid; but it does continue to be homogeneous, if the shape of the hollow is ellipsoidal.

(3) Given a spherical shell full of homogeneously rotating liquid, or a hollow of any shape in a rotating solid full of liquid, rotating homogeneously with the solid. By impulsive pressure at the boundary of the liquid, supposed now to be perfectly yielding, generate any prescribed normal components of velocity in all parts of the boundary. The effect will be to generate throughout the liquid an irrotational motion, the same as would have been generated had the fluid been given at rest. The resultant motion throughout will be the resultant of this irrotational motion, com-

* Rotation of the containing vessel round the axis of figure has no effect on the liquid, and need not be included to complicate our considerations.

pounded with the given rotational motion. The irrotational motion in the case of the spherical hollow is of course easily calculated by the well-known spherical harmonic analysis for fluid motion. We consider here only the instantaneous motion, which exists at the instant when the impulse is completed. The infinitely more difficult problem of working out the consequences according to any prescribed conditions as to force, or as to changing shape, for the boundary, we do not follow at present. It will be fully followed up for the case in which the boundary of the liquid is spherical or ellipsoidal to begin with, and is constrained to be always exactly ellipsoidal. It will be proved that in this case the molecular rotation of the fluid remains always homogeneous. We shall see in fact that the geometrical "strain" is essentially homogeneous throughout a liquid contained within a changing ellipsoidal boundary, provided that the motion of the fluid be either wholly irrotational, or be at any one instant homogeneously irrotational. The homogeneousness of the geometrical strain being established, it follows from Helmholtz's fundamental principles of vortex motion, that the molecular rotation must contiuue homogeneous; its magnitude, when there is any stretching or contraction in the axial direction, varying inversely as the length of a line of the substance in this direction, and the axial direction varying so as to keep always along the same substantial line.

If there is the slightest deviation from exactness in the ellipsoidal figure, the homogeneousness of the rotation of the liquid is not maintained, and there is no limit to the amount of deviation from homogeneousness which may supervene in consequence of motions which may be given to the boundary, whether in the way of change of shape, or of motion without change of shape. Confining our attention for the present to motion of the boundary without change of shape, we find it interesting to remark that we may go on indefinitely increasing or indefinitely diminishing the energy of the fluid motion by properly arranged action in the way of moving the containing vessel. To continually increase the energy I believe the following rule may be correct, although I do not yet see a perfect proof of it. Suppose the containing vessel to be given at rest, and the liquid within it to have perfectly homogeneous rotation within the not exactly ellipsoidal hollow, watch it for a little time—it may begin to move or it may not. If it does not begin to move of itself, give it a very slight motion of rotation round any axis. Generally it will begin to move of itself, but it will not do so if the interior fluid motion fulfils a definite condition of kinetic equilibrium, and therefore if you do not see the containing case beginning to move of itself you must set it in motion. When you see it in motion, act upon it with a couple in any direction to do some positive work upon it, and then suddenly stop it. Left to itself now, it will certainly begin to move of itself. When you see it moving again, again do some work upon it gradually, and stop its motion suddenly. Go on incessantly acting according to this rule. The positive work done gradually will exceed the work undone suddenly each time, or at all events on the aggregate of a large number of times of repetition of the operation. Thus on the whole you will increase the energy of the fluid motion without continually giving kinetic energy to the containing vessel, as might be the case if you continued always to apply a couple in such a direction as to do positive work. Thus by going on long enough operating in the manner described we can present the containing vessel at rest with the liquid moving inside it with any amount of kinetic energy we please.

A simpler rule suffices for diminishing the internal energy. Simply place the containing vessel on flexible imperfectly elastic supports, and leave it to itself, or leave it to itself immersed in a viscous fluid. Watch it for a while till you see it moving; or if you do not see it beginning to move of itself give it a slight motion, then leave it entirely to itself. It will never come to rest unless for an instant, and the internal energy will diminish asymptotically towards zero.

I now proceed to prove the propositions regarding fluid motion in an ellipsoidal hollow referred to above.

I. *Irrotational motion of liquid in a rigid ellipsoidal shell.*

Given the motion of the boundary: required the motion of the contained liquid.

Let ϖ, ρ, σ, be the component velocities of the shell, and let ϕ be the velocity potential of the corresponding determinate * motion

* Wm. Thomson, "On the Visviva of a Liquid in Motion," *Camb. and Dub. Math. Journal*, 1849; or Thomson and Tait's *Natural Philosophy*, secs. 312 and 317, example (3).

of the internal fluid. The component linear velocities of a point (x, y, z) of the shell are

$$\rho z - \sigma y, \quad \sigma x - \varpi z, \quad \varpi y - \rho x \quad . \quad . \quad . \quad (1),$$

and the component linear velocities of (x, y, z) are

$$\frac{d\phi}{dx}, \quad \frac{d\phi}{dy}, \quad \frac{d\phi}{dz}, \quad . \quad . \quad . \quad (2).$$

If (x, y, z) be any point of the inner surface of the shell, the normal component of velocity (1) must be equal to the normal component of velocity (2); or in symbols

$$\left.\begin{aligned} &(\rho z - \sigma y)\frac{px}{a^2} + (\sigma x - \varpi z)\frac{py}{b^2} + (\varpi y - \rho x)\frac{pz}{c^2} = \frac{d\phi}{dx}\frac{px}{a^2} + \frac{d\phi}{dy}\frac{py}{b^2} + \frac{d\phi}{dz}\frac{pz}{c^2} \\ &\text{where} \qquad \frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1 \end{aligned}\right\} (3);$$

the axes of coordinates being taken as coincident with the axes of the ellipsoid at the instant considered; (a, b, c) being the three semi-axes of the ellipsoid; and p being the perpendicular from the centre to the plane touching the ellipsoid at $(x, y, z,)$. To satisfy this, assume

$$\phi = Ayz + Bzx + Cxy \quad . \quad . \quad . \quad . \quad (4);$$

and determine A, B, C, to fulfil the first of equations (3). We find that (3) is now satisfied by

$$\phi = \varpi\frac{b^2 - c^2}{b^2 + c^2}yz + \rho\frac{c^2 - a^2}{c^2 + a^2}zx + \sigma\frac{a^2 - b^2}{a^2 + b^2}xy^{*} \quad . \quad (5).$$

It is important to remark that this expression for ϕ satisfies the first of equations (3) independently of the second, from which we infer that with the same angular velocity of rotation, the motion of any portion of the contained liquid is independent of the magnitude of the ellipsoidal body, and is determinate from the ratios alone of the three semi-axes. From (4) we find for the velocity components:—

$$\left.\begin{aligned} u &= \rho\frac{c^2 - a^2}{c^2 + a^2}z + \sigma\frac{a^2 - b^2}{a^2 - b^2}y \\ v &= \sigma\frac{a^2 - b^2}{a^2 + b^2}x + \varpi\frac{b^2 - c^2}{b^2 + c^2}z \\ w &= \varpi\frac{b^2 - c^2}{b^2 + c^2}y + \rho\frac{c^2 - a^2}{c^2 + a^2}x \end{aligned}\right\} (6),$$

* This solution is given in Lamb's *Fluid Motion*, sec. 102.

which is the explicit solution of the problem, so far as concerns merely the absolute velocity at any point of the fluid, which is generally considered far enough in the solution of a hydrodynamical problem. But it would be interesting in every case, and it is easy in this case, to complete it up to the determination of the position of every particle of the liquid at any time, and we may therefore go on to do so. Relatively to the axes of the ellipsoid let $(\mathfrak{x}, \mathfrak{y}, \mathfrak{z})$ be the coordinates at time t, of any particular particle $\mathfrak{P}$, of the liquid. The component velocities $(d\mathfrak{x}/dt, d\mathfrak{y}/dt, d\mathfrak{z}/dt)$ of the particle $\mathfrak{P}$, relatively to the ellipsoid are equal to the differences between the components (u, v, w), of the absolute velocity of $\mathfrak{P}$, and the corresponding components of the absolute velocity of an ideal point (x, y, z) rigidly connected with the ellipsoid, and coincident with $(\mathfrak{x}, \mathfrak{y}, \mathfrak{z})$ at the time t. These last components are

$$\rho\mathfrak{z} - \sigma\mathfrak{y}, \quad \sigma\mathfrak{x} - \varpi\mathfrak{z}, \quad \varpi\mathfrak{y} - \rho\mathfrak{x}, \qquad . \quad . \quad (7).$$

Hence, and from (6), at the instant $(\mathfrak{x}, \mathfrak{y}, \mathfrak{z})$ coincident with (x, y, z) we have

$$\left.\begin{aligned} \frac{d\mathfrak{x}}{dt} &= -a^2(\gamma\mathfrak{y} - \beta\mathfrak{z}) \\ \frac{d\mathfrak{y}}{dt} &= -b^2(\alpha\mathfrak{z} - \gamma\mathfrak{x}) \\ \frac{d\mathfrak{z}}{dt} &= -c^2(\beta\mathfrak{x} - \alpha\mathfrak{y}) \\ \text{where} \quad \alpha = \frac{2\varpi}{b^2+c^2}, \quad & \beta = \frac{2\rho}{c^2+a^2}, \quad \gamma = \frac{2\sigma}{a^2+b^2} \end{aligned}\right\} (8).$$

These are linear differential equations of the first order for determining $(\mathfrak{x}, \mathfrak{y}, \mathfrak{z})$ in terms of t. Denoting d/dt by δ, we may write them as follows—

$$\left.\begin{aligned} \frac{\delta}{a^2}\mathfrak{x} + \gamma\mathfrak{y} - \beta\mathfrak{z} &= 0 \\ -\gamma\mathfrak{x} + \frac{\delta}{b^2}\mathfrak{y} + \alpha\mathfrak{z} &= 0 \\ \beta\mathfrak{x} - \alpha\mathfrak{y} + \frac{\delta}{c^2}\mathfrak{z} &= 0 \end{aligned}\right\} (9).$$

Operating now on this in the usual manner we find

$$\begin{vmatrix} \frac{\delta}{a^2}, & \gamma, & -\beta \\ -\gamma, & \frac{\delta}{b^2}, & \alpha \\ \beta, & -\alpha, & \frac{\delta}{c^2} \end{vmatrix} = 0 \qquad . \quad . \quad . \quad (10);$$

whence by expanding the determinant and removing the superfluous factor δ, we have

$$\frac{\delta^2}{a^2b^2c^2} + \frac{\alpha^2}{a^2} + \frac{\beta^2}{b^2} + \frac{\gamma^2}{c^2} = 0 \quad . \quad . \qquad (11),$$

which gives

$$\left.\begin{array}{l} \delta = \iota\, a\, b\, c\sqrt{\left(\frac{\alpha^2}{a^2} + \frac{\beta^2}{b^2} + \frac{\gamma^2}{c^2}\right)} \\ \\ \text{where } \iota \text{ denotes } \sqrt{-1}. \end{array}\right\} \quad (12);$$

And from the second and third of (9) we have

$$\frac{\mathfrak{x}}{\frac{\delta^2}{b^2c^2} + \alpha^2} = \frac{\mathfrak{y}}{\alpha\beta + \gamma\frac{\delta}{c^2}} = \frac{\mathfrak{z}}{\gamma\alpha - \beta\frac{\delta}{c^2}} \quad . \quad . \quad (13),$$

which gives

$$\mathfrak{y} = \mathfrak{x}\frac{\alpha\beta + \gamma\frac{\delta}{c^2}}{\frac{\delta^2}{b^2c^2} + \alpha^2}, \quad \text{and } \mathfrak{z} = \mathfrak{x}\frac{\gamma\alpha - \beta\frac{\delta}{c^2}}{\frac{\delta^2}{b^2c^2} + \alpha^2} \quad . \quad . \quad (14).$$

In virtue of (12) we may take as the solution for any one of the coordinates, $\mathfrak{x}$ for example, as follows—

$$\left.\begin{array}{l} \mathfrak{x} = \mathrm{A}\cos\omega t \\ \text{where } \omega = 2abc\sqrt{\left[\left(\frac{\varpi}{b^2+c^2}\right)^2 + \left(\frac{\rho}{c^2+a^2}\right)^2 + \left(\frac{\sigma}{a^2+b^2}\right)^2\right]} \end{array}\right\} (15);$$

and from this (14) gives

$$\left.\begin{array}{l} \mathfrak{y} = \mathrm{A}\frac{\alpha\beta\cos\omega t - \frac{\gamma}{c^2}\omega\sin\omega t}{\alpha^2 - \frac{\omega^2}{b^2c^2}} \\ \\ \mathfrak{z} = \mathrm{A}\frac{\gamma\sigma\cos\omega t + \frac{\beta}{c^2}\omega\sin\omega t}{\alpha^2 - \frac{\omega^2}{b^2c^2}} \end{array}\right\} (16).$$

These equations give explicitly the position of any chosen particle at any time, and of course it would be easy to find from them what the path is; but it is easier to do this from the unintegrated equations (8). Multiplying the first of these by α/a^2, the second by β/b^2, and the third by γ/c^2 and adding, we find

$$\frac{\alpha}{a^2}\frac{d\mathfrak{x}}{dt}+\frac{\beta}{b^2}\frac{d\mathfrak{y}}{dt}+\frac{\gamma}{c^2}\frac{d\mathfrak{z}}{dt}=0 \quad . \quad . \quad . \quad (17);$$

which proves that the orbit lies in the plane

$$\frac{\alpha}{a^2}\mathfrak{x}+\frac{\beta}{b^2}\mathfrak{y}+\frac{\gamma}{c^2}\mathfrak{z}=\text{H} \quad . \quad . \quad . \quad (18),$$

where H denotes a constant.

Again multiplying the first of equations (8) by $\mathfrak{x}/a^2$, the second by $\mathfrak{y}/b^2$, and the third by $\mathfrak{z}/c^2$ and adding, we find

$$\frac{\mathfrak{x}}{a^2}\frac{d\mathfrak{x}}{dt}+\frac{\mathfrak{y}}{b^2}\frac{d\mathfrak{y}}{dt}+\frac{\mathfrak{z}}{c^2}\frac{d\mathfrak{z}}{dt}=0 \quad . \quad . \quad . \quad (19),$$

and integrating this we have

$$\frac{\mathfrak{x}^2}{a^2}+\frac{\mathfrak{y}^2}{b^2}+\frac{\mathfrak{z}^2}{c^2}=\text{K} \quad . \quad . \quad . \quad . \quad (20),$$

where K denotes a constant.

This proves that the orbit lies on the ellipsoid (20); and we conclude that the orbit is the ellipse in which this ellipsoid is cut by the plane (18).

Going back now to the explicit fully integrated solution (15) and (16), we see that a particle of the fluid describes, relatively to the moving solid in which the fluid is contained, the ellipse specified by (18) and (20), according to the law of a single particle describing an ellipse under the influence of a force towards a fixed centre varying in simple proportion to distance from the centre.

Now the period of revolution of the containing shell round its axis of rotation (ϖ, ρ, σ) is $2\pi/\epsilon$

where $$\epsilon=\sqrt{(\varpi^2+\rho^2+\sigma^2)},$$

which is easily seen to be less than $2\pi/\omega$ [the value of ω being given by (15) above]. Hence considering the shell and contained liquid at any instant, and again at the later instant when the shell is again in the same position after a single complete revolution round the axis of its rotation, we see that, relatively to the shell, the liquid will have performed less than a complete period of its retrograde revolution by the difference $(2\pi/\omega - 2\pi/\epsilon)$; or by the fraction $(1 - \omega/\epsilon)$ of the period of the fluid relatively to the shell. In the extreme case of $a = b = c$ (the ellipsoid a sphere), $\omega = \epsilon$ and the retrograde motion of the fluid relatively to the shell is one complete revolution, in the period of the forward revolution of the shell: that is to say, the fluid is perfectly left behind, and remains unmoved while the shell turns. In the other extreme case of any one or any two of the quantities a, b, c being infinitely small, ω is infinitely small: that is to say, the fluid makes an infinitely small fraction of its retrograde revolution during the time of one turn of the shell in the direction which we are calling forward. It must not from this be inferred that the fluid moves very nearly, as if solid, with the shell. On the contrary, it experiences large distortion even in the first complete turn of the shell, and largely increasing to a maximum in the course of the first quarter period of the liquid relatively to the shell.

(*To be continued.*)

2. The Sacral Index in Various Races of Mankind. By Professor Wm. Turner, M.B., F.R.S.

In a paper on "The Index of the Pelvic Brim as a basis of Classification," which I read in September at the meeting of the British Association in Aberdeen, and published in the *Journal of Anatomy and Physiology*, October 1885, I briefly referred to variations in the length and breadth of the sacrum in different races of men, and pointed out that in some races the length exceeded the breadth, and that in others an opposite relation prevailed. These differences may be expressed numerically by computing a sacral index by the following formula:

$$\frac{\text{sacral breadth} \times 100}{\text{sacral length}}.$$

When the sacral index is above 100 the breadth of the bone is greater than the length, when the index is below 100 the sacrum is longer than broad. The following descriptive terms may conveniently express these differences in the relative length and breadth of the sacrum. As the Greek word ἱερον is the equivalent of the Latin sacrum, the term *dolichohieric* would signify a sacrum in which the length exceeded the breadth, whilst *platyhieric* would signify a sacrum in which the breadth exceeded the length.

In considering the modifications in the sacral index, as in the index of the pelvic brim, it is important to bear in mind that sex modifies the relative proportions, and that in women the sacrum as a rule is broader in proportion to its length than in men.

In working out the results at which I have arrived, I have measured a number of aboriginal skeletons, a few of which were brought home by H.M.S. "Challenger," but the greater number of which are in the Anatomical Museum of the University of Edinburgh. The detailed measurements of these skeletons are given in the Tables in Part ii. of my Report on the Human Skeletons, now in type for the Challenger Reports. I have also examined the literature of the subject so far as I have had access to it, and have analysed the observations on the length and breadth of the sacrum recorded by previous observers.

Observations on the length and breadth of the sacrum in Europeans of both sexes by Verneau, Görtz, and Garson have shown that in them the breadth exceeded the length. The mean sacral index for European men was 112·4, and for women 117, so that the sacrum in them was platyhieric.

In aboriginal Australians, on the other hand, the measurements of Keferstein, Barnard Davis, Spengel and myself on men have shown that the length of the sacrum as a rule exceeded the breadth. The mean of thirteen adult males was 98·5, *i.e.*, they were dolichohieric. In women again the sacrum was relatively broader, and the mean of nine adult females measured by B. Davis, Verneau, Garson, and myself, was 102·5.

Of the aborigines of South Africa the mean sacral index of three Bushmen, measured by G. Fritsch and myself, was 94; and of four Bushwomen, measured by Verneau, Görtz, and G. Fritsch, was 94·7. The mean sacral index of three male Hottentots, measured by Wyman and Fritsch, was 83·9, and the index of one female was 85. In six male Kaffirs, the mean sacral index was 92·8. In the Bush, Hottentots, and Kaffirs the sacrum was dolichohieric.

The mean sacral index of twenty-nine Negros, measured by Verneau, Spengel, B. Davis, and myself, was 106, *i.e.*, they were platyhieric; whilst the mean of ten Negresses, measured by Verneau, Fritsch, and myself, was only 98·8, so that they were dolichohieric. If these specimens give a correct average for the Negro race, it would seem as if the sacrum is not so broad in the women in proportion to its length as in the men.

In eight male Andamanese measured by Flower, the mean sacral index was 94; but in a single adult male measured by myself it was 114, and in a young male 106. In nine females measured by Flower, the mean sacral index was 106; in three adult females measured by me it was 111, and in a young female it was 96·5. The high index of my male Andamanese is probably exceptional, and the standard of the race is dolichohieric.

Three male Tasmanians, measured by Barnard Davis, had a mean sacral index 87, so that they were dolichohieric. In a single female the index was 104.

From measurements of the sacrum in Pacific Islanders, both Polynesians and Melanesians, or perhaps a mixture of the two races, made by Verneau, Barnard Davis, and myself, the mean sacral index was above 100, so that its proportions were platyhieric.

The number of sacra belonging to the Guanche and Esquimaux races, which have as yet been measured, is too few to frame an average on; but from a few specimens measured by Verneau and myself, it is probable that the mean proportions of this bone are platyhieric. In the Hindoos and Sikhs also my measurements would point to a platyhieric bone.

The information regarding the proportions of the sacrum in the Chinese or other Mongolians is too scanty to enable one definitely to classify this bone. From measurements of the sacrum in male Malays by B. Davis and myself, it is probable that the bone is dolichohieric.

From the observations of von Franque, Barnard Davis, and Verneau on the sacrum in North American Indians, and from the measurements of Verneau, Davis, and Garson on South American aborigines, it seems probable that the sacrum in them is platyhieric.

Although additional observations are needed on the sacrum in a larger number of individuals of many of the races, yet from the material now before me a provisional arrangement of the races of men into two groups, according as the sacral index is below or above 100, may be made. In constructing the following table, the proportions of the male sacrum have been especially relied on:—

DOLICHOHIERIC *Sacral Index below* 100.	PLATYHIERIC *Sacral Index above* 100.
Australians.	Europeans.
Bushmen.	Hindoos.
Hottentots.	Negros.
Kaffirs.	Melanesians.
Andamanese.	Polynesians.
Tasmanians.	Guanche ?
Malays.	Esquimaux ?
Aïnos ?	North American Indians.
Chinese ?	South American Indians.

If this table be compared with the one which I gave in my article on the Index of the Pelvic Brim in the *Journal of Anatomy and Physiology*, Oct. 1885, it will be seen that a dolichopellic brim is in many races conjoined with a dolichohieric sacrum. This is the case, for instance, in the Australians, Bushmen, Kaffirs, Andamanese, Aïnos, and Malays. Again, a platypellic brim is conjoined with a platyhieric sacrum in Europeans, American Indians, and probably Guanches, Esquimaux, and Hindoos. The pelves, which I arranged in the mesatipellic or intermediate division, partly belong as regards the proportions of the sacrum, as in the Negros and Melanesians, to the platyhieric group, and partly, as in the Tasmanians, to that with dolichohieric proportions. As the width of the pelvic brim is materially influenced by the breadth of the sacrum, it was only to be expected that a platypellic pelvis would have a relatively wide sacrum, and that a dolichopellic pelvis would have a relatively narrow sacrum.

When in a human pelvis the conjugate diameter of the brim is in excess of the transverse diameter, *i.e.*, has dolichopellic proportions, and when the proportions of the sacrum are dolichohieric, then in these characters it accords with the proportions of the pelvis in the apes and other mammals which possess five vertebræ in the sacrum. It is animalised or degraded in its characters, as compared with a pelvis which is both platypellic and platyhieric.

3. On a Case of Interlacing Surfaces. By Professor Crum Brown.

The simplest form of the interlacing surfaces as spread upon a plane is illustrated in fig. 1. It will be seen that we have here

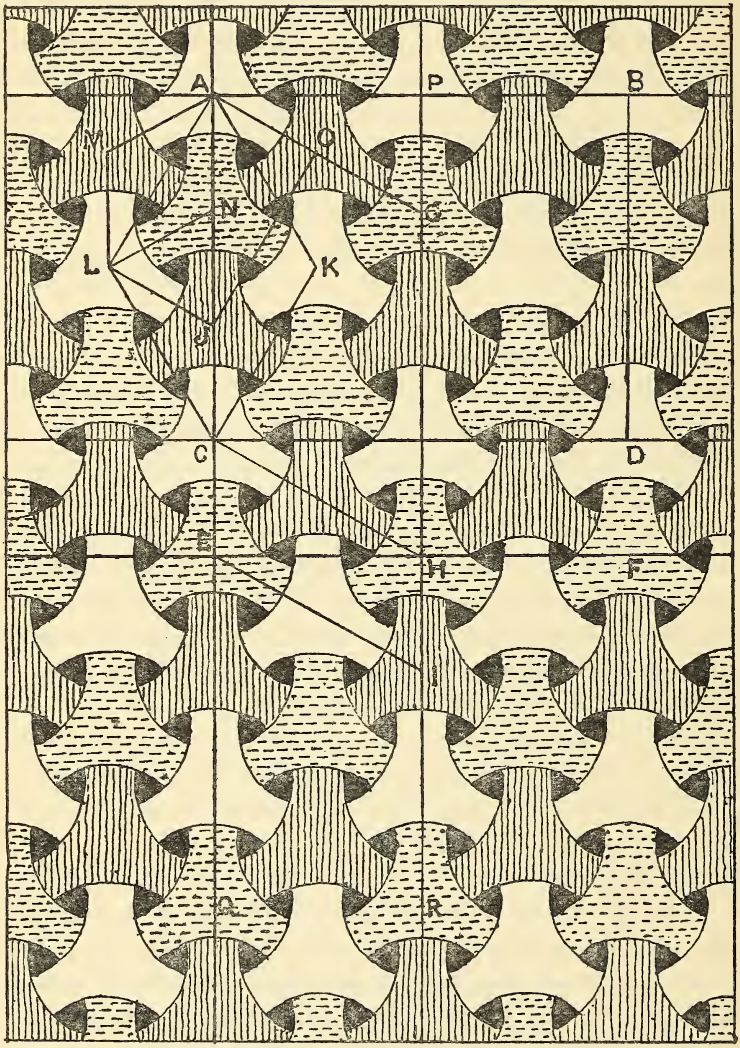


Fig. 1.

three sheets, differently shaded so as to distinguish them to the eye, but otherwise quite similar.

Each sheet is perforated by equal circular holes so arranged that any three neighbouring holes in the same sheet have their centres at the apices of an equilateral triangle. The radius of the holes must not be greater than half the distance between the centres of two neighbouring holes, otherwise the sheet would be cut into separate pieces, and must not be less than one-third of the said distance, otherwise there would not be room for the neck between two holes in one sheet to pass without crumpling through the chink caused by the overlapping of the holes in the other two sheets. In the figure the radius of the holes is about two-fifths of the distance between the centres.

The complex of three sheets is, as will be seen by inspecting the figure, a case of what Professor Tait calls *locking.* No two sheets are *linked* together; if any one sheet be abolished the other two come apart. Each sheet lies wholly above one of the other two, and wholly below the other.

The analogy of this complex to what we may call the Borromean * rings will be seen at once. In the Borromean rings figured below (fig. 2), each ring lies wholly above one of the other two, and wholly below the other, so that while all are inextricably locked together, no two are linked, and if any one is abolished the other two come apart.

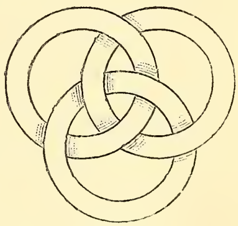


Fig. 2.

The complex of sheets may be applied to other surfaces besides the plane. Two other surfaces, viz., the cylinder and the anchor-ring, will be considered here.

To apply the complex to a cylinder or to clothe a cylinder with the interlaced sheets, we must cut the complex by two parallel lines, and roll up the strip thus cut out so that the two edges shall join and form what may be called the seam. But there must not be any peculiarity at the seam; the pattern must run through the seam without any discontinuity; therefore the two parallel lines must cut the complex in the same manner, so that each part of a hole divided by one line may find its exact continuation at the seam when the strip is rolled up.

* The interlocked rings shown above occur in the armorial bearings of the Italian family Borromeo.

There are, of course, an infinite number of ways in which such a strip may be rolled up into a cylinder. But in whatever way the cylinder is formed, if we cut it along a generating line, and unroll it, we may take the parallel edges of the flat strip as the two lines defining, on the plane complex, the particular cylinder. We may move these two parallel lines, parallel to themselves, retaining their distance from one another, in any way, and they will still represent the same cylinder, because we may form this flat strip by cutting the cylinder through any generating line. Two parallel lines will therefore represent a cylinder if the points in which they intersect a line at right angles to them are always similarly situated in reference to the complex.

The number of cylinders is obviously infinite, but they may all be grouped under two genera. For a part of a hole, cut off by one of the parallel lines, may, at the seam, find its continuation in a part of a hole, either first, in the same sheet, or second, in one of the other sheets.

In the first case we have three distinct sheets locked together. In the second we have only one sheet wound three times round the cylinder, and knotted. When we have three independent sheets we can colour or shade them independently, each having its own colour or shading, but when there is only one sheet this is not possible. In this case the only way of distinguishing the layers is by varying the colour, or shading, continuously as we go round the cylinder, so that after three turns we come back to the colour or shading with which we started. This has been done in the models exhibited.

We have assumed that the complex is flexible, we shall now assume that it is also extensible, so that we can draw it out in any particular direction, and make the circular holes into ellipses. We shall assume that any deformation may be produced without affecting the character of the complex as long as the topological relation of the layers is preserved. This extension is not of any use if we confine ourselves to cylinders, for there is no topological change produced by twisting a cylinder. The meaning of the extension will be seen when we come to apply the complex to an anchor-ring.

An anchor-ring can be made out of a cylinder in two ways. We may cut the cylinder by two planes at right angles to the axis, and bend the part thus cut out round so that its axis becomes the core of the anchor-ring; or we may cut the cylinder, and then widen out the two ends, and bend them over so that they may unite and form a seam not about the core, as in the last mentioned case, but about the axis of the anchor-ring. An anchor-ring has thus two seams—one a circle with its centre in the axis, and one a circle with its centre in the core—and it can be reduced to a cylinder, either by cutting the first, and, if we may coin the word, "unflyping," or by cutting the second, and unbending.

We see then that just as a cylinder can be represented by two parallel lines, so an anchor-ring can be represented by a parallelogram. The condition here is, that the parallel sides of the parallelogram cut the complex in precisely the same way. Such a parallelogram will in general represent two anchor-rings; we must therefore indicate which of the two pairs of parallel lines represents the seam about the axis, and which the seam about the core. To transfer from this plane plan to an actual anchor-ring—that is, to make a model such as those shown to the Society—we have only to remember that the four corners of the parallelogram represent the single point in which the two seams intersect; that the one pair of parallel sides represent the one seam, the other the other; and that lines parallel to these pairs of sides are to be measured on the anchor-ring, in the one case along the circumference of a circle about the axis, in the other case along the circumference of a circle about the core.

As there are two genera of cylinders, one knotted and one locked, so there are four genera of anchor-rings. 1st, locked about the axis and locked about the core; 2nd, locked about the axis and knotted about the core; 3rd, knotted about the axis and locked about the core; 4th, knotted about the axis and knotted about the core. Of these only the first, which is not knotted at all, consists of three distinct sheets; the second is reduced to a locked cylinder by cutting it along a seam about the axis, to a knotted cylinder by cutting it along a seam about the core; in the third these relations are reversed; in whichever way the fourth is reduced to a cylinder, a knotted cylinder is produced.

It is worthy of notice that anchor-rings of the fourth kind have necessarily "helicoidal asymmetry," a ring of this kind is necessarily enantiomorph to its mirror-image.

In the plate the lines AB, CD represent a locked cylinder; AB, EF a knotted cylinder; AQ, PR the smallest locked cylinder; CD, EF the smallest knotted cylinder; the parallelogram ABCD an anchor-ring of the first kind; AGCH one of the second kind, if AC and GH represent the seam about the axis; one of the third kind if these lines represent the seam about the core; AGEI one of the fourth kind; AKLC the smallest ring of the first kind, with one hole in each sheet; AOLJ the smallest ring of the second (or of the third) kind, with two holes altogether; MALN the smallest ring of the fourth kind, the smallest ring indeed of any, having only one hole altogether.

We have hitherto considered the complex as composed of *perforated* sheets locked together, or of a *perforated* sheet knotted, but there is another way in which it may be imagined.

We saw that the smallest circular hole had a radius of one-third of the distance between the centres of two neighbouring holes in the same sheet; but we can make the hole smaller if, instead of making it circular, we make it hexagonal. There is then no waste space; every part of the complex is composed of two layers, one over the other. Now we may suppose this hexagonal boundary to be, not the edge of a hole, but a line of intersection, where the surface, instead of ceasing, disappears between the two other sheets.

The knitted model exhibited illustrates this form of complex.

4. On the Foundations of the Kinetic Theory of Gases. By Professor Tait.

(*a*) On the ultimate average Distribution of Energy among Systems of smooth Colliding Spheres.

The following note was written at the instance of Sir W. Thomson. It is directed mainly to one extremely important point connected with the Kinetic Gas Theory; and is designed to show to the ordinary reader the nature of the investigation, and of the real evidence for the result, without the imposing array of symbols which is usually marshalled in papers on that Theory.

1. Prop. VI. of Clerk-Maxwell's well-known earliest investigation of this subject (*Phil. Mag.* 1860, I. 25) deals with two systems of colliding spheres (those in each system being equal to one another). Their coefficient of restitution is unity, and they rebound without loss of energy from the walls of the containing vessel. His statement is that, *after many collisions*, the average kinetic energy of a sphere is (ultimately) the same in each of the colliding systems.

Particular stress must be laid on the words I have put in italics, because they form the basis of the whole theory. Without collisions there could be no law of any kind ; the arrangement would be, and would continue to be, an absolutely haphazard one about whose character we could not possibly reason. And only after *many* collisions, among great numbers of spheres, can there be any approach to a statistical finality of arrangement.

The theorem is undoubtedly true, provided the number of spheres in *each* system be extremely large, while those of one system are not extremely numerous in comparison with those of the other ; but the proof given by Maxwell has more than one very objectionable feature.

2. The chief of these is the *assumption* (for it is nowhere justified) that the transference of energy from system to system can be calculated without taking account of the mode of its distribution among the particles of either system. This assumption enables Maxwell to reduce the question to the treatment of the consequences of a single impact between a P and a Q (these letters represent the *mass* of a sphere of either system) ; each having the average energy of the system to which it belongs, and being thus regarded as typical of its system. It is typical of all the impacts between a P and a Q (here called *simultaneous*) which take place in the average time which elapses between any two successive impacts of a particular P on some Q or other.

The elegance of the investigation is farther enhanced by the additional assumption that, in obtaining the results of this typical impact, the original directions of motion of the P and Q may be taken as at right angles to one another.

The basis for *this* assumption is, apparently, a previous proposition, which shows that the mean square relative velocity of a P and a Q is the sum of the mean square speeds of the Ps and the Qs.

This proposition is true, under the conditions assumed, and can be proved as below,* by a process much easier for the beginner than that of Maxwell.

But if this assumption were justifiable, a farther application of the same principle should bring out that P and Q (being treated as typical particles after, as well as before, colliding) also *separate* after impact with motions in directions at right angles to one another. For, in the cases here considered, an instantaneous reversal of each velocity would make the whole system retrace its motion.† Maxwell's formulæ, however, show that in general the directions of motion after the typical impact are *not* at right angles to one another. It is clear that this objection is fatal to the method.

But there is yet a farther objection. In interpreting the result obtained in virtue of the assumptions already described, Maxwell exaggerates the rate of equalisation of the average energy in each system by treating the question as if every P impinged on a Q in the "simultaneous" sense above spoken of; and thus ignoring the almost incomparably more numerous particles of each system which, during the very short period contemplated, were either free from impacts or impinged on fellow particles.

So that, finally, he arrives at the very startling conclusion that the difference of the average kinetic energies of a particle from each system is reduced at *every* group of simultaneous impacts in the ratio $(P-Q)^2/(P+Q)^2$. Thus the equalisation of average kinetic

* The mean value, of the square of the distance of any point on a sphere from an internal or external point A, is the sum of the squares of the radius of the sphere and of the distance of A from the centre. Divide the spherical surface into pairs of elements by double cones, of very small angle, whose vertices are at the centre. For each pair of these the theorem is obviously true. Hence if the speeds of two points be p and q, their mean square *relative speed* is p^2+q^2. From this the above statement follows at once; provided that all directions are equally likely for each amount of speed.

† Here we meet with a quasi-metaphysical difficulty, which must be mentioned in passing. For, it may be said, since there is perfect reversibility, the mere instantaneous reversal of a state which is approaching finality will give a state whose tendency is to *depart from* finality, *i.e.*, to get back to the exact reverse of its original condition. True, and most important, but *not* fatal to the conclusion; unless an infinite time has elapsed since the start. For, when the reversal has brought the system back to the same configuration as at starting, but with velocities reversed, it is a *new* departure:—which will lead towards, but never to, its own state of finality.

energy in the two systems would be instantaneous if the masses of the Ps and Qs were equal!

Sir W. Thomson has suggested that part of Clerk-Maxwell's MSS. must have been, by mistake, omitted in sending to press. But I do not think that this idea is confirmed by a careful examination of the text.

Thus it appears that the objections to Maxwell's proof depend, in the main, upon his having commenced too soon to simplify by means of averages. It does not appear that his method, when the objectionable assumptions are put aside, can be applied in any simple manner (see *Proc. R.S.E.*, Dec. 15, 1884). But the investigation may be conducted very simply, as follows, by a method which shows clearly, at every step, what assumptions are made and how they are to be justified.

3. When two impinging spheres are of equal mass, their velocities in the direction of the line joining their centres at impact are simply interchanged. Hence the impact of a P on a P alters (in general) the *distribution* of kinetic energy in the system, but does not alter its average value per particle. These results are, of course, obvious; but they show how it comes about that one particle among a very great number of equal ones (which originally had equal speeds, let us say) may attain any speed, however great; while others may be brought (for a brief period) to rest. This has always, in my experience, formed a serious difficulty to beginners. But, as will be seen, it is a necessary characteristic of *statistical* uniformity.

To take a simple case, this will occur whenever a special particle always impinges on others, so that its own direction of motion is perpendicular to, and that of the other along, the line of centres at each impact. For it thus gets at each impact the whole energy of the two, and it *might* go on doing so till it had reduced all the others to rest. No doubt the acquirement of large speeds is common enough, but only for a few at a time even among a very large group of particles. It will presently be shown that there is a special distribution of relative position and velocity among the particles; towards which there is, on the whole, an approximation, though not necessarily a continuous one. In this special distribution, all speeds occur, but the number of particles which have either high or low speeds (as compared with the *mean square* speed) is a very small fraction of the whole group. After a very long period the final state will be one of irregular fluctuation about this "special" distribution, a fluctuation confined within limits which are (relatively) narrower as the whole number of particles is greater. This special distribution, of course, is that of uniform number of particles, zero of average velocity in every direction, and "error-law" distribution of equal amounts of kinetic energy, in every region of given volume large enough to contain a very great number of particles. Of this proposition satisfactory proof has been given by Maxwell; but we may obtain it very simply by the following considerations.

4. The tendency is to *levelling* all round. The only things to be levelled are the distribution of the whole momentum in each direction, and the distribution of energy among the various velocities. The first depends on direction cosines, the second on their squares. From a point, lay off lines representing the velocities of the various particles. The ends of these lines of lengths r to $r+dr$ must be *uniformly* spread in the volume $4\pi r^2 dr$. This secures that the momentum is equally and similarly distributed in all directions. The energy condition requires that, if there be a final state at all, the number of ends in unit of that volume shall be subject to the "error-law," *i.e.*, expressed by Ae^{-r^2/a^2}. This law is the only one which (when the momentum condition is secured) does not make the calculated number of "ends" in a given volume dependent upon our choice of rectangular axes. We have now to show *how* the collisions tend to produce this result, and also to prove that they tend to maintain it.

Impacts on the containing vessel do not alter r, and thus can shift only the position of an "end" on the spherical surface of which r is the radius. And the impact of two equal particles (as we saw above), does not alter the *distribution* of velocity along the line of centres, nor in any direction perpendicular to it.

Hence impacts, in all of which the line of centres is parallel to one common line, produce no change in the arrangement of velocity-components along that line, nor along any line at right angles to it. But there will be, in general, changes along every other line. It is these which lead gradually to the final result, in which the distribution of velocity-components is the same for all directions.

When this is arrived at, collisions will not, in the long run, tend to alter it. For then the uniformity of distribution of the spheres in space, and the symmetry of distribution of velocity among them, enable us (by the principle of averages) to dispense with the only limitation above imposed, viz., the parallelism of the lines of centres in the collisions considered.

5. When a P impinges on a Q, let u and v be their velocity-components (measured towards the same parts) in the line of centres at impact. Let these be changed by the impact to u' and v' respectively. Then the ordinary text-book result is

$$P(u'-u) = -\frac{2PQ}{P+Q}(u-v) = -Q(v'-v).$$

From this we deduce immediately

$$P(u'^2-u^2) = -\frac{4PQ}{(P+Q)^2}\left(Pu^2 - Qv^2 - (P-Q)uv\right) = -Q(v'^2-v^2).$$

This shows the amount of energy transferred between the P and the Q at one impact.

6. To obtain an average from this we begin by assuming that the Ps and Qs are thoroughly mixed, and are *separately* in the "special" condition of § 4. Of course, this implies that there is a very large number of particles of *each* kind. We also assume, what will probably on consideration be granted, that the mutual actions of the Ps alone, and of the Qs alone, still tend to preserve in each system this "special" state; or to restore it if it should be disturbed by the action of some Ps upon Qs. This is based partly on the uniform mixing of the Ps and Qs, partly upon the small percentage of each system which is involved in any "simultaneous" collisions. If this be granted, it is clear that we may assume that for a great number of *simultaneous* (§ 2, above) impacts of Ps on Qs, the average value of uv is at least approximately zero.* The reader must bear in mind that u and v are velocity-components parallel to the line of centres, which may have *any* direction. But we also see that we may now look on the average value of $Pu^2 - Qv^2$ as being two-thirds of the

* There is no inconsistency between the two expressions above, viz., "great number of simultaneous impacts," and "small percentage of each system which is involved in any simultaneous collisions." For we must remember that the whole number of particles is *very great;* and even a "small percentage" of a very great number may itself be "a great number."

excess of energy of the *impinging* Ps over that of the corresponding Qs. Similarly the average value of $P(u'^2 - u^2)$ may be looked on as two-thirds of the increase of energy of the *impinging* Ps, and so forth. But the assumptions above enable us to say that, because there are many "simultaneous" collisions, the average value of Pu^2 for the *impinging* Ps is the average value for *all* the Ps. &c. Then our equation shows that, with the above assumptions, the *impinging* Ps lose energy on the whole if, and only if, their average energy is greater than that of the Qs they impinge on. But such gains or losses of energy distribute themselves through the systems of Ps and Qs separately; so that, on the whole, there is transference of energy from the Ps to the Qs so long, and only so long, as the average energy of a P is greater than that of a Q. Thus there is an approach (persistent in the long run, but not in general continuous) to equality between the average energy of a P and a Q; and, with these assumptions, Maxwell's proposition is undoubtedly true.

7. We may, in passing, make an approximation (of a very rough kind) to the rate at which this equalisation goes on, as follows:—

Let ϖ be the whole number of Ps,

ρ ,, ,, Qs;

ν the number of impacts between a P and a Q, in

τ the average interval which elapses, for each one P, between impacts on Qs. Let $Pp^2/2$ be the average energy of a P, $Qq^2/2$ that of a Q. Then our equations give (omitting the numerical factor $\frac{1}{3}$)

$$\varpi d(Pp^2) = -\frac{4PQ\nu}{(P+Q)^2}(Pp^2 - Qq^2)\tau = -\rho d(Qq^2).$$

Writing x for Pp^2, y for Qq^2, and N for $PQ\nu/(P+Q)^2$, this becomes

$$\varpi\dot{x} = -N(x-y) = -\rho\dot{y},$$

whence

$$Pp^2 = x = A - \rho B\epsilon^{-et}$$
$$Qq^2 = y = A + \varpi B\epsilon^{-et},$$

where

$$e = N\frac{\varpi+\rho}{\varpi\rho}.$$

8. It is foreign to my present purpose to enter into the calculation of the values of ν and τ, which depend on the diameters of a P and a Q, and the average distance between the centres of any two

proximate particles, as well as on the average speeds of a P and a Q. (This calculation can be effected by a simple method closely analogous to that in § 4 above. See the paper immediately following this.) But it is very much to my purpose to look back on what precedes, so that we may clearly see what assumptions *had* to be made in order that our results might be such as they are.

And we see at once that the investigation, from the point of view taken, would have been barren of interpretable result had it not been for the assumptions by which we [so far]* justified (in § 6) the statements:—

(*a*) Average value of $uv = 0$.

(*b*) Average value of $Pu^2 - Qv^2 = \frac{1}{3}(Pp^2 - Qq^2)$.

This last may be considered as including—

(*c*) Average value of $P(u'^2 - u^2) = \frac{1}{3}P(p'^2 - p^2)$ divided by the ratio, of the number of Ps which impinged on Qs, to the whole number of Ps.

Now these assumptions were themselves justified solely by the understood "special" state of the Ps and Qs separately; and by the "equalising" property, in virtue of which each system, so far as its own internal actions are concerned, tends in the long run to that special state. We are not warranted in concluding that either (*a*) or (*b*) would hold true unless the separate systems tended by their own internal actions to the "special" state. Thus, suppose the Ps to impinge on one another, and on the Qs; but the system of Qs to have no internal impacts. This would be the case if the Qs were mere points; *i.e.* particles of diameters infinitely small in comparison with the average distance between two proximate ones. Nothing above, so far at least as we have developed it, warrants us in concluding that the Qs will tend to a special state, and, therefore, acquire the same average energy as the Ps. Obviously, if the Qs were in a great majority, they would not only not themselves assume a special state, but would also tend to prevent the Ps from ever doing so. Think of Le Sage's ultramundane corpuscles and

* [Inserted Jan. 8, 1886.] I hope to show at the next meeting of the Society that, though neither of these assumptions is correct, Maxwell's Theorem is rigorously true. Neither in Maxwell's paper nor in this has any account been taken of the fact that collisions are more frequent as the *relative* speed is greater. This consideration affects only *numerically* the results of §§ 7, 9, 10 above, and does not interfere with the argument based on them.

their effects. Still less should we, under such limitations, be justified in the corresponding conclusions with regard to a mixture of three or more systems, each of equal spheres, which form the subject of the corollary to Maxwell's Prop. VI.

We now pass to a different, but closely connected subject.

9. Boltzmann's generalisation of the corollary to Clerk-Maxwell's Theorem, in which it is asserted that, after numerous collisions, the average energy is the same for each degree of freedom of the similar and equal complex particles of a colliding system, has proved a stumbling-block in the way of the Kinetic Theory, by being apparently irreconcilable with one or other of two experimental facts, (1) the value of the ratio of the specific heats of a gas, (2) the complexity of the spectrum of a self-luminous gas.

It appears from the above that there is an immediate mode of escape from this difficulty, provided the complex particles be so constructed that there is not perfect access for collision between *every* degree of freedom of one particle and *every* degree of freedom of every other. We cannot further consider this here, but pass for a moment to another view of the subject.

For, even if Boltzmann's Theorem were true without this condition, we must not at once conclude that a gas cannot consist of such complex particles. Every experiment shows that some, at least, of the quicker vibrating parts of the particle must be constantly losing energy by uncompensated radiation; and when the whole is, in spite of this, kept at what we call constant temperature, the requisite supply of energy comes in a translational form by impacts on the walls of the vessel. We may form an approximation, to what would then happen, by the simple expedient of supposing the coefficient of restitution to be less than unity for some of the degrees of freedom. In such a case the equations of § 5 become, respectively,

$$\mathrm{P}(u'-u) = -\frac{(1+e)\mathrm{PQ}}{\mathrm{P}+\mathrm{Q}}(u-v) = -\mathrm{Q}(v'-v)$$

and

$$\mathrm{P}(u'^2-u^2) = v\frac{2(1+e)\mathrm{P}}{(\mathrm{P}+\mathrm{Q})}\left\{\mathrm{P}u^2 - \mathrm{Q}v^2 + \frac{1-e}{2}\mathrm{Q}(u^2+v^2)\right\}$$

$$\mathrm{Q}(v'^2-v^2) = \frac{2(1+e)\mathrm{PQ}}{(\mathrm{P}+\mathrm{Q})^2}\left\{\mathrm{P}u^2 - \mathrm{Q}v^2 - \frac{1-e}{2}\mathrm{P}(u^2+v^2)\right\}.$$

We have omitted terms in uv from each of the right-hand sides; taking for granted that, in this case also, we may treat their mean value as nil if the number of colliding pairs is sufficiently great, and if the equalising process goes on in each system. These equations, with the proper alterations, apply to the internal impacts in the systems of Ps and Qs separately. The values of e may be different for a P and P and a Q and Q; but from them the value for a P and Q can be calculated. [Hodgkinson, *B. A. Report*, 1834.]

10. In particular there is a specially interesting case when $e=1$ for a P and P, and for a P and Q; but $e<1$ for a Q and Q. Here it is easy to see that the equations of § 7 are modified to

$$\begin{aligned} \varpi\dot{x} &= -\mathrm{N}(x-y) \\ \rho\dot{y} &= \mathrm{N}(x-y) - \mathrm{N}'y \end{aligned}$$

where N′ depends upon e and upon the frequency of impacts among the Qs.

[This, and all the equations which correspond to questions of the kind above proposed, are of the type

$$\left.\begin{aligned} \dot{x} &= -ax + c_1 y \\ \dot{y} &= c_2 x - by \end{aligned}\right\}, \quad ab - c_1c_2 > 0;$$

and the solutions are always of the form

$$\begin{aligned} x + \lambda_1 y &= \mathrm{A}\varepsilon^{-\mu_1 t} \\ x - \lambda_2 y &= \mathrm{B}\varepsilon^{-\mu_2 t} \end{aligned}$$

where the values of λ are given by

$$c_2\lambda^2 - (a-b)\lambda - c_1 = 0.$$

We have also $c_2\lambda - a = \mu$, so that the equation for μ is

$$\mu^2 + (a+b)\mu + ab - c_1c_2 = 0.$$

The root μ_2, which corresponds to the negative value of λ, is (numerically) greater than μ_1; so that the value of $x - \lambda_2 y$ dies away faster than that of $x + \lambda_1 y$. We may suppose the whole energy to be constantly recruited through the Ps, so that ultimately $x - \lambda_2 y = 0$. This gives the final ratio of the energies of particles, one from each system.]

In the present example, N′ vanishes when $e=1$, in which case we have the equations of § 7. For them we had $\lambda_2 = 1$, which is its least (numerical) value. Hence when $e<1$ we have ultimately

$$x > y;$$

that is, the average energy per Q tends to smaller value than that per P.

11. To work out the consequences of such equations as those of § 9, in the most general form, would lead to details too complex for the ordinary reader. We will therefore take another special case, in order to point out how the results are modified by other simple assumptions of the kind spoken of there.

Let there be three systems of particles such that Ps and Qs are as before, but each Q has an R, which cannot impinge on anything but its special Q. Thus we may suppose each Q in the former arrangement (§ 7) to be made hollow, and to have an R (free) put inside it.

We are not prepared, so far as we have gone, to treat this question if the R's, like the Ps and Qs, have unit coefficient of restitution. For, § 8 above, the R's do not impinge on one another.

But if we suppose the coefficient of restitution of Q and R to be less than unity, and the interior of a Q so nearly equal to the R inside, that between every two collisions of the Q with an external particle there is time for the R inside it to be reduced to relative rest (or what may be treated as such) we may approximate to the ultimate state of things.

The equations in § 6 still hold good for each impact of a P on a Q. But, immediately after the impact, the Q impinges on its R; with the result that, before the Q suffers another collision, v' is reduced to v'', where $(Q+R)v'' = Qv' + Rv$, so that instead of the equations in § 7, we have now

$$\varpi\dot{x} = -\frac{4PQ\nu}{(P+Q)^2}\left\{x - \frac{Q}{Q+R}y\right\}$$

$$\rho\dot{y} = \frac{4PQ\nu}{P+Q}\left\{-\frac{y}{Q+R} + \frac{Qx}{(P+Q)(Q+R)} + \frac{PQy}{(P+Q)(Q+R)^2}\right\}$$

$$-\frac{4QR+2R^2}{(Q+R)^2}y\nu',$$

where the last term in the value of y is due to $2\nu'$ sets of impacts between Qs and their Rs, *after* the Qs have collided in pairs.

To get a notion of the nature of this result, suppose as before $\varpi = \rho$, $\nu = \nu'$. Also let $Q = 3R$, $P = 4R$, then we find by the above methods that ultimately x is nearly the double of y.

If we had unit coefficient of restitution between Q and R, and were to assume Boltzmann's result here, we should have x to y as 1 : 2 ; because the Qs consist of two separate parts, *each* of which (having the same number of degrees of freedom) would ultimately have the same energy as a P.

12. Without more formidable mathematical processes we cannot well push these investigations further :—but enough has been done to show on what bases Clerk-Maxwell's Theorem really rests ; and, at the same time, to show that even were Boltzmann's extension of it rigorously proved, it need not prevent us from accepting the kinetic theory, which has furnished such simple and complete explanations of many puzzling phenomena. It is not at all likely that the particles of any gas (be it even mercury vapour) behave as if their coefficient of restitution were exactly unity. They would probably require, in order to do so, a steady supply of heat ; perhaps other things of which we have as yet no knowledge. Among these unknown conditions may be mentioned, so far as the specific heat question is concerned, the nature of the impacts between the particles and the walls of the containing vessel. The law of these impacts, and the mode in which the energy thus received is distributed among the degrees of freedom of a particle, may differ widely from those which regulate the impact of particle on particle.

(*b*) On the Length of the Mean Path among Equal Spheres.

The following investigation has been made as elementary as possible. It will be seen that it leads to a result somewhat different from that usually accepted. The source of the discrepancy is pointed out.

Let s be the diameter of a sphere. It protects a circular area πs^2 in any plane through its centre ; in the sense that another sphere, of the same diameter, moving perpendicularly to that plane, will necessarily collide with the first if the line of motion of its centre pass within the circle

Hence if there be a layer of thickness δx, in which quiescent spheres are evenly distributed, at the rate of n_1 per unit volume, and if a group of spheres (whatever their common speed) impinge perpendicularly on the layer, the fraction of them which pass through the layer without collision is

$$1 - n_1 \pi s^2 \delta x .$$

If they impinge obliquely on the layer, we must substitute for δx the thickness of the layer in the direction of their motion.

If the particles in the layer were all moving with a common velocity, we should have to substitute for δx the thickness of the layer in the direction of the *relative* velocity.

So far, all is so obvious as not to require proof. Now suppose v to be the common speed of the impinging spheres, and that they all move perpendicularly to the layer. Also suppose that all spheres in the layer are moving with common speed v_1, but in directions uniformly distributed in space.

Those of them which are moving in directions inclined from β to $\beta + \delta\beta$ to the direction of motion of the impinging particles are, in number per unit volume, $n_1 \sin\beta\, \delta\beta/2$

The virtual thickness of the layer in the direction of relative motion is, so far as these are concerned,

$$\delta x \frac{\sqrt{v^2 + v_1^2 - 2vv_1 \cos\beta}}{v} ;$$

the term involving the cosine having the negative sign, because the velocity v_1 has to be reversed in finding the relative velocity.

Thus the fraction of the impinging particles which traverses this set without collision is

$$1 - n_1 \pi s^2 \delta x \frac{\sqrt{v^2 + v_1^2 - 2vv_1 \cos\beta}}{2v} \sin\beta\delta\beta .$$

All such expressions, from $\beta = 0$ to $\beta = \pi$, each of them less than unity by an infinitesimal quantity, must be multiplied together to find the fraction of the impinging particles which traverse the layer without collision. The logarithm of this product is

$$-\frac{n_1 \pi s^2 \delta x}{2v} \int_0^\pi \sqrt{v^2 + v_1^2 - 2vv_1 \cos\beta} \sin\beta d\beta .$$

If v be greater than v_1, the value of this is

$$-n_1\pi s^2\delta x\left(1+\frac{v_1^2}{3v^2}\right);$$

but if v be less than v_1, it is

$$-n_1\pi s^2\delta x\left(\frac{v}{3v_1}+\frac{v_1}{v}\right).$$

These values are equal, as they ought to be, for the case of $v=v_1$.

We must now take account of the distribution of speeds among the particles in the layer. If there be n per unit volume, the number having speeds between v_1 and $v_1+\delta v_1$ is

$$n_1=\frac{4nv_1^2\delta v_1}{\sqrt{\pi}\,.\,a^3}\varepsilon^{-v_1^2/a^2}.$$

Hence the logarithm of the fraction of the whole number of particles, with speed v, which freely traverse the layer is

$$-\frac{4n\pi s^2}{\sqrt{\pi}\,.\,a^3}\delta x\left(\int_0^v\varepsilon^{-v_1^2/a^2}\left(v_1^2+\frac{v_1^4}{3v^2}\right)dv_1+\int_v^\infty\varepsilon^{-v_1^2/a^2}\left(\frac{vv_1}{3}+\frac{v_1^3}{v}\right)dv_1\right).$$

If we write this, for a moment, as $-e\delta x$, it is clear that

$$\varepsilon^{-e\delta x}$$

represents the fraction of a group of particles with speed v which penetrate unchecked the layer δx, and thus

$$\varepsilon^{-ex}$$

represents the fraction which pass without collision through a distance x. Hence the average depth to which particles with speed v can penetrate without collision is

$$\frac{\int_0^\infty\varepsilon^{-ex}x\,dx}{\int_0^\infty\varepsilon^{-ex}dx}=\frac{1}{e}.$$

The value of e is, of course, a function of v.

If we now suppose the impinging particles to have speeds assorted as they are in the statistically stable distribution, the average free path is to be found by multiplying the free path for each speed by the probability of the particle's having that speed, and adding the results. This gives

$$\frac{4}{\sqrt{\pi}.}\int_0^\infty \frac{{}^2dv}{e}\varepsilon^{-v^2/\alpha^2},$$

or, by the value of e above,

$$\frac{1}{n\pi s^2}\int_0^\infty \frac{v^2 dv\,\varepsilon^{-v^2/\alpha^2}}{\int_0^v \varepsilon^{-v_1^2/\alpha^2}\left(v_1^2+\frac{v_1^4}{3v^2}\right)dv_1+\int_v^\infty \varepsilon^{-v_1^2/\alpha^2}\left(\frac{vv_1}{3}+\frac{v_1^3}{v}\right)dv_1},$$

which may be written, after some reductions of an easy kind, in the simpler form

$$\frac{1}{n\pi s^2}\int_0^\infty \frac{4x^4dx}{x+(2x^2+1)\varepsilon^{x^2}\int_0^x \varepsilon^{-x^2}dx}.$$

It is obvious, from what precedes, that if the particles of the medium traversed had been quiescent, the mean path through them (at any speeds) would have been simply the first factor of this, viz.,

$$\frac{1}{n\pi s^2}.$$

Hence the definite integral above, which is, of course, a mere numerical quantity, expresses the ratio in which the mean path is shortened in consequence of the motion of the particles of the medium traversed. By a rough process of quadratures (at intervals of 0·25 from 0 to 3), I find its value to be about

0·677 +

but I hope soon to evaluate it more exactly. To check this result I traced by points the curve whose area is expressed by the integral, cut it out in stout tinfoil, and compared its weight with that of a square unit. The result was 0·682, but I had probably allowed too much for the infinitely extended part of the area, which it was very difficult to represent properly by a process of this nature.

Clausius gave, from his point of view (equal speeds, equally distributed in all directions), the factor

$$0{\cdot}75.$$

This can be readily obtained from the above formulæ *before* the introduction of the distribution of speed. It is accurate from the point of view taken by Clausius, but it is inapplicable to the kinetic theory.

Clerk-Maxwell gave the value $\frac{1}{\sqrt{2}}$ or, nearly,

$$0{\cdot}707.$$

But his process is, I think, based on a questionable definition, which has since been adopted by Meyer, Watson, and others, who have written on the Kinetic Theory. It involves the assumption that the mean free path is expressed by

$$\frac{\text{Average speed of a particle}}{\text{Average number of collisions per particle per second.}}$$

But, in order to find either the numerator or the denominator of this fraction, recourse is had to the *ordinary* definition of a mean, that which we have used above.

Those who adopt this deviation, from the ordinary method of finding a mean, must face the question :—Why not adopt another equally plausible deviation, and define the mean free path as

(Average time of describing a free path) × (average speed) ?

If n_v be the fraction of the whole particles which have speed v, p_v *their* mean free path; the definition of the mean free path, which we have adopted as the natural one, gives for its value

$$\Sigma(n_v p_v).$$

The definition usually adopted gives

$$\frac{\Sigma(n_v v)}{\Sigma\left(n_v \frac{v}{p_v}\right)}.$$

That which is suggested above, as an alternative to this last, gives

$$\Sigma\left(n_v \frac{p_v}{v}\right) . \ \Sigma(n_v v).$$

It gives for the reducing factor the approximate value 0·647; which falls short of 0·677 nearly as much as that, in its turn, falls short of 0·707.

From the point of view here taken, the process usually adopted virtually amounts to assuming that the mean value of a number of fractions is to be found by dividing the mean of the numerators by the mean of the denominators. The reason for the close approximation of the results obtained by these different methods is to be sought in the fact that the great majority of the particles have speeds differing but little from the mean square.

It is usual to express the result of this investigation in the form of the ratio of two fractions;

$$A = \frac{\text{Mean Path}}{\text{Diameter of Particle}},$$

and

$$B = \frac{\text{Volume occupied by the particles}}{\text{Sum of the volumes of the particles}}.$$

The values of B/A are

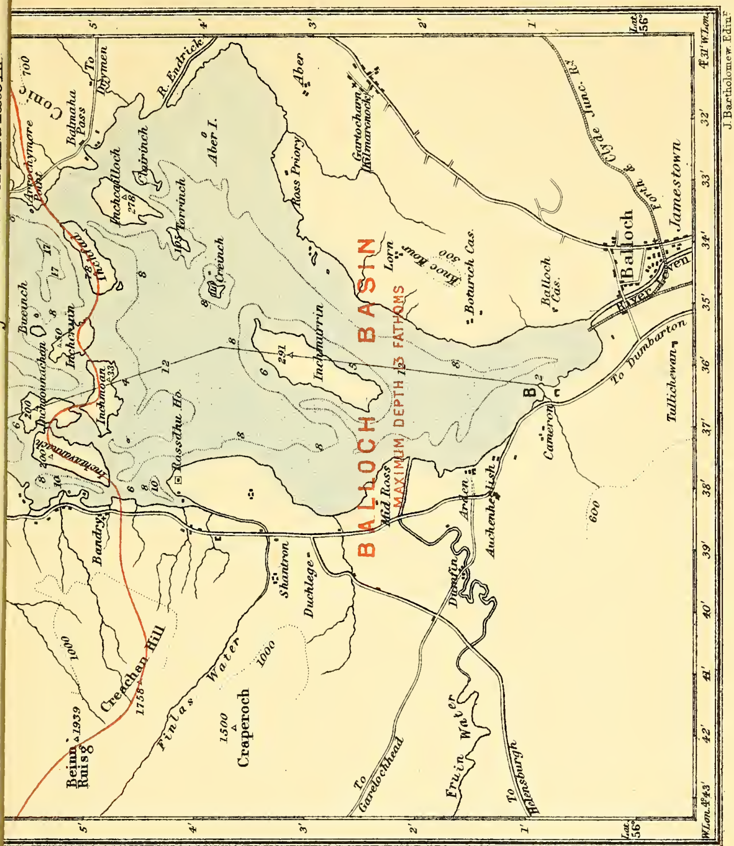
According to Clausius		8
,, ,,	Clerk-Maxwell	$\sqrt{72} = 8{\cdot}48$ nearly
,, ,,	above reasoning	$\frac{6}{0{\cdot}677} = 8{\cdot}86$,,
,, ,,	alternative	$\frac{6}{0{\cdot}647} = 9{\cdot}27$.

It may be worth while to remark, in this connection, that the somewhat elaborate process, by which Meyer* obtains the mean number of collisions undergone by a particle in unit of time, can be very much simplified. For, by what is said above, it is easy to see that ev represents the average number of collisions which will be undergone, per second, by a particle whose speed is, *and remains*, v. Hence, taking account of the distribution of speed among the impinging particles, we have for the average number of collisions per particle, per second, Meyer's expression

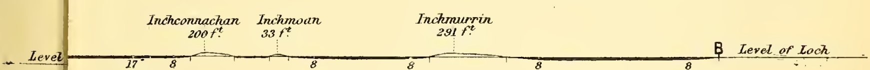
$$\frac{16ns^2}{\alpha^6}\int_0^\infty \varepsilon^{-v^2/\alpha^2} v^3 dv \left(\int_0^v \varepsilon^{-v_1^2/\alpha^2}\left(v_1^2 + \frac{v_1^4}{3v^2}\right)dv_1 + \int_v^\infty \varepsilon^{-v_1^2/\alpha^2}\left(\frac{vv_1}{3} + \frac{v_1^3}{v}\right)dv_1\right).$$

* *Dissertatio de gasorum theoriâ*, 1866. Quoted in his work *Die Kinetische Theorie der Gase*, 1877, p. 294.

Proc. Roy. Soc. Edinr. Vol. XIII. Plate XI.

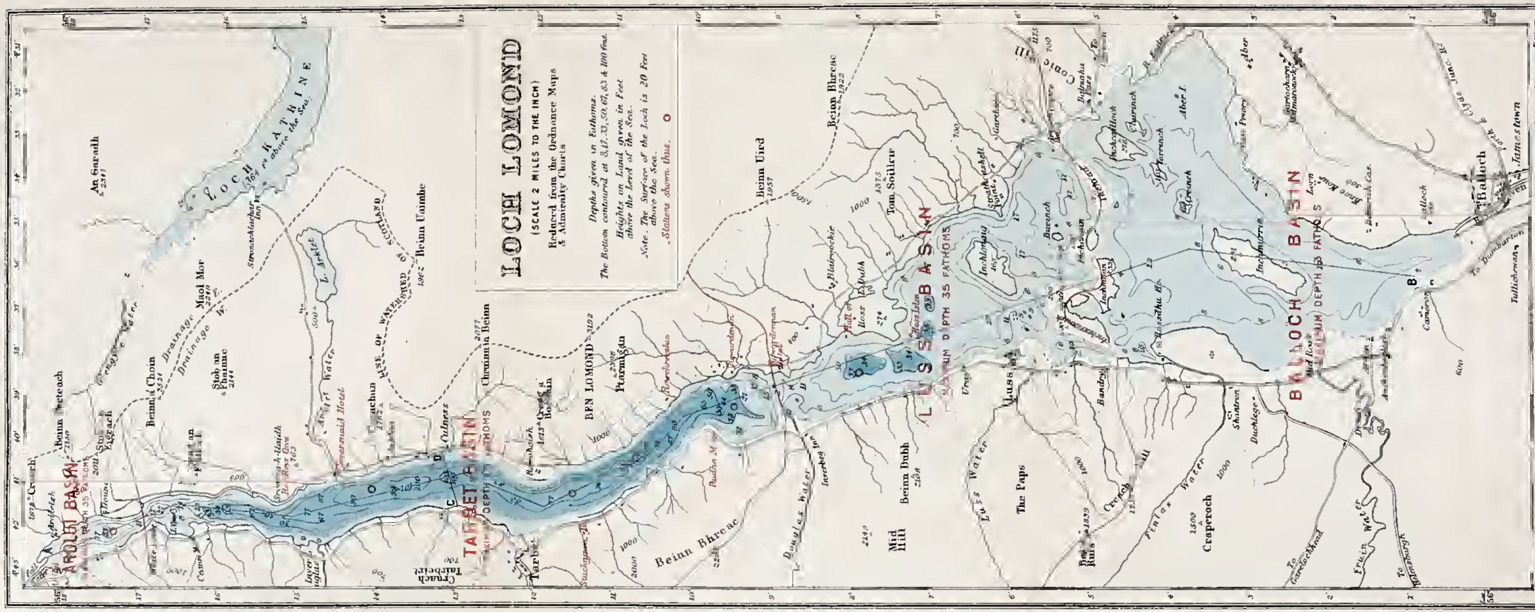


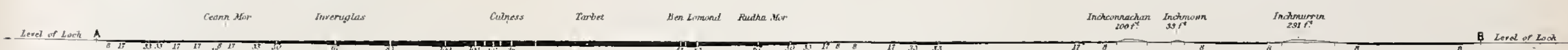
With the permission of Prof. Jas. Geikie, this map is printed from the plate in his "Great Ice Age.")



HE LINE A B ON MAP

Proc. Roy. Soc. Edinr. Vol. XIII. Plate XI.





SECTION OF LOCH LOMOND ON THE SCALE OF HALF AN INCH TO THE MILE THROUGH THE LINE A B ON MAP

Depths in Fathoms · Height of Islands in Feet

SECTION ACROSS LOCH LOMOND ON SAME SCALE

With the permission of Prof. Jas. Geikie, this map is printed from the plate in his "Great Ice Age."

The value of this (which Meyer obtains by expanding in an infinite series, integrating, and summing) may be obtained by noting that while the two parts must, from their meaning, be *equal*, the second part can be integrated at once as it stands.

Or we may change the *order* of integration in the first, and find that it is transformed into the second.

Or we may obtain it by inspection, if we merely transform the double integrals by the assumptions

$$v = r\cos\theta\,,\ v_1 = r\sin\theta\,.$$

Note now that the limits for r are 0 to ∞ in both; but those for θ are 0 to $\pi/4$ in the first, and $\pi/4$ to $\pi/2$ in the second. When this is done we find that the mean number of collisions is $2\sqrt{2\pi}\,ans^2$. Dividing, by this, the mean speed $2a/\sqrt{\pi}$, we have Clerk-Maxwell's value of the mean path $\frac{1}{\sqrt{2}\,.\,\pi ns^2}$.

PRIVATE BUSINESS.

The following Candidates were balloted for, and declared duly elected Fellows of the Society:—Dr A. B. Griffiths, F.C.S., Technical College, Manchester; Daniel M. Connan, Esq., Education Department, Cape Town; and David Cunningham, M.Inst.C.E., Dundee.

Monday, 21st December 1885.

PROFESSOR DOUGLAS MACLAGAN, M.D., Vice-President, in the Chair.

The following Communications were read:—

1. On the Distribution of Temperature in Loch Lomond during the Autumn of 1885. By J. Y. Buchanan. (Plate XI.).

In the course of the autumn of this year (1885) I have taken several occasions to determine the distribution of temperature in the water of Loch Lomond. The results of these observations are interesting, as indicating the march of temperature in the different layers at different localities in the lake, and also the gain and loss of heat with the changing seasons.

Loch Lomond is divided naturally into three basins. If the level of the water were reduced by about 8 fathoms, it would form three lakes,—the upper and largest extending from the head of the loch to Rowardennan, the middle one from Rowardennan to the chain of islands stretching from Luss to Balmaha, and the third, and shallowest, from these islands to Balloch. The ridges which separate these basins are covered in the present state of the lake by from 5 to 8 fathoms of water. The lowest, or Balloch basin, is of great extent and comparatively shallow, having a maximum depth of 13 fathoms. The middle, or Luss basin, is also of considerable extent, and has a maximum depth of 35 fathoms. The upper, or Tarbet basin, is long and narrow, and very deep, the maximum depth being 105 fathoms. At the upper end of this basin is a subsidiary one, which I call the Ardlui basin, with a maximum depth of 34 fathoms, and separated from the main basin by a ridge with a probable maximum depth of 17 fathoms.

The general direction of the lake is north and south, so that the prevailing westerly and south-westerly winds blow across it, and, as is always the case in mountainous districts, they are diverted into squalls, which blow sometimes up and sometimes down the lake. At Tarbet there is a deep rift in the mountains separating Loch Lomond from Loch Long, which gives access to the westerly winds to this part of the lake. On the whole, the geographical position of the lake tends to neutralise the effect of the prevailing winds.

Extended temperature observations were made on the following days:—18th August, 5th and 22nd September, 15th October, and 14th November. On the 18th August observations were made only in the Tarbet basin, and only down to a depth of 30 fathoms. On the 5th September observations were made in the Luss basin, at four stations in the Tarbet basin, and at one station in the Ardlui basin. On the 22nd September observations were made in the Luss basin, and at two stations in the Tarbet basin. On the 15th October observations were made at the same stations as on 5th September, omitting Culness; and on 14th November observations were made in the Luss basin and at Inversnaid.

The observations were made with an improved form of protected six's thermometer, having a millimetre scale on the stem and a Fahrenheit's scale on slips at the side. The average length of a degree Fahrenheit was 3 millimetres, and all the thermometers had been carefully and repeatedly compared with each other, and with a Kew corrected standard. The temperatures given are all in terms of the Kew standard. As a rule, the same thermometer has been sent to the same depth. Further, the same sounding line was used on all occasions.

The results are collected in tables, and in some cases they are represented graphically by curves.

If we represent the distribution of temperature graphically by a curve, having depths measured along the horizontal line of abscissæ and temperatures along the ordinates, the winter distribution will be represented by a straight line parallel to the line of abscissæ, such as A. As the spring advances and the meridian altitude of the sun daily increases, the temperature of the surface rises rapidly. The heat received at the surface is, during this season, propagated downwards, chiefly by conduction, which, in water, is a comparatively slow process, hence the temperature of the surface, and of the layers near it, rises much more rapidly than that of those below it, and consequently the curve representing the vertical distribution takes the form B, which, from the bottom to within about 15 fathoms of the surface, preserves its parallelism to the line of abscissæ, but then bends sharply upwards, presenting a well-marked convexity to the origin. This convexity of the curve is the distinctive feature of a *vernal* distribution of temperature. As the summer advances the temperature of the surface no longer increases at the same rate as before, indeed it tends always more and more to become constant. The heat of the surface layers is, however, always being propagated downwards by conduction, and when the temperature of the surface layer has become nearly constant, it follows that, at some depth a little below the surface, the temperature will be rising more quickly than in the layers above, and this produces a slight bulge in the curve C, representing the distribution. This part of the curve presents a concavity to the origin which, combined with the pronounced convexity below and the less marked convexity above, produces the typical *summer* distribution. When the autumn has set in, and the surface temperature falls from day to day, heat is still being propagated downwards by conduction and convection, the curve takes the typical autumnal form D, consisting of a horizontal piece near the surface united to another horizontal piece near the bottom by the summer concavity and the vernal convexity. Hence in the autumn the waters of a

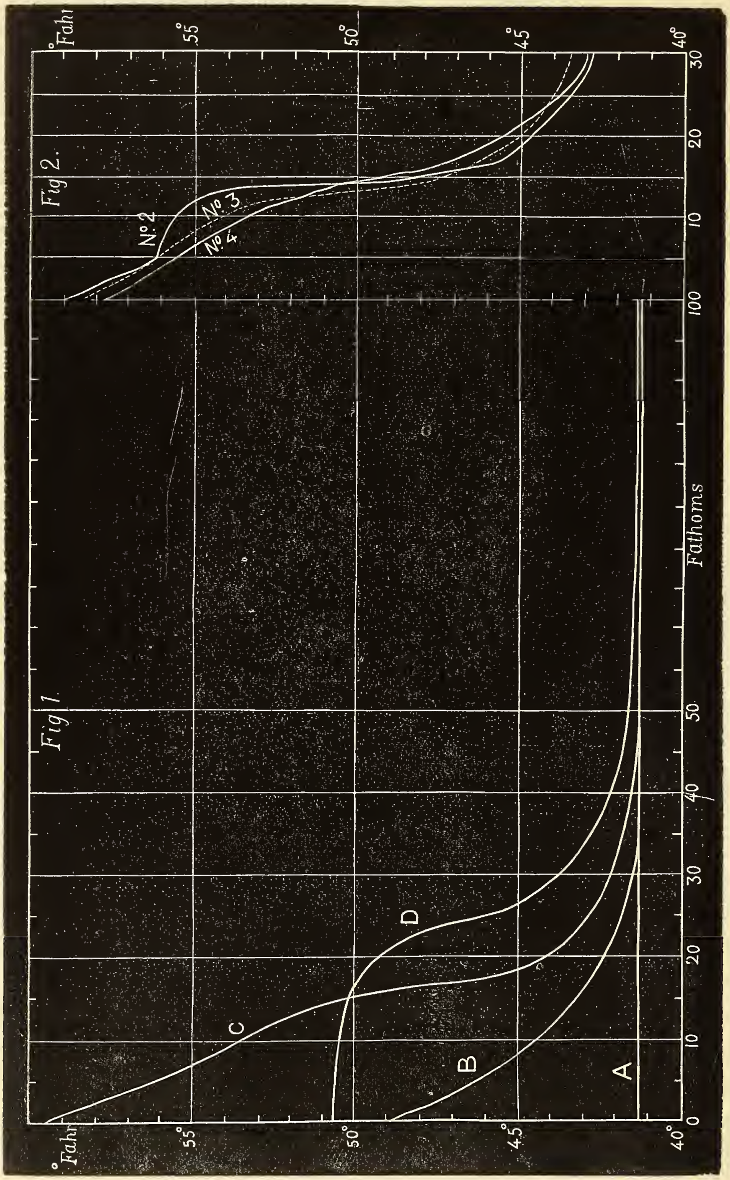


Fig. 1.—Typical Curves of Distribution of Temperature in a Scottish Lake 100 fathoms deep. A, in winter; B, in spring; C, in summer; and D, in autumn.

Fig. 2.—Curves of Temperature, 18th August 1885.

deep lake are exposed to all the different conditions of the four seasons of the year. In the deeper layers heat is propagated downwards most rapidly in the first half of the month of October. As the winter progresses heat leaves the water so rapidly by the surface that conduction downwards is checked and the deeper waters derive but very slight benefit from the summer heat at the surface.

Observations on 18th August 1885.—These observations were confined to the Tarbet basin, and were only carried to a depth of 30 fathoms. The weather was perfect for sounding operations, being quite calm, so that the steam launch, which was used for the work, remained in position without trouble. The sun was very

TABLE I.—*Observations in Loch Lomond, 15th October* 1885.

Locality,		Rowardennan.	Rowcreeshie.	Culness.	Rob Roy's Cave.	Range of Temperature at the same depth.
Miles from Balloch Pier,		9	10	12¾	15	
Depth at Station,		25	70	100	60	
Hour of day,		noon.	3.30 P.M.	1 P.M.	2 P.M.	
No. of Station,		1	2	3	4	
Depth. Fathoms.	No. of Thermometer.	Temperature (Fahr.).				
0	...	57°·5	58°·7	58°·4	57°·7	1°·2
5	21	56·75	56·2	56·3	55·5	1·25
10	9	56·0	55·75	54·3	53·45	2·55
15	23	49·45	48·85	47·95	50·0	2·05
20	47	44·5	45·0	45·2	45·8	1·3
25	79	43·35	43·85	44·0	43·8	0·65
30	80	...	42·95	43·35	43·0	0·4
0 to 30 mean,		...	50·90	49·74	49·8	0·35
Steepest Gradient,	Degs. per fm.	1·31	1·38	1·26	0·84	...
	Depth,	13	13	12	17	...

powerful all day, and its heating effect may be judged from the fact that at 10 A.M. the surface water in the channel off Camstradden was 58°·9, and at 5.30 P.M. in the same position it was 62°·6 F., indicating a rise of 3°·7 in the course of the day. As an assistance to finding the positions of the stations, I give the distance in nautical miles in a straight line from Balloch pier; as a rule, they were made in the deepest part of the loch in the locality.

The distribution in series Nos. 2, 3, and 4 is graphically represented in fig. 2, and it will be seen that the curves have a marked summer character. The steepest gradients are between 10 and 15 fathoms. At Culness (No. 3) the fall of temperature is 6°·9 in this interval, or 1°·38 per fathom. The least steep gradient is on the northmost station, No. 4, indicating greater mixture of the layers

TABLE II.—*Observations in Loch Lomond, 5th September 1885.*

Name of Basin,		Luss.	Tarbet.				Ardlui.
Locality,		Ross Mill.	Rowardennan.	Stuckgowan.	Culness.	Inversnaid.	Doune Farm.
Miles from Balloch Pier,		7½	9	11	12¾	14	17
Depth at Station,		33	37	87	100	100	34
Hour of day,		11 A.M.	Noon.	1 P.M.	2 P.M.	3 P.M.	4.20 P.M.
No. of Station,		5	6	7	8	9	10
Depth. Fathoms.	No. of Thermometer.	Temperature (Fahr.).					
0	...	56°·2	56°·5	56°·4	...	56°·0	56°·5
5	9	55·9	55·1	55·3	...	55·8	56·3
10	80	55·75	54·8	54·8	...	55·75	55·75
15	79	49·1	51·25	49·0	...	49·8	48·1
20	47	48·3	45·6	45·8	...	45·6	46·5
30	21	47·0	43·2	43·5	...	43·2	45·25
35	47	...	...	...	42·4	42·7	...
40	79	...	...	42·5	...	...	...
45	79	...	...	...	42·15	42·2	...
50	9	...	...	42·05	...	...	...
65	9	...	...	...	41·85	41·8	...
70	80	...	...	42·0	...	...	...
80	47	...	...	41·75	...	...	...
85	80	...	...	...	41·8	41·7	...
Btm. { 87	21	...	...	41·8	...	...	...
Btm. { 100	21	...	...	...	41·8	41·8	...
0 to 30 mean,		53·93	51·23	50·87	...	51·32	51·57
Steepest gradient,	Degs. per fathom,	1·33	1·13	1·16	...	1·19	1·53
Steepest gradient,	Depth,	13	16	13	...	15	13

of water towards the head of the loch. The curves show also, in a remarkable manner, the difference in temperature of the water at the same depth in different localities. The greatest difference is found at 10 fathoms, at which depth the temperature at Rowardennan exceeds that at Rob Roy's Cave by 2°·55. Although the distribution varies at the different stations, there is little difference in the mean temperature of the 30 fathoms, it is higher at Rowcreeshie than farther north. From the surface to 10 fathoms the highest temperatures are at the lower end of the basin, from 15 to 30 they are nearer the upper end. At 15 fathoms the temperature at Culness is lower than either north or south of it.

5th September 1885.—All day the weather was most favourable for experimenting, except perhaps at Culness, when it threatened for a few minutes to blow and rain. Otherwise it was almost quite calm, with overcast sky, so that there was no overheating by the sun or cooling by the wind.

Positions—No. 5.—Outer Ross Island bears S. 27° E. (true), distant 0·74′.

No. 6.—Rowardennan Lodge bears N. 102° E. (true), distant 0·43′.

No. 7.—Stuckgowan Lodge bears S. 67° W. (true), distant 0·32′ to 0·37′.

No. 8.—Tarbet Pier bears S. 43° W. (true), distant 1·3′.

No. 9.—Inversnaid Inn bears N. 34° E. (true), distant 0·7′.

No. 10.—Stuckindroir House bears N. 60° W. (true), distant 0·38′.

All the places mentioned in this paper are to be found in the Admiralty Chart of the lake.

Owing to the overcast state of the sky, there is little variation in the temperature of the surface. Below the surface there is again considerable variation, but the maximum range, 2°·25 at 15 fathoms, is less than was observed on 18th August. The character of the distribution is distinctly autumnal. On 18th August the observations were confined to the Tarbet basin and were limited to 30 fathoms; to-day they extend to the three deep basins of the loch. The Ardlui and the Luss basins resemble each other in that their maximum depth is about the same—34 fathoms; but the Ardlui basin is separated from the Tarbet one by a ridge of probably 17 fathoms, while the ridge shutting off the Luss basin has a maximum depth of only 8 fathoms, cold deep water is thus enabled to penetrate from the Tarbet basin into the Ardlui basin, but not into the Luss basin. Further, the Ardlui basin receives, for its size, a much greater supply of the affluent waters from the land, so that its waters in winter are probably colder than those of the lake lower down.

In accordance with the autumnal character of the distribution, the temperature of the first 10 fathoms approaches uniformity at all the stations. It is highest at Ardlui, being 56°·2, and lowest at Rowardennan, being 55°·1. The steepest gradients are all between 10 and 20 fathoms. They are steeper in the shallow basins than in the deep ones; in the Ardlui basin the average gradient is 1°·53 per fathom between 10 and 15 fathoms.

On 7th September the Inversnaid station was revisited, and the temperatures on the gradients accurately ascertained by sending thermometers to every fathom, from 13 to 17 inclusive, with the following result:—

Observations at Inversnaid, 7th September 1885.

Depth.	No. of Thermometers.	Temperature degs. Fahr.	Gradient, deg. per fathm.
13	21	52°·0	° ...
14	47	51·25	0·75
15	79	49·8	1·45
16	9	48·8	1·0
17	80	47·25	1·55

The mean gradient in these four fathoms of water is 1°·19 per fathom, the maximum is 1°·55 between 16 and 17 fathoms. It is therefore probable that the actual maximum gradient in the Ardlui basin may be as much as 2° per fathom.

Owing to a mistake, 105 fathoms of line were paid out at Culness and Inversnaid instead of 100, which accounts for the irregular intervals between the thermometers at the deeper depths. From 30 to 70 fathoms the temperature of the water is slightly higher at Stuckgowan than at Inversnaid. From 70 fathoms to the bottom the water at the three deep stations is sensibly uniform, namely, 41°·8. On 7th September the three thermometers, Nos. 47, 79, and 80, were sent down together to 60 fathoms at Inversnaid, and their corrected temperatures were 41°·9, 41°·9, and 41°·85. There is, therefore, a fall of 0·1° between 60 and 100 fathoms at this season of the year. The same thermometers were also sent to 30 fathoms in the Luss basin, and their corrected readings were 47°·0, 47°·0, and 47°·0.

TABLE III.—*Observations in Loch Lomond, 22nd September* 1885.

Name of Basin,		Luss.	Tarbet.	
Locality,		Ross Mill.	Rowan-dennan.	Inversnaid.
Miles from Balloch Pier,		7½	9	14
Depth at Station,		33	37	100
Hour of the day,		1.30 P.M.	2.30 P.M.	4 P.M.
No. of Station,		11	12	13
Depth. Fathoms.	No. of Thermometer.	Temperature (Fahr.).		
0	...	53°·6	53°·6	53°·7
5	9	53·5	53·35	53·7
10	80	53·45	53·4	53·65
15	79	53·4	52·3	52·25
20	47	48·8	45·1	47·2
30	21	47·55	42·9	43·5
35	47	...	...	42·6
45	79	...	...	42·25
65	9	...	...	42·0
85	80	...	...	41·8
Btm. 100	21	...	...	41·8
0 to 30 mean,		51·94	50·49	51·08
Steepest gradient,	Degs. pr. fath.,	0·9	1·44	1·01
Steepest gradient,	Depth,	18	17	18

22nd September 1885.—The weather was very stormy, and had been so for a fortnight, with much rain, so that the level of the lake was very high. Wind fresh from the south-west. The weather was so squally that it was difficult to keep station. At the Ross Mill station I kept the launch head to wind with a couple of oars out, but it was not very successful. At the other two stations I kept her stern to wind, with a steer-oar out over the bow and occasionally driving the engine astern. At Inversnaid the wind was so strong that I was able to keep the engine going continually dead slow astern, and kept station well.

The character of the distribution is pronouncedly autumnal, cooling at the surface is going on rapidly while heat is being propagated into the lower layers. The surface layer of approximately constant temperature is now about 15 fathoms thick at all the stations, and the steepest gradients are found between 15 and 20 fathoms, the maximum being 1°·44 per fathom at Rowardennan.

The bottom temperature has not sensibly altered at Inversnaid since 5th September. In the Tarbet basin the greatest difference of temperature at the same depth is 2°·1 at 20 fathoms.

TABLE IV.—*Observations in Loch Lomond, 15th October* 1885.

Name of Basin,		Luss.	Tarbet.			Ardlui.
Locality,		Ross Mill.	Rowar-dennan.	Stuck-gowan.	Inver-snaid.	Doune Farm.
Miles from Balloch Pier,		7½	9	11	14	17
Depth at Station,		33	37	91	100	34
Hour of the day,		11 A.M.	Noon	1 P.M. 4.30 P.M.	1.30 P.M. 3.30 P.M.	2.30 P.M.
No. of Station,		11	12	13	14	15
Depth. Fathoms.	No. of Thermo-meter.	Temperature (Fahr.).				
0	...	49°·4	49°·1	49°·1	48°·7	47°·8
5	9	49·2	49·0	49·05	48·4	46·7
10	80	49·05	49·05	49·0	48·2	46·3
15	79	49·0	49·0	49·0	48·1	46·3
20	47	49·1	48·95	48·8	47·8	46·2
30	21	48·9	42·44	42·9	45·3	45·9
35	47	...	...	...	44·2	...
40	79	...	...	42·4	...	...
45	79	...	...	...	42·8	...
50	9	...	...	42·2	...	...
65	9	...	...	...	42·2	...
70	80	...	...	42·1	...	...
80	47	...	...	42·0	...	...
85	80	...	...	...	42·0	...
90	21	...	...	42·0	...	...
Btm. 100	21	...	...	...	42·0	...
0 to 30 mean,		49·0	48·37	48·37	47·9	46·47
0 to 20 ,,		49·12	49·04	49·00	48·24	46·58

15th October 1885.—A very fine day, with moderate north-easterly wind. For three days a strong northerly wind had been blowing with dry weather, and for a fortnight before there had been a succession of cyclonic gales, with much rain, so that at the beginning of the week the level of the lake was higher than I have ever seen it, and quite 3 feet above its usual summer level. The operations were all successfully carried out, the launch being kept stern to wind.

Amongst the salient features of the distribution of temperature at this date may be mentioned the rapid cooling which has taken place in the interval since 22nd September, the mean temperature of the first 30 fathoms having fallen about 3° F. at Ross Mill and Inversnaid. It will be seen that in the Luss basin the distribution has become nearly quite uniform from surface to bottom, and at Ardlui the water is rapidly approaching the same condition. The temperature of the water from the surface to 20 fathoms is practically uniform. At Ross Mill, in the Luss basin, and at Rowardennan and Stuckgowan, in the Tarbet basin, it is much alike, namely, 49°·12, 49°·04, and 49°. At Inversnaid it has fallen to 48°·24, and

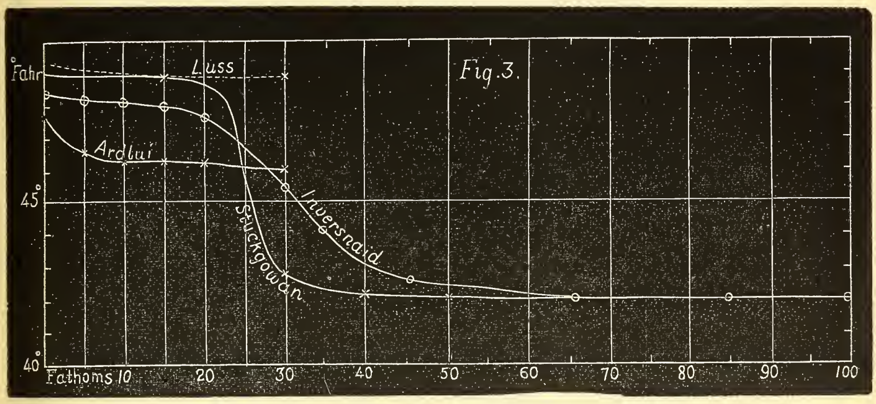


Fig. 3.—Curves of Temperature, 15th October 1885.

at Ardlui it is as low at 46°·58. The depth of water at Ross Mill and at Ardlui is nearly identical (34 fathoms), but the Luss basin is large, broad, and situated near the outflow of the lake; while the Ardlui basin is small and confined, and situated close to the head of the loch, so that it might almost be taken as forming part of the embouchure of the river Falloch. On the 5th September the temperature of the water down to 15 fathoms was nearly alike in the two basins, but below 15 fathoms it was much colder at Ardlui than at Ross Mill, the difference being 1°·75 at 30 fathoms.

In the following table the mean temperature of the water found between the surface and 20 fathoms, the surface and 30 fathoms, and between 20 and 30 fathoms, are given for Luss and Ardlui as observed on 5th September and 15th October:—

Table V.—*Comparative Table of the Mean Temperature of certain intervals in the waters of the Ardlui and the Luss Basins on 5th September and 15th October* 1885.

Interval, . . .		Surf. to 20 fms.		Surf. to 30 fms.		20 to 30 fms.	
Date, . . .		Sept. 5	Oct. 15	Sept. 5	Oct. 15	Sept. 5	Oct. 15
Mean Temp. at	Luss,	53°·24	49°·12	51°·37	49°·00	47°·65	49°·00
	Ardlui,	52°·90	46°·58	50°·33	46°·40	45°·85	46°·05
Difference, . . .		0°·34	2°·54	1°·04	2°·60	1°·80	2°·95

A comparison of these data brings out very clearly the difference in conditions obtaining in the two basins notwithstanding their likeness in depth. At Ardlui the predominating influence is that of the important tributary, the Falloch, which influences the temperature of the lake water in its neighbourhood most, while its temperature is lower than that of the lake. On 16th October the temperature of the water of the Douglas was 44°·6 F., while that of the surface of the lake in its neighbourhood was 49°·0. On 13th November the temperature of the stream at Inversnaid was 40°, and that of the lake surface 46°. From its rise and course the Falloch is more likely to be colder than warmer than these streams, so that even in October it must have begun to spread its cooling influence over the lower waters of the Ardlui basin. When the water of the stream is warmer than that of the lake surface, it passes away with the drainage, and imparts as much of its heat to the atmosphere above it as to the water below. When its temperature is lower than that of the lake surface, and in all probability it is so for more than half the year, it sinks into the body of the lake, and imparts its cold entirely to its deeper waters. It is obvious then that during the time that it is colder than the lake, the water of the Falloch must produce a much greater effect on it than during the opposite season; hence the position of the Ardlui station, with respect to the principal tributary of the lake, renders it natural to expect that its waters would be colder than they are found to be in the Luss basin, which, from its size and position, is comparatively exempt from the direct influence of tributary waters.

Both in September and in October the temperature of all these bodies of water is lower at Ardlui than at Luss, but the contrast is much greater in the colder than in the hotter month.

In the Tarbet basin a salient feature is the greater mixture of waters at Inversnaid than at either Rowardennan or Stuckgowan, the curves at the latter localities being much steeper than at Inversnaid. The same phenomenon was observed on the 18th August. But, perhaps, the principal feature in the Tarbet basin is that both at Inversnaid and at Stuckgowan the water at and near the bottom has risen in temperature by 0°·2 F., or from 41°·8 to 42°·0 since the 22nd September. As the temperature of the bottom water at these localities was 41°·8 on the 5th September, it is probable that it had been so during the summer, and it is only by the end of September or beginning of October that the summer heat begins to have any effect on the water near the bottom. The steepest gradients are at Rowardennan and Stuckgowan between 20 and 30 fathoms. With a view of further investigating this body of water, I returned on 16th October to the Rowardennan and Stuckgowan stations, and took the temperature at 20, 22½, 25, 27½, and 30 fathoms, using, at 20 and 30 fathoms, the same thermometers as had been used the day before. As the temperatures at 20 and 30 fathoms were found very different from those observed the day before, the observations in the Rowardennan locality were repeated close to the east side of the loch, the usual station being nearer the west side. The following table gives the temperatures observed on 16th October and also the corresponding ones of 15th October.

TABLE VI.—*Temperatures on Steepest Gradient at Rowardennan and Stuckgowan, 16th October* 1885.

Locality,		Rowardennan.			Stuckgowan.	
		West Side.		East Side.	West Side.	
Date,		Oct. 15.	Oct. 16.	Oct. 16.	Oct. 16.	Oct. 16.
Depth.	No. of Thermometers.	Temperature (Fahr.).				
0	...	49°·1	49°·0	48°·9	49°·1	49°·0
20	47	48·95	47·8	47·6	48·8	48·4
22½	9	...	47·4	46·4	...	47·3
25	79	...	46·55	46·0	...	47·0
27½	80	...	45·3	45·5	...	46·75
30	21	42·45	45·2	45·25	42·9	44·5

These results go to accentuate the fact borne out by all the observations quoted in this paper, and by all the observations which I have been able to make in other lakes, namely, that at any one date, especially during the warm half of the year, the isothermal surfaces, even at depths where there is no rapid change of temperature, are not planes, but have many curvatures and unevennesses. These unevennesses are particularly accentuated in the region of most rapid change of temperatures or on the steepest gradient of the temperature curve. Here the movements of the thermometer a few yards in a horizontal direction may place it in water of very different temperature. On both days a fresh breeze was blowing, and, though it was possible to keep station very satisfactorily from a nautical point of view, the station kept was an average one—that is, instead of being a point, it was an area, and an area perhaps 20 to 30 yards long by 10 to 20 yards wide. The investigation of the body of water having the steepest temperature gradient is very interesting, but it should be attempted only under the most favourable circumstances—either the weather should be perfectly calm, or the boat should be anchored. In future work the minute delineation of the steepest part of the temperature gradient should have an important place.

TABLE VII.—*Observations in Loch Lomond, 14th November* 1885.

Name of Basin,		Luss.	Tarbet.
Locality,		Ross Island.	Inversnaid.
Miles from Balloch Pier,		7	14
Depth at Station,		34	100
Hour of day,		3 P.M.	1 P.M.
No. of Station,		16	17
Depth. Fathoms.	No. of Thermometer.	Temperature (Fahr.).	
0		46°·6	46°·0
10	Negretti's overturning Thermometers.	46·3	45·8
20		46·3	45·8
30		46·3	44·3
30		...	44·2
40		...	42·3
50		...	42·2
65	9	...	42·15
84	80	...	42·1
100	21	...	42·1

14*th November.*—It had been raining all night, but cleared when I arrived at Balloch. I was accompanied by Mr Morrison, from the Scottish Marine Station at Granton, who brought with him three overturning thermometers. A very heavy snow squall occurred on the way up the loch, but it cleared off before we arrived at Inversnaid. While at Inversnaid the weather was very favourable, and we had no difficulty in getting this series of observations. The temperatures at 65, 85, and 100 fathoms were taken with my thermometers, the others were taken with the overturning thermometers of the Negretti type. In the afternoon a series of temperatures was taken with the overturning thermometers in the Luss basin west of the Ross Islands.

The salient feature at both stations is the great cooling which has taken place since 15th October. The whole body of water in the Luss basin has been cooled $2\frac{1}{2}°$. The temperature of the bottom water at Inversnaid has risen 0°·1, and it has probably reached its maximum.

Having described and discussed the observations made at the different stations at the same date, it will be useful to consider some of the stations with respect to the variation in the distribution of temperature with changing season, and for this purpose it will be convenient to take two typical stations, namely, that at Ross Mill in the Luss basin, which represents a shallow lake, and that at Inversnaid, representing a deep one.

The Luss Basin.—Observations were made in this basin on 5th September, 22nd September, 15th October, and 14th November. Already on the 5th September the curve has almost lost its summer feature, and is becoming pronouncedly autumnal. On 15th October it has assumed the winter form, and between that date and 14th November the nearly uniform temperature of the water has fallen about 2°·6 F. The surface temperature falls from 55°·2 on 5th September to 53°·6 on 22nd September, to 49°·4 on 15th October, and 46°·6 on 14th November. The autumnal zone of nearly uniform temperature in the surface layer extends on 6th September to 15 fathoms, and on 15th October to the bottom. Therefore, until some date between the 22nd September and 15th October the upper stratum of water is being cooled on both sides—that is, it loses heat by radiation and convection upwards into the atmosphere, and by conduction and convection downward into the lower strata of the water. By the 15th October the loss down-

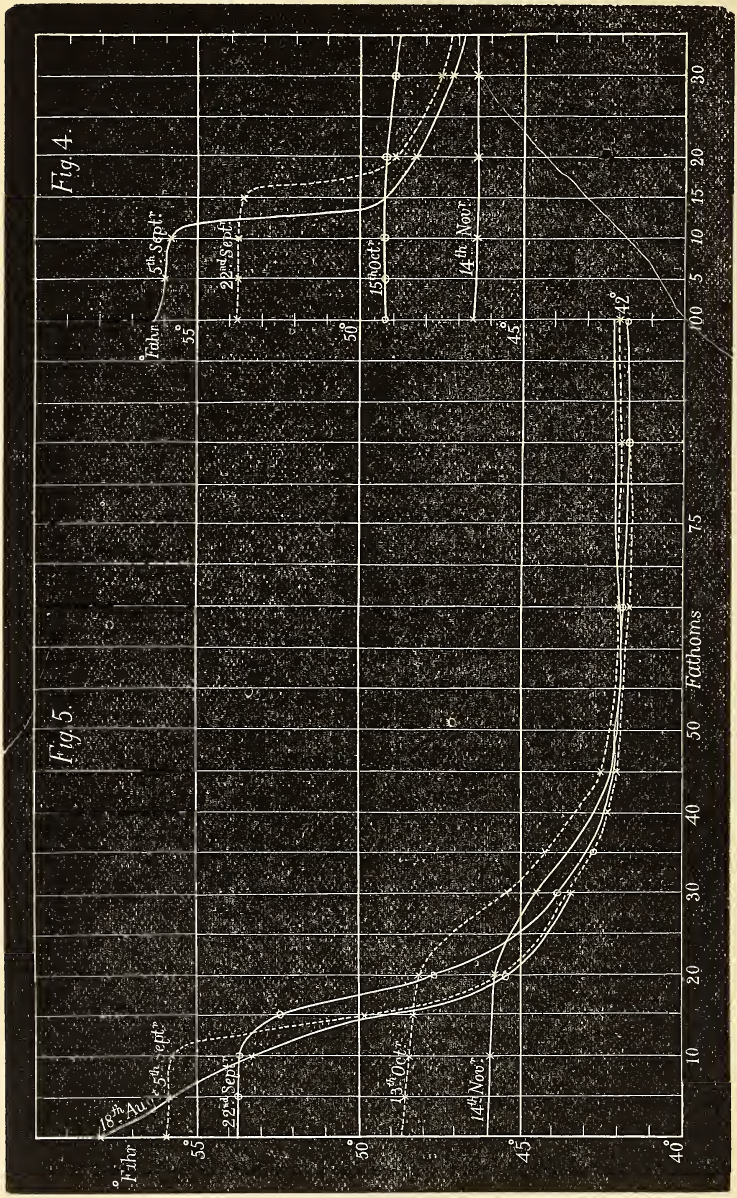


FIG. 4.—Curves of Temperature in Luss Basin, 1885.

FIG. 5.—Curves of Temperature in Tarbet Basin Inversnaid, 1885

wards has ceased, and the heat lost between that date and 15th November has escaped by the surface.

TABLE VIII.—*Collected Observations in Luss Basin,* 1885.

Date,	Sept. 5.	Sept. 22.	Oct. 15.	Nov. 14.
Depth.	Temperature (Fahr.).			
0	56°·2	53°·6	49°·4	46°·6
5	55·9	53·5	49·2	...
10	55·75	53·45	49·05	46·3
15	49·1	53·4	49·0	...
20	48·3	48·8	49·1	46·3
30	47·0	47·55	48·9	46·3

Taking the depth at the Ross Mill station as 35 fathoms, we have the following values for the mean temperature of the whole of the water :—

Date, . .	5th Sept.	22nd Sept.	15th Oct.	14th Nov.
Mean temperature,	50°·71	50°·71	49°·03	46°·3

The mean temperatures on the 5th and 22nd September are identical, hence the epoch of maximum heat in the water must fall between these two dates, and as cooling goes on more rapidly than heating, it will fall nearer the 22nd than the 5th, and may with safety be said to occur in the third week of September. The curves of the 5th and 22nd September intersect at a depth of 13·5 fathoms, hence the temperature at 13·5 fathoms was the same on both these dates. But on the earlier one the temperature of the water at that depth was rising, whereas at the later one it is falling, therefore it must have attained a maximum some time between these dates, and no doubt in the third week of September. The curves of 22nd September and 15th October intersect at 19·5 fathoms; here the temperature of the water at both dates was 49°·0. The maximum temperature in this layer must have been attained towards the end of the first week of October. Similarly, from the intersection of the curves of 5th September and 15th October, we should infer that the maximum temperature at 16 fathoms occurs in the last days of September. It is probable that temperature at the bottom (35 fathoms) was about its maximum on 15th October.

TABLE IX.—*Gain and Loss of Heat above and below the Depth corresponding to the intersections of each pair of Curves for the Station in Luss Basin* (1885).

Dates.	Sept. 5.	Sept. 22.	Sept. 5.	Oct. 15.	Sept. 22.	Oct. 15.	Oct. 15.	Nov. 14.
Interval, days, .	17		40		23		30	
Depth of intersection, fathoms,	13·5		16		19·5		none.	
Mean temp. of water above intersection,	55°·7	53°·45	55°·0	49°·2	52°·89	49°·1	49°·03	46°·30
Heat in fathom-degrees in water above intersection, . .	780	748	880	787	1031	957	1716	1620
Loss of heat in interval, . .	32		93		74		96	
Mean temp. of water below intersection, .	46°·28	47°·85	47°·10	48°·90	48°·07	48°·95		
Heat in fathom-degrees in water below intersection, . .	995	1028	895	929	745	759		
Gain of heat in interval, . .	33		22		14			
Percentage of heat passed downwards, .	100		24		19		0	
Heat passed into the air per day,	0		1·78		2·61		3·2	
Heat passed down to water per day, . .	1·94		0·55		0·61		0	
Mean temp. of the 35 fathoms,	50°·71	59°·71	...	49°·03	...	...	...	46°·30

The points of intersection of the curves indicate depths where the temperature of the water was found to be the same on both days. Although the temperature of the water at this depth has risen and fallen in the interval, it has returned to the same thermal state at the end of the interval as at the beginning. In Table IX. the distribution of heat in the water above and below these points is indicated for the different pairs of dates. For convenience' sake, heat units are expressed in *fathom-degrees.**

From the table we see that between the 5th and 22nd September the water as a whole has lost as much heat as it has gained, so that all the heat that the layer above the intersection at 13·5 fathoms has lost appears in the deeper water below the intersection. On an average over the whole period, no heat has been dissipated to the atmosphere. This, of course, is only true on an average; for during the first portion of the period the water has been receiving heat, and during the second portion it has been dissipating it at the surface. During this interval the heat passed downwards to the deeper layers has been at the rate of 1·94 fathom-degrees per day. Between the 22nd September and 15th October the amount of heat transmitted downwards has been 14 per cent. of the total loss above the intersection. The heat dissipated per day to the atmosphere is 2·61 units, and that passed downwards 0·61 unit. The curve of 14th November does not cut that of 15th October, and the loss of heat is at the rate of 3·2 units per day, all of which has gone out into the atmosphere. On the 23rd November 1876 I found the water of the Luss basin to have a uniform temperature 47°·8 from surface to bottom. In the year 1876, therefore, the water had a temperature 1°·5 higher on the 23rd November than it has in 1885 on 14th November, or nine days earlier. For the same date the water is this year at least 2°·5 colder than it was in 1876, and with this rapid and severe autumnal cooling it will require no very hard or long-continued frost to freeze the great shallow Balloch basin of the loch. In fact, it will be found that in years when Loch Lomond has been frozen there has always been an exceptionally cold autumn. The prolonged action of the low temperature of a cold autumn prepares the water for any severe frost which may occur in the long nights about Christmas. Under its influence the water rapidly freezes. When the Balloch basin was frozen in the winter of 1878–79, I took the temperature of the water beneath the ice in several places, the deepest water being 11 fathoms. The temperature of the whole of the water was

* The fathom-degree is one fathom heated 1° F. If the fathom has a sectional area such that the volume of water weighs one pound, then the fathom-degree is the same as the ordinary heat unit.

under 35° F., and varied from 32° in contact with the ice to 34°·5 at the bottom. In the long clear nights of a severe winter the temperature of the atmosphere may often be 30° below that of the surface of the water, so that both by radiation and convection cooling goes on with great rapidity, notwithstanding the fact that water expands in being cooled below 39° F.; and it is remarked by people dwelling by the side of the lake that the moment ice begins to freeze it spreads with great rapidity, so that the whole basin is usually frozen over in a night, and as soon as a skin of ice has been formed it very rapidly becomes thick enough to bear.

Epochs of Maximum Temperature.—From the curves and their intersections we see that the maximum temperature of the surface water occurred before the 5th September. At 13·5 fathoms it occurred some time between the 5th and 22nd September, and as cooling goes on faster than heating, the date of maximum temperature at this depth will be nearer the 22nd than the 5th September, probably about the 15th. Similarly at 16 fathoms it occurs between the 5th September and 15th October, and probably about 30th September. At 19·5 fathoms the maximum temperature occurs about 6th October, and in the second week of October (in 1885) all water from 20 fathoms to the bottom attained and passed its maximum temperature. The maximum temperature of the surface occurs about the middle of August, and that of the bottom in 35 fathoms about the middle of October.

Inversnaid Station.—The observations at this station at the different dates have, in many respects, greater interest than those made in the Luss basin. The depth here is 100 fathoms, and is so great that for a thickness of 40 or 50 fathoms above the bottom the change of temperature during the course of the season amounts only to a fraction of a degree, and is so slight as to elude detection, except by using very delicate thermometers. The observations made at Inversnaid are collected in Table X., and the results are expressed graphically in the curves (fig. 5). On 18th August no observations were made exactly on the Inversnaid station, but observations were made at two neighbouring stations, Rob Roy's Cave, about a mile north, and Culness, about a mile south of it. The curve has been drawn from the means of the temperatures observed at these two stations.

TABLE X.—*Inversnaid Station, Collected Observations.*

Date.	Sept. 5.	Sept. 22.	Oct. 15.	Nov. 14.
Depth.	Temperature (Fahr.).			
0	56°·0	53°·7	48°·7	46°·0
5	55·8	53·7	48·4	...
10	55·75	53·65	48·2	45·8
15	49·8	52·25	48·1	...
20	45·6	47·2	47·8	45·8
30	43·2	43·5	45·3	44·3
35	42·7	42·6	44·2	...
40	...	...	...	42·3
45	42·2	42·25	42·8	...
50	...	...	...	42·2
65	41·8	42·0	42·2	42-15
85	41·7	41·8	42·0	42·1
100	41·8	41·8	42·0	42·1

Table XI. gives the analysis of the results of the observations at Inversnaid, and is a form of *heat account* for the period—that is, it gives the receipt and expenditure of heat during the various intervals with reference to the points of intersection of the curves, where receipt and expenditure exactly balance each other over the period under consideration. Between the 18th August and the 5th September, an interval of 18 days, during which the temperature of the layer immediately at the surface had begun to fall, five times as much heat was conveyed downwards as was dissipated from the surface. Between the dates 5th September and 22nd September the two quantities almost exactly balance one another. Between 22nd September and 15th October the amount transmitted downwards is only half what leaves the surface; and between the 15th October and 14th November the amount transmitted downwards is quite insignificant—not more than 4 per cent. of what escapes to the air. The activity in the heat exchange has been greatest between 22nd September and 15th October when it has been dissipated at the surface at the rate of 3·74 fathom-degrees, and conveyed downwards at the rate of 2 fathom-degrees per day. The crest of the heat wave passes from surface to bottom in about three months, the height of it decreasing very rapidly as the depth increases.

TABLE XI.—*Gain and Loss of Heat above and below the Depths corresponding to the intersections of each pair of Curves for the Station at Inversnaid,* 1885.

Dates.	Aug. 18.	Sept. 5.	Sept. 5.	Sept. 22.	Sept. 22.	Oct. 15.	Oct. 15.	Nov. 14.
Interval (days), . .	18		17		23		30	
Depth of intersection (fathoms), . .	5		14		19·5		65	
Mean temperature of water above intersection, . . .	57°·0	55°·9	55°·62	53°·62	52°·65	48°·24	45°·21	43°·93
Heat in ditto (fathom-degrees), . . .	285·0	279·5	779	751	1027	941	2939	2856
Loss of heat in interval, . . .	5·5		28		86		83	
Mean temperature of water below intersection, . . .	43°·67	43°·93	42°·74	43°·05	42°·51	43°·08	42°·0	42°·1
Heat in ditto (fathom-degrees), . .	4148	4174	3676	3703	3422	3468	1470	1473·5
Gain of heat in interval, . . .	26		27		46		3·5	
Percentage of heat passed downwards, .	473		96		53		4·2	
Heat passed out to air per day, . .	0·30		1·65		3·74		2·77	
Heat passed downwards per day, .	1·44		1·59		2·00		0·12	
Mean temperature of 100 fathoms, . .	44°·33	44°·53	44°·55	44°·54	44°·49	44°·09	44°·09	43°·30

Dates of Maximum Temperature at Different Depths.—The intersections of the curves give, as above shown, an indication of the date of maximum temperature at the particular depth. In Table XII. will be found the depths corresponding to the principal intersections and the mean dates. The actual dates of maximum temperature will always be a day or two later than the mean dates. The number of observations is too small to enable us to say what the maximum temperature at these depths has been.

TABLE XII.

Depth.	Dates of intersecting Curves.		Mean Date.
5	18th August.	5th September.	27th August.
9	18th August.	22nd September.	5th September.
14	5th September.	22nd September.	14th September.
16	5th September.	15th October.	26th September.
19½	22nd September.	15th October.	4th October.
23	22nd September.	14th November.	19th October.
65	14th October.	14th November.	31st October.

As the autumn of 1885 has been a cold one, the above mean dates may be taken as the earliest dates of maximum temperature at the depths indicated.

If we compare the mean temperature of the whole column of 100 fathoms of water at Inversnaid on the 5th and the 22nd September, we have on the 5th the mean temperature 44°·54 F., and on the 22nd September 44°·52, the difference being 0°·02 F. Remembering that heat is lost more quickly in autumn than it is gained in spring, and considering that these temperatures are nearly identical, we shall not be far wrong if we put the epoch of maximum heat in the water of the deepest part of the lake as occurring some time in the third week of September. This brings it very near the date of the equinox, and it seems natural to expect the heat to accumulate in the water so long as the day is longer than the night, and to decrease so soon as the conditions are reversed. This conclusion is supported by the observations of Fischer, Forster, and Brunner, who made a most interesting series of observations on the distribution of temperature in the Lake of Thun, in Switzerland, during the years 1848 and 1849. They found hardly any increase of heat between 3rd February and 28th March, but after the latter date the influx of heat was very rapid. It is probable, therefore, that the temperature of the bottom water in our deepest lakes depends chiefly on the temperature of the air between the preceding autumnal and vernal equinoxes. Two causes combine, namely, the greater meridian altitude of the sun and the greater length of the day in the summer than in the winter half year. The latter cause has the effect that the water is exposed to heating for a greater portion of the twenty-four hours than it is to cooling, while the former cause ensures a greater supply of heat per minute during the day in summer than in winter.

Further, the rate of loss of heat, due to radiation alone, must be very much greater during a winter night than during a summer one.

The rise of temperature in the bottom water and deeper layers is made more apparent by considering the actual readings of the thermometer employed as given by the millimetre scale on the stem.

Depth, . . .		65 fathoms.			85 fathoms.			100 fathoms.		
No. of thermometer,		9			80			21		
Date.	Interval.	Reading.	Difference.		Reading.	Difference.		Reading.	Difference.	
	days	mm.	mm.	F.	mm.	mm.	° F.	mm.	mm.	° F.
September 5, .	...	51·0	...	...	70·1	...	...	60·5	...	...
September 22, .	17	51·6	0·6	0·17	70·4	0·3	0·10	60·4	−0·1	−0·03
October 15, .	23	52·4	0·8	0·23	71·0	0·6	0·21	60·9	+0·5	+0·16
November 14, .	30	52·2	−0·2	−0·06	71·2	0·2	0·07	61·2	0·3	0·09

The position of the index in the thermometers when referred to this scale can be fixed almost to one-tenth of a millimetre, certainly to one-fifth. In thermometer No. 9, 1 millimetre = 0°·285 F.; in No. 80, 1 millimetre = 0°·345 F.; and in No. 21, 1 millimetre = 0°·31 F. The difference of 0·1 millimetre between the readings of No. 21 on 5th and on 22nd September cannot be depended on as real. It is probable that between these dates and during the whole of the summer the temperature had been quite constant. Between 22nd September and 14th November the whole rise of temperature at the bottom is only 0°·25, and it may be confidently affirmed that at a depth of 100 fathoms the whole range of temperature during a single season does not exceed 0°·3 F. By season is meant the summer and winter half of the year, or the period between the date when heating begins in the spring, and that at which the summer heat has been almost wholly lost, and when the water begins again to assume a sensibly uniform temperature from top to bottom. At 85 fathoms the temperature had begun distinctly to rise on 5th September, and by 14th November it had evidently reached about its maximum. At this depth, therefore, the summer range is at least 0°·4 F. At 65 fathoms the water had begun to cool between 16th October and 14th November. In order to determine the range at this depth, it will be necessary to have observations earlier than 5th September.

The bottom temperature has been determined in the deepest part of Loch Lomond by several observers in different years, and the results show that it varies from year to year. James Jardine found it to be 41°·1 F. on the 8th September 1812. Sir Robert Christison found it 42°·0 F. in 1871. I found it to be 40°·2 in April 1872, and 41°·4 F. on 23rd September 1876. About these figures there is always some uncertainty, from the want of comparison between the thermometers. The best evidence of the variation of the temperature of the deep water of our lakes, from year to year, is furnished by my observations in Lochs Lochy (80 fathoms) and Ness (120 fathoms) in five consecutive years in the second week of August. These were all made with the same thermometers, and are to be relied on to one-tenth of a degree. They are—

Years, ...	1877.	1878.	1879.	1880.	1881.
Loch Lochy, . . .	44°·0	43°·7	42°·0	43°·8	42°·25
Loch Ness, . . .	42°·4	42°·3	41°·2	42°·4	41°·45
Mean winter temp. of air at Corran, . .	42°·3	42°·7	38°·9	42°·0	38°·6

The mean winter temperature of the air is the mean temperature of the months of October to March (inclusive) preceding the dates of observation in the lakes. The place of observation is Corran lighthouse, on Loch Linnhe. It is too remote from the lochs themselves to give more than an indication of the climate at the surface of the lakes. Still the bottom temperature of Loch Ness does follow very closely the mean winter temperature at Corran. In the two severe winters, 1878–79 and 1880–81, the mean winter temperatures fell below 39°, and as might have been expected the temperature of the deep water of the lake was slow to follow it, owing to the change in the properties of water at this temperature. Hence the higher the mean temperature of the cold months of the year is, the more closely is it reproduced in the deep water of the lake. Forty years ago Amié showed that the temperature which he observed in the abyssmal regions of the Western Mediterranean agreed sensibly with the mean winter temperature of the air at its surface. The later view, which ascribed the temperature of the deep water in the Mediteranean to the Atlantic water flowing over the ridge at Tarifa, which has the same temperature as the Mediterranean water within the ridge, left out of account the fact that there is on the whole an outflow of pure Mediterranean water at the bottom which affects the temperature and density of the Atlantic water outside. In sea water, owing to its saltness, convection currents are set up more actively by cooling than is found to be the case in fresh water. In lakes, however, and especially in those situated in mountainous districts, the production of convection currents is powerfully assisted by local differences of climate. These are due to differences of exposure, to radiation, and to prevailing winds. Such local differences of climate produce local differences of temperature, and consequently of density in the superficial layers. If we compare, for instance, the observations made at Ardlui and at Inversnaid on 15th October, we find that the mean temperature of the first 20 fathoms is 48°·24 at Inversnaid, and only 46°·58 F. at Ardlui. The stations are only three miles apart, and yet there is a difference of 1°·66 F. in the mean temperature of the first 20 fathoms. Another cause affects the distribution of temperature in a lake, namely, the drainage, but this more particularly affects shallow lakes or basins. It is probable that the most powerful means of supply and removal of heat is direct radiation. The most powerful mixing agency is the wind.

I hope, with Mr Morrison's assistance, to secure monthly observations during the coming winter and spring, the results of which cannot fail to be interesting.

2. On Oceanic Shoals discovered in the s.s. "Dacia" in October 1883. By J. Y. Buchanan, F.R.S.E.* (Plate XII.)

Owing to the kindness of the India Rubber, Gutta Percha, and Telegraph Works Company of Silvertown, and especially of their engineer-in-chief, Mr Robert Kaye Gray, I was enabled to accompany their expedition for laying the telegraph cable between Cadiz and the Canary Islands. It consisted of two steamers belonging to the company, the "Dacia" and the "International"; and I was allotted a place and all facilities for working on board the "Dacia," where Mr Gray had charge. I joined the expedition at Cadiz on 3rd October 1883.

* A portion of the narrative part of this paper appeared as a correspondence in the *Times* of 7th December 1883.

The contour lines indicate the depths in fathoms

———————— Track of the "Dacia" October, 1883.

The "Dacia" left Cadiz on the afternoon of the 4th October. The entrance to the Straits of Gibraltar was reached the next morning, and two days were spent in thoroughly sounding its shallowest part, which lies nearly on a straight line connecting Cape Spartel on the African with Cape Trafalgar on the European coast. On existing published charts the bottom is seen to be very uneven. From Cape Trafalgar south, for more than half the distance across, the water does not exceed 100 fathoms in depth; then it deepens to 150 fathoms, suddenly shoals to 45 fathoms, then deepens again, and remains deep till close to the African shore. In order to assist in fixing the positions of the soundings, a buoy was anchored on the mid-channel bank. It remained down for two days. When it was brought on board again, the thick wire mooring-rope was found nearly chafed through by the violent currents rubbing it on the hard coral bottom. During the two days spent on this ground, a large number of soundings were taken, the result of which was to define and enlarge the mid-channel shoal from a patch a mile and a half long and half a mile broad to a bank 7 miles long from east to west by 2 miles broad from north to south; further to show that the deep water runs between this bank and the African shore, and that the greatest depth on this, the shallowest ridge, is not less than 200 nor more than 210 fathoms. Considerable interest attaches to a knowledge of this depth. It has been supposed that on it depends the temperature of the deep water of the Mediterranean, as on it would depend the temperature of the coldest water which could find entrance into it from the Atlantic. In the Atlantic, however, outside the Straits, the temperature of the water at 200 fathoms below the surface is decidedly lower than that of the deep water of the Mediterranean. Moreover, it was proved by the observations of Sir George Nares and Dr Carpenter, in Her Majesty's ship "Shearwater," that, though the currents in the Straits are affected by the tides, there is, on the whole, an inflow of Atlantic water at the surface and an outflow of dense Mediterranean water at the bottom. It was also shown by M. Aimé, in 1848, that the temperature of the deep water of this part of the Mediterranean agrees with the mean temperature of the coldest half of the year at its surface. It is probable, therefore, that the deep overflow of the Mediterranean has more effect in raising the temperature and density of the deep water of the Atlantic than the Atlantic has in reducing that of the Mediterranean. The observations made on board the "Dacia" quite bear out this view.

The observations of bottom temperature made by the "Challenger" in the north-eastern part of the Atlantic, and by the "Dacia" in this restricted part, show a higher temperature and density of the water at great depths than is found to exist in any other part of the ocean. Although other causes are at work to produce this, it cannot be doubted that the warm and dense overflow of the Mediterranean has its share in its production, especially in its immediate neighbourhood.

From the Straits of Gibraltar a westerly course was steered for about 150 miles, then a south-easterly one until the African coast was sighted, when the course was again altered to a westerly one. It was the intention to have taken soundings and other observations along this line for a distance of 180 miles. On continuing the line representing the course on the chart, it was found to cut the line of soundings taken by the steamship "Seine" between Lisbon and Madeira close to a point where the bottom seemed to rise from a depth of 2400 fathoms to 1800 fathoms.

This line of soundings was run previous to the laying of the cable from Lisbon to Madeira by the s.s. "Seine." The soundings were taken at distances of about 25 miles apart, and showed a tolerably level bottom with an average depth of rather over 2000 fathoms. Slight unevennesses had been observed, such as two successive soundings differing by 300 fathoms, but it never occurred to any one to suppose that they indicated anything that could interfere with the laying of the cable or its security when laid; and accordingly the cable was laid over the line sounded. During the process, and when the ship was passing over one of the unevennesses indicated, where the depth seemed to fall from 2400 fathoms to 1967 fathoms, and to increase again to 2332 fathoms, the cable suddenly parted; and, on making a sounding, a depth of *one hundred* fathoms was found in place of 2000 expected. The sudden shoaling of the water had naturally snapped the cable. No blame could be attached to those in charge of the work, because the soundings, on which they based their calculations, were considered sufficiently close, and were supposed to give quite sufficient guarantee of a suitable bottom.

While the "Dacia" was running the second long line to seaward it was found that, on prolonging it, it cut this Lisbon-Madeira line of soundings at a point where there was a shoaling from 2400 to 1800 fathoms.

Before the discovery of the "Seine bank," with under 100 fathoms of water on it, there was no indication of its existence except a similar shoaling from 2322 to 1967 fathoms. It was thought, therefore, that another similar bank might exist, and the ship was kept on the same course with the view of going as far as the "Seine's" 1885 fathoms sounding. At the point where it had been intended to turn, a depth of 2400 fathoms was found; at the next sounding, 50 miles farther west, bottom was struck in 485 fathoms. This depth was found at 4 A.M. on the 12th of October, and the sounding was immediately repeated, with the same result. The whole day was then devoted to the exploration of the bank thus revealed.

The discovery of this bank or "Coral patch" may fairly be claimed as a success in marine diagnosis. The shoalest water found on it was 435 fathoms, in lat. 34° 57′ N., long. 11° 57′ W., and the depth ranged up to 600 fathoms. The shallow water extends for a distance of 6 miles in an east and west direction, and about 3½ miles in one from north to south. On the western edge it seemed to fall away precipitously from 550 to about 850 fathoms, when the slope became gentle, and the bottom changed from hard coral to soft ooze. In one sounding on this ledge the sinker distinctly struck bottom in 550 fathoms, tumbled over and continued to sink, struck in 620 fathoms, again tumbled over, and finally found a resting place in 835 fathoms. When it came up it had a large brownish-black streak, where it had evidently struck obliquely on manganese rock. This was a very remarkable sounding, and quite undoubted. All the conditions were the most favourable—no wind, the sea calm, and the ship motionless. A grapnel with extemporised dredge and hempen swabs was put over in 530 fathoms, and on being brought up the dredge was found much torn, and on the swabs a large quantity of beautiful white coral and many fragments of a crinoid. The coral was examined by Professor Moseley, and determined as *Lophohelia prolifera*. It was found to be growing luxuriantly, the living stalks being rooted on dead and decaying branches of the same species. The dead branches were in many instances beginning to get coloured brown from deposited manganese. One of the earliest and most interesting of the "Challenger's" dredgings was in 1500 fathoms, about 200 miles south-west of Teneriffe. The dredge came up full of beautifully branching jet-black coral attached to a soft black rock. Thickly clustered among the branches were large siliceous sponges, like masses of spun glass. Both the rock and the enamel-like coating of the coral consisted of black oxide of manganese. The same has been found on the ridge connecting Teneriffe and Grand Canary at a depth of 1000 fathoms, and after severe storms it is sometimes washed ashore on the islands.

It is not unlikely that if the ground about the "Challenger" station in 1500 fathoms were closely and carefully explored a very interesting shoal might be discovered.

The fragments of the crinoid obtained were determined by Dr Herbert Carpenter to be *Actinometra pulchella*, which is common in the Caribbean Sea. One specimen of it had been previously got by the "Porcupine," in 477 fathoms, near Gibraltar.

The temperature of the water was taken at different depths with the following results :—

Depth (fathoms),	Surf.	50	100	150	300	500
Temperature (Fahr.),	68°·5	60°·2	56°·8	54°·8	51°·9	50°·0

After exploring this coral bank, so far as time permitted, the ship was directed towards Mogador, on the Morocco coast. Independently of the high land, which is visible for many miles at sea, the approach to the coast is indicated by a rapid fall in the temperature of the water of the sea surface and a remarkable change in its colour. Outside the temperature of the surface was very constantly 69° F. After sighting the land it fell at first slowly, then rapidly, and when two miles from Mogador it was only 61° F. The presence of this body of cold water must have an important effect in moderating the climate of places situated on this somewhat desert coast. In the open sea, and away from shore influences, the ocean water in all moderately warm latitudes has the same deep, transparent, ultramarine colour. In colder latitudes this becomes greenish-blue and green, and the water loses its transparency. The colour of the water off the Morocco coast is particularly remarkable, for it becomes of a deep and, at the same time, very transparent olive-green colour, unusual in any but icy latitudes. Closer in shore it loses its transparency.

A similar phenomenon is observed on the west coast of South America. Close in shore all the way from Valparaiso to Cape Blanco, in lat. 4° 30′ S., there is a fringe of cold, green, comparatively fresh water teeming with life. In the course of a voyage along that coast in April 1885 I found the temperature of the water identical in the harbours of Coquimbo in lat. 30° S., and Payta in lat. 5° S., namely, 63°·5 F. This is an exceedingly low temperature even for the more southerly of the two stations, and is of course very much more remarkable for the more northerly one, Payta, which indeed may be said to be almost on the equator. Along this coast to the southward of Callao there is no marked current or stream setting in either direction. In order to bring water of 63°·5 F. by a surface current to so low a latitude as 5° S. would require a rapidity of transport which, under the circumstances, is inconceivable. Similarly on the African coast the set of the water along the shores of Morocco is not towards the equator, but towards the north; and it was observed by Sir George Nares, in H.M.S. "Shearwater," that this cold, in-shore water actually penetrates past Cape Spartel into the Mediterranean.

In low latitudes there is only one source of cold water, namely, the climate of higher latitudes. The water cooled in these high latitudes may make its way towards the equator either as a surface current or as a movement of the deeper waters. If it is conveyed as a surface current, it is exposed to the heating on the way in passing through regions of progressively warmer climates, and in order to keep a low temperature into anything like low latitudes it would require to form a current of great volume and velocity. In all latitudes we find almost ice-cold water at a few hundred fathoms from the surface, and in fact the nearer we come to the equator the nearer does the cold water come to the surface. In the latitude of Payta, and away from the coast, water of 60° F. would naturally be found at a depth of 100 fathoms; at the surface and in the open ocean it would not be found at a less distance than 2000 miles.

The western coasts of the continents are the *weather shores* of the oceans. Both the continents mentioned occupy positions which extend from the northern trade-wind region through the equatorial calms to the southern trade-wind region. The trade winds blow from the north-east and the south-east, and the result of their mechanical action is to drag away the water from their weather shores and drive it to leeward. As the wind acts at the surface it removes chiefly surface water, and it is the surface water which assumes the temperature due to the local climate. The water so removed must be supplied, and it is supplied from the readiest source. As the surface water is being removed by the wind, it draws on the deeper layers to supply the deficiency. But in low latitudes the deeper water in the ocean has always a very much lower temperature than that at the surface. Hence, at the weather shores of the oceans we have a constant removal of surface water to leeward and replacement of it by colder water from greater depth. The cold water found along the west coast of South America has always been considered evidence of the "Humboldt current." And so it is. But the Humboldt current, or at least the current which brings the cold water there, is not a horizontal current from higher latitudes, but a vertical one from greater depths.

From Mogador a course was shaped for the Seine bank above referred to. It is indicated on the chart by two soundings of 100 and 118 fathoms respectively, at a distance of 12 miles apart. The bank was struck on the position of the 118 fathom sounding, and a day was devoted to its exploration. A couple of "balloon buoys" were anchored in the noon position, namely, lat. 33° 47′ N., long. 14° 1′ W., the depth being 89 fathoms. Hempen swabs were attached to the end of the anchoring line. These balloon buoys are made of india-rubber and canvas, and when not in use occupy very little space. They are used for floating the shore end of a cable from the ship to the land, and they are then inflated with air by means of a small pump. They are much like footballs 3 feet in diameter. The bank was crossed and recrossed in different directions, and found to occupy less surface than was expected. Its length in an approximately north and south direction is 6 miles, and its breadth from east to west 3 miles. The depth of water over an area of about 15 square miles varies only from 86 to 100 fathoms. When the sounding work was done the buoys, with their moorings, were got on board, and the swabs, which had been brought up without dragging, were found to contain a rich harvest of large crinoids of a delicate, reddish colour. Dr Herbert Carpenter has determined them to be *Antedon phalangium* of the Mediterranean and the Atlantic coasts of Spain. It was obtained by the "Porcupine" as far north as the Minch and the Faerœ Banks. Along with the crinoids pieces of broken coral and shells came up, all stained of an intense yellowish-green colour, which was freely communicated to the spirit into which the shells were put for preservation. The colouring matter so extracted was examined by Professor Hartley of Dublin, and found to be chlorophyll. Specimens of spirit coloured by deep-sea animals collected on the "Challenger" expedition were also examined, in consequence of this discovery, and they also were found to have the spectroscopic character of chlorophyll.

The bottom temperature on the Seine bank was 60°·2 F. On leaving the Seine bank, the intention was to have reached in towards the African coast, then outwards to the small group of Salvage and Piton, and then to make a straight course to Grand Canary. The day after leaving the Seine bank the value of marine diagnosis was again vindicated. When about 170 miles south of the bank, a sounding gave 1189 fathoms with hard bottom, where at least 1800 fathoms were looked for. Another bank was immediately suspected. Three miles farther, on the same course, 1386 fathoms were found. If a bank existed it had, therefore, been passed over. The course was immediately reversed, and after steaming 7 miles back a sounding gave 810 fathoms; 3 miles farther back 414 fathoms were found, and 2 miles farther 66 fathoms. Half a mile beyond this sounding 230 fathoms were found. The ship was again turned round and steered to the southward for about a mile and a half, when a buoy with lights was put over in 175 fathoms, and, as it was already past midnight, the ship lay by it till daylight. As this bank lay very close to the proposed line of cable, two days were devoted to its exploration. It was found to be of an irregularly triangular shape, broader towards the north and tapering towards the south. Its greatest length from north to south and breadth from east to west were found to be equal, and 8½ miles respectively, while the total area, with less than 100 fathoms of water on it, was 50 square miles. A boat was anchored in the noon position of the 21st October—namely, lat. 31° 9′ 30″ N., long. 13° 34′ 30″—in 58 fathoms of water. This is near the centre of the bank, and a little to the southward of the shoalest sounding, 49 fathoms; swabs had been attached to the mooring rope of the buoy; they had also been attached to the moorings of a couple of balloon buoys in rather shallower water, but during the two days that they were down the ropes got so chafed that they broke when being recovered. Swabs had been attached to the boat's cable, and they were recovered, but, as they had been only a very short time on the bottom, little was expected and little was found on them. A few broken and decayed shells made up the harvest.

Advantage was taken of the buoy being anchored in mid-ocean to make some current observations. It is an almost universal experience of ships making a passage from the north to the Canary Islands to be set very considerably to the eastward of their course, and many disastrous shipwrecks have been the consequence. It appears from recently-collected observations that the general set of the current is about E.S.E., and its velocity averages 16 miles per day. Only a few weeks previously a buoy belonging to the United States Lighthouse Department had been washed ashore on the north coast of Teneriffe. Knowing how the tidal wave is transformed into a current on approaching the coast, it seemed not unlikely that the occurrence of so extensive a shoal as the "Dacia bank," as it has been called according to recognised precedent, might produce the same effect. Accordingly, before the buoy was brought on board again, I spent some hours in a boat riding to it, and determined the direction and rate of the surface current at frequent intervals, while the ship went on with the sounding at a distance. The result of these observations was, shortly, to show that the south-easterly current in this part of the ocean is affected and at times reversed by a tidal current. Down to a depth of 70 fathoms the current was found to be setting in nearly the same direction as at the surface, but with somewhat greater strength. The "current drag" used on this occasion was a "tow-net" made of fine but stout muslin, about 3 feet long and 1 foot diameter at the mouth, tapering to a cone in the bag. The mouth was kept open by a stout iron ring, which was made fast to the sounding line which passed diametrically across it. The water was of so clear and transparent a blue that it could be distinctly seen down to a depth of 19 fathoms; and, with a weight of 14 lb. at the end of the line, it set itself perfectly steadily and almost rigidly in its direction.

The results of the observations of the current at the surface on 21st October 1883 were—

Hour P.M., . . .	2.15	2.40	3.30	4.6
Direction (true), . .	N. 11° E.	N. 41° E.	N. 56° E.	N. 101° E.
Rate, knots per hour,	0·47	0·30	0·26	0·30

It will be seen from these observations that, in the two hours, the current had shifted its direction through 90°, and had passed through a minimum velocity of 0′·26 per hour without there having been any period of "slack water." The observations are too few in number to make it worth while submitting them to analysis, but a little study of them will show that they indicate a current which is the resultant of a constant current and a periodic one. A constant current running to S.E. by E., combined with a tidal current running N.N.W. and S.S.E., the maximum velocity of which, in either direction, is twice that of the permanent current, would give a resultant current agreeing fairly with that observed. Under these circumstances, the path of a particle, floating freely in the water and moving with the water, would describe in twenty-four hours a path having the shape of the letter S, the larger axis of which has a N.W. by W. and S.E. by E. direction. If the tidal current be supposed to have motion in an elliptical orbit, instead of a simple oscillation in one direction, the path in the twenty-four hours would take some such form as the figure 3. Without insisting further on the numerical value of the results, the observations are of importance as showing decidedly the existence of tidal currents in the open ocean. Amongst the islands of the Canary group these currents are strongly developed. Between Grand Canary and Teneriffe the channel is broad, and, at its shallowest part, over 1000 fathoms deep; yet the tidal current reaches to the very bottom, and its scouring action is shown by the nature of the bottom. To seaward, in 1800 or 2000 fathoms, the bottom is a fine Globigerina ooze, which gets coarser and sandier as the water shoals in the channel, until, on the summit of the ridge, there is generally no deposit at all, and the bottom is rock or coral often coated with black oxide of manganese.

An essential condition of the existence of coral, whether in the deep sea or in the shallow water of the atolls of tropical seas, seems to be circulation of the water. This serves the double purpose of bringing food and removing sediment. In shallow water this circulation is produced by the breaking of ordinary storm waves on the shore or on shoals; in deep water it is produced by the transformation of the tidal wave into a current on meeting with obstructions such as ridges or banks, even though they may have a thousand or more fathoms of water on them. In both cases the current is produced in the same way, namely, by the annihilation of a wave.

In Mr Murray's theory of the formation of coral islands, the growth (in height) of a shoal, owing to the greater amount of sediment which reaches it from the surface compared with the amount which can reach an equal area of ground at a greater depth, is an important feature. We have seen, however, that it is probable that, wherever the bottom rises in the path of the tidal wave, a portion of the wave is transformed into current. This current would naturally keep the summit of the shoal clean swept of all freshly falling sediment, and would thus tend to limit the growth of such a shoal.

But this very agency must favour the existence of such animals as deep-sea corals on the areas kept clear of sediment. It seems reasonable, therefore, to expect that such areas would be occupied by deep-sea corals. These would not be likely to extend laterally beyond the cleared summit of the rising, but would grow upwards, the living resting on the débris of the dead. The tendency would be to raise a massive pillar with perpendicular sides up through the water, and it would grow until the conditions, principally of temperature, set a limit. In the "Coral patch" we have undoubtedly such a structure, the base of which rests on the crest of a hill 800 fathoms below the surface. Its summit is now rather over 400 fathoms below the surface, and it is in full growth. Judging from what could be obtained from the surface of the Seine bank and the Dacia bank, they have reached limiting conditions. Had they risen to their present level in equatorial regions, they would doubtless have been occupied by reef-building species, and would have formed true coral islands.

We have seen above that, on the Coral patch, the lead was dropped by chance on the face of a precipitous cliff at least 200 fathoms high. On the Dacia bank the mark buoy happened to be let go just on the edge of the bank in 175 fathoms. On trying to lift the moorings the buoy-rope carried away, and it was found to have been chafed through about 100 fathoms from the surface, or 75 fathoms above the ground. The currents had evidently been rubbing it against the edge of the cliff during the two days that it was down. From the mark buoy the "Dacia" steamed west for about 10 miles, taking up and down soundings every mile, and "flying soundings" with a pneumatic sounding-machine which I constructed on board. It worked extremely well with the ship going 7 knots, and in water ranging from 50 to 100 fathoms in depth. About 8 miles west of the buoy, the edge of the bank was again struck. After an up and down sounding of 86 fathoms, a flying sounding gave 110 fathoms. The engines were immediately stopped and put astern, when an up and down sounding gave 333 fathoms. The distance between these soundings could not have been more than a quarter of a mile, which gives an average gradient between the soundings of nearly 45°. To the westward of the 333 fathoms sounding, 619 fathoms were found at 1 mile, and 844 fathoms at 2 miles. At this sounding a $1\frac{1}{2}$-inch mud tube was used, and it brought up a good sample of very coarse-grained Globigerina ooze, with many pteropod and other shells.

In the following table will be found the slopes on the Dacia and the Seine banks, as observed between adjacent soundings, also those on the slope of Bermuda and adjacent banks, taken from the most recent Admiralty charts :—

Seaward Slopes of Oceanic Islands and Shoals.

Locality.	Slope.	Depth Intervals. From Fms.	Depth Intervals. To Fms.	Difference.	Distance between Soundings.	Tangent of Angle of Slope.	Angle of Slope.
Dacia bank.	West.	110	333	223	0·25	0·92	43°
,,	,,	330	619	289	1·00	0·29	16
,,	,,	619	884	225	1·00	0·23	13
,,	S.W.	97	629	532	1·50	0·36	20
,,	South.	79	335	256	0·50	0·51	27
,,	,,	335	757	422	1·50	0·28	16
,,	East.	100	200	Precipitous.			
,,	,,	200	430	230	0·25	0·92	43
,,	,,	430	605	175	1·50	0·12	7
,,	,,	605	1102	479	2·00	0·25	14
,,	North.	72	306	234	0·75	0·31	18
,,	,,	306	751	445	2·00	0·22	13
Seine bank.	South.	107	530	423	1·00	0·42	23
,,	East.	120	598	478	2·00	0·24	13
,,	N.E.	99	215	116	2·00	0·06	3
,,	,,	215	679	464	2·00	0·23	13
,,	North.	111	1149	1038	3·00	0·35	19
Bermuda.	S.E.	115	420	305	0·45	0·68	34
,,	,,	27	315	288	0·45	0·64	33
,,	,,	55	307	252	0·60	0·42	23
,,	,,	26	329	303	0·70	0·43	24
,,	,,	326	400	71	0·45	0·10	5
,,	,,	33	160	127	0·20	0·64	33
,,	,,	160	380	220	0·60	0·37	21
,,	,,	35	355	320	0·65	0·50	27
,,	,,	355	780	425	1·60	0·27	15
,,	,,	24	240	216	0·60	0·36	20
,,	,,	18	200	182	0·55	0·33	19
,,	,,	20	380	180	0·60	0·30	17
,,	,,	320	435	115	0·70	0·17	9
,,	,,	60	235	175	0·45	0·39	22
,,	,,	11	260	251	0·28	0·89	42
,,	N.E.	30	225	195	0·30	0·65	33
,,	,,	16	180	164	0·40	0·41	23
,,	,,	180	250	70	0·20	0·35	19
,,	,,	21	137	116	0·25	0·46	25
,,	,,	25	145	120	0·25	0·48	26
,,	West.	42	1950	1908	3·50	0·55	29
,,	South.	26	230	204	0·40	0·51	27
,,	,,	506	1075	569	2·30	0·25	14
,,	,,	30	950	920	2·70	0·29	17
Challenger bank.	West.	36	1350	1314	2·50	0·52	28
,,	,,	1350	2175	825	3·70	0·22	13
,,	North.	175	1250	1075	1·30	0·83	40

Bermuda is a coral island, crowning an eminence, which rises abruptly out of the deepest water of the North Atlantic. Besides the island of Bermuda, this eminence carries two shoals or banks to the south-west of the island. These banks seem to exactly resemble the "Dacia" and "Seine" banks. The minimum depth on the "Challenger" bank is 24 fathoms, and on the "Argus" bank, which lies farthest to the southward, is 10 fathoms. The separating channels have a depth of 1000 and 600 fathoms respectively. On the reef, which surrounds the island of Bermuda, the water deepens very slowly to 25 fathoms. As soon as this depth is passed, the declivity becomes very steep, and is no doubt in many places precipitous. The mean angle of slope for depth-intervals between 34 and 344 fathoms is 25°·3, between 29 and 239 fathoms it is 26°·4, and between 24 and 155 fathoms it is 27°. The western and northern sides have a steeper average slope than the southern and eastern ones. On the western side we have, from 42 fathoms on the reef to 1950 fathoms, the enormous average slope of 29°; and on the north side of the "Challenger" bank, between the depths 175 and 1250 fathoms, we have an angle of 40°. It is difficult to believe that these average slopes are not made up of large portions which are really vertical, with gentler slopes at greater depths. The closer soundings on the "Dacia" bank and Coral patch revealed such precipices.

While the "Challenger" was at Tahiti, very careful soundings were made to determine the actual slope of the reef. At a distance of 125 fathoms from the edge of the reef, a depth of 30 to 35 fathoms is found; at 150 fathoms from the reef the depth is from 90 to 100 fathoms. In this interval the slope attains its maximum angle of from 60° to 70°. "It is believed to have been formed by huge masses and heads of coral which have been torn away from the ledge between the edge of the reef and 35 fathoms during storms, or by overhanging masses which have fallen by their own weight. In this way a talus has been formed on which the corals, living down to 35 fathoms, have found a foundation on which to build farther seawards, for this seaward slope is the great growing surface of the reef."* If the steepest part of the slope is a talus, it is evident that the solid rock face inside the talus must be still steeper, and a slope steeper than 70° is a precipice.

* *Challenger Narrative*, vol. i. p. 781.

Seaward Slopes on the Morocco Coast.

Lat. N.	Depth inward.		Difference.	Distance.	Tangent of Angle of Slope.	Angle of Slope.
	From Fms.	To Fms.				
33° 20′	526	1964	1438	8′·0	0·180	10°
	1964	2338	374	8·0	0·047	2¾
33 10	224	636	412	4·0	0·103	6
	636	386	−250	2·0	−0·130	−7½
	386	768	382	5·0	0·076	4½
	768	1095	327	4·0	0·082	4¾
	1095	2060	965	10·0	0·097	5½
32 40	664	787	123	3·0	0·041	2½
	787	1050	263	2·0	0·131	7½
	1050	1325	275	6·0	0·046	2¾
32 15	220	600	380	2·0	0·190	11
	600	892	292	7·0	0-041	2½
	892	1290	398	5·0	0·080	4¾
	1290	1405	115	5·0	0·023	1¼
	1405	1620	215	8·0	0·027	1½
32 0	106	220	114	2·0	0·057	3¼
	220	596	376	9·0	0·041	2½
	596	780	184	5·0	0·036	2
	780	843	163	4·0	0·041	2½
	843	995	138	3·0	0·046	2¾
	995	1640	645	14·0	0·046	2¾
	1640	1763	123	10·0	0·012	⅔

The soundings off the west coast of Morocco which are given in the second table were taken too far apart to give anything more than rough averages of the slope. They indicate, however, a feature of continental slopes which calls for further and minute investigation. Roughly speaking, the sea bottom slopes very gently from the coast-line to a depth of 100 fathoms; between 100 and 500 fathoms a steep descent is met with. From 500 to 700 or 800 fathoms the angle of slope is smaller, and between 800 and 1200 fathoms it again becomes steeper, and flattens between 1200 and 1500 fathoms, sometimes becoming again steeper below 1500 fathoms. From the continental profiles which we have, the existence of these *terraces* seems to be very probable. It is to be hoped that, in future work, the soundings will be made so close to one another that this matter may be put out of doubt.

In the accompanying map (Plate XII.) the positions of the banks found and explored by the "Dacia" are given, as well as the "Josephine" and the "Gettysburg" banks, lying nearly in the latitude of the Straits of Gibraltar, the former with 80 and the latter with 30 fathoms. In the *North Atlantic Directory** a chapter is devoted to cataloguing the shoals and rocks which have been reported to have been found by different navigators in the open ocean. The great majority of these are very doubtful, but there are one or two which it would be exceedingly interesting to explore, as their existence rests on positive evidence. I would particularly mention the Chaucer bank, in lat. 42° 45′ N., long. 29° W. It was discovered by Captain Robert Henderson of the ship "Chaucer," on a voyage from Mauritius to Glasgow, on 28th October 1850. Having noticed the water discoloured, he sounded and found hard bottom at 48 fathoms. Two hours afterwards he sounded again in 50 fathoms, and two hours later he found bottom in 70 fathoms. These soundings put the existence of the "Chaucer" bank beyond a doubt. Similarly the Sainthill bank, in lat. 42° 37′ N., long. 41° 45′ W., on which Captain Sainthill, R.N., got a good sounding in 100 fathoms, hard bottom; and the Milne bank, in lat. 43° 35′ N., long. 38° 50′ W., on which Admiral Milne got three soundings in 92, 81, and 100 fathoms, with fine sand and ooze, obviously exist, though they may perhaps form parts of one and the same shoal. The soundings of the "Dacia" show that obtaining one or two deep soundings in the neighbourhood affords no evidence whatever of the non-existence of a reported or suspected shoal. When a ship is sent to look for such a shoal she must be fitted with the necessary apparatus for taking deep soundings with ease and rapidity. Arrived on the ground, she must start sounding at close intervals, and always follow the lead of her own soundings, proceeding in the direction in which they get shallower until she either finds the shoal or the water deepens again. This method was used with great success, and by it the Coral patch, and more particularly the "Dacia" bank, were discovered.

* Findlay's *Atlantic Directory* (1865), p. 558.

3. On the Phylogeny of the Tunicata. By W. A. Herdman, D.Sc., F.L.S., Professor of Natural History in University College, Liverpool.

(*Abstract.*)

This paper deals with the relationships between the different groups of Tunicata, and the attempt is made to trace their phylogeny, and to construct a tree-like figure, showing the course of evolution of the group, and based upon anatomical and enbryological observations. The following are the chief results which are discussed :—

The Proto-Tunicata were derived from the Proto-Chordata by degeneration and modification, and they are represented at the present time by the Appendiculariidæ.

The Proto-Thaliacea and the Proto-Ascidiacea diverged in two different directions from the Proto-Tunicata, close to the ancestral Appendiculariidæ. The Doliolidæ and the Salpidæ form two divergent lines from the Proto-Thaliacea. *Anchinia* is an offshoot from the ancestral Doliolidæ.

The Proto-Ascidiacea gave up their free-swimming pelagic mode of life and became fixed. This ancestral process is repeated at the present day by the free-swimming larva of the fixed Simple and Compound Ascidians. The Proto-Ascidiacea are probably most nearly represented at the present day by the genus *Clavelina.* They have given rise, directly or indirectly, to the various groups of Simple and Compound Ascidians.

Two chief divergent lines arose from the ancestral Clavelinidæ— one leading to the more typical Compound Ascidians, and the other to the Ascidiidæ and other Simple Ascidians. The first of these ancestral lines gave rise to *Diazona* and the Distomidæ, and later on to the primitive Didemnidæ. The Polyclinidæ form a side branch from the base of the primitive Distomidæ. One important new family, the Cœlocormidæ (formed for the reception of *Cœlocormus huxleyi*, obtained off the east coast of South America, from a depth of 600 fathoms, during the "Challenger" Expedition), was derived from the primitive Didemnidæ, and in its turn gave rise to the Pyrosomidæ, thus connecting the aberrant and highly modified *Pyrosoma* with the Distomidæ, the most typical Com-

pound Ascidians. The Diplosomidæ were derived from the ancestral Didemnidæ.

The remaining two families of the Compound Ascidians, the Botryllidæ and the Polystyelidæ, were derived independently from the ancestral Simple Ascidians, and are therefore not closely allied to the Polyclinidæ and the Distomidæ. Probably the Botryllidæ arose from the primitive Cynthiidæ which were derived from the Ascidiidæ. The Polystyelidæ, on the other hand, form a modified offshoot from the Styelinæ. The new "Challenger" genus *Chorizocormus* shows how the transition may have been effected from such a Simple Ascidian as *Polycarpa* to such a Compound Ascidian as *Goodsiria.*

The Proto-Ascidiacea were probably colonial forms, and gemmation was retained by the Clavelinidæ and by the typical Compound Ascidians (Distomidæ, &c.) derived from them. The power of forming colonies by budding was lost, however, by the primitive Ascidiidæ (Simple Ascidians), and must, therefore, have been regained independently by the ancestral forms of the Botryllidæ and the Polystyelidæ derived from the Simple Ascidians. In the Polystyelidæ the differentiation of the colony has not gone so far as in most other groups of the Compound Ascidians, and the Ascidiozooids have not become arranged in true systems.

The ancestral Cynthiidæ split into two lines of descent—one leading to the Styelinæ and the Polystyelidæ, and the other to the primitive Cynthinæ. This latter group is represented most nearly at the present day by the genus *Cynthia*, while the Bolteninæ form a side branch. The Molgulidæ were also derived from the primitive Cynthinæ; they have undergone considerable modification.

In the paper the details of the changes which the various families and genera have probably undergone during their evolution are discussed, and the more important hypothetical ancestral forms are considered. The two most striking conclusions which have been arrived at are—(1) the relationship of *Pyrosoma* with the Distomidæ through *Cœlocormus;* and (2) that the Compound Ascidians are a polyphyletic group derived from the ancestral Simple Ascidians at three distinct points.

4. On Dew. By Mr John Aitken.

(*Abstract.*)

The first point referred to in this paper is the source of the vapour that condenses to form dew. A few observations of the temperature of the ground near the surface and of the air over it, first raised doubts in the mind of the author as to the correctness of the now generally-received opinion that dew is formed of vapour existing at the time in the air. These observations, made at night, showed the ground at a short distance below the surface to be always hotter than the air over it; and it was thought that so long as this excess is sufficient to keep the temperature of the surface of the ground above the dew-point of the air, it will, if moist, give off vapour; and it will be this rising vapour that will condense on the grass and form dew, and not the vapour that was previously present in the air.

The first question to be determined was whether vapour does, or does not, rise from the ground on dewy nights. One method tried of testing this point was by placing over the grass, in an inverted position, shallow trays made of thin metal and painted. These trays were put over the ground to be tested, after sunset, and examined at night, and also next morning. It was expected that, if vapour was rising from the ground during dewy nights, it would be trapped inside the trays. The result in all the experiments was that the inside was dewed every night, and the grass inside was wetter than that outside. On some nights there was no dew on the outside of the trays, and on all nights the inside deposit was heavier than the outside one.

Another method of testing this point was employed, which consisted in weighing a small area of the exposed surface of the ground, as it was evident that if the soil gave off vapour during a dewy night it must lose weight. A small turf about 6 inches (152 mm.) square was cut out of the lawn and placed in a small shallow pan of about the same size. The pan with its turf, after being carefully weighed, was put out on the lawn in the place where the turf had been cut. It was exposed for some hours while dew was forming, and on these occasions it was always found to lose weight. It was thus evident that vapour was rising from the ground while dew was forming, and therefore the dew found on the grass was formed of part of the rising vapour, trapped or held back by coming into contact with the cold blades of grass.

Another method employed for determining whether the conditions found in nature were favourable for dew rising from the ground on dewy nights, was by observations of the temperatures indicated by two thermometers, one placed on the surface of the grass, and the other under the surface, amongst the stems, but on the top of the soil. The difference in the readings of these two thermometers on dewy nights was found to be very considerable. Ten degrees was frequently observed, and occasionally it was as much as eighteen degrees. A minimum thermometer placed *on*, and another *under*, the grass, showed that during the whole night a considerable difference was always maintained. As a result of this difference of temperature it is evident that vapour will rise from the hotter soil underneath into the colder air above, and some of it will be trapped by coming into contact with the cold grass.

While the experiments were being conducted on grass land, parallel observations were made on bare soil. Over soil the inverted trays collected more dew inside them than those over grass. A small area of soil was spread over a shallow pan, and after being weighed was exposed at the place where the soil had been taken out, to see if bare soil as well as grass lost weight during dewy nights. The result was that on all nights on which the tests were made the soil lost weight, and lost very nearly the same amount as the grass land.

Another method employed of testing whether vapour is rising from bare soil, or is being condensed upon it, consists in placing on the soil, and in good contact with it, small pieces of black mirror, or any substance having a surface that shows dewing easily. In this way small areas of the surface of the earth are converted into hygroscopes, and these test-surfaces tell us whether the ground where they are placed is cooled to the dew-point or not. So long as they remain clear and undewed, the surface of the soil is hotter than the dew-point, and vapour is being given off, while if they get dewed, the soil will also be condensing vapour. On all nights observed, these test-surfaces kept undewed, and showed the soil to be always giving off vapour.

All these different methods of testing point to the conclusion that during dewy nights, in this climate, vapour is constantly being given off from grass land, and almost always from bare soil; that the tide of vapour almost always sets outwards from the earth, and but rarely ebbs, save after being condensed to cloud and rain, or on those rarer occasions on which, after the earth has got greatly cooled, a warm moist air blows over it.

It seems probable that when the radiation is strong, that soil, especially if it is loose and not in good heat-communication with the ground, will get cooled below the dew-point, and have vapour condensed upon it. On some occasions the soil certainly got wetter on the surface during the night, but the question still remains, Whence the vapour? Came it from the air, or from the soil underneath? The latter seems the more probable source: the vapour rising from the hot soil underneath will be trapped by the cold surface-soil, in the same way as it is trapped by grass over grass land. During frost, opportunities are afforded of studying this point in a satisfactory manner, as the trapped vapour keeps its place where it is condensed. On these occasions the *under sides* of the clods, at the surface of the soil, are found to be thickly covered with hoar-frost, while there is little on their *upper or exposed surfaces*, showing that the vapour condensed on the surface-soil has come from below.

The next division of the subject is on dew on roads. It is generally said that dew forms copiously on grass, while none is deposited on roads, because grass is a good radiator and cools quicker, and cools more, than the surface of a road. It is shown that the above statement is wrong, and that dew really does form abundantly on roads, and that the reason it has not been observed is that it has not been sought for at the correct place. If a road is examined on a dewy night, and the gravel turned up, the under sides of the stones are found to be dripping wet.

For studying the formation of dew on roads, slates were found to be useful. One slate was placed over a gravelly part of the road, and another over a hard dry part. Examined on dewy nights the under sides of these slates were always found to be dripping wet, while their upper surfaces, and the ground all round, were quite dry.

The importance of the heat communicated from the ground may be illustrated by a simple experiment with two slates or two iron weights, one of them being placed on the ground, either on grass or on bare soil, and the other elevated a few inches above the surface. The exposed surface of the one resting on the ground, and in heat-communication with it, is found always to keep dry on dewy nights, whereas the elevated one gets dewed all over.

The effect of wind in preventing the formation of dew is referred to. It is shown that, in addition to the other ways already known, wind hinders the formation of dew by preventing an accumulation of moist air near the surface of the ground.

From an examination of the different forms of vegetation made on dewy nights it was soon evident that something else than radiation and condensation was at work to produce the varied appearances then seen on plants. Some kinds of plants were found to be wet, while others of a different kind, and growing close to them, were dry, and even on the same plant some branches were wet, whilst others were dry. The examination of the leaf of a broccoli plant showed better than any other that the wetting was not what we might expect if it were dew. The surface of the leaf was not wet all over, and the amount of deposit on any part had no relation to its exposure to radiation, or access to moist air; but the moisture was collected in little drops, placed at short distances apart, along the very edge of the leaf. Further examination showed that the position of these drops had a close relation to the structure of the leaf; they were all placed at the points where the veins in the leaf came to the outer edge, at once suggesting that these veins were the channels through which the liquid had been expelled. An examination of grass revealed a similar condition of matters: the moisture was not equally distributed over the blade, but was in drops attached to the tips of some of the blades. It therefore seemed probable that these drops, seen on vegetation on dewy nights, were not dew at all, but were an effect of the vitality of the plant.

It is pointed out that the excretion of drops of liquid by plants is no new discovery, as it has been long well known, and the experiments of Dr Moll on this subject are referred to; but what seems strange is that the relation of it to dew does not seem to have been recognised.

Some experiments were therefore made on this subject in its relation to dew. Leaves of plants that had been seen to be wet on dewy nights were experimented on. They were connected by means of an india-rubber tube with a head of water of about 1 metre, and the leaf surrounded with saturated air. All were found to exude a watery liquid after being subjected to pressure for some hours, and a broccoli leaf got studded all along its edge with drops, and presented exactly the same appearance it did on dewy nights. A stem of grass was also found to exude at the tips of one or two blades when pressure was applied.

The question as to whether these drops are really exuded by the plant by internal pressure, as in the above experiments, or are produced in some other way, is then considered. The tip of a blade of grass was put under conditions in which it could not extract moisture from the surrounding air, and, as the drop grew as rapidly under these conditions as did those on the unprotected blades, it is concluded that these drops are really exuded by the plant. Grass was found to get "dewed" in air not quite saturated.

On many nights no true dew is formed, and nothing but these exuded drops appear on the grass; and on all nights when vegetation is active, these drops appear before the true dew, and if the radiation is strong enough and the supply of vapour sufficient, true dew makes its appearance, and now the plants get equally wet all over, in the same manner as dead matter. The difference between true dew on grass, and these exuded drops, can be detected at a glance. The drops are always exuded at a point near the tip of the blade, and form a drop of some size, while true dew is distributed all over the blade. The exuded liquid forms a large diamond-like drop, while the dew coats the blade with a pearly lustre.

Towards the end of the paper the radiating powers of different surfaces at night are considered. By means of the radiation-thermometer, described by the author in a previous paper, the radiating powers of different surfaces were compared. Black and white cloths were found to radiate equally well: soil and grass were also almost exactly equal to each other. Lamp-black was equal to whiting. Sulphur was about 2/3rds of black paint, and polished tin about 1/7th of black paint. Snow in the shade on a bright day was at midday 7° colder than the air, while a black surface at the same time was only 4° colder. This difference diminished as the sun got lower, and at night both radiated almost equally well. In the concluding pages of the paper some less important subjects are considered.

5. Observations on the Structure of *Lumbricus complanatus*, Dugès. By Frank E. Beddard, M.A., F.R.S.E., F.Z.S., Prosector to the Zoological Society of London.

A very considerable number of earthworms have been referred to the genus *Lumbricus*, and its immediate allies *Dendrobæna*, *Allolobophora*, &c., which have in reality no marked affinities with any of these genera. Such are, for example, *Lumbricus corethrurus* of Fritz Müller, which Perrier has shown to belong to a distinct generic type described by him under the name of *Urochæta*, and *Lumbricus microchæta* of Rapp, which is also the type of a new genus, widely differing from *Lumbricus* proper. On the other hand, a very large number of species have been referred to the latter genus, concerning which there is little or no knowledge, so that it is impossible to speak with any certainty as to their exact systematic position.

No less than fifty-nine such species are enumerated by Vejdovsky, in his lately-published *System und Morphologie der Oligochæten*, some of which, however, are evidently members of the genus *Lumbricus*, or its immediate allies. In the memoir referred to, which is not merely a record of new observations, but a thoroughly digested summary of previous work upon the subject, Dr Vejdovsky only allows three species that can be at present unhesitatingly assigned to the genus *Lumbricus;* of the other *Lumbrici*, eighteen species belong to Eisen's genera *Tetragonurus*, *Allolobophora*, *Allurus*, and *Dendrobæna;* twenty-eight probably belong to one of the four genera enumerated, while thirty-two may or may not (in some cases, *e.g.*, *L. microchæta* certainly not) belong to any of these genera; they are put under the head of "species inquirendæ." It is with one of these latter that the present paper deals. I do not, however, wish to identify the species that I am about to describe with *Lumbricus complanatus* of Dugès without a certain reservation. Absolutely nothing is known about the structure of by far the majority of the species of *Lumbricus;* and it is evidently therefore a matter of impossibility to determine its systematic position with any pretence to accuracy.

The following observations rest upon the examination of a single specimen, which I owe to the kindness of Professor A. G. Bourne; the specimen was brought from Naples, and has been excellently preserved by means of perchloride of mercury.

One of the earliest writers on the structure of earthworms—Dugès—has left a valuable paper* on the anatomy and systematic characters of those species of *Lumbricus* which he was able to obtain in France. He distinguishes six separate species of *Lumbricus* as occurring in that country; but it is at present quite impossible to state how far his systematic determinations are of value. The whole subject wants to be gone into afresh with the help of anatomy, and until that is done there can be no real attempt to classify the species of *Lumbricus*, as well as to decide how far the generic characters adopted by Eisen are of value.

Of the species described by Dugès two appear, so far as I can judge, to approach very nearly the species described in the present paper. These are *Lumbricus gigas* and *L. complanatus*. The structure of both species is very closely similar to that of my own species, but the external characters of the latter correspond more with those of *L. complanatus*.

The anatomy of *L. gigas* is described in some detail, and the descriptions are illustrated by a number of figures. There are, of course, numerous statements in the paper which require correction in the light of more recent knowledge; the spermathecæ are spoken of as testes, and the testes themselves, or rather the vesiculæ, are generally denominated ovaries, and their ducts oviducts. The canal which Dugès figures as connecting the spermathecæ has not, as far as modern investigations go, any existence. Another figure illustrates with sufficient accuracy the two vasa deferentia funnels, their ducts uniting into a common vas deferens; the "testes" are shown as being in continuity with the margins of the funnels, so that it is evident that in this species, as in others of *Lumbricus*, the testicular sacs are not the true testes, but merely a mass of spermatozoa in various stages of development, enclosed in a sac-like structure which is simply an outgrowth of the margins of the vas deferens funnel.

The main point of interest in connection with these figures is the presence of four distinct vesiculæ seminales, and no less than seven copulatory pouches on each side of the body.

* *Annales d. Sciences Nat.*, t. xv. (1828), p. 286, pls. viii., ix.

It is well known that in the common British *Lumbricus* there are only three pairs of vesiculæ seminales, and two pairs of small spherical copulatory pouches, which are found in the same segments. The only exceptions to this rule mentioned by Vejdovsky, apart from the present species, are *Allolobophora chlorotica*, which has three pairs of copulatory pouches (according to Dugès), and *Dendrobœna*, which has only one pair. Dugès mentions that seven pairs of copulatory pouches are not invariably characteristic of *L. complanatus.* He says :—" Ces séries n'ont pas toujours la même étendue, puisque le nombre des vésicules varie de deux à sept pour chaque côté. Ces différences sont-elles spécifiques, comme le pense M. Savigny? Je crois plutôt qu'il faut les rapporter au temps où l'on en fait l'étude : en effet, à mesure que l'époque de l'accouplement s'éloigne, le volume de ces organes diminue; les plus extrêmes, aux deux bouts de la série, s'atrophient les premiers, et il arrive une époque où l'on n'aperçoit qu'avec peine les rudiments de ces parties si saillantes en un autre temps."*

It appears to me that the latter supposition is the correct one, and that the greater number of copulatory pouches is in all probability the typical number in fully-developed specimens.

I have recently had the opportunity of confirming Dugès' supposition in a species of *Perichæta* (probably *P. affinis*). My friend Mr H. E. Barwell, of Manila, kindly forwarded me a large number of earthworms from that locality at my request, and among them were numerous individuals of this *Perichæta*, in which the copulatory pouches varied in the most extraordinary way in number, though not, as far as I could ascertain, in structure. There were no other differences in structure between the different individuals.

On the other hand, no individual of the British species of *Lumbricus* has, so far as I am aware, ever been recorded which possesses more than two pairs of copulatory pouches. The number of copulatory pouches present may serve as an indication of specific rank, but it is necessary to make use of this character with great caution. In the present instance it may be taken for granted that seven separate copulatory pouches distinguish *L. gigas* from most other species of the genus.

* *Loc. cit.*, p. 327.

A subsequent paper by Dugès * considerably augments the number of species. In that paper (p. 23) the author states that *L. complanatus* agrees with *L. gigas* in possessing seven pairs of copulatory pouches and four pairs of vesiculæ seminales. For this reason I am inclined for the present to regard the species to be described in the present note as identical with *L. complanatus;* it differs from *L. gigas* as described by Dugès (1) in the distribution of the setæ, and (2) in the position of the clitellum. In *L. gigas* the setæ of the two pairs are closely approximated together, while in *L. complanatus* they are rather more widely separated. The arrangement of the setæ in *L. complanatus* is figured in the first of the two memoirs referred to, and corresponds, so far as I can make out, exactly with the species studied by myself; the two setæ of the ventral pairs are rather further apart than those of the dorsal pair. The clitellum in my species extended from segments 28–38, occupying therefore 10 segments. Dugès states that in *L. complanatus* the clitellum extends from 29–39, which, as he counts the buccal lobe as a distinct segment, is precisely the same; in *L. gigas*, on the other hand, the clitellum occupies 22 rings, ending with the 53rd.

In Hoffmeister's *Familien der Regenwürmer* three species are mentioned in which the clitellum occupies *about* the same segments as in *L. complanatus*, *L. stagnalis* (apparently identical with *L. planatus*) is one species; the other two are *L. agricola* (= *L. terrestris*, *Enterion herculeum*) and *L. riparius* (= *L. octœdrus*, *chloroticus*, *virescens*, *anatomicus*); in all these, however, the setæ of each pair are very closely approximated, and, moreover, except in *L. agricola*, the segments contained in the clitellum are not more than nine; so, at any rate, does it appear from Dugès' table of classification of the species in the second of his two memoirs referred to.

Dugès does not give an elaborate account of the generative apparatus in *L. complanatus*, merely remarking that there are four seminal vesicles and seven pairs of copulatory pouches.

In the specimen before me there are four seminal vesicles on each side of the body, occupying apparently segments 8–11; they are approximately of equal size and rounded in shape, firmly attached to the mesentery dividing these segments. The copulatory pouches have an arrangement rather different from that figured by Dugès in

* *Loc. cit.*, t. xv. pl. ix. fig. 25.

*L. gigas.** He gives no figure of those structures in *L. complanatus*, only mentioning that they are four to seven pairs in number. In the individual dissected by myself the copulatory pouches are disposed as shown in the accompanying figure (fig. 1). In the fifth, sixth, and seventh segments are a pair of spherical pouches, one to each segment, furnished with a very short duct, which perforates

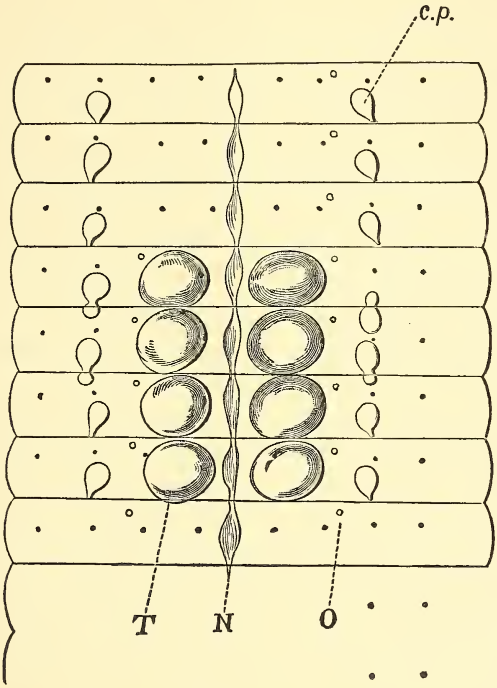


Fig. 1.—Diagram of the genital region of *Lumbricus complanatus*. T, vesiculæ seminales; *c. p.*, spermathecæ; N, nerve cord; O, orifices of nephridia. The setæ are indicated by black dots.

the body-wall on a line with and behind the innermost seta of the dorsal pair; in the eighth segment the pouch, on the left side of the body, opens in the posterior region of the segment in common with a small diverticulum lying in the segment behind; on the right side of the body the condition of this pouch is exactly reversed, the small diverticulum lying in the eighth segment and the larger portion of the pouch in the ninth; in the ninth segment, in addition to the

* *Tom. cit.*, . ix. fig. 1.

diverticula just mentioned, is a large pouch in the posterior region of the segment, connected with a small diverticulum in the following segment; in segments ten and eleven were a pair of pouches lying close to the posterior mesentery, and apparently unprovided with any diverticulum. The pouches were in every case fully distended with the contained semen. I also studied the series of copulatory pouches of one side of the body (the right) by means of longitudinal sections, which revealed the position of the external apertures not visible on an inspection of the intact worm. These apertures are situated at the anterior extremity of each segment, in the groove which separates it from the segment in front and on a line with the innermost seta of the more dorsally placed pair. It has been already mentioned that the copulatory pouches themselves lie in most instances in the posterior region of their segments, in close contact with its posterior wall. The duct of each pouch, which is extremely narrow, perforates the body wall just at the point where the mesenteries arise, and, running obliquely backwards, opens on to the exterior in the place already mentioned, which corresponds with segment *behind* that which contains the pouch itself.

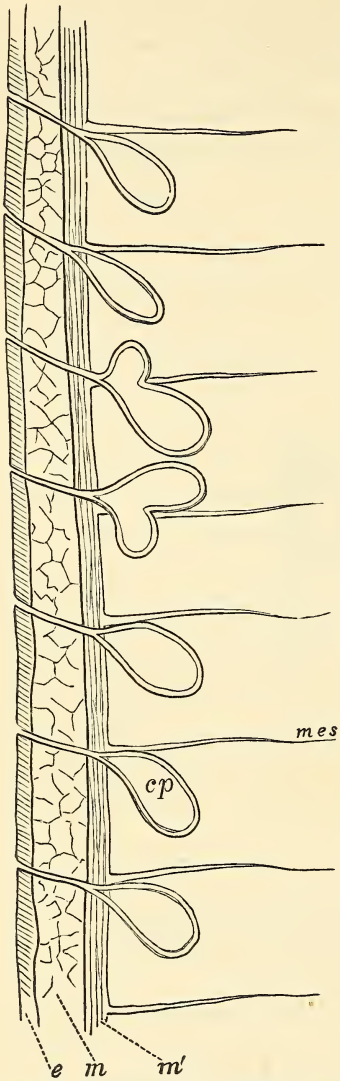


Fig. 2.—Diagram of longitudinal section through spermathecæ of right side of body. The spermatheca at the top of the figure is the last, *i.e.*, that occupying segment 11; *mes*, mesenteries; *c p*, spermatheca; *e*, epidermis; *m*, transverse muscular layer; *m′*, longitudinal muscular layer.

This fact is illustrated by the accompanying woodcut (fig. 2), which represents a vertical section through the seven pouches of the right-hand side of the body. In segments 8 and 9, it has already been mentioned that the pouches are not contained in a single segment, but are furnished with a diverticulum which passes through the mesentery into the segment behind. The series of sections confirm these statements, and also show that the duct of the copulatory pouch arises from about the junction of its two halves, which are only separated from each other by a slight constriction at the mesentery; as diverticula, in fact, they are not well marked, the structure being identical throughout.

In every case the interior of the spermatheca was filled with a mass of spermatozoa.

I am able therefore, generally speaking, to confirm the accuracy of Dugès' observations on the copulatory pouches of *Lumbricus complanatus*, and such a confirmation is evidently necessary, since it is often stated, when dealing with the structure of *Lumbricidæ*, that *Lumbricus* differs from other genera in the fact that the copulatory pouches are contained in the same segments as the testes, and are only two or three pairs in number. The present species combines the characters of most *Lumbrici* on the one hand, and such genera as *Pontodrilus*, *Urochæta*, &c., on the other, in so far that the copulatory pouches are present both in the segments which contain the testes and in certain of those which precede them. The number of pairs also is larger than is met with in any other known earthworm.

Another fact of interest is the presence of diverticula, which, characteristic of many other genera, *Perichæta*, &c., have not to my knowledge been described in *Lumbricus;* they have apparently escaped the attention of Dugès, always supposing that his species is the same as that described in the present paper. It is rather difficult, however, in the present species to say which part should be regarded as the copulatory pouch itself and which the diverticulum. In segment nine, for example, the pouch on the right-hand side of the body was considerably larger than its "diverticulum," and on the left-hand side smaller. In *Perichæta* there is never any such difficulty, for the diverticula have a very different appearance; they are usually different in shape from the copulatory pouch; and in a species of *Acanthodrilus*, I have pointed out that there is also a difference in minute structure * between the two portions of the copulatory pouch. In *Lumbricus complanatus* there is no difference in shape; only a difference in size, and the structure is identical. This matter is a little more important than might appear at first sight, because if we are to allow that the two large pouches in segment nine are each the equivalent of a copulatory pouch, we shall have the apparent anomaly of two pairs of copulatory pouches in the same segment. It is generally believed that the segment which contains the gizzard is in reality the equivalent of two segments which have become fused through the abortion of the intervening septum, possibly of mechanical advantage to the gizzard, as rendering its movements more free. In *Perichæta affinis*, Perrer records † the presence of two pairs of copulatory pouches in the gizzard "segment," besides two rings of setæ. I have observed the same thing in other species of this genus. Is it legitimate to suppose that in *L. complanatus* we have a record of the former presence of the gizzard in the same region of the body where it now occurs in *Perichæta*, though not in any *Lumbricus?*

The supposition of an aborted mesentery and a consequent fusion of two segments is not, however, so trustworthy in this species as in *Perichæta*, because there is certainly only one nephridium and one row of setæ as in all the adjacent segments, and so, perhaps, it is better to suppose that the copulatory pouch of segment 8 has a very large diverticulum,—larger than the pouch itself,—a more normal arrangement being found on the left side of the body. A third alternative is possible, viz., that more than a single pair of copulatory pouches may be present in the same segment. As an evident abnormality, I have observed a case of this kind in a specimen of *Perichæta affinis*—the species which has already been referred to above as affording an instance of variability in the number of the copulatory pouches in different individuals of the same species; in one specimen of this worm there were three copulatory pouches in one segment placed in a row. An inspection of fig. 2 would appear at first sight to prove that the second alternative mentioned above is the correct one. In every case it will be noticed that the duct of the pouch passes backwards to open on to the exterior at a point opposite the

* *Proc. Zool. Soc.*, 1885, p. 829.

† *Nouv. Arch. d. Mus.*, t. viii. p. 111.

segment behind that which contains the pouch. In this way we must assume, for the sake of making all the pouches of the series to correspond, that the minute portion of the pouch which lies in segment 8 is the pouch itself, and not a diverticulum. On the other hand, perhaps, the fourth and fifth pouches still retain the characters that are met with in most species of *Lumbricus*,* where the pouch is situated near to the anterior region of its segment, and the duct opens on to the body-wall in the groove between this segment and the one in front, with this difference, that a part of the pouch has grown through the wall and forms a kind of diverticulum; if the diverticulum continues to grow at the expense of the pouch until the latter vanishes altogether, we arrive at the condition which is characteristic of certain other *Lumbrici;* in any case, the two pouches of segments 8 and 9 appear to be an indication of a connection between the unusual disposition of the pouches in the present species and their more usual arrangement in *Lumbricus* generally, and in other earthworms (*i.e.*, situated in the anterior region of the segment, and opening in the groove between this segment and the one in front).

I have, therefore, been able to show in the present paper that a

* This is not, however, invariably the case. In some individuals the spermathecæ are, as in the present species, placed near to the posterior wall of the segment which contains them; in other individuals, possibly different species, the spermatheca, as in the majority of earthworms, is placed nearer to the anterior wall of the segment. This may prove to be a difference of specific importance. I find that this variation exists in the figures of other observers. Lankester (*Quart. Jour. Micr. Sci.*, 1865) figures the two spermathecæ as lying by the anterior wall of their segments (9 and 10), and opening in the groove between each of those segments and the one in front. On the other hand, Hering (*Zeitsch. f. Wiss. Zool.*, 1857) states that the spermathecæ are situated in 9 and 10, and open between 9–10 and 10–11. D'Udekem (*Mem. Cour. d. l. Acad. roy. de Brux.*, 1856) figures and describes a disposition of the spermathecæ identical with that observed by Hering.

Note added May 15, 1886.—A paper by Dr Rosa, "I lumbricidi del Piemonte," which I had overlooked in writing the above, has come into my hands through the kindness of the author. *L. complanatus* is described in this paper under the name of *Allolobophora complanata;* the author, however, does not mention the diverticula of the spermathecæ, nor is there any indication of them in his figure; if the presence of these should ultimately prove to be a specific character, I would propose to name my species *Lumbricus* (*Allolophora*) *rosæ*, after the Italian naturalist. I notice also that in this paper the position of the spermathecæ in the anterior or posterior region of the segment is used as a specific character. The specimen described in the present paper shows how the change of position of the spermathecæ is brought about.

certain species of earthworm, characterised by the fact that the clitellum occupies 10 segments ending with the 38th, that the setæ of each pair are rather widely separated, the nephridial pores being placed in front of and a little to the outside of the outermost of the two ventral setæ, has a certain internal structure, the most marked characters being (1) the presence of four distinct vesiculæ seminales, (2) the presence of seven distinct pairs of spermathecæ situated in segments 5–11 inclusive. It is only by such comparisons of internal and external structure that the limits of genera and species can be determined, and the at present confused synonymy of *Lumbricus* reduced to anything like order.

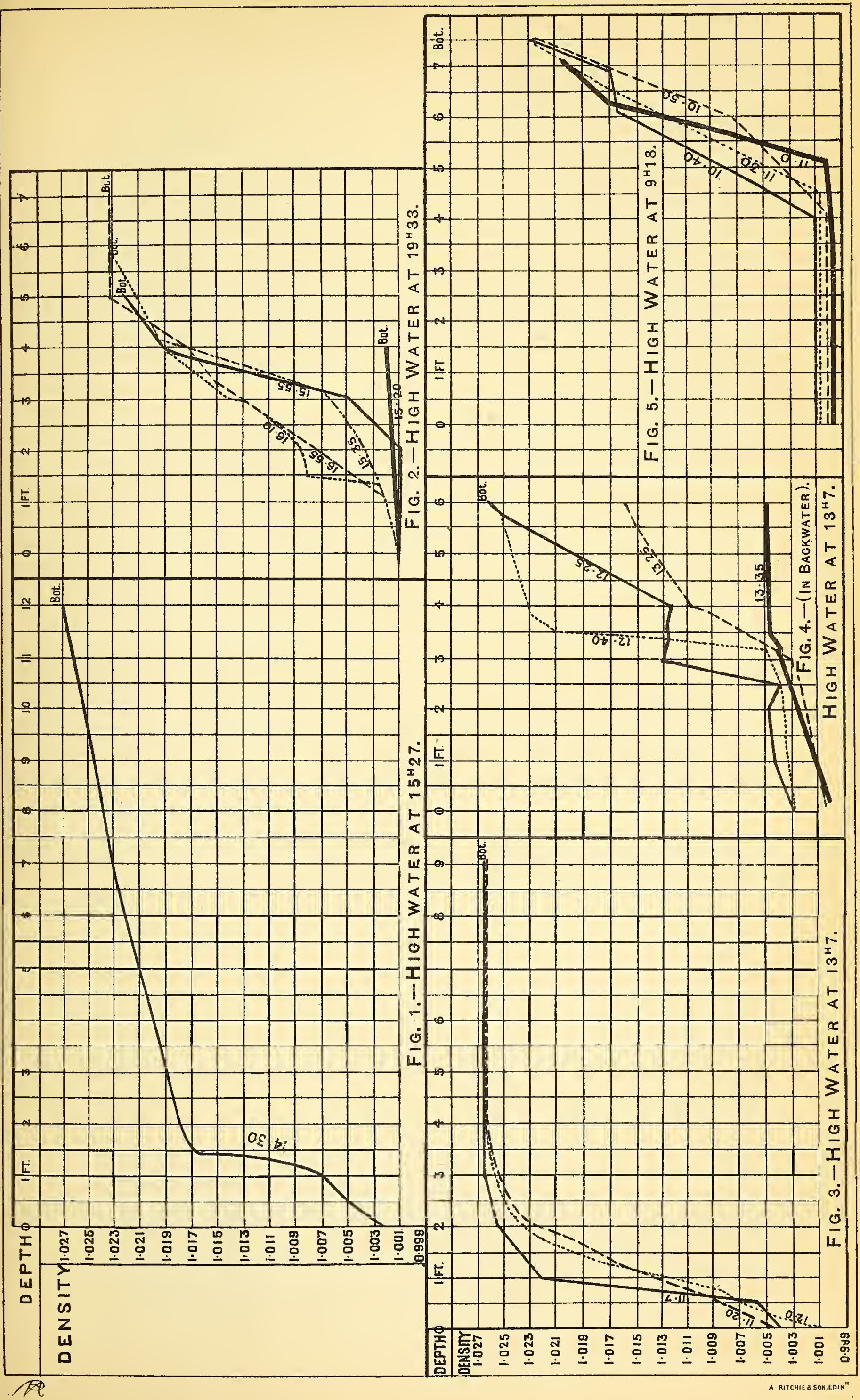
6. On the Physical Conditions of Rivers entering a Tidal Sea; from Observations on the Spey. By Hugh Robert Mill, B.Sc., and T. Morton Ritchie, B.Sc. (Plates XIII., XIV., XV.)

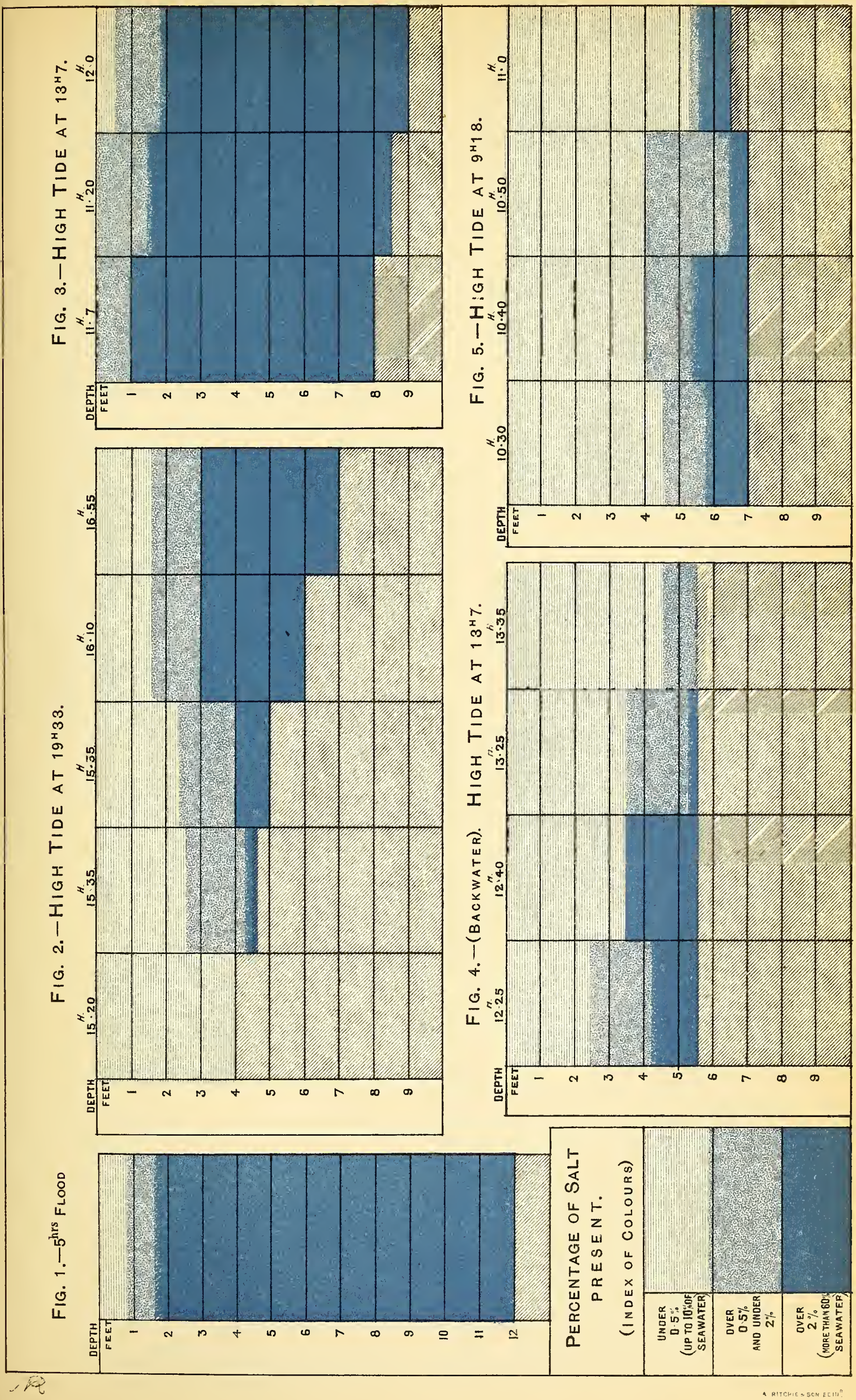
In connection with the observations carried on by one of us on the salinity and temperature of estuaries,* it seemed desirable to examine the condition of the water near the mouth of a river flowing directly into the sea. For this purpose it was necessary to select a stream of considerable volume and free from pollution. As the Spey appeared to be the most suitable river, we spent the month of August at Garmouth, a small town close to the old port of Kingston, on the west side of the river mouth. We have to express our thanks to Mr Balmer, Commissioner at Fochabers to the Duke of Richmond and Gordon, for much kindly interest in our work, and for affording us the use of the facilities presented by the salmon-fishing station of Tugnet on the east bank of the river.

The Spey is the most rapid river in Scotland, and next in size to the Tay. It is 120 miles long, including windings, and drains an area of 1245 square miles. It flows in a northerly direction into the Moray Firth, which is not an estuary in any sense of the word, but

* Mill, "On the Salinity of the Water in the Firth of Forth," *Proc. Roy. Soc. Edin.*, xiii. pp. 29–64; Abstract in *Nature*, xxxi. p. 541; "On the Temperature of the Water in the Firth of Forth," *Proc. Roy. Soc. Edin.*, xiii. pp. 157–167; "On the Salinity of the Estuary of the Tay and of St Andrews Bay," *ibid.*, pp. 347–350; "On the Physical Conditions of Water in Estuaries," *Brit. Ass. Rep.*, 1885, and *Scottish Geographical Magazine*, ii. pp. 20–26.

RIVER SPEY—VARIATION OF DENSITY WITH DEPTH AND TIME.





A. RITCHIE & SON EDIN^R.

FIG. 1.—SUPPOSED FLOW OF TIDE INTO RIVER SPEY.

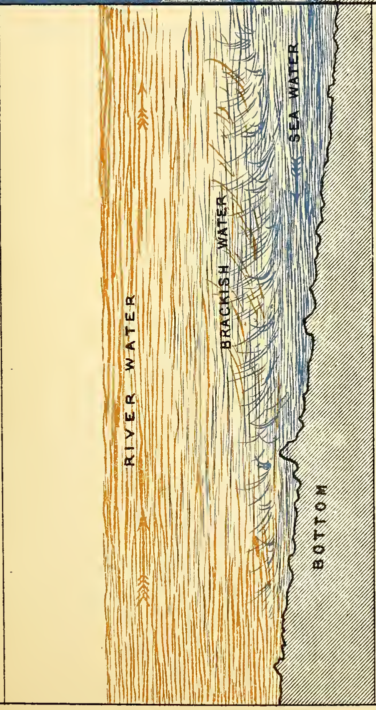


FIG. 2.—SALINITY OF SPEY BAY, 18TH AUGUST 1885.

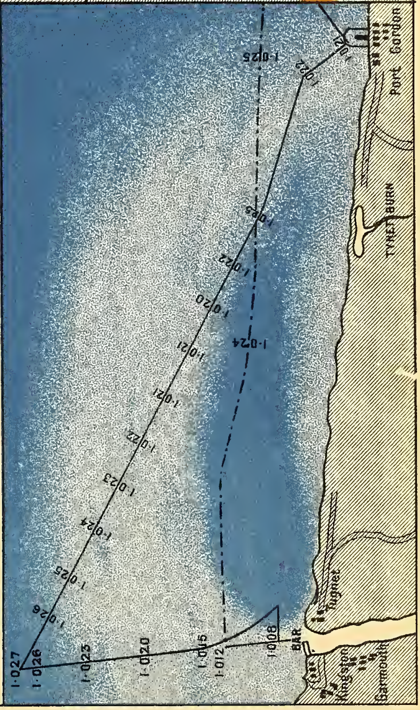


FIG. 3.—COURSE OF SPEY WATER IN THE BAY, 13TH AUGUST 1885

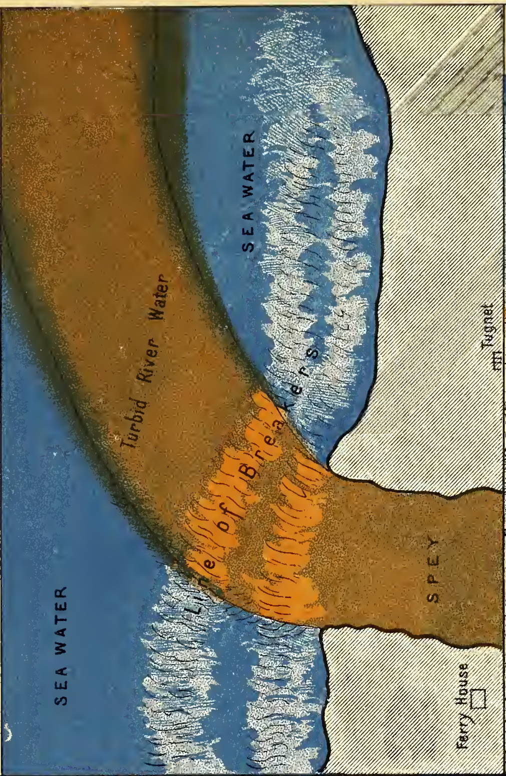
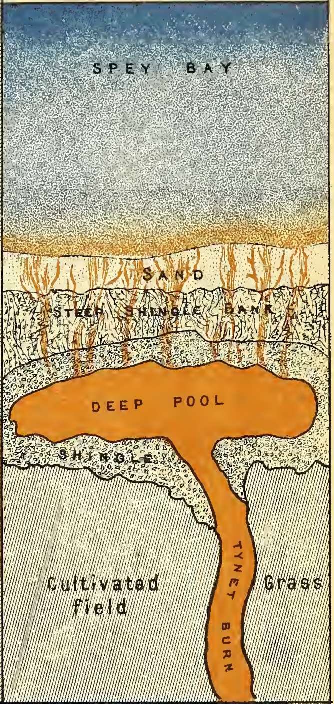


FIG. 4.—OUTLET OF TYNET BURN



A. RITCHIE & SON. EDINR.

an inlet of the sea, and as such possessed of the distinctive marine characteristics. As a salmon river, it ranks next to the Tay and the Tweed. It is particularly noted for the suddenness and intensity of its floods, and for the variable nature of the channel, the stream being frequently diverted in a new direction. Twenty-five years ago a channel was cut to turn the river from the village of Kingston, many of the houses of which had been undermined and carried away. One result was the destruction of the harbour, so that now a boat can enter or leave the river only in the calmest weather, and then at high tide. This fact added considerably to the difficulties of work in the bay, and prevented it from being so complete as we desired. The bay is very shallow near the shore, and the depth is yearly diminishing on account of the stones and silt brought down by the river. The beach on each side for several miles is covered with fields of river-borne shingle massed in wave-like ridges parallel to the coast line, and hardly touched by vegetation.*

The town of Lossiemouth lies 7½ miles to the west of the Spey, and Buckie 5 miles to the east. Halfway to Buckie, 2½ miles east of Tugnet, is the fishing village of Port Gordon, the nearest harbour to the Spey available in ordinary weather.

The river near the mouth is confined to a narrow channel (250 feet wide at high water, and about 150 at low tide), and partly on this account and partly because of the slope of its bed, it is very rapid. The depth varies from 3 to 6 feet at low tide, and every flood effects some change in the position of the shingle banks and shoals. The western side of the river near the mouth is a shingle bank running into a line of low sandy islands; on the east there are simple shingle heaps forming a breakwater about 30 yards wide which separates the river from the sea. Just at the mouth a ridge of shingle, entirely bare at low tide, runs in an east-north-easterly direction, and sends the river current out to sea towards

* Mr Balmer informs us that the river was diverted in February 1860 to a straight course, in the expectation that by its action on the shingle banks it would gradually move back to its old westerly position. Instead of doing so, it cut a new channel more to the east, and continued for several months to extend this until the mouth had advanced about quarter of a mile to the eastward. Then the normal action recommenced, and shingle has been steadily laid down on the east bank and cut off from the western ever since, so that the mouth is moving westward every month; and in a few years it is expected to come back to the position it occupied prior to 1860.

the east: its prolongation forms a bar across the channel with not more than 2 feet of water on it. Since the bar and banks are constantly shifting in size, shape, and position, all observations which depend in any way on the form of the river mouth must be considered as applicable only to the time when they were made.

The salmon-fishing station of Tugnet stands on the east shore about one-third of a mile from the river mouth. A backwater separated, except at high tide, from the main stream by a sandy flat, runs up from near the river mouth to Tugnet. On the west side a narrow shallow channel, separated by a low grassy island from the river, comes down past Garmouth, and at its termination a burn which trickles across the mud of Kingston Basin at low tide, enters the river. At high tide this burn becomes a passage with considerable depth of water, leading to a broad expanse below the houses at Kingston, and separated from the sea by a high shingle bank. The relative positions of these parts of the river may be understood from the accompanying sketch (fig. 1), which is drawn roughly from memory, and is not to scale.

Even when the river is small and the tide full the water is fresh on the surface.* The rising tide diminishes the velocity of the current, both by damming back the fresh water and by widening the connection with the sea, and so letting it spread over a larger area.

The conditions of working in a small coble in a rapid stream of slight depth, in which considerable variations of salinity might be expected, necessitated some modifications of the usual modes of obtaining and examining samples of water. The slip water-bottle was useless as a collector, because it enclosed a vertical column of water a foot high, and it soon became apparent that very considerable changes of density took place in a distance of 3 inches. It was found best in the circumstances to use an ordinary stoppered bottle (of about 1·5 litre capacity) lashed to a pole or attached to a sounding-line which was heavily weighted,† and to draw out the

* The fact that sea water forced its way up the bed of a tidal river under the opposing current of fresh water has been known at any rate since 1812, when the phenomenon was studied on the Dee at Aberdeen by Mr Robert Stevenson.—David Stevenson, *Canal and River Engineering*, 2nd ed., p. 124.

† The *hydrophore* of Mr Robert Stevenson (*Canal and River Engineering*, p. 126) would have been more suitable, but there was no opportunity of getting one made.

stopper by a cord when the desired depth was reached. The pole or line was graduated to feet. By this means, the bottle being lowered full of air, water was let in from a plane that could be

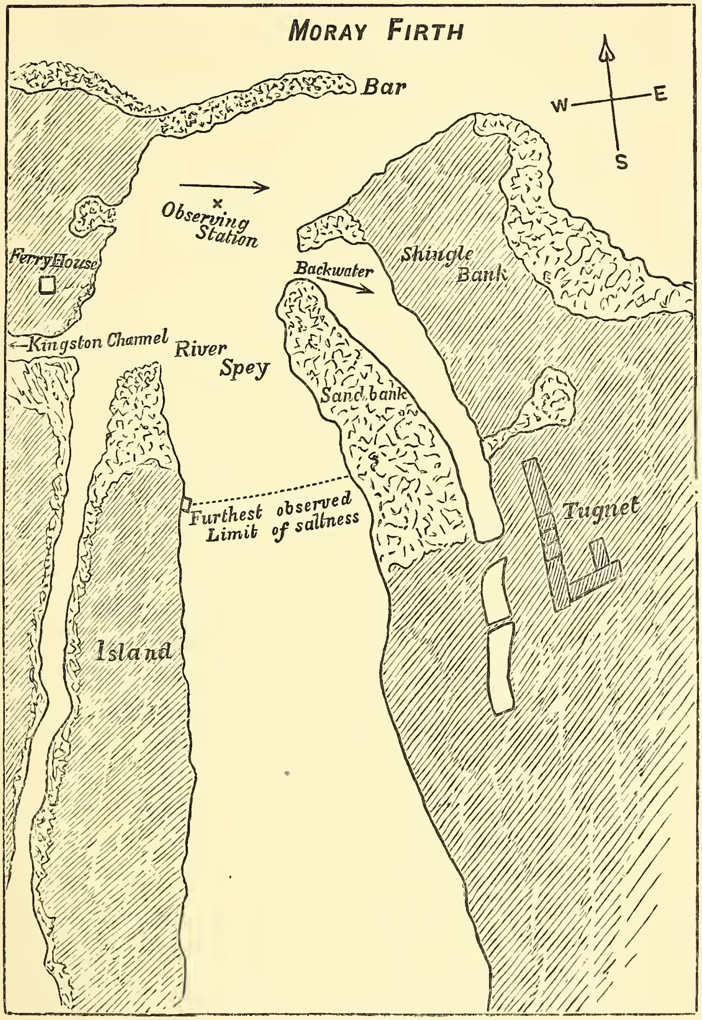


FIG. 1.—Sketch-Map of Mouth of Spey, August 1885. Light shading shows parts covered at high water.

determined to 1 inch in calm weather. It was a little difficult to get a true bottom sample in this way; but it was secured, when a sounding-line was used, by fixing a weight to the neck of the bottle and paying out line enough to let it lie flat.

It was impracticable, on account of the time required, to use the delicate hydrometer for determining the density of the hundreds of samples taken in tracing the mixture of sea and river water; and we were obliged to be content with occasionally reserving a bottom, intermediate, and surface sample for careful determination, while a small directly-graduated hydrometer was made use of in the boat. This hydrometer was marked to read "specific gravities" from 1·000 to 1·030 at 60° F., but since only an indication of the salinity was required the temperature, which averaged about 58° and which often varied 1° or even 2° between surface and bottom, was neglected.

Throughout this paper the density of water when given to the third or fourth decimal place (*e.g.*, 1·026 or 1·0255) is only roughly approximate, and is not corrected for temperature; the observations were made, as a rule, while the water had a temperature of from 12° to 16° C. When it is given to five places (*e.g.*, 1·02345) it is accurate to within 0·00005, and is calculated to 15°·56 C. whatever the original temperature of the sample was. The observed temperature of water and air is given in degrees Fahrenheit, in consistence with the usage of meteorologists. Instrumental errors are not allowed for, as the same thermometers were always used for air, surface-water, and deep-water temperatures respectively; the absolute uncertainty, which is a constant for each thermometer, does not exceed 0°·2 in any case. Time is reckoned from 0 hours, midnight, to 24 hours.

Observations on Tidal Variations of Salinity.

Numerous observations were made at a point about 100 yards inside the bar when tide was flowing, and some in the same position while it was ebbing. The mode of working was to anchor the coble in mid-stream, and, beginning at the surface, to take samples at every foot of depth, to observe the density with the small hydrometer, and where there was a sudden rise in density between any two specimens, to examine samples from every 3 inches in that foot. By this means the vertical distribution of salinity was traced. After a few minutes the process was repeated, and so on until the work had to be stopped by the ebb current becoming too strong for the anchor. It was sometimes found advisable to begin at the bottom and work upwards.

The following are the observations made in this way :—

I. *Flowing Tide.*—August 1, observations at $14^h.30$; high water at $15^h.27$. Depth 12 feet (spring tide). Temperature of water at surface 62°·5, at 6 feet 58°·7, and at bottom 55°·6.

Depth, ...	Surf.	8 in.	1 foot.	1 ft. 6 in.	3 feet.	6 feet.	Bot. 12 ft.
Density (rough), . .	1·002	1·006	1·007	1·017	1·019	1·022	1·027
,, at 15°.56, .	1·00108	...	...	...	...	1·01668	1·02481

This, being a representative case, is shown by the curve, Plate XIII. fig. 1, and on the coloured diagram, Plate XIV. fig. 1, where the depth of colour is proportional to the amount of salt in solution at each position.

II. *Flowing Tide.*—August 3, observations at $15^h.25$ and $16^h.0$; high water at $16^h.56$. Depth 8 feet. Weather bright and calm; heavy surf on the bar. Temperature of air 54°·5, surface water 60°·0, at 4 feet 58°·0, bottom 56°·7. A shower on the previous night might have raised the river very slightly.

At $15^h.25$.

Depth, .	Surf.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	Bot. 8 ft.
Density (rough), .	1·000	1·010	1·015	1·020	1·020	1·022	1·0235	1·0235
Density at 15°·56 C.	0·99972	...	...	1·01571	...	...	...	1·02162

At $16^h.0$.

Depth,	Surf.	1 in.	3 in.	6 in.	9 in.	1 ft.	1 ft. 6 in.	2 ft.	3 ft.	6 ft.	Bot. 8 ft.
Density (rough), .	1·002	1·0025	1·002	1·003	1·003	1·0035	1·007	1·015	1·021	1·0235	1·0235
Density at 15°·56C.	1·00000	...	...	...	...	...	...	...	1·01382	...	1·02037

The water on the shore half a mile east of the river mouth had, at $14^h.0$, the density 1·02420.

III. *Flowing Tide.*—August 5, observations from $14^h.15$ to $16^h.55$; high water at $19^h.33$. Depth increasing from 4 feet to 7 feet. Heavy surf on the bar; no wind. Temperature of air 53°·0, of surface water (mean for the whole time) 57°·2, at half depth 56°·7, and at bottom 56°·4.

At $14^h.15$. Surface 1·001, correctly 0·99927; bottom 1·002, correctly 0·99937.

Bottom density observed at the following hours, that at $15^h.30$ being the same for mid-stream and near each bank.

Hour,	$14^h.50$	$14^h.57$	$15^h.5$	$15^h.18$	$15^h.20$	$15^h.30$	$15^h.35$
Bottom density (rough),	1·001	1·001	1·002	1·003	1·002	1·004	1·018

At $15^h.55$.										
Depth,	Surf.	1 ft.	1 ft. 3.	1 ft. 6.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.
Density (rough),	1·0015	1·001	...	...	1·001	1·005	1·019	1·022	...	...
Density at 15°·56 C.	0·99917	...	...	...		1·00600	...	1·01810	...	...
At $16^h.10$.										
Density (rough),	1·001	1·001	1·002	1·008	1·008	1·014	1·019	1·017	1·022	...
At $16^h·55$.										
Density (rough),	1·001	1·002	...	...	1·004	1·014	1·016	1·023	1·022	1·023
Density at 15°·56 C.	0·99944	...	...	...	...	...	1·02041	...	...	1·02258

These data are used in constructing the curves on Plate XIII. fig. 2, and the coloured diagram Plate XIV. fig. 2.

IV. *Flowing Tide.*—August 11, observations from $10^h.40$ to $11^h.40$; high water $13^h.7$. Very strong wind blowing down the river. Temperature at surface 57°·5. The high wind made it impossible to read the hydrometer with great accuracy.

At $10^h.40$. Depth,	Surf.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.
Density (rough),	...	...	...	1·026	1·025	1·0265	1·0265	...	1·027	1·028

	Surf.	3 in.	6 in.	9 in.	1 ft.	1 ft. 3.	1 ft. 6.	1 ft. 9.	2 ft.	3 ft.	4 ft.	9 ft. bot.
At $11^h.7$,	1·004	1·004	1·006	1·014	1·022	1·024	1·024	...	1·0255	1·026	...	...
At $11^h.20$,	1·004	1·006	1·007	1·011	1·0145	1·017	1·017	1·022	1·024	1·025	...	...
At $12^h.0$	1·001	1·004	...	...	1·013	...	...	...	...	...	...	...

These figures are represented by curves in Plate XIII. fig. 3, and by colours in Plate XIV. fig. 3.

IV*a*. *High Water and Ebb Tide.*—In the backwater near its entrance, where we were driven by the gale, the wind that was blowing *down* the river was blowing *up* (see the arrows in fig. 1, p. 463). There the following observations were made :—

	Surf.	1 ft.	2 ft.	2 ft. 3.	2 ft. 6.	2 ft. 9.	3 ft.	3 ft. 3.	3 ft. 6.	3 ft. 9.	4 ft.	5 ft. 6. bot.
From $12^h.25$	1·003	1·004	1·005	1·005	1·004	1·004	1·013	...	...	...	...	1·025
to $12^h.40$,	...	...	...	...	...	...	1·005	1·016	1·021	1·023	...	...
At $13^h.25$,	1·000	1·002	1·0025	...	...	...	1·003	...	...	...	1·011	1·014
At $13^h.35$,	...	...	...	...	...	...	...	1·004	1·004	1·005	...	1·005

This shows how the salinity increased until close upon high water, and how it then suddenly vanished. The curves of density are given in Plate XIII. fig. 4, and the diagram of salinity in Plate XIV. fig. 4.

V. *Ebbing Tide.*—August 7, observations at $12^h.15$; high-water $9^h.28$. Depth 6 feet. Weather calm, thick mist; surface temperature 58°·0.

The bottom water had a density of 1·014, and on our taking samples at every foot from the surface downwards immediately after this observation, the density was found only to increase from 1·000 to 1·004. The withdrawal of the last of the sea water in a thin layer was observed in this case.

VI. *Ebbing Tide.*—August 8, observations from $10^h.40$ to $12^h.0$; high water $10^h.59$. Depth diminishing from 9 feet to 7 feet. Surface temperature 58°·0.

	Surf.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	6 ft. 3.	6 ft. 6.	6 ft. 9.	7 ft.	8 ft.	9 ft.
$10^h.40$ to $11^h.20$,	1·001	1·001	1·001	1·001	1·003	1·003	1·011	...	...	...	1·013	1·015	1·018
$11^h.25$ to $11^h.45$,	1·0005	...	...	...	1·001	1·0015	1·002	1·003	1·006	1·007	1·011	1·018	...
$11^h.45$ to $12^h.0$,*	1·000	...	...	...	1·0015	1·0015	1·004	...	...	...	1·009	...	...

At $12^h.0$ the density at the bottom was 1·0035.

VII. *Ebbing Tide*—August 21, observations from $10^h.30$ to $11^h.40$; high water at $9^h.18$. River much in its former conditions. Depth, 8 to 7 feet. Surface temperature 55°·8. All the observations made from the bottom upwards.

	Surf.	3 ft. 6.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.
From $10^h.30$ to $10^h.40$ . . .	...	1·001	1·001	...	1·006	1·017	1·023
„ $10^h.45$ to $10^h.50$ . . .	...	...	...	...	1·007	1·017	1·023
„ $11^h.0$ to $11^h.5$ . . .	...	...	...	1·001	1·017	1·020	...
„ $11^h.30$ to $11^h.40$ . . .	...	1·0005	1·0005	1·0005	1·018	...	...

The density observed in this set of experiments is plotted in Plate XIII. fig. 5, and the salinity is shown in Plate XIV. fig. 5.

Tidal Variations of Salinity at the River Mouth.

Taking the observations of No. III. at $16^h.55$ as typical of the state of matters in the river at half flood, we may represent in the following table (Table I.) the calculated amount of salt present, and the ratio of sea to river water at each point.

Table II. shows the same particulars for a typical case of the ebb tide, that recorded in No. VII., $11^h.0$.

* From the bottom upwards.

Table I.

Depth in feet.	Density.	Percentage of Salts Present.	Percentage of Fresh Water Present.	Percentage of Sea Water Present.
0	1·001	0·09	99	1
1	1·002	0·45	92	8
2	1·004	0·62	84	16
3	1·014	1·96	44	56
4	1·016	2·22	36	64
5	1·023	3·10	8	92
6	1·023	3·10	8	92
7	1·023	3·10	8	92

Table II.

Depth in feet.	Density.	Percentage of Salts Present.	Percentage of Fresh Water Present.	Percentage of Sea Water Present.
0	1·001	0·09	99	1
1	1·001	0·09	99	1
2	1·001	0·09	99	1
3	1·001	0·09	99	1
4	1·001	0·09	99	1
5	1·001	0·09	99	1
6	1·017	2·34	33	67
7	1·020	2·72	20	80

In the coloured diagrams (Plate XIV.) the shades represent roughly the quantity of dissolved salts at each depth as deduced by calculation on the assumptions—which are accurate enough for the purpose of diagrammatic representation—that the indications of the rough hydrometer are correct, and that brackish water is ocean water diluted with pure water.

If in a river running directly into salt water the channel should gradually deepen as it enters the sea, so that there should be no obstacle to the entrance of salt water as the tide rose, and if at the same time it were so narrow as not to be in any sense an inlet of the sea, the conditions in it would be truly comparable with those of a river gradually merging into a firth. This is never the case so far as we have been able to ascertain, as a bar exists at the mouth of all rivers. As a consequence, the sea water enters by first rising to the level of the top of the obstacle, and then pouring down on the other side through the fresh water, and so produces a large volume of brackish or not fully salt water inside the bar.

The action of the breakers over the bar or in the shoal water outside serves still more to effect mixture. Were it not for the great rapidity and volume of the Spey, the tide would probably produce a uniform brackish mixture at the mouth of the river, and a much less marked series of salinity strata farther up, than those that were observed.

The data already given represent the actual manner in which the salt or slightly freshened sea water fights its way up the bottom of the river from the sea, while the fresh river water runs down above. The greatest distance up the stream to which salt water penetrated on the bottom was not satisfactorily determined, but it was certainly less than half a mile. At high tide a very thin layer of salt water was found at the bottom in a deep hole close to the west bank of the river about a quarter of a mile from the mouth. On the east side the shallow backwater (fig. 1) was found on a calm still day to be filled with perceptibly brackish water at two hours' ebb, the fresh upper water having evidently run off most quickly. On another occasion, when there was a gale blowing the fresh surface water into the backwater, the salt layer flowed out from the bottom during the first half-hour of ebb (Plate XIII. fig. 4, and Plate XIV. fig. 4). In this case the pressure of the accumulated water at the upper end of the *cul-de-sac* evidently set up a reaction current outwards, thus reversing the ordinary mode of emptying.

In the open river the sea water appears always to flow and ebb under the fresh water; but some shipmasters, who know the Spey well, told us that at the ebb the river often "ran salt" for a considerable time, the fresh upper water flowing away first; no such phenomenon was presented, according to them, on the flood tide. We looked specially for this effect, but did not observe it.

On one occasion, August 11, two hours before high water, the density from the bottom up to 2 feet from the surface was that of sea water (over 1·024), and the river was brackish even at 6 inches from the surface. A strong wind was driving the river water out to sea on this occasion, and so stripping off the usual layer of fresh water. On another day, August 8, when the ebb was unusually rapid, there was a depth of 6 feet of perfectly fresh water half-an-hour after high tide.

The salinity at any depth during flood or ebb tide is influenced by a number of conditions, such as the density of the sea water coming in, the rate of the out-going current, the height of the tide, the wind, and other variable factors. Supposing, to take the normal conditions, that just outside Spey bar, where the depth is about 1 fathom, the lower $\frac{3}{4}$ fathom has a density of 1·0250 at

60° F., the time being that of low water on a calm day without wind. The river is flowing out by a narrow channel about two feet deep over the bar. The tide gradually rises, and opposes an increasing resistance to the outflowing current, the salt water rises over the bar and creeps up the bottom of the channel, raising the level and so gradually widening the opening by covering sand-banks. At about quarter flood the river begins to rise near the mouth from the damming back of the fresh water, then suddenly (see observations III. on p. 466) a thin wedge of brackish water is found inserting itself between the bottom and the fresh water; a few minutes later there is a layer of salt water a foot deep topped by an equal stratum of brackish, and as time proceeds the salinity at the bottom remains constant, but extends higher, and passes through a brackish zone into the river water, about a foot or eighteen inches of which remains hardly touched by salt, or even quite fresh, and flows out to sea slowly, tearing itself across the layers of denser water flowing at a lower level more slowly but resistlessly upwards. About an hour before full tide there is a state of balance; the wedge of salt water has pushed its brackish edge to the highest point, and the enfeebled force of the tide only suffices to hold back the dammed up water above. This continues for some time; then there is a turn, the salt wedge is forced slowly out, the dammed back water rushes down unchecked, keeping up the level of the river near the mouth for some time, while the salt and finally brackish water withdraws along the bottom; and by half ebb the river down to the bar is entirely fresh, and rapidly returning to its low-water level.

The diagrams on Plate XIV. may be explained on the supposition that water containing less than 0·5 per cent. of salts in solution may be considered *fresh*, while when the percentage of salt is greater, but does not exceed 2 per cent., it is *brackish*, and when more than 2 per cent. of salt is present it is thoroughly *salt*. In order to be truly representative, the shades of colour in these figures should have the margins blended, but reference to the curves (Plate XIII.) will show that if the abrupt transitions did not take place at points corresponding to 0·5 and 2 per cent. of salt respectively, they did take place very near those positions. The diagrams show how with the rising tide the layers of "fresh" and "brackish" water remain of nearly equal depth, while the "salt" water below increases from a mere film on the bottom until it fills more than half of the river bed at the point of observation. The interface between the fresh and salt water is much sharper at some times than at others. We were anxious to find the direction of the plane of contact when it was clearly marked, and to see how it varied at different places, but to make an attempt of this kind a number of observers working simultaneously would be required, and these we could not command.

The theory to which our observations have given rise regarding the mixture of salt and fresh water inside the bar is one which, although not proved, seems to be at least probably true. It is that the fresh water running down the inclined bed of the river meets the wedge of salt water pushing its way up and acting in virtue of its superior density as a sort of soft false bottom sloping in the the opposite direction to the inclination of the river bed. The lower layers of the fresh water have now to run along a level surface or even to force their way up-hill, but in doing so the friction between the two tears off thin streams of salt water, and mixes it with the fresh to form the brackish layer. This is represented diagrammatically in Plate XV. fig. 1. The part that diffusion plays in causing mixture is probably a small one, but it must be increased by the gouging action of the rapid rush of fresh water on the slow push of the salt wedge.*

Observations on Salinity in Spey Bay.

The work outside the river was seriously hampered in consequence of Spey bar being impassable during the least swell, and of the dependent fact that there are no fishing boats at Garmouth or Kingston. Once we went out in a little open boat, and on two occasions in a half-decked yawl from Port Gordon. The rest of the time devoted to outside work was spent on the shore taking samples of water in the surf, westward and eastward, from the

* Since writing the above our attention has been directed to a paper by M. Adolphe Guèrard, of Marseilles, read this summer (1885) and printed in vol. lxxxii. of the *Minutes of Proceedings Inst. C.E.*, pp. 305–336, in which he employs (p. 334) almost identical expressions to describe the manner in which a tidal river is affected by the sea. His treatment of the subject is entirely from the engineer's point of view.

river mouth at regular intervals for several miles. The results of this method are made uncertain by the fact—which we in part verified after it was reported to us—that much of the Spey water reaches the sea by filtering through the enormous shingle banks, and so trickling down almost imperceptibly, but still exerting a distinct freshening influence along the shore line.

VIII. The first trip of about 3 miles straight out from the Spey was made on 30th July, from about 1 hour before high water to three quarters of an hour after it.

		Outside Bar.	1 mile out.	2 miles out.	3 miles out.	¾ mile out.	¼ mile out.	Bar.
Position,		Outside Bar.	1 mile out.	2 miles out.	3 miles out.	¾ mile out.	¼ mile out.	Bar.
Depth,		2 fm.	...	6 fm.	10 fm.	...	...	...
Temperature,	Surface,	59·0	58·0	58·0	58·0	58·2	64·0	65·0
	Bottom,	56·5	...	53·7	52·8	...	...	...
Density,	Surface,	1·01109	1·02546	1·02497	1·02557	1·02534	1·01339	1·00065
	Bottom,	1·02527	...	1·02587	1·02598	...	...	...

IX*a*. On 10th August, when the river was very low, a trip was made from Port Gordon, and samples were collected on the outward voyage at regular intervals along the circumference of a circle of 3 miles radius, with the mouth of the river as a centre. It was impossible to get the compass placed high enough to enable us to take bearings accurately, so the positions were only approximately determined. The weather was on the whole bright, with occasional showers. There was a stiff breeze from the south-south-west, which became very squally towards afternoon. The five sets of observations made from $9^h.30$ to $12^h.30$, when it was high water, are as follows:—

Position and Depth,		Off Port Gordon. I. 3 fm.	II. 8 fm.	Opposite the Spey. III. 10 fm.	IV. 10 fm.	Near Boar's Head Rock. V. 5 fm.
Temperature,	Surface,	56·6	56·5	56·9	56·8	56·2
	Half depth,	...	56·3	57·6	...	56·1
	Bottom,	56·4	55·3	53·2	53·3	56·0
Density	Surface,	1·02562	1·02554	1·02539	1·02536	1·02576
	Half depth,	...	1·02564	1·02549	1·02531	1·02564
	Bottom,	1·02564	1·02569	1·02584	1·02577	1·02579

On returning nearer land the surface density at Station IV. was 1·02572, and further in-shore it was 1·02376.

IX*b*. When opposite Tugnet (on the east side of the river) the density was observed by the small hydrometer at intervals of a minute while sailing west about a quarter of a mile off-shore until opposite Kingston. Tide 2 hours ebb.

Off Tugnet, $14^h.18$.				Off the Spey.		Off Kingston, $14^h.25$.	
1·028	1·018	1·014	1·015	1·010	1·010	1·020	1·026.

Off the mouth of Spey in 2 fms. the density at the surface was 1·01051, at 3 feet deep 1·02448, and at the bottom 1·02509. At $15^h.15$ the density at Station II. was 1·02551 at the surface and 1·02557 at the bottom in 6 fathoms.

X*a*. Another trip from Port Gordon was made on 18th August, between $10^h.50$ and $16^h.40$. The river, which had come down in heavy spate on the 13th, was still unusually full. The weather was bright and warm, the wind very light, and a considerable swell was coming in from the north-east. The wind was dead on land, and too light for the boat to sail up to, consequently we had to keep near the shore, about half a mile out, while going westward, until off the Spey. The water was swarming with medusæ of all sizes and colours. The following observations were made in the course of the day, the densities being determined on shore by the delicate hydrometer, and reduced by calculation to 15°·56 C.:—

Position.		Off Buckie.	Off Port Gordon.	Halfway to Spey.	Off Spey Bar.		Between Spey and Port Gordon.	
					½ mile out.	¼ mile out.		
Hour and tide, . . .		$10^h.50$. 5 hrs. ebb.	$11^h.45$. l.w.	12^h42. ½ hr. fld.	$13^h.50$. 1¾ hr. fld.	$14^h.15$. 2 hrs. fld.	$15^h.15$. 3 hrs. fld.	$15^h.55$. 3¾ hrs. fld.
Depth, ...		8 fm.	6½ fm.	5 fm.	4½ fm.	4 fm.	7 fm.	5 fm.
Temperature,	Surface, .	54·9	55·1	56·2	57·1	56·1	57·7	57·1
	Half-depth,	55·2	55·2	55·9	55·6	...	55·6	55·7
	Bottom .	53·8	55·2	55·3	55·2	...	55·0	55·3
Density,	Surface, .	1·02285	1·02383	1·02445	1·01227	1·02435	1·02267	1·02328
	Half-depth,	1·02548	1·02554	1·02403	1·02535	1·02525	1·02555	1·02538
	Bottom .	1·02318	1·02562	1·02544	1·02536	1·02545	1·02554	1·02540

Quarter of a mile off Port Gordon the surface density was 1·02164, and at the harbour mouth 1·02140.

X*b*. When we were in the neighbourhood of the mouth of the river, a great many observations were made with the small hydrometer. The high density of the sample of water taken home from near the river mouth (1·02435 at the surface) must be explained by the boat's drifting a little to the east of the fresh current before the sample was bottled, for while coming straight in steering for the bar from the previous position, the readings of the small hydrometer were—

1·013, 1·015, 1·012, 1·0125, 1·0125, 1·010, 1·0085, 1·0085.

Returning from that position, and steering N. by W., in the direction of the axis of the river, we found the density to vary as follows:—

1·026, 1·022, 1·020, 1·018, 1·0185, 1·019, 1·0195,
1·020, 1·021, 1·023, 1·0235, 1·0245, 1·0245, 1·025.

The temperature steadily rose from 57·3 until at the point where the density was 1·021 it was 57°·8; it then fell gradually to 57°·1 at the point where the density was 1·025, about $1\frac{1}{2}$ mile off-shore.

X*c*. From that position we steered SE. by E. straight for Port Gordon until about 1 mile from the harbour. The temperature rose steadily from 57·1 to 58·2, and the density varied as follows:—

1·026,	1·0265,	1·026,	1·0255,	1·025,	1·025,	1·0245,
1·024,	1·024,	1·023,	1·023,	1·022,	1·022,	1·021,
1·020,	1·0205,	1·0215,	1·022,	1·025,	1·024.	

The approximate distribution of salinity is shown in Pl. XV. fig. 2.

XI. On August 26, at $8^h.15$, by the kindness of Captain Linklater of the "St Clair," a sample of surface water was taken in the centre of the Moray Firth between Aberdeen and Wick. The weather was bright, with an easterly swell. The temperature of the water was 52°·7, and the density, afterwards determined, as 1·02612. Another sample was taken on September 18, at $10^h.30$ when off Stonehaven, about 2 miles from shore; the weather was bright and clear, the sea calm, air temperature 55°·4, and that of surface water 54°·5. The density was found to be 1·02592.

Salinity of the Sea Margin.

Observations were made on several occasions along the shore at regular intervals. The density was observed by means of the small hydrometer, the samples of water being collected in the surf by wading as far out as circumstances would permit.

XII*a*. On August 15 the river, which had been in high flood on the 13th and 14th, had subsided considerably, but was still flooded. A swell coming in, caused a heavy surf. Samples were taken every $\frac{1}{4}$ mile from a position $1\frac{1}{4}$ mile east of the river mouth, westwards to the river; time, from $10^h.45$ to $12^h.20$. High water, $16^h.27$.

1·026(58°·0), —(58°·0), —(56°·5), 1·021(56°·2), 1·021(56°·0), —(56°·3).

XII*b*. August 16. From $15^h.30$ to $16^h.25$ (high water) the following observations were made at the same places:—

1·026(56°·9), 1·0245(57°·2), 1·024(57°·6), 1·021(58°·0), 1·0245(57°·2), —(—).

XIII*a*. August 17. From Port Gordon, $2\frac{1}{2}$ miles east, to mouth of Spey. High water, $17^h.20$. Observations every $\frac{1}{4}$ mile.

From $1\frac{1}{2}$ miles east of Spey to Port Gordon, $11^h.35$ to $12^h.20$.

1·020(56°·7), 1·023(56°·2), 1·0225(57°·0), 1·026(59°·3).

$1\frac{1}{2}$ mile east of Spey to river mouth, $13^h.10$ to $14^h.25$.

—(58°·0), 1·020(57°·8), 1·0215(57°·3), 1·022(57°·0), 1·023(56°·8), 1·023(56°·5) —(57°·02).

From $1\frac{1}{4}$ mile east to $1\frac{3}{4}$ mile east. $16^h.50$ to $17^h.10$.

1·0225(56°·3), 1·0215(56°·5), 1·022(56°·6).

From 1 mile east westward to river mouth, $17^h.25$ to $18^h.0$.

1·024(56°·2), 1·025(56°·1), 1·024(56°·0), 1·024(56°·0), 1·018(55°·8), 1·014(56°·1).

XIII*b*. Near the mouth of the river on the west side density at $20^h.0$ was 1·014, and $\frac{1}{4}$ mile west from it 1·027.

On 19th August a large number of observations was made on the shore to the west and to the east of the river:—

XIV*a*. High water at $7^h.0$. On the west shore observations were made on the sand-bank at the mouth of the river, which was just uncovered at $10^h.2$. On the south (riverward) side of it the temperature of the water was 56°·3, and the density 1·004; on the north or seaward side the temperature was 55°·6, and density 1·023. Passing up the river we found the water to become perfectly fresh within 200 yards of the bar.

Temperature and density were observed along the shore for about $1\frac{3}{4}$ mile to the west, both going and returning at the same points. This occupied from $10^h.30$ to $11^h.42$ in going, and from $12^h.10$ to $12^h.55$ coming back. Observations from the river mouth made every 200 yards westward:—

	1	2	3	4	5
Going,	1·0225(55°·7)	1·022(56°·0)	1·021(55°·7)	1·023(56°·0)	1·023(56°·0)
Returning,	1·022(56°·3)	...	1·0225(57°·0)	1·023(56°·4)	1·023(56°·3)

Then at distances of 400 yards—

	6	7	8	9	10
Going,	1·022(56°·0)	1·023(56°·0)	1·0235(56°·0)	1·023(55°·9)	1·023(55°·9)
Returning,	...	1·0235(56°·3)	1·0225(56°·0)	1·023(56°·0)	1·024(56°·3).

XIV*b*. On the east side observations were made eastward from the river mouth for about 2 miles, the time occupied being from $14^h.15$ to $16^h.16$. High water at $19^h.40$.

At intervals of 100 yards from the river mouth—

1·002(58°·5), 1·004(58°·2), 1·005(59°·3), 1·006(59°·3), 1·004(58°·5), 1·015(57°·3), 1·014(57°·2), 1·015(57°·0), 1·017(56°·7).

Then at points 200 yards apart—

1·020(56°·8), 1·021(56°·8),

and at intervals of 400 yards—

1·0205(57°·0), 1·021(57°·3), 1·020(57°·6), 1·020(57°·8), 1·021(58°·0), 1·019(58°·7).

XV. On 20th August observations made at Portessie, 6 miles east from the Spey, showed at $9^h.50$ a density of 1·026, at $11^h.5$ of 1·026, and at $18^h.15$ of 1·027.

The Salinity of Spey Bay.

The mean density at 15°·56 C. of the bottom water in Spey Bay was found to be 1·02567. It varied in twelve cases from 1·02540 to 1·02598, while the surface water varied in density from 1·02000 to 1·02576. The observations made seem to warrant the conclusion that the water is, as a whole, of a density slightly greater than 1·02550 in Spey Bay, and considerably greater in the centre of the Moray Firth. Whether the slight reduction in density is due to the action of the Spey water, or to the vicinity of the Cromarty and Inverness Firths, can hardly be said, and it is unimportant in connection with the immediate subject of which we treat.

The Spey water runs rapidly out of its comparatively shallow channel: at low tide, partly on account of its shallowness, and at high tide, partly on account of the bar, it flows across the surface of the sea water in a thin stream, freshening to a marked extent only the upper few feet, and spreading out laterally in the form of a fan. The exact shape and direction of this expansion are dependent on the volume of the river, on the state of the tide, on the conformation of the mouth, which is subject to incessant change, and on the direction of the wind. The usual trend of the river current in the bay appears to be north-easterly.

The observations VIII. (p. 472) show that when the boat sailed due north, the density at $\frac{3}{4}$ mile from the river mouth was 1·02557 on the surface, strong sea water; while those under IX*a*., with the river in the same state as regards flood, show no clear indication of the course of the stream on the circumference of a circle 3 miles in radius described from the mouth of the Spey. The pocket hydrometer readings, IX*b*., show that when $\frac{1}{4}$ mile off shore the stream was clearly defined, its margin shading off gradually on the eastern side and abruptly on the western, where the transition from brackish to salt water was very sharp. The stiff breeze which was blowing from the S.S.W. would help to carry the stream to the N.N.E., and it might have been narrow enough to pass between two of the observing points and so elude detection.

The observations X*a*. show an entirely different set of conditions. The river was partially flooded, and the wind had been easterly for some days, thereby probably keeping the freshened surface water from spreading to the eastward. The result was that, within a mile of the shore there was an area, the surface density of which varied from 1·012 to 1·024, the bottom water being scarcely below the normal (about 1·0256). The observations, X*b*. and X*c*., with the small hydrometer, show how the density increased steadily in a northerly direction from the river until the water was quite salt on the surface, and how, when the boat was turned towards Port Gordon, the salinity at first increased and then diminished as the fresh current sweeping to the eastward against the flood tide was entered on. The diagram, Plate XV. fig. 2, gives an idea of the manner in which these, combined with numerous other observations not recorded in detail, indicate the direction in which the river runs through the bay. The colouring shows the difference between the salt and brackish surface water, the former being represented by the darker shade. Density by the small hydrometer is marked at intervals along the course of the boat.

It is evident, from the numerous observations of density made along the beach by means of the small hydrometer, that the shore water is much fresher on the east than on the west side of the river, and that on going eastward from the river the observer finds the density increase to a certain point (XIII*a*.), and then diminish, as if the current at first swept out to sea, and then curved back along the shore. This is indicated in a general manner in the diagram referred to above. The series XIV*a*. and XIV*b*. show the greater freshness on the east side very clearly, although on the day when those observations were made the salinity on the west side was considerably less than usual. The generally-accepted fact, which we in part verified, that much of the Spey water finds its way to the sea by percolating through the shingle, may account for the uniformly low density along the shore.

The phenomenon of percolation is presented on the small scale by the Tynet burn, near Port Gordon (Plate XV. fig. 2). It is a small stream flowing into a long, narrow deep pool without an outlet, one side of which is a shingle bank, sloping down to the sand. Its length is parallel to the shore line, and nearly at right angles to the course of the burn. Although there is no apparent outlet, close examination shows that an immense number of trickling streamlets, varying in breadth from half an inch to about a foot, and in depth from that of a mere film to several inches, escape all along the lower margin of the bank, and meander across the sand to the sea, the edge of which is perceptibly freshened by this means. The condition of outflow is represented in the diagram, Plate XV. fig. 4, fresh water by a red, sea water by a blue colour.

The variation of salinity with depth throughout Spey Bay depends almost entirely on the amount of flood in the river, and on the direction in which it runs. On August 10, when the river was low, and the boat in cruising about the bay did not encounter any freshened surface water, there was, as a rule, a uniform and slight increase of density with depth; while on August 18, when the river was flooded and the surface water of a great part of the bay comparatively fresh, the bottom and half-depth densities remained as before, and the surface was greatly freshened, although to a slight depth. One or two cases were observed where the water from half the depth was denser than that from the bottom, and one in which it was less dense than at the surface. These differences may be due to irregular and incomplete mixing of river and sea water.

The course of the fresh water stream through the bay is beautifully seen during a flood. Fishermen told us that when a heavy spate occurred with a southerly gale they have seen the coloured water running due north in a wide stream, but that it usually runs towards the east.

A great spate occurred on the night of August 12, the largest, according to the ferryman at Garmouth, for over fifteen years. The average state of the water during our stay had been lower than it had almost ever been observed before. On the morning of the 12th the river was low, and the water very clear and perfectly colourless. At $17^h.30$ the water had a clear amber colour, was very slightly increased in volume, and had the temperature $50°\cdot0$. Next morning (August 13) the river was a broad sheet of leaping yellow waves, sweeping from bank to bank, and carrying down planks, salmon boxes, and potatoes, a field of which had been flooded and destroyed some miles up the river. As the current crashed round the shingle heaps with tremendous velocity great slices of the bank, from a few inches to more than a foot thick, 8 to 10 feet high, and many yards long, were undermined, and rushed down into the stream with a hoarse rattle. From the rate at which these banks were carried away it could be easily understood how the sea in the neighbourhood of the mouth is constantly shoaling. In the forenoon, with the tide at half-flood, and a gale blowing from the north-west, the whole bay was bordered by a broad band of surf; the waves first breaking more than a quarter of a mile from shore, re-formed in the foam to break and form again over and over before the final dash upon the shingle. As far as vision extended the sea, reflecting the intense blue of the sky, was tasselled with feathery jets of foam, shooting up with constant change of form and position all over its surface; and across it, as if drawn by a brush dipped in brown paint, lay the turbid stream of the river, disappearing towards the north-east. It was seen in the afternoon quite distinguishable from the rest of the water at Portessie, 6 miles away, where it hugged the shore, but not so closely as to prevent a belt of clear water lying within it. Where the line of breakers crossed the river mouth, the white colour of the waves gave place to yellow. As the river shot out the clear ripples of the sea waves ran up from the north-west, struck the rapid-running stream of muddy fresh water, and seemed to recoil as if from a solid obstacle: the whole stream was bent abruptly towards the east, no discoloration of the water being perceptible to the west of the river mouth. The diagram (Plate XV. fig. 3), where the sea water is shown in blue and the river water in brown, shows the manner in which the stream curved, and hardly exaggerates the contrast of colour it presented. The temperature of the river near the mouth was 48°·3, a fall of 6°·9 from the previous afternoon; that of the surf at the river mouth was 51·5, and a quarter of a mile west it was 55°·0. It was matter of extreme regret that no observation could be make on the bay or on the east side of the river, but no boat could face the weather. The roar of wind and thunder of surf, the rattle of the pebbles along the shore, and the periodical crash of the bank into the stream, were sometimes almost drowned by the sound of an impetuous hail-shower, which one moment was tearing up the sand and gravel, and the next sweeping over the country, followed by magnificent sunshine.

Alkalinity.

We intended to observe the alkalinity of numerous samples of sea and river water, and for this purpose we had procured the necessary standard solutions from Professor Dittmar. Practical difficulties prevented the carrying out of this plan, and few determinations were made. It is advisable to mention the results obtained (Table III.), meagre though they be. The only conclusions we can draw from the consideration of them, and these we present with some diffidence, are—

1. The alkalinity (which is a measure of the potential carbonate of lime present) is less, for waters of the same density, than in the Firth of Forth.

2. In water taken on different occasions from the same position the alkalinity is *not* proportional to the density, but appears to be liable to variation.

3. There are indications that the alkalinity of the water in Spey Bay is, for the same density, greater to the east of the river mouth—that is, in the direction of the fresh current. This may be due to the carbonate of lime carried down in solution by the fresh water.

4. There are no distinct indications of a uniform change of alkalinity with depth, although surface water is more alkaline than that at the bottom, even when the density of the former is less.

In Table III. *alkalinity* is represented by the number of milligrammes of carbonic acid (CO_2) existing in normal carbonates ($R''CO_3$) in one litre of water. Thus, if a sample had alkalinity 50·00, it contained 50 milligrammes of carbonic acid in combination with lime or with some other base, equivalent to 113·7 milligrammes of normal calcium carbonate ($CaCO_3$).

Temperature of the Water.

The temperature of the water in the bay was lower than in the river. The water at the bottom was colder than at the surface, the difference being about 3°, where the depth was 10 fathoms. Full particulars of the observations are given under VIII., IX*a*., X., XI., and of those along the shore under XII., XIII., XIV.

The temperature of the river was observed once or twice daily

TABLE III.—*Alkalinity of Water in Spey Bay.*

Date.	Position.	Depth.	Position of Sample.	Density at 15°·56.	Alkalinity. I.	II.	III.	Mean.
1.8.85	Inside Spey Bar,	$1\frac{1}{2}$ fm.	S.	1·00108	13·04	13·40	...	13·22
17.8.85	Shore at Port Gordon,	...	S.	1·02368	46·84	...	...	...
30.7.85	1 mile off Spey mouth,	...	S.	1·02546	47·40	48·16	49·80	48·45
10.8.85	West of Kingston, near shore,	...	S.	1·02576	48·48	48·52	...	48·50
10.8.85	Spey Bay,	8 fm.	4 fm.	1·02564	49·44	...	...	...
30.7.85	3 miles off mouth of Spey,	10 fm.	B.	1·02598	50·40	50·40	50·20	50·33
10.8.85	3 miles off shore, E. of river,	"	5 fm.	1·02531	50·48	50·24	...	50·36
10.8.85	" "	"	B.	1·02577	51·24	51·00	...	51·12
10.8.85	" "	"	S.	1·02536	52·04	52·00	...	52·02

TABLE IV.—*Temperature of River Water.*

Date,	July 30	31	August 1	3	5	6	7	8	11	12	13	14	15	17	19	21	24
Forenoon observation,	62·3	62·0	62·3	59·0	56·2	57·3	57·3	58·0	57·2	...	48·3	...	53·0	55·2	...	55·8	56·7
Afternoon observation,	66·0	66·5	63·0	60·0	57·2	...	58·0	...	...	55·0	...	52·8	57·0	...	58·9	...	...
Range,	3·7	4·5	0·7	1·0	1·0	...	0·7	...	...	...	...	...	4·0	...	...	...	...

when it was possible for this to be done. Table IV. shows the result of the observations, which are unfortunately very fragmentary. The rise of temperature between the hours 10 and 18 was found to be about 2° as an average. For the month the variation may be described as a gradual fall of temperature with a sudden depression on the 13th—the day of heavy spate already alluded to—from which there was a partial recovery.

Conclusion.

The importance to engineers of a knowledge of the relationship between salt and fresh water at the mouths of rivers is generally allowed; and much information regarding the variations of salinity in estuaries with tide and depth doubtless exists in the note-books of marine surveyors, but so far as we know, no definite investigation of the matter has been published. Since our work was done without knowing the volume and velocity of the fresh water stream, there is a want of that quantitative element which gives precision to an engineering survey. The two objects are, in fact, distinct; but so much can be done by each, that it would form a definite advance in our knowledge of the circulation of water in the world if a conjoint study of the physical properties of a series of typical rivers and firths could be made simultaneously by a chemist and engineer, somewhat on the lines of Mr R. W. Peregrine Birch's work on the Thames,* but in a more complete and satisfactory manner.

A quantitative analysis of the soluble mineral constituents in the Spey river water is at present being carried out by one of us, with the view of ascertaining the influence of the river water on the ratio to each other of the principal components of the salt in the sea water near the estuary.

Our work on the Spey corroborates the observations of engineers on the water at the mouth of tidal rivers, and shows more precisely than has to our knowledge previously been done, in this country at least, how sea and river water meet and mingle. We are also able to divide river estuaries into at least three classes, the conditions of all these being perfectly distinct.

* *Min. Proc. Inst. C.E.*, lxxviii. 212, and lxxxi. 295.

1. *Rivers without Firths*, such as the Spey.—In such rivers the water inside the bar is entirely fresh during the greater part of ebb-tide, since all the sea water which forces its way up the short estuary during flood-tide runs out again along the bottom, and does not at any time render the surface layers brackish. The fresh water, running out at all states of the tide, spreads over the surface of the sea, and persists in a thin layer or in patches to a considerable distance, overlying water of uniformly high salinity. The conditions as to temperature are not fully known, but except during certain periods in spring and autumn, the river water is either much warmer or much colder than that of the sea.

2. *Rivers with narrow, shallow Firths*, such as the Tay.—The bar lies out at sea, where the water is always salt. The tide exerts a great influence throughout the estuary, the sea water being only partly withdrawn by the ebb; and the currents, setting up and down with great velocity, effect a tumultuous though transitory mixing of the water. During ebb-tide the water inside the bar is comparatively fresh at the surface, and the ridge it has to pass over in reaching the sea directs it out over the surface of the salt water in a brackish layer, like a river of the first class. The temperature relations are not well known, but appear to be similar to those of estuaries of the third class. The range is, however, greater, and variations more irregular.

3. *Rivers with wide and deep Firths*, such as the Forth.—Here the sea water is never withdrawn from the estuary by the tide, and the tidal currents are less rapid than in rivers of the second class. The landward portion (the "river proper compartment" of engineers) is comparable to a river of the first class, but the conditions are much less distinctly defined. Further seaward comes a division (the "tidal compartment") resembling an estuary of the second class, without a bar, but exhibiting all its other characteristics in a modified degree. Finally, nearest the sea, and comprising most of the firth, there is the region specially characteristic of this kind of river entrance. The difference of density between surface and bottom is slight, and it is scarcely affected by the tides; the water throughout its whole mass is slightly freshened, and so meets the true sea water beyond as a great wall of only slightly reduced salinity. The curve representing the salinity of the surface water is

very nearly constant; floods affect it slightly, but uniformly. It shows that in the "river proper" and "tidal" compartments there is rapid increase of density per mile of length, and much influence by tide; while, as the firth is entered on, the increase of density per mile becomes less and less, and the tidal disturbance vanishes.

The temperature rises steadily from the river out to sea in winter, and the bottom water is warmer than that at the surface; in summer the temperature rises from the sea towards the river, and the surface water is warmer than that below. The annual range of temperature in the water is greater the further up the river observations are made, but the mean temperature appears to be nearly the same everywhere.

Summary.

The Spey, the most rapid river in Britain, is 120 miles long, and drains 1245 square miles. It flows into the Moray Firth—a bight of the North Sea—at Garmouth; the river entrance is shallow, and subject to change of form and position by shifting banks.

Observations on the effect of tide on the mixing of sea and river water inside the bar are described. The exact vertical distribution of salinity was investigated by means of the hydrometer at intervals during the rise and fall of the tide, and the results are embodied in tables, diagrams, and curves. They show that the sea water slowly forces its way like a wedge between the river water and the bottom as the tide rises, and dams back the water further up stream; while the surface water always remains quite fresh, and a brackish zone separates the two strata. When the ebb sets in the salt water runs out very rapidily, and before half-ebb there is only fresh water inside the bar.

The salinity of the water in Spey Bay was studied during short trips in fishing-boats from Garmouth and Port Gordon, and by observations made along the shore. These are fully recorded. The bottom water of the bay was found to be of the density 1·02567 on an average; the surface water varied much in density; and the river's course could be traced as a stream sweeping to the north-east. The western margin of this stream was sharply defined; on the east no abrupt change can be found, the river water gradually merging into the sea. During a spate the discoloration of the river water

enables its progress through the Firth to be traced as a dark band to a distance of more than 6 miles. The shore water appears to be freshened by water percolating through the shingle beaches from the river.

Alkalinity and temperature observations are described and discussed.

In conclusion, a classification of river entrances into three groups is put forward tentatively. The Spey typifies a large river entering a tidal sea directly across a bar; the Tay, a large river, entering by a short, narrow, shallow, barred estuary; and the Forth, a small river, merging into a long, wide, deep, and open firth.

7. The Distribution and Significance of Micro-Organisms in Water. By A. Wynter Blyth.

The results of more than a year's study of the distribution of micro-organisms, that is, bacteria and fungi in water, are I think of sufficient interest to justify a short communication.

Methods.—The micro-organisms in water being for the most part in the form of isolated spores or seeds so small as to be practically invisible, the first step was to make them visible by "cultivation." This cultivation took place in nutrient gelatin, according to principles too well known to require description. I will, therefore, confine my remarks merely to the details of certain special modifications of the ordinary process which I adopt.

The cultivation takes place on glass plates 4 inches × 4 inches; on to these plates are cemented glass rings $\frac{1}{4}$ inch broad, $\frac{1}{4}$ inch deep, and 3·8 inches in diameter, thus forming large shallow cells. The method of cementing the rings on to the plates is novel; both are sterilised at a high temperature in a hot-air oven, and while still hot drops of the nutrient gelatin are placed on the ground surface of the ring, the ring is then applied to the plate, rotated, and put under a dust-proof shade to cool and set.

The water to be examined is weighed in a special form of drop-bottle (see fig. 1). A drop is then dropped on the plate by the aid of the pipette stopper, and the bottle reweighed so as to obtain by difference the weight of the drop. The nutrient gelatin is melted at a gentle heat in a Lister flask, and sufficient poured into the cell so as to mix with the drop of water and to form a layer of one-tenth of an inch deep. The glass cell thus prepared is placed in a special glass shade or chamber, the air of which is kept saturated with moisture. After from three to five days, the colonies developed are counted by the aid of a lens. To facilitate the enumeration, the plates are all ruled by a writing diamond into squares.

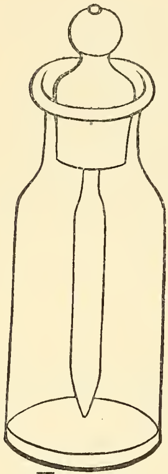


Fig. 1

The collection of ordinary samples was by means of small 2-oz. phials, washed out with boiling water, and then heated for many hours in an oven to about 250° C.

In order to obtain samples of water at different depths, a very efficient and simple apparatus was invented for me by an ingenious friend.* To the disc of wood *a* (see fig. 2), weighted with lead, is fixed a frame of brass *g*; in each side of the frame are slots, in which a clip *x* slides freely. A small stoppered bottle is firmly attached to the disc, and the clip secured to the stopper; the clip, and with it the stopper, is firmly held down by means of two pieces of elastic at *s* and *s′*; the apparatus is let down to any required depth by means of a line attached to the stout copper wire *w*; to take deep sea samples the line is best marked into fathoms like a deep sea line. The stopper is opened at any time by pulling on a string attached to the ring *r*; on releasing this string the stopper is immediately pulled into its place by the elastics.

Sewage.—I found it practically impossible to make a quantitative determination of the micro-organisms in sewage unless the liquid was very much diluted. A convenient dilution is 1 c.c. of sewage to a litre of sterilised water. Drops of this dilute sewage, weighing from 40 to 50 milligrams, and added to nutrient gelatin, yield, after a few days' cultivation, from 100 to 200 colonies—numbers the counting of which present no difficulty, and a simple calculation gives the

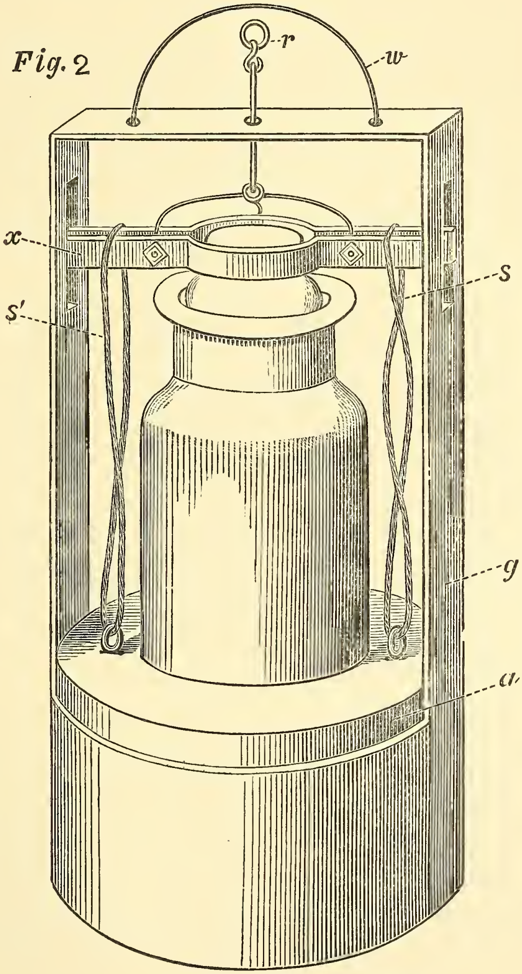
* Mr Stafford L. Archer, whom I have to thank for the trouble he took in perfecting the mechanism.

amount per gramme of the original sewage. The following are examples of results obtained from London sewage :—

	Colonies per grm.
London sewage, June 1885, ...	1,490,000
London sewage, July 1885, ...	4,226,804
London sewage, November 1885, . . .	773,800

It is therefore evident that the sewage is considerably influenced

Fig. 2



by season, containing more in the summer than in the winter season, but for the most always yielding colonies approaching to or above a million per gramme. The colonies are of all kinds of fungi, more especially aspergilli, bacteria, bacilli, and microccoci.

Pond Water and open Wells.—A typical open pond which received no drainage, and was frequented by ducks and geese, contained water which yielded to cultivation 3534 colonies to the gramme; 465 of these were bacilli liquefying the gelatin, and 47 were bacteria, agreeing in general characters with *Bacterium termo.*

An open well in Devonshire gave the following analytical values:—* Nitrogen as nitrates, ·0984; chlorine, 3·2; ammonia, 0014; albuminoid ammonia, ·0078; oxygen consumed in 15 minutes, ·0648; oxygen consumed in 4 hours, ·1666; hardness, 22·9; total solids, 32·5. The ordinary microscopical examination detected epithelial cells, vegetable débris, and moving animalcules; 35 mgrs. of the water yielded to cultivation 330 centres, 4 of which slowly liquefied the gelatin. This is equal to 9428 per gramme.

Canal Water.—The Regent's Canal, in its course through the Metropolis, has been for years little better than a stagnant ditch, and the composition of its waters approximates to that of dilute sewage. A sample, taken a foot below the surface, gave colonies equal to 32,352 per gramme; whilst, just above the mud, another sample gave 521,739 per gramme.

River Water.—The water of a stream with an appreciable velocity shows the same general fact, viz., more micro-organisms near the bottom than the surface; *e.g.*, samples taken from the Thames at Sunbury just opposite the intake of the water companies, yielded to cultivation the following figures:—

Near the surface, ...	11,050 per grm.
Close to the bottom, ...	59,800 ,,

In the same locality a second sample, taken above some black mud, yielded colonies equal in number to 6,430,000 per gramme.

It thus appears that in canals and rivers the bacteria slowly subside, probably by adhering to the mineral and organic substances which are continually sinking. That the richness of the bottom layer in bacteria is intimately connected with the precipitation of particles, is evident from the following experiment:—A wide upright glass vessel 2 feet 5 inches in height was filled with sterilised

* In grains per gallon.

water, 1 c.c. of sewage added, the whole shaken, and then allowed to stand for twenty-four hours; at the end of which time samples were taken from the surface, the middle and bottom respectively, with the following result:—

	Colonies per grm.
Surface,	411
Middle,	333
Bottom,	160

Sea Water.—In the sea water around the English coast, the water at or near the surface seems to be uniformly richer than at deeper depths.

A sample of sea water, taken off the old Pier at Brighton in July, gave the following results :—Surface, 50 mgrms. yielded 843 centres—that is, 16,860 per gramme; while a sample from the bottom only yielded 230 per gramme.

A sample of sea water, taken from the surface of the Yarmouth coast in September, gave 14,887 per gramme. Dr Vacher of Birkenhead kindly supplied me with samples of sea water, taken from the surface and at the depth of 20 fathoms off Holyhead, and the number of colonies at the surface gave a very similar result while the deep sea sample yielded comparatively few centres.*

Cultivation of ordinary Drinking Water.—For some time past I have made cultivations of all waters analysed by me in my capacity of a public analyst, and have now sufficient experience to justify a judgment as to the utility and limits of the method. A public water supply, derived from flowing rivers, or from any surface water, varies as to its composition according to season, the more especially as the water has a winter character due chiefly to winter rains, and summer character due chiefly to the summer drought. It hence follows that a standard of purity, which does not take into account natural seasonal variations, cannot be correct.

The water supplied to London by the West Middlesex and Grand Junction Companies is analysed by me month by month, and since April have also been submitted to cultivation. The analytical results, and the number of organisms per gramme, are detailed in

* I have to my great regret entirely lost my notes of the numbers, but as stated, the general facts agreed with the experiments on the shallower waters nearer the coast.

Table I. It may be useful here to allude to a similar investigation published in the *Arbeiten aus dem Kaiserlichen Gesundheitsamte,* Band I. Berlin, 1885, on the water supplied to Berlin. The cultivations were made daily from July 1884 to March 1885. The mean of the numbers of colonies raised from unfiltered river water (Stralauer Works) was 1435 per gramme, the maximun being in October 3251, the minimum in February 685. Filtration altered the water very considerably, the mean of the filtered water being 107 (maximun 277, and minimun 21).

Lake water (Tegeler Works) when unfiltered gave a mean for the nine months of 441, the maximum 890 falling in March, the minimum in August. The mean number of colonies in the filtered lake water was 51, and the extremes were 14 and 121.

It is therefore clear that the filtered Berlin river water is, so far as bacterial life goes, purer than the filtered London river water, the mean number of colonies per gramme being for the West Middlesex Company 468, and that of the Grand Junction 261.*

With regard to other waters, I give in the following tables examples of good, indifferent, and polluted waters, from which I think it may be concluded that, irrespective of the special kind of micro-organism in a water, any number of colonies which exceed 1000 per gramme is indicative of considerable impurity.

Summary.—To briefly sum up the facts already detailed—

(1) Impure liquids, such as sewage, pond and canal waters contain hundreds of thousands or even millions of micro-organisms per gramme.

(2) In canals and rivers the number of micro-organisms at or near the bottom, is greater than at or near the surface.

(3) In sea water the conditions are reversed, the number of organisms being greater at or near the surface.

(4) A good water should not contain more than 1000 colonies of micro-organisms in every gramme.†

* My numbers for the London waters have been hitherto in excess of the one or two other observers working at this subject. I always cultivate the water twenty-four hours after collection, during which period of rest there may be some considerable increase, especially in summer.

† That is, when cultivated within twenty-four hours after collection.

TABLE I.

Monthly Analyses of the Water supplied by the Grand Junction Water Company, with the Number of Colonies of Micro-Organisms per gramme.

	May	June	July	Aug.	Sept.	Oct.	Nov.
	Grains per gal.	Grains per gal.	Grains per gal.	Grains per gal.	Grains per gal.	Grains per gal.	Grains per gal.
Chlorine,	1·3	1·15	1·30	1·25	1·20	1·20	1·3
Nitrogen as ammonia,	·1398	·1362	·1309	·1453	·1403	·1307	·1601
Free ammonia,	·0009	·0006	·0006	·0008	·0007	·0010	·0009
Albuminoid ammonia,	·0039	·0036	·0048	·0063	·0051	·0061	·0039
Oxygen consumed in 15 minutes at 100° F.,	·0714	·0388	·0431	·0592	·0292	·0386	·0047
Oxygen consumed in 4 hours at 100° F.,	·1050	·0967	·0754	·1001	·0544	·0648	·1680
Hardness before boiling,	11·3	11·79	12·59	12·49	12·00	14·91	13·91
,, after boiling,	2·9	2·85	3·44	1·76	2·44	2·64	2·23
Total solid residue,	17·0	17·0	18·0	17·5	18·0	20·5	20·0
No. of colonies of micro-organisms in 1 gramme of the water,	160	68	276	1000	96	173	54

TABLE II.

Monthly Analyses of the Water supplied by the West Middlesex Water Company, with the Number of Colonies of Micro-Organisms per gramme.

	April	May	June	July	Aug.	Sept.	Oct.	Nov.
	Grains per gal.	Grains per gal.	Grains per gal.	Grains per gal.	Grains per gal.	Grains per gal.	Grains per gal.	Grains per gal.
Chlorine,	1·25	1·20	1·20	1·25	1·15	1·20	1·2	1·2
Nitrogen as ammonia,	·1438	·1264	·1438	·1273	·1320	·1487	·1260	·1570
Free ammonia,	·0012	·0014	·0004	·0008	·0006	·0008	·0008	·0007
Albuminoid ammonia,	·0084	·0045	·0041	·0052	·0051	·0057	·0042	·0039
Oxygen consumed in 15 minutes at 100° F.,	·0749	·0636	·0466	·0538	·0329	·0233	·0518	·0020
Oxygen consumed in 4 hours at 100° F.,	·1631	·1225	·1414	·0861	·0686	·0472	·0777	·1540
Hardness before boiling,	12·63	10·8	12·93	11·38	11·84	12·66	13·76	12·78
,, after boiling,	2·48	3·1	2·64	3·74	1·91	2·85	2·38	2·05
Total solid residue,	17·00	16·5	18·0	17·5	16·5	18·5	19·0	18·0
No. of colonies of micro-organisms in 1 gramme of the water,	90	140	225	1223	125	979	583	30

TABLE III.

Examples of Good Waters.

	Chlorine.	Phosphoric Acid.	Nitrogen as Nitrates.	Ammonia.	Albuminoid Ammonia.	Oxygen, Absorbed in		Hardness, Clark's Scale, in degrees.		Total Solid Matter, dried at 220° Fahr.	No. of Colonies of Micro-organisms in 1 Gramme of the Water.
						Two Minutes at 80° Fahr.	Four Hours at 80° Fahr.	Before Boiling.	After Boiling.		
	Grains per gal.		Grains per gal.	Grains per gal.	Grains per gal.	Grains per gal.	Grains per gal.	Grains per gal.	Grains per gal.	Grains per gal.	
A deep well water supplying the County Asylum, Northampton, . .	1·8	None	·4981	·000	·0026	·0323	·0405	14·01	3·89	19·5	37
A well near Truro, Cornwall, ...	2·4	s. trace	·1153	·0006	·0052	·0646	·1107	2·32	·88	7·0	400
A surface well near Totness,	1·4	s. trace	·0101	·0014	·0006	·0215	·0827	5·56	2·9	13·0	457
Another well, also a surface well, near Totness, . .	1·6	...	·0067	·0004	·0017	·0397	·0963	5·21	3·20	12·5	394
A deep well in Hampshire, .	2·7	...	·6755	·0003	·0027	·0297	·0447	25·83	5·81	34·0	913

TABLE IV.

Examples of Bad Waters.

	Chlorine.	Phosphoric Acid.	Nitrogen as Nitrates.	Ammonia.	Albuminoid Ammonia.	Oxygen, Absorbed in		Hardness Clark's Scale, in degrees.		Total Solid Matter, dried at 220° Fahr.	No. of Colonies of Micro-organisms in 1 Gramme of the Water.
						Two Minutes at 80° Fahr.	Four Hours at 80° Fahr.	Before Boiling.	After Boiling.		
Water contaminated from being in a dirty cistern, .	2·8	s. trace	·671	·004	·0028	·0272	·0586	25·91	5·75	34·5	2,257
Water from a deep well near the sea shore, . .	23·0	trace	·0274	·0419	·0035	·0329	·0437	22·89	8·09	62·0	5,769
A surface well near Exeter, contaminated by dust and dirt, ...	2·15	trace	·2017	·0036	·0031	·1030	·1288	10·33	4·01	22·0	30,250
A well contaminated slightly by sewage in Essex, .	5·2	...	·4894	·0016	·0084	·0612	·1680	43·26	12-64	83·0	7,281
A well contaminated by sewage near Truro, Cornwall, ...	5·2	...	·7494	·0042	·0028	·0772	·0948	13·83	2·38	28·0	5,032

Monday, 4th January 1886.

THOMAS STEVENSON, Esq., M.Inst.C.E., President, in the Chair.

The following Communications were read:—

1. Notes on Experiments for the Board of Trade, made at the South Foreland Lighthouse by the Trinity House of London, on Lighthouse Illuminants, &c. By Thomas Stevenson, *Pres.* R.S.E., M.Inst.C.E.

A very important inquiry—suggested by Mr Chamberlain when President of the Board of Trade—has just been concluded by the Trinity House of London into the relative merits of electricity, gas, and oil, as lighthouse illuminants, on which I think it advisable to make a few remarks, as the general results of the investigation ought to possess a certain amount of interest for this Society.

Mr Wigham, gas engineer, Dublin, has long taken a great interest in the best means of increasing the power of our sea lights by means of gas and large burners. So far back as 1865 he proposed to increase the diameter of gas burners to 7 inches; and in 1868, the Scotch Lighthouse Board was asked by the Board of Trade to investigate the subject. Certain experiments were accordingly made at Granton in that and the following year. In 1869 the engineers of the Northern Lighthouse Board reported in the following terms, on the results of the experiments which had been made on the employment of large burners:—

"It has been found that the second series of experiments so far corroborated those previously made as to leave no room for doubt that the gas light when used with an annular lens, notwithstanding the greater size of the flame, was not superior to the effect of the smaller flame of the mechanical lamp, the explanation being that the greater portion of the large-sized 7-inch gas flame, consisting of 52 jets, is *ex-focal*, and is therefore lost, so that with the lens no advantage is gained by increasing the size of the flame beyond certain limits, and these seem to be pretty nearly attained in the ordinary 4-wick lamps. So apparent was this, that with Mr Wigham's concurrence, it was agreed to give up the idea of experimenting on the gas burner in its present form as applicable to revolving lights, and to confine the experiments to its use for fixed lights, in which, owing to the light being distributed equally over the horizon by the cylindric refractor, some advantage is gained by the employment of the larger flame of the gas." And the Report concludes as follows:—"We have to point out that the experiments made, have been highly valuable in showing the limit to which the size of a radiant may with advantage be increased when used in the focus of the apparatus now employed in lighthouses."

Mr Wigham, with great perseverance, nevertheless continued his labours in improving his large burners, and in producing new burners of still larger sizes. He also introduced several of these large-sized burners into the same lantern, in connection with Fresnel's 1st order lenses, so that from the same lantern he exhibited, under the name of biform, triform, and quadriform, two, three, and four burners, with a like number of Fresnel lenses, arranged one above another.

The employment of this multiple system of lights in the same lantern was, on the recommendation of Mr Wigham, adopted by the Irish Lighthouse Board, at Galley Head, in the county of Cork, in 1878. One important advantage of this multiple system was the power of lighting or extinguishing one or more of these burners, according to the greater or less amount of haze or fog in the atmosphere.

The Trinity House erected three experimental towers placed along side each other at the South Foreland Lighthouse, near Dover, and the photometric experiments were carried out by Mr Harold Dixon, M.A., of Balliol College, Oxford, while the officials of the Northern Lighthouse and Irish Lighthouse Boards were kindly invited to attend the experiments from time to time, as well as Mr A. G. Vernon Harcourt for the Board of Trade.

The conclusions which the Trinity House have arrived at are the following, and I may state, that in so far as my opportunities of observation have enabled me to form an opinion, I fully concur in their judgment:—

1. "That the electric light as exhibited at South Foreland has proved to be the most powerful light under all conditions of weather, and to have the greatest penetrative power in fog."

2. "That for all practical purposes the gas light, as exemplified by Mr Wigham's multiform system, and the oil light, as exemplified by the Trinity House Douglass 6-wick burners, in multiform arrangement up to triform when shown through revolving lenses are equal, light for light, in all conditions of weather; but that quadriform gas is a little better than triform oil."

3. "That when shown through fixed lenses, as arranged in the experimental towers, the superiority of the super-posed gas light is unquestionable. The larger diameter of the gas flames, and the lights being much nearer to each other in the gas lantern, give the beam a more compact and intense appearance than that issuing from the more widely separated oil burners."

4. "That for lighthouse illumination with gas, the Douglass patent gas burners are much more efficient and economical than the Wigham gas burners."

5. "That for the ordinary necessities of lighthouse illumination, mineral oil is the most suitable and economical illuminant, and that for salient headlands, important landfalls, and places where a very powerful light is required, electricity offers the greatest advantages."

There were employed during these experiments a variety of forms of photometer, but the most important was the Pentane standard photometer, the invention of Mr Vernon Harcourt, which was recommended to the Board of Trade, as giving the most uniform standard of comparison, by Professors Williamson and Odling, and Mr Livesey of London; while for outdoor observation, there was used a liquid photometer, consisting of a water-tight telescope, filled with a partially opaque fluid, supplied to the telescope from a small cistern fixed above, so that as the eyepiece is moved out or in, the length of the fluid through which the light has to pass increases or diminishes, and the length of the fluid through which the light so passes, is recorded by an attached graduated scale. This form of photometer was first proposed by me in the *Edinburgh New Phil. Journal* in 1863, and has since been employed in numerous experiments on lighthouse apparatus at Edinburgh.

The South Foreland experiments extended over a period of twelve months, and many interesting observations were made, besides those which related to the questions which were the more immediate cause of the investigations being instituted.

Electric Light.—The mean candle power of the electric arc given by one of De Meriten's machines, in a lamp with 40 mm. carbons, was found by Messrs Dixon and Harcourt to be 10,000 candles. It was found that the core carbons gave a better result than the solid carbons; also that two machines coupled do not give double the light of one; this result, according to the report of Professor Grylls Adams of Cambridge, was however due to the electric energy being expended in heating some of the "leads," which were of too small size. A considerable waste was also due to the regulator of the lamp.

Gas Burners.—The Wigham gas burners experimented with varied from 108 jets down to 28 jets, and from 2300 to 250 candle power; while the Douglass Argand gas burners varied from 6 to 10 rings, and their powers varied from 825 candle power to 2500.

Oil Burners.—The 6-wick Douglass oil burner was found to give 730 candle power, while another of similar construction with 9 wicks gave 1785 candle power.

These results show how successfully the effectiveness of lighthouse burners has been lately increased through the efforts of Mr Wigham and Sir James Douglass.

Variations in the Transparency of the Atmosphere.—Very remarkable variations in the transparency of the atmosphere were found to occur in the course of the observations, without any haze or fog or cloud being visible to the eye. Sometimes the experimental lights suffered a loss of $\frac{1}{4}$ to $\frac{1}{3}$ of their power, when inspected at a distance of a mile and a quarter; while the French lights on the other side of the Channel, 25 and 30 miles distant, continued to show with their usual steadiness and brilliancy without any variation.

The lenses employed in connection with the burners, which I have described were of two forms:—

1. The Mew Island lens, which is an ordinary Fresnel lens of the first order, 920 mm. focal distance.

2. The type employed at the New Eddystone Lighthouse, having the same focal distance, but with the addition of flint glass prisms above and below the central lens, so as to intercept a larger number of rays coming from the burner.

So far as the experiments at the South Foreland dealt with the optical instruments and burners *submitted for trial*, they may be held as conclusive and exhaustive. But in the experiments made in Edinburgh in 1869, it was pointed out to Mr Wigham, as a result of these experiments, that when his 52 gas jet burner (7 inches in diameter), was employed in combination with lenses suited for utilising the light from a flame of the diameter adopted originally by Fresnel, the effectiveness of this larger flame was to a great extent lost, as much of the light was *ex-focal*, thus escaping condensation by the Fresnel lens. It was not, however, until a comparatively recent date, that the matter of larger burners again came before Messrs Stevenson, as a question requiring settlement in practical lighthouse optics, when the Northern Lighthouse Board resolved to increase the size of the burners in a first order light in the service.

Provision had therefore to be made for utilising, as far as possible, the light from this increased size of burner, and in doing so it was decided, on the suggestion of Mr Alan Brebner, to test by actual trial whether Messrs Stevenson had been right in reporting that Fresnel's proportion insured the best results, and should not be violated.

An experimental lens in that proportion, suited for a 6-wick burner, was constructed and tried at the South Foreland, the focal distance of the lens being increased, while the holophotal system which I proposed in 1850, with totally reflecting prisms concentric with the refracting portion of the apparatus, was also adopted.

The lens as designed has a focal distance of 1330 mm., and has two reflecting prisms above and below the refracting portion, the whole subtending an angle of 60° horizontally and of 70° vertically.

A panel of this design renders unnecessary the use of special flint glass refractors, such as are employed in the New Eddystone apparatus, and also prevents the loss of light due to the square form of the Fresnel lens.

After the experiments on electricity, gas, and oil were concluded at the South Foreland, this lens, before being used in the Northern Lighthouse service, was kindly allowed to be tested by comparative trials. This was done by Sir James Douglas and Mr D. A Stevenson by comparing the depths of the shadows thrown by the different apparatus, and by exact photometric observations made by Mr Dixon, of which the following are the results :—

Time.	No. of Burner.	Lens.	Illuminating Power in Pyres or 1000 Candles.	Rate of Gas Consumption.
7.30	I. 108 Gas	Mew Island	22·8	300
7.40	I. 6-wick Oil	Stevenson	29·3	...
7.48	I. 108 Gas	Mew Island	23·4	300
7.55	I. 6-wick Oil	Eddystone	18·1	...
8.	II. 108 Gas	Mew Island	41·6	298
8.8	I. 10-ring Gas	Eddystone	31·8	225
8.15	I. 10-ring Gas	Stevenson	62·2	...
8.20	II. 108 Gas	Mew Island	43·2	298
8.25	High Light	...	7·6	...
8.30	I. 108 Gas	Mew Island	23·1	310
8.35	I. 6-ring Gas	Stevenson	28·9	100
8.50	I. 6-ring Gas	Eddystone	13·7	110
8.55	I. 108 Gas	Mew Island	21·	310
9.15	I. 108 Gas	Mew Island	22·4	310
9.20	I. 108 Gas	Stevenson	42·6	330
9.25	I. 108 Gas	Mew Island	22·4	310

The following conclusions from these photometrical trials seem warranted :—

1. That a single large burner shown in a complete panel of a revolving apparatus composed of the new lens, with totally reflecting top and bottom prisms of corresponding size added, would give a more intense light than burners and ordinary Fresnel lenses, arranged as biform and equal to triform.

2. That the consumpt of oil or gas would be a $\frac{1}{2}$, $\frac{1}{3}$, and $\frac{1}{4}$ of that of biform, triform, or quadriform arrangements respectively.

3. That the new lens apparatus would avoid all the disadvantages of superposed lenses, including excessive heat in the lightroom, difficulty of management of the burners, and obstruction of light by the necessary ventilating tubes.

The practical result is obvious, that for lighthouse purposes, on the grounds of superior illuminating power, economy and ease of management, the principle of increasing the diameter of the apparatus in proportion to the size of the burner, is superior to that of superposing lenses and burners; in a word, that the new lens apparatus is superior to the biform, triform, and quadriform arrangements.

The trials at the South Foreland were made with apparatus in existence at the time when the experiments were instituted, and I have since proposed to take advantage of the natural properties of the electric light, by adapting to it more fully the condensing system, now largely employed on the Scottish coast, both for flashing and fixed lights. This system has been employed for the new electric group flashing light for the Isle of May, in connection also with a mode which I proposed of dipping the rays below the horizon on the occurrence of haze or fog, so as at such times to increase the power of the light at short distances from the lighthouse, where alone it is likely to be seen in such states of the atmosphere.

In the apparatus experimented with at the South Foreland by the Trinity House, the condensing principle was also applied, but to a very small extent, viz., the condensation of 30° into 5° or 6 times, while in the Isle of May apparatus the light proceeding from 45° is condensed into 3° or 15 times, and the emergent beam admits of being dipped to any extent which may be found necessary during fogs.

The peculiar property of this azimuthal condensing arrangement is that, where the light is intermittent, the power is increased in proportion to the intervening periods of darkness. Thus, neglecting the loss of light by absorption &c., the power is *doubled* when the periods of light and darkness are equal, *trebled* when the dark periods are made twice as long as the light, and so on in proportion, while in every case the rays are spread uniformly over each illuminated sector.

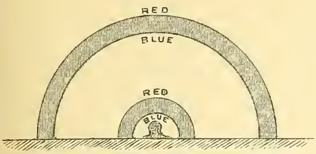
2. Glories, Halos, and Coronæ seen from Ben Nevis Observatory. Extracts from Log Book. By R. T. Omond. Communicated by Professor Tait. (Plate XVI.)

Dec. 1, 1883.—Glory seen at 9^h 15^m (see fig. 1). Red outside in both rings. Smaller one almost filled up by shadow of head. Radius of outer red = 2°. At 11^h 12^m and 12^h 0^m *white* fog bow. When very bright it was coloured red outside. Too large to measure.

Dec. 6, 1883.—Corona round moon all evening. Red outside. Radius of red, 2° 8′. Occasionally an outer circle of a bluish colour, extending from red ring outwards to a radius of 4°, was visible.

Bluish
Red
Yellow
Blue
☽

Dec. 17, 1883.—Corona at 2^h. Double ring, red outside in both. At 22^h corona again. Triple ring, red outside in all three. Radius of middle red = 1° 45′. At same time lunar



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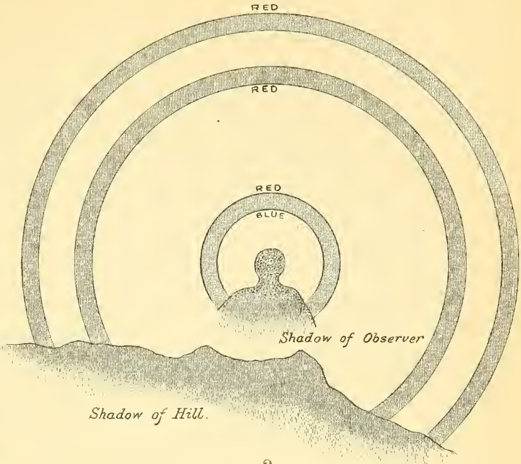

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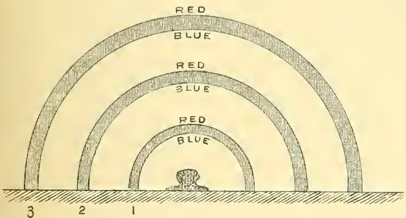

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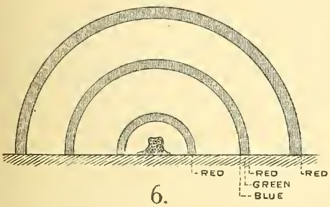

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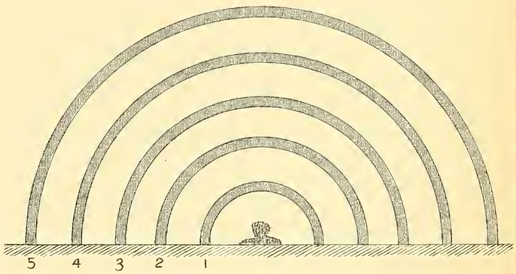

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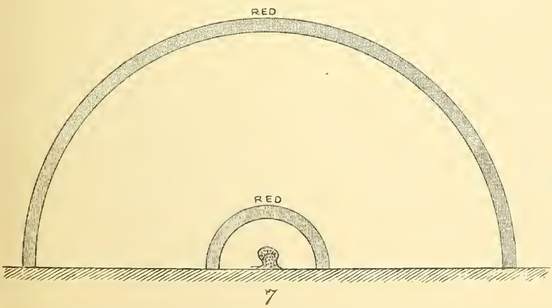

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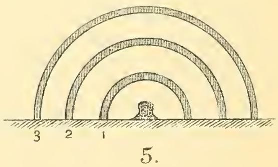


5.

M^{c}Farlane & Erskine, Lith^{rs} Edin^{r}

rainbow, radius 26°, colours if any very faint. Lunar fog bow a 23^{h}. Too large to measure.

Dec. 18, 1883.—Badly defined corona at 6^{h}, red outside. Radius of red about 2°.

Dec. 23, 1883.—At 12^{h} 30^{m} reddish hue round sun; radius about 7° or 8°. At 15^{h} 10^{m} sun sank into cloud bank. As it went down semicircle of colours formed over edge of cloud bank; red outside, like badly-defined corona. Sky above covered with detached stratus clouds, and not coloured at all.

Dec. 25, 1883.—Fleeting, badly defined glories seen all afternoon on fog in northern valley. Red always outside.

Jan. 3, 1884.—At 17^{h} 35^{m}, lunar halo, white, very faint. Diameter 17° (*sic*).

Jan. 15, 1884.—At 1^{h} lunar corona seen. Distinct orange ring, 2° 30′ radius, inside of which is the true corona, with blue next moon. Outside orange ring a bluish green space edged with red or orange rim. This space did not look like a second corona; the colour was too uniform. Radius of outer red ring, 5°. This green in the outer ring strongly resembled the green tints seen in the recent sunsets. At 2^{h} the moon was surrounded by a very faint corona entirely blue.

Red or Orange
Bluish green
Orange
☽

> *Note.*—This was found afterwards to be a common type of corona.

March 4, 1884.—At 10^{h} 50^{m}, solar halo observed. Red inside. Colours very faint; approximate radius = 22°. At 20^{h} lunar halo observed, white, very faint; approximate radius, 23° 45′. At 21^{h} corona observed. Double. Usual colours out to first red ring; then bluish annular space tinged with red outside. Radius of first red, 2°; radius of second red, 4°.

Faint red
Bluish
Red
☽

April 7, 1884.—At 3^{h} lunar halo observed; not well defined, white. Radius by stef., 22° to 23°.

April 8, 1884.—At 23^{h} blue lunar corona observed. Radius (of red) about 4° 25′. Same corona seen till 3^{h} on April 9.

Faint red
Blue
☽

April 10, 1884.—At 2^{h} lunar corona observed. Inner space blue; then green ring, and red ring outside all. Radius of red, 4° 15′.

Red
Green
Blue
☽

April 13, 1884.—At 4^h lunar corona observed, very misty looking, with red ring inside an outer green one.

Green
Red
☽

N.B.—Probably usual colours inside red, though not noted in log.

Red
Green
Reddish yellow
☽

May 3, 1884.—At midnight brilliant lunar corona observed; colours as in diagram. It disappeared suddenly at 0^h 5^m before there was time to measure it.

May 6, 1884.—Badly defined corona seen at midnight. Radius of red ring 3° 15′, and of blue 2°.

May 11, 1884.—Solar halo observed at 10^h. Well defined. Red inside. Radius, 22° 30′.

May 23, 1884.—Solar halo at 13^h. Radius about 20°. Colours very brilliant. Red inside, blue outside.

Blue
Red
☽

June 8, 1884.—At midnight lunar corona seen. Red outside, with blue margin beyond. Radius of red, 2° 30′. Very misty; size apparently varying.

Faint red
Blue
Red
Yellow
Blue
☽

June 9, 1884.—At 1^h double lunar corona observed; colours as in diagram. The inner one had all the gradations of spectroscopic colours, the outer only blue and faint red. Radius of inner red, 2°; radius of outer red, 4°. At 2^h inner ring as before, but no outer colours.

June 17, 1884.—At 19^h double and triple glories seen. Colours as noted in fig. 2. No. 1 was very indistinct—a mere blotch of colour. No. 2 was the brightest; No. 3 was not so bright as No. 2, and sometimes was not seen, but when visible was quite sharp and distinct:—

Measured by	Red (2)	Blue (2)	Red (3)
R. T. Omond, . .	1° 55′	1° 50′	3° 10′
A. Rankin, . .	1° 55′	...	3° 30′

June 18, 1884.—At 8^h double fog bows seen, with faint glory round the shadow of observer. About $\frac{3}{4}$ of the circles were visible (270°), the rest being cut off by the shadow of the hill. Colours as noted in fig. 3. The inner (fog) bow was narrower, and not so distinctly coloured as the outer. Both were too large to measure with stephanome.

July 26, 1884.—At 10^h solar halo observed; colours quite distinct, red inside.

Radius of red, . . .	1st measurement, 22° 45′
	2nd „ 22° 30′
	3rd „ 23° 0′
Mean 22° 54′.	4th „ 23° 20′

August 12, 1884.—At 3^h badly defined lunar corona, red outside. Radius of red, 2° 50′.

August 31, 1884.—At 21^h 12^m double lunar corona and a lunar fog bow observed. Colours of corona as in diagram. Radius of outer red, 4° 32′; radius of inner red, 2° 15′.

Red
Yellow
Green
Blue
Red
Yellow
White
☽

Sept. 11, 1884.—At 1^h lunar corona observed. Radius of red ring, 3° 22′. Yellow inside the red, and outside the red a blue margin.

Blue
Red
Yellow
☽

Sept. 17, 1884.—In the afternoon glories were seen on the fog in the valley to northward. Red outside, with yellow, green, and blue inwards. At times a faint outer (second) one was seen, but they were all too evanescent for measurement.

Similar glories were seen on Sept. 20.

Oct. 4, 1884.—While the moon was partially eclipsed a strong double corona appeared round it. Radius of outer red, 3° 53′; radius of inner red, 2° 26′.

Oct. 5, 1884.—At 1^h 15^m double fog bow observed. Radii approximately $37\frac{1}{2}°$ and $32\frac{1}{2}°$. At 1^h 30^m triple corona observed. Radii: 1st ring (outside of red), 2° 3′; 2nd (outside of red), 3° 1′; 3rd (outside of red), 4° 5′.

N.B.—For details of the last two coronæ see *Nature*, Oct. 23, 1885, vol. xxx. p. 613.

Oct. 12, 1884.—Lunar corona at 5^h. Colours as in diagram. The outer blue in coronæ of this type forms a distinct margin or *glare.* This corona was formed on passing fog or scud; its size appeared to vary.

Blue
Red
Blue
☽

Nov. 3, 1884.—At 11^h solar fog bow observed, with colours; red inside.

Nov. 7, 1884.—At midnight faint misty corona observed; red outside. Radius of red = 2° 30′.

Nov. 13, 1884.—At 6^h faint corona seen; no distinct colours, but a faint red ring with white inside it and blue outside as in diagram. At noon glory and fog bow seen in valley to northward.

Blue
Red
White
☽

Nov. 23, 1884.—From 9^h onwards glories observed on fog to northward, apparently about 2 miles distant. The number of rings varied from 3 to 5 (see fig. 4). At 14^h measurements were taken—1st red, too small to measure (under 1° 40′); 2nd red, 2° 0′ radius; 3rd red, 6° 30′; 4th red, 9° 40′; 5th red, too faint to measure. The 1st ring was blurred and indistinct looking; the 5th was incomplete and very faint; in each ring red outside and blue inside.

Blue
Red
Yellow
☽

Blue
Red
☽

Nov. 29, 1884.—At 2^h small lunar corona seen. Very yellow looking inside the red, and with blue margin outside. Radius of red, 1° 55′. At 22^h corona as in (lower) diagram. Colours inside the red not distinct. The outer blue not always seen. Radius of red, 1° 55′.

Blue
Red
Blue
☽

Dec. 1, 1884.—(At 1^h?) Corona with red outside but blue margin formed on scud passing over the hill. Radius of red = 4° 0′. Space inside the red blue looking. When the scud cleared off at any time the corona disappeared, but the moon was seen surrounded by a very much smaller one, very yellow-looking, inside the red. At 3^h, misty-looking corona formed on scud; red outside. Radius of red = 2° 52′.

Dec. 4, 1884.—At 1^h, corona with same arrangement of colours as in diagram above (Dec. 1), but the blue margin only seen at times. Radius of red = 2° 0′.

Red
Yellow
and green
☽

Blue
Red
Yellow
☽

Dec. 25, 1884.—At 17^h lunar corona observed, very misty-looking. Radius of red, 2° to $2\frac{1}{2}$°. Very green and yellow in appearance; no blue, and red faint. At 20^h very faint blue corona round moon, no other colour visible; radius of this blue space about 2° 5′. At 22^h small corona. Red too small to measure (under 1° 40′). Blue extending to about 3° 10′ radius. At midnight corona similar to that at 22^h, but without the outer blue margin. Radius of red = 2° 0′.

Dec. 27, 1884.—At 18^h lunar corona observed; colours as in diagram. Radius of $blue^2 = 1° 50'$; radius of $red^2 = 2° 25'$; radius of $red^3 = 4° 30'$. At 20^h lunar corona, with colours as in diagram. Outer red, rather faint. Radius of red^1, 2° 2′; radius of red^2, 4° 5′. At 21^h double corona still seen. Its size appeared to vary, being small when the sky was clear of low clouds, and enlarging as the scud passing over the hill thickened.

Red^2
Blue^3
Red^2
Blue^2
Red^1
Whitish
☽

Red^2
Blue
Red^1
Yellow
☽

Dec. 28, 1884.—At 21^h moon was surrounded by a white *glare* about 5° radius; no halo or corona. At 23^h and midnight, moon surrounded by blue corona. No other colours visible; outside radius, 3° 25′. At the same time the white glare had increased to about 15° radius.

Dec. 29, 1884.—At 20^h single corona; red outside. Radius of red = 3° 28′. At 23^h double corona; colours as in diagram; outer red very faint; rather misty-looking; the size appeared to vary. Two measurements of the radius of the inner red (red^1) gave 3° 40′ and 3° 55.′

Red^2
Blue
Red^1
Blue and Yellow
☽

Jan. 24, 1885.—At 22^h faint misty lunar corona. Red outside. Radius of red = 2° 30′.

Jan. 29, 1885.—At 4^h misty lunar corona; colours as in diagram. Outer red very faint, making the blue look more like the *margin* often seen than a part of the corona proper. Radius of inner red, 2° 14′; radius of outer red, 3° 38′. At 21^h faint blue corona on scud.

Red^2
Blue
Red^1
Yellow
☽

Feb. 4, 1885.—At 7^h 5^m double corona observed; colours as in diagram. Radius of inner red, 2° 36′; radius of outer red, 5° 10′.

Red^2
Blue
Red^1
Whitespace
☽

Feb. 19, 1885.—At 21^h lunar corona observed; colours as in diagram. Radius of red, 2° 30′.

Blue
Red
Yellowish
☽

Feb. 20, 1885.—At 21^h small yellow lunar corona with blue margin, the margin being faintly tinged with red (outside). Radius of this red = 4° 3′. [Really a double corona with the inner red cut out.]

Red
Blue
Yellow
☽

Feb. 23, 1885.—At 19^h faint lunar corona formed on upper clouds. One red ring, rather broad. Radius of inside of this red ring = 1° 45′; radius of outside of this red ring = 2° 40′.

Bluish pink
Yellow
Pink to Violet
Blue
Yellow (pale)
Whitish yellow
*

Feb. 28, 1885.—Solar corona seen by Mr Rankin from Plateau of Storms at about $16^h 15^m$. Formed on scud. Colours as in diagram. Outside these portions of circles were seen flashing for a short time, but their colour was not determined.

Red
Orange
Greenish blue
Red
Yellow
White
☽

March 1, 1885.—At 3^h lunar corona; colours as in diagram. Formed on scud. Radius of inner red = 3° 18′; radius of outer red = 4° 49′. Solar halo at $14^h 23^m$; faint red inside; radius by steph. about 18°.

March 21, 1885.—At 20^h lunar halo observed. Radius by stephanome = 23° 15′.

Red
Blue
Red
Watery yellow
☽

March 22, 1885.—At 20^h double lunar corona; colours as in diagram. Radius of inner red, 1° 53′; radius of outer red, 4° 40′. It was formed on passing cloud, but when the sky was clear a faint blue *glare* surrounded the moon.

March 30, 1885.—At 22^h lunar halo on cirrus clouds. Radius by stephanome = 18°.

April 8, 1885.—Solar halo at 10^h and 11^h. Red inside. Radius by stephanome (doubtful observation), 25° 50′. At 11^h the top and bottom of this halo were brighter than the sides.

April 17, 1885.—At 6^h faint solar halo, which vanished at $6^h 10^m$, except two very bright spots with red towards sun, one on each side of sun, and at the same height above the horizon. Radius by stephanome, 24°. At 7^h faint halo was again observed; at 8^h the highest part appeared brightest, and at 9^h only that part remained visible. At 13^h the halo was again visible, and five measurements were made as under:—

1st radius	=	22° 45′	To inside of red ring.
2nd „	=	23° 40′	
3rd „	=	22° 15′	
4th „	=	23° 0′	
5th „	=	22° 15′	

At 14^h upper part only visible, with colours as shown in diagram.

Radius of red, { 23° 0′ / 24° 15′ / 23° 0′

Bluish white
Yellow
Red
Bluish purple
✳

July 3, 1885.—At 1^h and 2^h small misty lunar corona observed; colours as in diagram, with a very faint blue margin outside red. Radius of red ring = 1° 52′.

Red
Greenish yellow
☽

July 18, 1885.—At 6^h solar halo observed. Radius by stephanome, 22° 48′. Rather indistinct.

July 19, 1885.—At 9^h solar corona observed; coloured as in diagram.

Faint white
Strong white
Faint red
Pink
✳

July 24, 1885.—Solar halo at 17^h. Radius by stephanome (mean of 6 readings), 22° 27′.

August 2, 1885.—At 3^h misty lunar corona; colours rather blurred; red outside; radius of red, 3° 16′. At 11^h, glories on fog in valley to northward. Radius by stephanome, 3° 36′. [Probably red ring.]

August 22, 1885.—At 23^h, misty corona; colours as in diagram, the blue margin being well marked. Radius of red about 1° 50′.

Blue
Red
Yellow
☽

August 25, 1885.—At 1^h double lunar corona observed; colours as in diagram. Radius of outer red about 9° 4′; radius of inner red about 5° 14′; radius of yellow about 3° 36′. Too misty-looking to measure accurately. [A similar corona had been seen on the two previous nights, but was not measured.]

Red
Blue
Red
Yellow
Whitish
☽

Oct. 20, 1885.—At 22^h double lunar corona, with faint outer blue margin, formed on fog passing across the hill top; colours as in diagram. Radius of inner red, 1° 45′; radius of outer red, 3° 52′.

Faint blue
Red
Green
Red
Yellowish white
☽

Oct. 22, 1885.—Double lunar corona observed at 19^h; colours as in diagram. Radius of outer red, 10° 53′; radius of green and blue, 6° 55′; radius of purple, 4° 40′; radius of inner red, 3° 42′; radius of white, 2° 25′. Similar corona observed at midnight;

Red
Green and Blue
Purple
Yellowish red
White
☽

Red
Yellow
Green
Red
Yellowish
white
☽

colours as in diagram; the (outer) yellow a very narrow strip. Occasionally traces of a third ring were seen. Radius of outer red, 4° 56′; radius of inner red, 2° 11′; radius of yellow, 4° 23′. All good measurements.

Oct. 23, 1885.—Lunar corona at 2^h, similar to that at midnight on 22nd, except that the inner yellow was more distinctly marked. No blue or green inside the inner red. Yellows, both outer and inner, only thin strips; reds and green broader than, and not so sharply defined as, the yellows. Radius of inner red, 2° 29′; radius of outer red, 4° 43′; radius of inner yellow, 2° 4′; radius of outer yellow, 4° 8′.

Oct. 23, 1885.—Lunar halo, colourless, seen at 3^h. Radius to inside of halo, 21° 48′; radius to outside of halo, 25° 13′. The halo was somewhat indistinct, and the measurements are rather rough.

Red
Yellow
Bluish green
Red
Bluish white
☽

At midnight double corona formed on scud. The size varied according to the sort of cloud or fog it was formed on. The following measurements were taken within three minutes of each other [colours as in diagram]—1st radius of inner red, 2° 14′; 1st radius of outer red, 4° 18′; 2nd radius of inner red, 2° 50′; 2nd radius of outer red, 4° 49′.

Red
Yellow
Green
Red
Yellow
Watery white
☽

Oct. 25, 1885.—At 4^h double lunar corona with traces of third ring; colours as in diagram. As before, the yellows were narrow and the green broad. Radius of inner red, 2° 10′; radius of outer red, 4° 20′; radius of inner yellow, 1° 45′; radius of outer yellow, 2° 50′.

Nov. 11, 1885.—At 9^h glory, with only one broad red ring observed. Radius to inside of ring, 1° 44′; radius to outside of ring, 2° 21′. At 15^h glory with three rings, as in fig. 5; the innermost a mere blotch, the next a well-marked ring with all the colours; the outermost the same, but fainter. Radius of red^3, 3° 46′; radius of red 2^2, 1° 52′. [Red outside in both rings.]

Nov. 16, 1885.—At 9^h glory seen on passing fog; colours as in fig. 6. The inner red close to the shadow of the observer's head. Radius of red^2, 7° 38′; red^3, too faint to measure.

Nov. 18, 1885.—At 23^h double lunar corona, red outside. The size varied very much; at times the two sets of colours merged into one misty corona which shrank rapidly in, a new second set forming outside as the former one contracted.

Nov. 22, 1885.—Lunar corona formed on high cirro-cumulus clouds at 19^h and 20^h; colours as in diagram, but very badly defined. At 19^h red very broad. Radius to inside of this red, 1° 54′; radius to outside of this red, 4° 18′. At 20^h colours better marked a little, but still vague. Radius of red, 2° 54′; radius of yellow, 2° 35′; radius of outside of blue, 1° 42′. Blue much broader than the red or yellow, and with no defined inner margin.

Pale red
Yellow
Bluish white
☽

Nov. 23, 1885.—Double lunar corona on cirro-cumulus at 4^h. Badly defined, but coloured as in diagram. Radius of outer red, 6° 48′; radius of inner red, 3° 7′; radius of yellow, 2° 42′. Yellow a narrow line; green a broad belt.

Red
Green
Red
Yellow
Bluish
☽

Dec. 16, 1885.—Double lunar corona at 20^h; colours as in diagram; the outer yellow very faint. Formed on scud; no corona visible when scud clears off. Radius of outer red, 3° 48′; radius of inner red, 1° 58′; radius of outer yellow, 3° 38′; radius of inner yellow, less than 1° 40′. Similar corona at 22^h. When the scud got very thick the outer part was more yellow and less blue looking. Radius of outer red, 3° 33′; radius of inner red, 1° 53′; radius of outer yellow, 3° 0′; radius of inner yellow, 1° 23′. Two minutes after—outer red, 3° 8′; inner red, 1° 42′. Very faint traces of third ring at times.

Red
Yellow
Blue green
Red
Yellow
Watery yellow
☽

Dec. 18, 1885.—At 11^h solar halo, white. Very faint except in one spot to eastward of sun (horizontally). Radius = 23° 3′.

Dec. 19, 1885.—At 3^h faint blue lunar corona; radius, 3° 4′. The edge of this corona was the brightest part, but the whole space inside was blue, and no other colour was visible. At 4^h similar corona, but with very faint red edge outside. Radius = 3° 20′. At 17^h lunar corona; red outside. Radius to outside of red = 4° 13′; to inside of blue, 2° 55′.

Red
Yellow
Blue
Red
Pale yellow
Bluish white
☽

Dec. 20, 1885.—Double lunar corona at midnight; colours as in diagram, but very pale and faint. Radius of inner red, 3° 3′.

Dec. 21, 1885.—At 5^h triple lunar corona. Reds outside. Radius of innermost red, 1° 5′; radius of middle red, 1° 55′; radius of outermost red, 2° 55′.

Dec. 22, 1885.—Lunar halo, white, at 23^h. Radius to inside, 20° 41′ and 20° 16′; radius to outside, 27° 29′ and 27° 23′. Two measurements.

Red
Yellow
Blue
Red
Yellow
Pale green
Red
Yellow
Bluish yellow
☽

Dec. 23, 1885.—Triple corona at 4^h; colours as in diagram, but outermost ring very faint. Radius of innermost red, 1° 35′; radius of innermost yellow, 1° 11′; radius of outside of green, 2° 26′; radius of middle yellow, 2° 48′; radius of middle red, 3° 12.

Red
Yellow
Yellowish
☽

Jan. 18, 1886.—At 17^h double lunar corona observed; colours as in diagram. Radius of red, 1° 41′; radius of yellow, 0° 58′. Similar corona seen at 21^h.

Red
Yellow
Bluish green
Red
Orange
Yellow
Whitish
☽

Jan. 20, 1886.—Double lunar corona observed at 2^h. Formed on scud. Colours as in diagram. Very fleeting, and size varying. Two measurements made within one minute of each other gave for radius of inner red, 3° 33′ and 3° 7′. The colours were always the same, though the size varied.

Feb. 10, 1886.—Double solar fog bow seen at 11^h. Traces of red on outside of outer bow, and on inside of inner. Radius of outer bow about 42° 4 ; radius of inner bow about 33° 0′.

Feb. 14, 1886.—At 11^h glory and fog bow seen on fog in northern valley (see fig. 7). Fog bow tinged with red outside; outside of glory red also. Outer radius of fog bow, 45° 12′; inner radius, 40° 0′; radius of *red* of glory, 1° 6′.

Feb. 15, 1886.—At 9^h solar halo, with portion of reverse arc on upper side of it *in large* halo, red inside and blue outside; in portion above, red next sun and blue inside curvature. This upper arc overlapped on the main circle, bringing their reds together.

Radius from centre of sun to point where the two reds overlapped,	21° 42′
	21° 49′
	22° 0′
	22° 0′
	22° 0′
	22° 0′

The upper arc was very distinct, but the blue in it was fainter than the blue of the main circle. The radius of upper arc was not determined. Double solar corona at 11^{h}. Radius of outer red, 40° 53′; radius of inner red, 2° 55′. From 19^{h} to 23^{h} lunar halo on cirrus clouds, and for most of the time misty corona also on cirrus. At 19^{h} the following measurements were made :—

Corona.		Halo.	
Outside radius, . .	4° 20′	Radius, . . .	24° 28
,, ,, . .	4° 28′	,, . . .	23° 17′
This corona was a mere bluish space, with a red rim on outside edge.		,, . . .	22° 24′
		,, . . .	22° 36′
		,, . . .	23° 30′
		,, . . .	23° 44′

At 20^{h} the measurements got were—Radius of corona, 2° 59′; halo, 21° 13′.

Feb. 16, 1886.—At 2^{h}, misty-looking lunar corona on cirro-cumulus; colours as in diagram. Radius of red, 1° 43′.

Faint blue
Red
Yellow
☽

Feb. 17, 1886.—At 3^{h}, blue corona round moon. Misty corona on cumulus at night; no measurement made.

Feb. 25, 1885.—Lunar corona at 5^{h}. Colours were in the following order out from moon :—

☽ White. Yellow. Red. Violet. Green. Yellow. Red.

Feb. 26, 1886.—At 12^{h} solar corona. Double rings rapidly varying in size. Radius of outer red, 8° 22′; radius of inner red (3 measurements), 4° 34′; 4° 23′; 3° 38′. Similar corona at 13^{h}, but outer ring very faint. Radius of inner red, 3° 3′; 2° 47′; 3° 25; 3° 10′; 3° 2′; 2° 24′; radius of outer red, about 5° 30′.

March 5, 1886.—At 8^{h} fog bow; corona (3, 4, and 5 rings) and glory (2 and 3 rings) on passing fog,—all too fleeting to measure.

March 7, 1886.—At 7^h thin pallium over sky just above the level of the hill tops round. At 7^h 13^m the sun broke through this cloud layer, and at 7^h 16^m a white beam was seen stretching vertically downwards from sun to edge of Ben Nevis (to eastward). It passed through a stratus cloud. Corona observed at the same time. At 7^h 24^m the beam was again seen. At 10^h double solar corona was observed. The following measurements were made:—

Radius of inner red, 3° 46′	Radius of outer red, 7° 30′
,, ,, 3° 37′	,, ,, 5° 34′
,, ,, 3° 30′	,, ,, 6° 29′
,, ,, 4° 1′	,, ,, 6° 35′
,, ,, 3° 42′	
,, ,, 3° 42′	
,, ,, 2° 50′	

N.B.—The last measurement of the inner red and the second of the outer were taken about the same time.

Solar halo observed at 11^h, at 12^h, and again at 13^h. The following measurements were made:—

	At 11^h.	At 12^h.	At 13^h.	
Radius, . .	23° 30′	23° 44′	21° 48′	22° 24′
,, . .	22° 0′	21° 13′	21° 24′	23° 3′
Extreme inside,	21° 13′	22° 12′	22° 24′	21° 48′
,, outside,	25° 44′		21° 13′	22° 0′
			22° 12′	22° 12′

March 13, 1886.—Fleeting lunar corona, sometimes single and sometimes double, formed on scud at night.

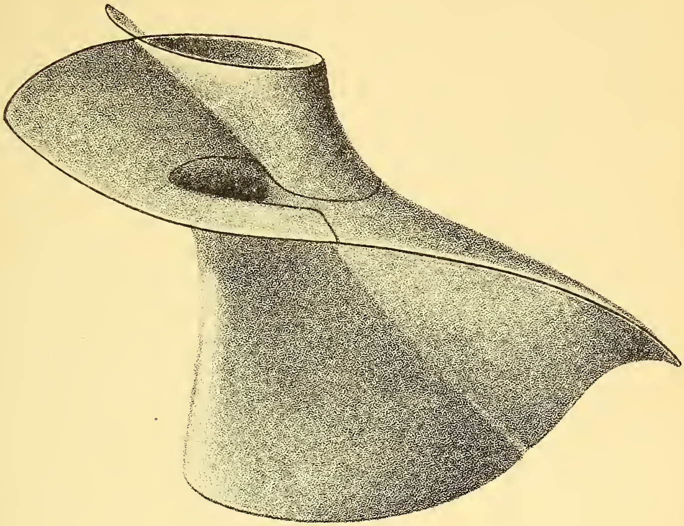
Notes.

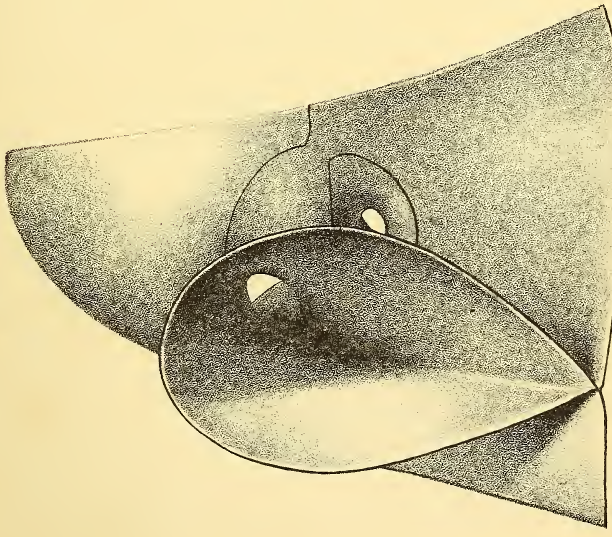
Whether specially mentioned or not, all the measurements were made by the stephanome. Up to and including that on July 3, 1885, the sliding rings ($1\frac{1}{2}$-inch and 8-inch) were used; after that the sliding bar with points on it.

The measurements made with the bar are considerably more accurate than those with the rings, the bar being more easily handled, and the points capable of more accurate adjustment to the object observed.

The type of corona seen on August 22, 1885, is of very common

MODEL OF THE HALF-TWIST SURFACE.





occurrence. When there are two complete sets of colours, the outer is always green or blue looking, and the inner yellow.

The measurements of halos may serve to show the limits of error of the instrument.

3. On a Model of the "Half-Twist Surface." By Professor Crum Brown. (Plate XVII.)

The "twist surfaces," of which this is a case, stand in the same relation to the helicoid surface as the anchor-ring does to the cylinder. In the helicoid the generating line, at right angles to the axis, rotates about the axis as the point of intersection moves along it. In the twist surfaces the generating line is always at right angles to a fixed circle, and rotates about the tangent to the circle at the point of intersection, as the point of intersection moves round the circle. The species of twist surface is defined by the ratio of the angular motion of the generating line to that of the point of intersection. In the particular case illustrated by the model, the generating line turns through two right angles, while the point of intersection makes one whole revolution; that is, the rate of angular motion of the generating line is one-half of that of the point of intersection.

The idea of making such a model was derived from the "one-sided surfaces" exhibited by Professor Tait, formed by gumming together the ends of a strip of paper, after giving it half a turn about its axis. Such a strip has only one side and only one edge, or, perhaps more accurately, its two sides are continuous, and its two edges are continuous. If such a strip is very narrow, and if it is so arranged that its central line is a circle, it may be considered as a portion of a "half-twist" surface. Without entering into any detailed mathematical discussion of the surface, there are some points of interest which may be indicated. A straight line passing through the centre of the circle and at right angles to its plane, obviously lies wholly in the surface, as every generating line cuts it. We may call this line the axis of the surface. Every plane through this axis contains two generating lines; the intersections of these pairs of generating lines lie in a straight line touching the circle, and inclined at an angle of $\frac{\pi}{4}$ to its plane. The surface therefore intersects itself in this straight line. It is obvious that the surface has "helicoid asymmetry"; as for each sense in which the point of intersection may rotate, there are two senses in which the generating line may rotate. This gives four forms, which obviously coincide in pairs.

4. On the Linear Section PR of a Knot M_n, which passes through two Crossings P and R, which meets no Edge, and which cuts away a $(3+r)$-gonal Mesh of M_n. By Rev. Thomas P. Kirkman, M.A., F.R.S.

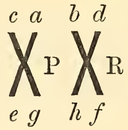
1. The purpose of this paper is to give rules for the construction of knots M_n of n crossings, having each one or more linear sections PR, such that by unkissing at P and at R, shall be obtained two unifilar knots of $n-1$ crossings. See my paper "On the Twists of Listing and Tait," page 363 of the *Proc. R.S.E.* The knot M_n is always made by a section *ffc*, *i.e.*, by uniting the P's and R's of two 2-gons (PR) on K_{e+2} and L_{n-e}, after cutting away the four edges PR. These 2-gons can only be (a bifilar 2-gon has edges in two circles)—

(*a*) Bifilars found on bifilars K and L;
(*b*) Bifilar found on bifilar K, and even on unifilar L;
(*c*) Odd laid on even of unifilars K and L;
(*d*) Odd laid on odd of unifilars K and L;
(*e*) Even laid on even of unifilars K and L; or
(*f*) Bifilar of bifilar K laid on odd of unifilar L.

2. (*a*) *Bifilar on Bifilar.*—Let the pairs (A) and (B)

$$\left.\begin{matrix} \ldots a\mathrm{PR}b\ldots \\ \ldots c\mathrm{PR}d\ldots \end{matrix}\right\}(\mathrm{A}) \qquad \left.\begin{matrix} \ldots e\mathrm{PR}f\ldots \\ \ldots g\mathrm{PR}h\ldots \end{matrix}\right\}(\mathrm{B})$$

be the circles of the bifilar knots K_{e+2} and L_{n-e}. In (A) the angles aPc and RPR are covertical, as are bRd and PRP. In (B) ePg and RPR are covertical, and also fRh and PRP. If we effface the four edges PR and make $a\mathrm{P}c$ covertical over $e\mathrm{P}g$, c and e on the left, and $b\mathrm{R}d$ covertical over $h\mathrm{R}f$, b and h on the left, $c\mathrm{P}g$ crossing $a\mathrm{P}e$, and $b\mathrm{R}f$ crossing $d\mathrm{R}h$, we have before us the two summits P and R of M_n. Draw this figure, and call it (C). No change has been made at any crossing besides P and R. Beginning to read in (C) along $c\mathrm{P}g$, we find the two circles



$$c\mathrm{P}g \dots h\mathrm{R}d \dots, \text{ and } a\mathrm{P}e \dots f\mathrm{R}b \dots,$$

of the bifilar M_n; for $\mathrm{P}g$ in (B) brings us to $h\mathrm{R}$, *i.e.*, in (C) to $h\mathrm{R}d$; and $\mathrm{R}d$ in (A) brings us to $c\mathrm{P}$, *i.e.*, in (C) to $c\mathrm{P}g$, repeating the round. Also along $a\mathrm{P}e$ in (C) we reach by (B) $f\mathrm{R}$, *i.e.*, in (C) $f\mathrm{R}b$; and $\mathrm{R}b$ in (A) brings us to $a\mathrm{P}$, *i.e.*, in (C) to $a\mathrm{P}e$, repeating the circle.

3. Let us now unkiss at R in (C), so as to make the section PR into $\mathrm{P}rr'$. We are to read not fb and hd crossing at R, but fd and hb kissing at R; and evidently this can make no difference in the course of the thread from R through b, d, h, or f. We find the circle of an unifilar of $n-1$ crossings,

$$frd \dots c\mathrm{P}g \dots hr'b \dots a\mathrm{P}e \dots,$$

or omitting the creases r and r',

$$fd \dots c\mathrm{P}g \dots hb \dots a\mathrm{P}e \dots,$$

containing all the sequences $d \dots c$, $g \dots h$, $b \dots a$, $e \dots f$; for $\mathrm{R}d$ in (A) brings us to $c\mathrm{P}$, *i.e.*, by (C) to $c\mathrm{P}g$; and $\mathrm{P}g$ in (B) leads to $h\mathrm{R}$, *i.e.*, in C to $hr'b$, whence $\mathrm{R}b$ in (A) brings us to $a\mathrm{P}$, *i.e.*, by (C) to $a\mathrm{P}e$; and $\mathrm{P}e$ in (B) brings us to our start in frd.

Unkissing next at P we get the circle

$$ga \dots b\mathrm{R}f \dots ec \dots d\mathrm{R}h \dots,$$

of an unifilar on which lies the triangular section $\mathrm{R}pp'$. Thus we have proved

Theorem E.—If we unite by the section ffc two bifilar knots K_{e+2} and L_{n-e} by bifilar 2-gons PR and PR, we construct a bifilar M_n, which gives by unkissing at P and R two unifilar knots each of $n-1$ crossings.

4. (*b*) *Bifilar on Even of Unifilar.*—Let the pair

$$\ldots aPRb \ldots \text{ and } cPRd \ldots \quad (A)$$

be the circles of a bifilar knot K_{e+2}, having the bifilar 2-gon PR, and let

$$\ldots ePRf \ldots hRPg \ldots \quad (B)$$

be the circle of an unifilar L_{n-e} which has the even 2-gon PR; and let the knots be joined by the section *ffc*. We have a knot M_n whose crossings P and R show *c*P*a* covertical over *e*P*g*, *c* and *e* on the left; and *b*R*d* covertical over *h*R*f*, *b* and *h* on the left. Call this figure (C). Reading from *c* in (C) we get the circle

$$\ldots cPg \ldots ePa \ldots bRf \ldots hRd \ldots,$$

i.e., M_n is unifilar. Unkissing in (C) at R, we find the circle

$$\ldots hb \ldots aPe \ldots gPc \ldots df \ldots$$

of an unifilar of $n-1$ crossings; and another such unifilar by unkissing at P, thus proving

Theorem F.—If the bifilar knot K_{e+2}, at its bifilar 2-gon PR, be joined by section *ffc* to the unifilar L_{n-e} at its even 2-gon PR, an unifilar M_n is contracted which gives, by unkissing at P and at R, two unifilars of $n-1$ crossings.

5. (*c*) *Odd on Even of Unifilars.*—Let the circles

$$\ldots mPRk \ldots sPRi \ldots \quad (A)$$
$$\ldots fRPe \ldots aPRh \ldots \quad (B)$$

be those containing the odd and even 2-gons PR, PR. Joined by section *ffc* they form the knot M_n, whose crossings P and R show *e*P*a* covertical over *s*P*m*, *e* and *s* on the left, and *h*R*f* covertical over *k*R*i*, *h* and *k* on the left. Call this configuration (C). Reading from *e* in (C), we get the circle

$$\ldots ePm \ldots iRh \ldots fRr \ldots sPa \ldots,$$

proving M_n unifilar.

Unkissing at R in (C) we get

$$if \ldots hk \ldots sPa \ldots ePm \ldots$$

the circle of an unifilar of $n-1$ crossings; and by unkissing at P we find another such unifilar, thus establishing

Theorem G.—If at its odd 2-gon PR, we join by section *ffc* the unifilar K_{e+2} and the unifilar L_{n-e} at its even 2-gon PR, we construct an unifilar M_n, from which by unkissing at P and R we obtain two unifilars each of $n-1$ crossings.

6. (*d*) *Odd on Odd of Unifilars.*—Let

$$\ldots a\mathrm{PR}h \ldots e\mathrm{PR}f \ldots \qquad \text{(A)}$$
$$\ldots m\mathrm{PR}k \ldots s\mathrm{PR}i \ldots \qquad \text{(B)}$$

be the circles of the unifilars K_{e+2} and L_{n-e} which have each an odd 2-gon PR. Making the angle $e\mathrm{P}a$ covertical over $s\mathrm{P}m$, e and s on the left, and $h\mathrm{R}f$ over $k\mathrm{R}i$, h and k on the left, we have the crossings P and R of M_n, the result of joining (A) and (B) by the section *ffc*. Call this figure (C). Reading in (C) from e, we get the two circles

$$\ldots e\mathrm{P}m \ldots i\mathrm{R}h \ldots \text{ and } \ldots a\mathrm{P}s \ldots k\mathrm{R}f \ldots ,$$

proving that M_n is bifilar.

Unkissing at R in (C) we obtain

$$\mathrm{K}h \ldots e\mathrm{P}m \ldots if \ldots a\mathrm{P}s \ldots$$

an unifilar of $n-1$ crossings, which has every summit of (A) and (B) except R, and every edge of them but the four PR's. And by unkissing at P in (C) we get another such unifilar. This proves

Theorem H.—If at their odd 2-gons PR, PR, we unite the unifilars K_{e+2} and L_{n-e} by the section *ffc*, we construct a bifilar M_n, which yields by unkissing at P and at R, two unifilars each of $n-1$ crossings.

7. (*e*) *Even on Even of Unifilars.*—Let

$$\ldots a\mathrm{PR}h \ldots f\mathrm{RP}e \ldots \qquad \text{(A)}$$
$$\ldots s\mathrm{PR}i \ldots k\mathrm{RP}m \ldots \qquad \text{(B)}$$

be the circles of two unifilars having each an even 2-gon PR. Uniting them at those 2-gons by the section *ffc*, we get the knot M_n whose R linear section PR shows at P the angle $e\mathrm{P}a$ over $s\mathrm{P}m$, e and s on the left, and at R the angle $h\mathrm{R}f$ over $i\mathrm{R}k$, h and i on the left. Call this figure (C). Reading from e and h in (C) we get two circles

$$\ldots ePm \ldots sPa \ldots, \text{ and } hRh \ldots iRf \ldots,$$

of the bifilar M_n.

Unkissing at R we get the circle

$$\ldots hi \ldots kf \ldots$$

which contains neither of the sequences $e \ldots a$ and $m \ldots s$, so that its knot of $n-1$ crossings is no unifilar.

Unkissing at P, we get the circle

$$\ldots me \ldots as \ldots$$

which contains neither $i \ldots k$, nor $f \ldots h$, and is not the circle of an unifilar. Both the knots of $n-1$ crossings are plurifils. This proves

Theorem J.—If at their even 2-gons PR, PR, we unite two unifilars K_{e+2}, and L_{n-e} by the section fc, we construct a bifilar knot M_n, which gives by unkissing at P and R two plurifil knots each of $n-1$ crossings.

8. (*f*) *Bifilar on Odd of Unifilar.*—Let

$$\ldots aPRb \ldots \text{ and } \ldots cPRd \ldots \qquad (A)$$

be the circles of a bifilar knot having the bifilar 2-gon PR. And let

$$\ldots ePRf \ldots hPRg \ldots \qquad (B)$$

be the circle of an unifilar, on which is the odd 2-gon PR. Drawing the angle aPc covertical over hPe, a and h on the left, and bRd covertical over gRf, b and g on the left, we have the crossings P and R of M_n constructed by the union of the knots at their 2-gons PR. Call this figure (C). Reading from a in (C) we find the circle

$$\ldots aPe \ldots gRd \ldots cPh \ldots fRb \ldots$$

of this M_n, showing that it is unifilar. Unkiss now at R in (C); we get.

$$\ldots Fd \ldots cPh \ldots$$

a circle of the knot so formed of $n-1$ crossings, which contains neither $d \ldots a$, nor $g \ldots e$; so that the knot is not unifilar; and by unkissing at P, we form another plurifil knot of $n-1$ crossings. This proves

Theorem K.—If we unite the bifilar knot K_{e+2} at its bifilar 2-gon PR to the unifilar L_{n-e} by its odd 2-gon PR, we construct an unifilar M_n of n crossings, which yields by unkissing at P and at R two plurifil knots each of $n-1$ crossings.

9. It is evident from the above reasoning that in the construction of M_n which has a linear section PR, at which by unkissing two unifilars of $n-1$ crossings can be got, we are in every case to use one of the Theorems E, F, G, H, in articles 3, 4, 5, 6; and that these are both necessary and sufficient rules. By them we can form all the required unsolid knots M_n without omission or repetition.

We have only to lay e upon $n-e$, *i.e.* K_{e+2} upon L_{n-e}, where $e+2 \ngtr n-e$, beginning at $e=2$.

In forming the unsolid knots (M_{12}) which I herewith present to Professor Tait, I have begun with $e=4$; *i.e.*, I have laid 4 upon 8, and 5 upon 7. For not only is the number of figures for $e=2$ and $e=3$ enormous, but I am sure that they would be of no service to Professor Tait, in his rapid handling of his twists. Nor am I at all sanguine in the hope that these results for $e=4$ and $e=5$ will assist him except by furnishing a ready mode of verifying the most complex work of his grouping of the 11 folds with which I have had the honour to supply him. I have for myself never attempted this task of grouping the twisted knots of eight or more crossings, as this problem appears to me of less consequence than an accurate census of the knots with a description of their symmetry.

10. I should have remarked in my paper "On the Twists, &c.," that a complementary pair of n-fold unsolids will give only one couple of convertible $(n-1)$ folds, if each of the pair has P and R alike, which can be only when a zonal trace passes between P and R. And I was in error in saying that "every 9-fold so got from P and R alike is a 9-fold having a triangular section at which it can be twisted into its reflected image." The truth is that every $n-1$-fold got from P and R alike on the knot M_n, whether M_n has or has not a complementary, is a knot which has a triangular section at which it can be twisted either into itself or into its reflected image.

I believe that no M_{12} that I have drawn, which has no complementary about the section PR, has P and R alike; and that such drawn M_n will always give a pair of mutually convertibles.

11. Every K_{e+2} imposed on L_{n-e} in the (M_n) above constructed is supposed to be either a subsolid defined in page 283 of *Trans. R.S.E.*, vol. xxxii. part 2; or such a subsolid carrying a plural flap, of which neither P nor R is a crossing.

In laying 4 on 8, I have never laid 2·2 on 8; nor have I laid 2·3 nor 3·2 on 6 (*vide*, for this kind of operation, the memoir above cited); and this for the reason given in art. 9.

12. The number of unsolid knots (M_{12}), a portion of U_{12} (see my paper "On the Twists, &c."), which I herewith offer, is 577, of which 199 are bifilars and 378 unifilars. They are few in comparison of the entire U_{12}. As they will be useful, if ever the 12-fold knots are wanted, it is worth the while to give a summary of them, which will, to a student working on this subject, be of almost as much service as the 577 engraved figures. The references to $_7$A, &c.; $_8$A, &c., are to knots nearly all engraved in my plates in the *Trans. R.S.E.*, and clearly given in the text when not engraved.

Under the heading, *Bifilar on bifilar*, 4 on 8, are 47 bifilars, constructed on

$_8$A 2,	$_8$P 2,	$_8$V 2,	$_8$B*l* 6,
$_8$C 4,	$_8$R 4,	$_8$A*w* 6,	$_8$B*m* 2,
$_8$D 2,	$_8$S 3,	$_8$B*a* 1,	$_8$B*x* 3, of
$_8$I 4,	$_8$U 4,	$_8$B*k* 2,	the 47.

Under *Even of unifilar on bifilar*, 4 on 8, are 67 unifilars, constructed on

$_8$A 3,	$_8$P 3,	$_8$V 3,	$_8$B*l* 7,
$_8$C 6,	$_8$R 5,	$_8$A*w* 9,	$_8$B*m* 2,
$_8$D 3,	$_8$S 3,	$_8$B*a* 2,	$_8$B*x* 6, of
$_8$E 6,	$_8$U 4,	$_8$B*k* 3,	the 67.

Under *Bifilar on even of unifilar*, 4 on 8, are 47 unifilars, constructed on

$_8$E 4,	$_8$Q 1,	$_8$A*v* 4,	$_8$B*w* 5,
$_8$F 1,	$_8$Y 1,	$_8$A*x* 6,	$_8$B*z* 3.
$_8$G 4,	$_8$A*t* 4,	$_8$B*n* 4,	
$_8$L 4,	$_8$A*u* 4,	$_8$B*v* 2,	

Under *Odd on even of unifilars*, 4 on 8, are 88 unifilar knots, constructed on

$_8$E 8,	$_8$Q 2,	$_8$A*v* 8,	$_8$B*v* 2,
$_8$F 2,	$_8$Y 2,	$_8$A*x* 12,	$_8$B*w* 8,
$_8$G 8,	$_8$A*t* 8,	$_8$B*n* 6,	$_8$B*z* 5.
$_8$L 8,	$_8$A*u* 8,	$_8$B*q* 1,	

Under *Even on odd of unifilars*, 4 on 8, are 81 unifilar knots, constructed on

$_8$B 3,	$_8$T 3,	$_8$A*x* 3,	$_8$B*q* 4,
$_8$E 3,	$_8$X 3,	$_8$A*z* 12,	$_8$B*v* 6,
$_8$F 3,	$_8$A*b* 3,	$_8$B*i* 6,	$_8$B*w* 3.
$_8$G 3,	$_8$A*u* 3,	$_8$B*j* 12,	
$_8$Q 3,	$_8$A*w* 6,	$_8$B*n* 3,	

Under *Odd on odd of unifilars*, 4 on 8, are 108 bifilar knots constructed on

$_8$B 4,	$_8$T 4,	$_8$A*x* 4,	$_8$B*q* 4,
$_8$E 4,	$_8$X 4,	$_8$A*z* 16,	$_8$B*v* 4,
$_8$F 4,	$_8$A*t* 4,	$_8$B*i* 8,	$_8$B*w* 4.
$_8$G 4,	$_8$A*u* 4,	$_8$B*j* 8,	
$_8$Q 4,	$_8$A*w* 4,	$_8$B*n* 4,	

Under *Bifilar on bifilar*, 5 on 7, in which of K_{5+2} and L_{12-5} either is laid on the other, are 36 bifilars, on

$_7F_7F$ 4,	$_7F_7R$ 2,	$_7K_7R$ 2,	$_7N_7N$ 2,
$_7F_7K$ 4,	$_7K_7K$ 4,	$_7M_7M$ 2,	$_7N_7R$ 2,
$_7F_7M$ 2,	$_7K_7M$ 2,	$_7M_7N$ 2,	$_7N_7R$ 2.
$_7F_7N$ 2,	$_7K_7N$ 2,	$_7M_7R$ 2,	

Under *Even of unifilar on bifilar*, 5 on 7, are 63 unifilars, constructed on

$_7C_7F$ 4,	$_7D_7F$ 4,	$_7E_7F$ 8,	$_7L_7F$ 2,
$_7C_7K$ 4,	$_7D_7K$ 4,	$_7E_7K$ 8,	$_7L_7K$ 2,
$_7C_7M$ 2,	$_7D_7M$ 2,	$_7E_7M$ 4,	$_7L_7M$ 1,
$_7C_7N$ 2,	$_7D_7N$ 2,	$_7E_7N$ 4,	$_7L_7N$ 1,
$_7C_7R$ 2,	$_7D_7R$ 2,	$_7E_7R$ 4,	$_7L_7R$ 1.

Under *Odd on even of unifilars*, 5 on 7, are 32 unifilars, constructed on

$_7E_7C$ 4,	$_7E_7L$ 2,	$_7L_7E$ 4,	$_7U_7D$ 1,
$_7E_7D$ 4,	$_7L_7C$ 2,	$_7L_7L$ 1,	$_7U_7E$ 2,
$_7E_7E$ 8,	$_7L_7D$ 2,	$_7U_7C$ 1,	$_7U_7L$ 1.

Under *Odd on odd of unifilars*, 5 on 7, are 8 bifilars, constructed on

$_7E_7E$ 4,	$_7E_7L$ 2,	$_7E_7U$ 1,	$_7L_7U$ 1.

Every one m_{12} of these 577 knots gives by unkissing at P and R of its linear section PR two unifilar 11-folds which, if the knot m_{12} has no complementary about PR, can be twisted either one into the other, and which, if m_{12} has a complementary, are two knots in a group of mutually convertibles, if I rightly conceive the matter. But not every two in a group can be twisted each into the other by a single twist. When m_{12} has a complementary, two pairs of unifilar 11-folds are thereby given, each pair being two knots convertible into each other by a single twist, and both pairs, if I am not in this point mistaken, belonging to the same group.

When m_{12} has a complementary about PR, it stands drawn next to m_{12} among the 577 figures herewith presented.

I have had no difficulty in the cases 1 and 2 of art. 1, because I have the bifilars of 8 and 9 crossings. As the bifilars of ten crossings are not before the student, he may find it useful to know how to lay 2 of the unifilar K_{2+2} on the bifilar L_{12-2}, without drawing the bifilar 10-folds, and by inspection only of the unifilar 9-folds. The rule is this:—Make every odd angle at the crossing P of an unifilar 9-fold covertical with the figure P*ab*, *ab*R; *i.e.*, with two triangles collateral with the 2-gon *ab* and having their third angles at P and R in the constructed linear section PR. Every result of laying an even 2-gon on a bifilar 2-gon of a 10-fold is thus obtained. The proof of this is easy by my theorems A and C given recently in these *Proceedings*, applied to the figure P*ab* *ab*R on the 12-fold completed by it. By similar devices the use of bifilar bases and charges can always be evaded in our constructions.

Fig. I.

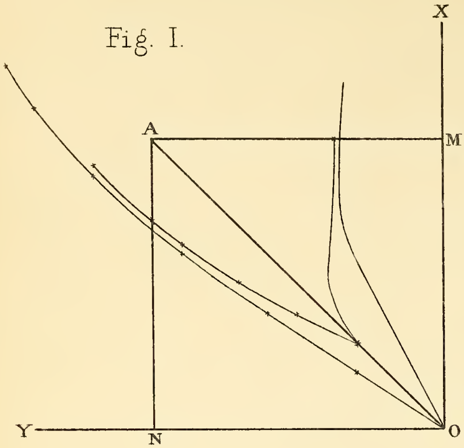


Fig. II.

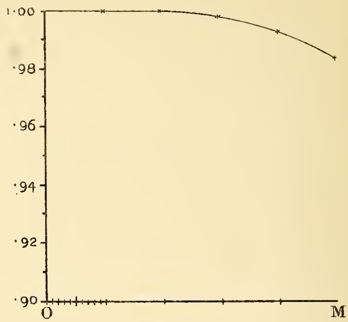


Fig. III.

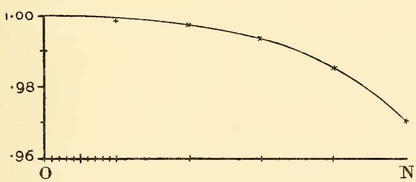


Fig. IV.

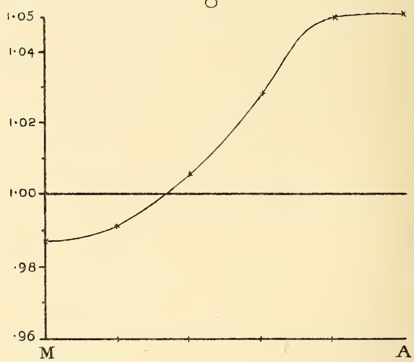


Fig. V.

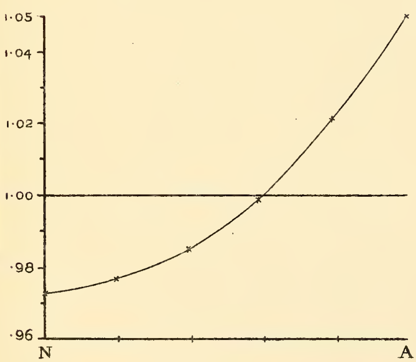
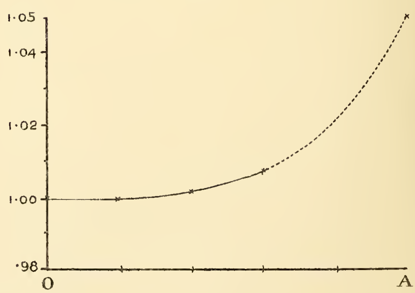


Fig. VI.



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5. Experiments on the Field of a Helmholtz Tangent Galvanometer. By R. Ellis, C.E.; R. D. Clarkson; and H. Rainy, M.A. (Plate XVIII.)

The object of the following experiments, which were suggested by Professor Chrystal, was to determine the relative values of the intensity of the horizontal component of magnetic force, due to a current flowing in the coils of the Helmholtz galvanometer, for different parts of its field.

The experiments were conducted as follows :—A sheet of ground glass was carefully ruled into squares, whose sides were 1 cm. long, and it was placed horizontally within the coils of the Helmholtz galvanometer. On it stood a sensitive reflecting galvanometer, the horizontal plane of the centre of the mirror containing, as nearly as possible, the axis of the coils of the Helmholtz galvanometer. The position of the sensitive galvanometer with reference to the centre of the Helmholtz field could be readily obtained by means of the graduated glass plate.

For the first experiment the sensitive galvanometer was placed in the centre of the field, when a current was split and the two parts sent in opposite directions through the coils of the sensitive galvanometer and of the Helmholtz respectively; resistances being added to the former circuit until no deflection of the needle took place. The resistance of the whole circuit of the sensitive galvanometer was then determined; after which the experiment was repeated to guard against any accidental error. The sensitive galvanometer was then removed to the next point of the field which was to be tested, and the same process repeated; when the intensity at that point (that at the centre being taken as unity) was obtained by dividing the former by the latter resistance.

The error in placing the sensitive galvanometer was within ± 1 mm. at any part of the field; the error in the graduation of the glass plate was less than 1 per cent. A very slight alteration of the resistance inserted in the circuit—less than ·0001 of the total—produced a very considerable deflection.

No perceptible error was introduced if the axes of the two instruments were slightly inclined to each other, instead of being exactly parallel. If the axes of the instruments made with each other an angle of $\tan^{-1} 1/6$ [*i.e.*, $\tan^{-1} 1 \cdot \dot{6} = 9° \ 28'$], scarcely any difference was perceptible in the readings from those taken with the axes parallel; a marked difference is visible if the angle be $\tan^{-1} 1/3$ [*i.e.*, $\tan^{-1} \cdot \dot{3} = 18° \ 26'$].

Experiments repeated with a small galvanometer on the Helmholtz model instead of the sensitive galvanometer, proved that no great error had been introduced by any accidental change of relative position between the coils and needle of the reflecting galvanometer, such as might have been produced by a slight tilt to the side.

The dimensions, &c., of the coils of the Helmholtz galvanometer are as follows :—

Each coil consists of 16 turns of wire, and is of rectangular section. The wire is wound on in 4 layers, each of 4 turns. The mean radius of both coils is 24·65 ± ·02 cm., the distance between their centres is 24·51 cms. The following are the measurements for each layer :—

Bed of coils, . . .	24·18 cm.
Outer side of 1st layer, . .	24·41 cm.
„ 2nd „ . .	24·66 cm.
„ 3rd „ . .	24·89 cm.
„ 4th „ . .	25·12 cm.

Explanation of the Tables.

The tables are arranged as follows :—In the first column is a reference number to the experiment; in the second column the position of the centre of the needle is recorded; y being the direction along the Helmholtz axis, and x the direction perpendicular to y in the horizontal plane; the numbers being the distances in cms. from the origin. The third column contains the values of the resistance $\mathfrak{r}$ of the reflecting galvanometer circuit; the fourth the logarithms of these resistances; the fifth the resulting value of the intensity $\mathfrak{J}$ of that point of the field, obtained by the formula $\mathfrak{J} = \frac{\mathfrak{r}'}{\mathfrak{r}}$, where $\mathfrak{r}'$ is the value of $\mathfrak{r}$ for the centre of the field; while the sixth shows the difference of each value of $\mathfrak{J}$ from that preceding it, except in the case of Exp. VII., where the difference is between the value of $\mathfrak{J}$ for its position, and that at the centre.

There is also a table giving two series of pairs of points, the value of $\mathfrak{J}$ being constant throughout each series. Thus there are two points in every quadrant, for *each* value of x, which give the same value of $\mathfrak{J}$.

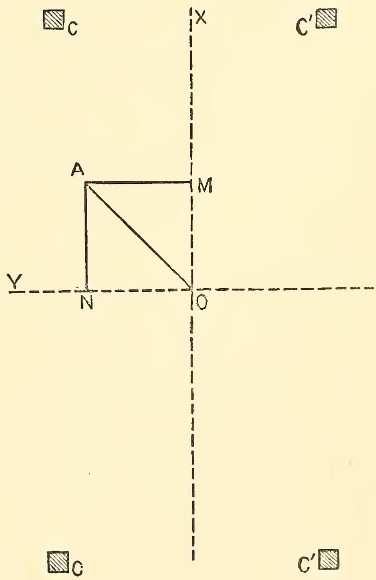
Explanation of the Diagrams (*Plate XVIII.*).

Fig. 1 represents a portion of the Helmholtz field, where O is the centre, and OY the axis. The two pairs of curved lines are of equal values of $\mathfrak{J}$, being constructed from the data given in the last table. The scale in this figure is 5 divisions per cm.

Figs. 2, 3, 4, and 5 represent the values of $\mathfrak{J}$ along OM, ON, MA, and NA respectively; the scale for the distance along these lines being in every case 5 small divisions per cm. along the one co-ordinate, while the values of $\mathfrak{J}$ are measured along the other.

In fig. 6 the values of $\mathfrak{J}$ along OA are represented; but, as it is inconvenient to represent the actual distances of the points along the diagonal on same scale, the distances from the centre of their projections on the axis are substituted.

The accompanying sketch represents the whole of the horizontal section along the axis of the Helmholtz, indicating the position of the part of the field given in fig. 1, CC and C′C′ being the two coils, and OY the axis of the galvonometer.



Number of Expert.	Position. x,	y.	ξ	Log ξ.	$\mathfrak{J}$	Differences.
I.	0,	0	68·360	1·8348021	1·000000	·000000
II.	2,	0	68·360	1·8348021	1·000000	·000000
III.	4,	0	68·360	1·8348021	1·000000	·000000
IV.	6,	0	68·523	1·8358364	·997621	– ·002379
V.	8,	0	68·840	1·8378409	·993027	– ·004594
VI.	10,	0	69·380	1·8412343	·985298	– ·007729
VII.	0,	2	68·506	1·8357286	·997869	– ·002131
VIII.	0,	4	68·563	1·8360898	·997039	– ·000830
IX.	0,	6	68·810	1·8376516	·993460	– ·003579
X.	0,	8	69·360	1·8411091	·985582	– ·007878
XI.	0,	10	70·380	1·8474493	·971298	– ·014284
I.	0,	0	68·880	1·8380931	1·000000	
XII.	2,	2	68·880	1·8380931	1·000000	·000000
XIII.	4,	4	68·710	1·8370199	1·002473	+ ·002473
XIV.	6,	6	68·360	1·8348021	1·007607	+ ·005134
I.	0,	0	68·140	1·8334021	1·000000	
XV.	0,	10	69·920	1·8446014	·974542	[– ·025458]
XVI.	2,	10	69·730	1·8434197	·977063	+ ·002521
XVII.	4,	10	69·175	1·8399492	·985038	+ ·007975
XVIII.	6,	10	68·180	1·8336570	·999413	+ ·014375
XIX.	8,	10	66·720	1·8242560	1·021283	+ ·021870
XX.	10,	10	64·860	1·8119769	1·050570	+ ·029287
I.*	0,	0	68·0927	1·83310049	1·000000	
XXI.	10,	0	68·957	1·8385784	·987466	[– ·012534]
XXII.	10,	2	68·690	1·8368935	·991304	+ ·003838
XXIII.	10,	4	67·483	1·8291944	1·009035	+ ·017731
XXIV.	10,	6	66·390	1·8221027	1·025646	+ ·016611
XXV.	10,	8	64·844	1·8118698	1·050100	+ ·024454
XXVI.	10,	10	64·815	1·8116755	1·050570	+ ·000470

* Calculated value.

The following positions required no alteration in the value of ξ :—

Set I.

x.	y.	
0·0	0·0	
2·0	1·0	3·0
3·3	...	4·0
4·0	...	6·0
5·6	...	8·0
6·0	3·0	9·0
7·2	...	10·0
8·7	...	12·0
10·0	3·5	...
11·1	...	14·0
12·0	3·4	...
12·6	...	15·0

Set. II.

x.	y.	
3·0	3·0	
5·0	4·0	
6·4	...	9·0
7·0	3·9	...
7·3	...	10·0
9·1	...	12·0
10·0	3·6	...

6. On the Partition of Energy between Systems of Colliding Spheres. By Professor Tait.

7. On the Effect of Pressure on the Maximum Density Point of Water. By Professor Tait.

8. Chemical and Microscopical Studies on the Action of Salicylic Acid on Ferments. By Dr A. B. Griffiths, F.R.S.E., F.C.S. (Lond. and Paris), Lecturer on Chemistry, Technical College, Manchester, &c.

My attention has been occupied of late with a chemical and microscopical study on the action of various compounds on the lower forms of plant-life. I have already presented to the Chemical Society of London a paper on the Action of a Solution of Ferrous Sulphate on certain Parasitic Diseases which attack our Crops. (This paper will be published presently.) I wish here to detail some studies on the action of salicylic acid ($C_7H_6O_3$) on certain ferments (organised and unorganised). A solution of salicylic acid was prepared containing 0·2 gram. of the acid in 1000 c.c. of water.

A drop of yeast was placed upon a slide under the microscope, and then a few drops of the above salicylic acid solution was run in between the slide and cover-slip, when I found that it had no action on the true alcoholic ferment, for I was *unable* to stain the protoplasm of the cells with a solution of eosin, showing that the protoplasm was not dead. But, when I operated in a like manner on certain other organised ferments, namely, *Mycoderma aceti*, *Bacterium lactis*, and the *Butyric bacillus*, it was very different. On running in the same salicylic acid solution upon slides containing these various ferments they were quickly destroyed. What was observed under the highest powers of the microscope was that the salicylic acid acts chemically upon the cellulose, or the form of cellulose making the external walls of these lowly organisms. It was evident that the acid dissolved the cellulose wall, and in some cases I could see that the cellulose wall had been perforated by the acid solution.

Beyond these facts, I have found that the above named aqueous solution of salicylic acid also prevents the chemical action of hydration by means of the soluble zymases. If yeast is added to a solution of cane sugar, and to this solution the salicylic acid solution is added, *no* decomposition according to the following equation takes place:—

$$C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 + C_6H_{12}O_6 .$$

That is, the salicylic acid has acted upon the soluble zymase which is secreted by the *Torula cerevisiæ.* Hence no fermentation takes place. I allowed the above to stand for two or three days at a temperature most suitable to engender alcoholic fermentation (about 80° F.), and then tested for glucose sugars by means of Fehling's solution without any result.

I also tried the action of salicylic acid solution upon a solution of starch which had previously been inoculated with a small quantity of saliva. After standing several days, I could not find the smallest trace of glucose sugar.

From this, salicylic acid acts upon the soluble ferment (ptyalin) contained in saliva, preventing the hydrating action upon the amyloses.

Then again, I have found that the above solution of salicylic acid acts chemically upon the cellulose walls of *dead* Torulæ, destroying them in a similar manner to the organised ferments already described at the commencement of this paper, but it has no action on the *living* Torula. This shows that a chemical change must have taken place in the molecular structure of the cellulose wall of the cell after the death of the organism.

It is a well-known fact, that in every brewery the yeast becomes deteriorated at certain times, and hence the beer brewed by such yeast is not so good as formerly. This is due to "diseased ferments" in the yeast (viz., the organisms I have alluded to in the early part of this paper). The common remedy is for the brewer to change his yeast. But I have found that this is not essential, if the brewer waters the "diseased yeast" (*i.e.*, yeast containing these thread-like ferments) with a solution of salicylic acid, the "disease ferments" are all destroyed, and the yeast is not acted upon by this solution. Yet at the same time the yeast so treated is not so active in its decomposition of a glucose solution into alcohol. This yeast can be revivified by an aqueous solution containing 0·25 gram. of potassium nitrate and 0·2 gram. of sodium phosphate in 2000 c.c. of water. In fact, the Torula appears to decompose a much larger quantity of sugar (in wort) into alcohol in a given time after the above salts have been added to 2 titres of wort than when the wort is not so treated. It appears that the Torula lives its life-history to a certain extent by extracting the potash and phosphoric acid from the compounds containing them, which come into the wort from the barley and hops. Mitscherlich long ago showed that the ash of yeast gave no less than 53 to 59 per cent. of phosphoric acid, and from 28 to 39 per cent. of potash. Hence it may be that a larger amount of alcohol would be produced in beers by the addition of small quantities of the above substances to the wort.

From the above investigations the following conclusions are to be drawn :—

1. That a certain solution of salicylic acid has *no* action upon the *living* Torula, but dissolves it when dead; thus showing that some chemical change (post-mortem) has taken place in the cellulose of the cell-wall.

2. That the solution of salicylic acid destroys "disease ferments," by acting upon the cell-walls; showing that their cellulose most probably differs from the cellulose of the *Torula cerevisiœ.*

3. That the solution of salicylic acid prevents the hydrating action of the various soluble zymases.

4. A solution of sodium phosphate and potassium nitrate revivifies exhausted yeast, and even increases the yield of alcohol in saccharine solutions.

5. Salicylic acid acts as an antiseptic agent of great value, because it acts directly upon the "disease ferments" in beers, and not upon the true alcoholic ferment.

6. Salicylic acid is not a poison in quantities far exceeding the amount in the solution given in this paper. This acid is largely used in France and Germany as a medicine.

For those interested in the application of this acid in medicine, I refer them to the following excellent memoirs :—

(*a*) Wagner's "Le traitement de la diphterie des maladies de l'estomac et des intestins," *Moniteur Scientifique,* 1885, p. 354; also *Journal für praktische Chemie,* xi. pp. 57 and 211.

(*b*) Dr Germain See's "L'acide salicylique et le salicylates dans le traitement de la goutte et des rhumatismes," *Rapport à l'académie de Médecine de Paris*, June and July 1877.

(*c*) Fontheim's "De l'action de l'acide salicylique employé comme médicament," *Moniteur Scientifique*, 1875, p. 853.

PRIVATE BUSINESS.

Letters were read by the Secretary from Mr Dudgeon of Cargen, and from Mr Aitken, on the recent display of Iridescent Clouds.

Mr A. J. G. Barclay was balloted for, and declared duly elected a Fellow of the Society.

Monday, 18th January 1886.

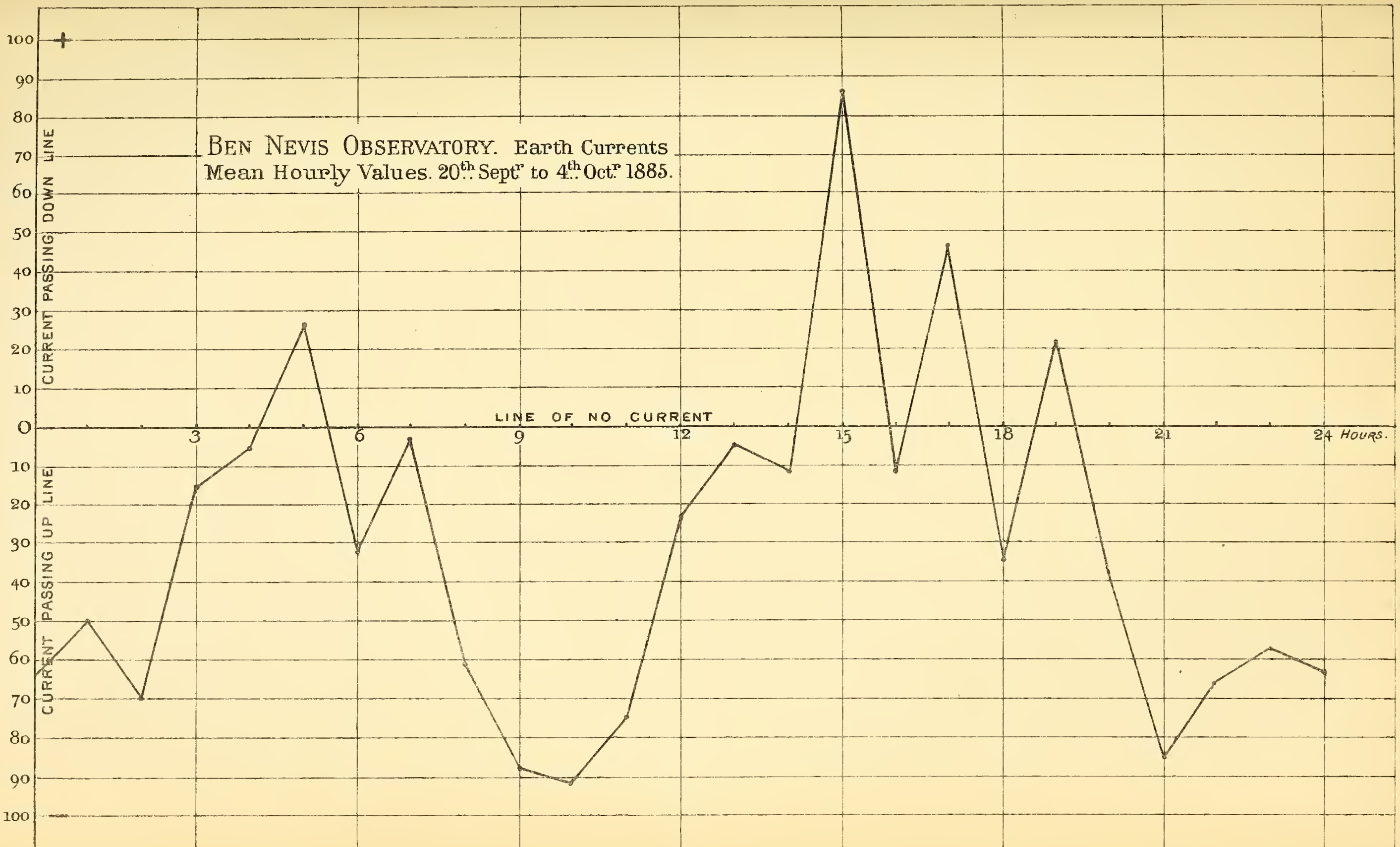
SHERIFF FORBES IRVINE, Vice-President, in the Chair.

The following Communications were read:—

1. On the Relation between the Densities and the Atomic Weights of the Elements. By Professor Crum Brown.

2. Observations on Earth-Currents in Ben Nevis Observatory Telegraph Cable. By H. N. Dickson. (Plate XIX.).

Telegraphic communication between Ben Nevis Observatory and Fort-William Post Office is kept up by means of a line which consists of an ordinary telegraph wire from Fort-William to Auchintee Farm at the base of the mountain, and a cable laid underground from thence to the summit. At Fort-William the wire is put to earth in the usual way, while at the Observatory the return wire is attached to the iron-wire sheath of the cable. Formerly the wire was worked by means of Wheatstone's ABC instruments, but in April last these were replaced by single needle "sounders." With both instruments the presence of earth-currents has been frequently observed, occasionally of such strength as to interfere with the proper transmission of signals, and from the working of the needle



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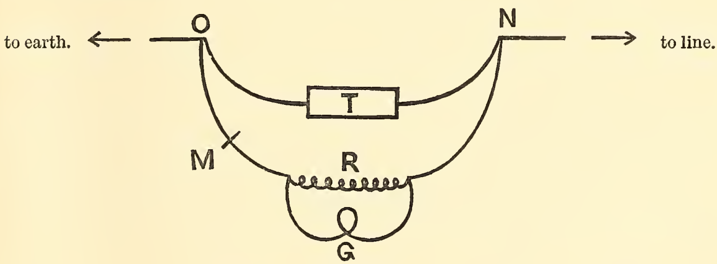
instrument especially, I was led to suppose that these currents were always present, and that they were subject to more or less regular variations, both in direction and intensity.

A detailed investigation would require more elaborate electrical apparatus than can at present be obtained at the Observatory, and would interfere with the ordinary use of the wire. The observations which form the subject of this communication were made entirely by means of a Thomson mirror galvanometer, and were so arranged as not to affect in any way the transmission of signals in either direction.

A preliminary trial was first made by putting a coil of copper wire in circuit, and placing in the field an ordinary pocket-compass. When this was done no observable deflection could be obtained. The mirror galvanometer was then put in, and after a few further trials the arrangement shown below was adopted, and found to give suitable deflections.



In the figure O is binding screw leading to wire attached to sheath of cable.

N, binding screw attached to line wire of cable.

T, telegraph instrument.

A coil R, consisting of 24 feet of iron wire, No. 17 B.W.G., was attached to O and N, along with the telegraphic instrument, and in multiple arc with this the galvanometer G was inserted. Contact was broken at M, except while readings of G were actually being taken, so that no part of the current was diverted from the telegraph instrument. As no means of accurately measuring resistance was at hand, absolute measurements of the current passing at any time could not be obtained, but a rough estimate from tables of resistances of iron wire gave R = about 0·4 ohms; and the resistance of the telegraph instrument is not less than 200 ohms. The resistance of the galvanometer was given at 22·9 ohms, so that about $\frac{1}{60}$ of the whole current may be taken as the fraction passing through G. The galvanometer was powerfully controlled by external magnets, the time of vibration of the mirror being extremely short. The direction of the currents was determined directly by comparing the deflections due to them with those given by a Daniell cell.

We can by means of this arrangement ascertain at any time the direction of the currents passing through the line, and observe the variations in intensity from time to time. These currents I have assumed to be due to a difference of potential between the earth at Fort-William and the summit, and I think we are justified in treating the sheath of the cable as equivalent to an earth-plate at the Observatory, but it would be advisable in further investigations to have an actual earth-plate similar to that at the other end.

The observations extend from 20th September to 4th October 1885, and are hourly, the readings being taken just before the usual hourly meteorological observations. The curve of hourly values obtained by taking the mean deflection for each hour during the successive days shows a well-marked daily variation. During the early part of the night we have a current passing through the cable *up* the hill, which appears to reach a maximum at 21 hours, and again at 2 hours. After 2 hours a rapid diminution takes place, and at 5 hours we have the current reversed. Immediately after this the potential at the summit again falls relatively to that at Fort-William, and we have a current coming up, increasing in strength to a well-marked maximum at 10 hours. This is succeeded by another equalisation, and the current is again reversed about 13 hours, after which it passes *down* the line till about 18 hours. This part of the curve, however, is much more irregular, the current being very unsteady. After 18 hours the current again sets in an upward direction through the line, increasing pretty regularly till the maximum at 21 hours.

During the time over which these observations extend, the summit of Ben Nevis was almost continuously enveloped in fog or mist, and a succession of heavy storms passed over the Observatory about the end of September. The daily curve shown may therefore be taken to hold only for conditions under which the air is saturated, and further observations must be made before the actual daily variation can be determined. A careful comparison of the observations with the ordinary meteorological sheets of the Observatory, however, brings out some points of very great interest, especially when looked at in the light of the theory advanced by Professor C. Michie Smith, in a paper communicated by him to the Society on 1st June 1885 (*Trans. R.S.E.*, xxxii. p. 583). As the result of observations on atmospheric electricity, made on the summit of Dodabetta, the highest hill in the Neilgherries, Professor Smith finds that on the edge of a *dissolving* mist the potential is lower than the normal, while it is higher on the edge of a condensing mist. A study of the following table, with the notes appended, shows at once that in nearly every case where the top of Ben Nevis became clear for a short time, a strong current was found coming *up* the line, while as soon as the summit was again enveloped, the current was reversed. The connection between the moisture of the air and the earth currents is still further shown by studying the rainfall. During a fall of rain or snow the current is almost always found to pass *down* the cable; and, in the case of a sudden shower, the current sometimes drove the mirror of the galvanometer violently off the scale. A cessation of rain or snow will be seen in most cases to have exactly the opposite effect.

If we assume that the summit of Ben Nevis takes the potential of the masses of vapour covering it, and consider the earth-plate at the base as the real "earth" or zero of potential, it is at once obvious that these results agree with those of Professor Smith, and form important additional evidence of the truth of his theory, a conclusive proof of which would be of the greatest value in investigations connected with thunderstorms.

Following out the above conclusions, we should expect the mean daily curve for earth currents to be intimately connected with that for relative humidity, but as yet no observations have been taken except in saturated air. Further study of the curves shows that the currents are probably affected by other causes besides those connected with cloud. The approach of cyclones seems to disturb the electrical conditions to a certain extent, but the observations are not sufficiently numerous to allow of any definite inferences being drawn. My object in writing this paper has been chiefly to draw attention to the great additions which a complete series of electrical observations, made at Ben Nevis Observatory, would be likely to make to our knowledge of these subjects, if the experimental difficulties in the way could be surmounted.

The figures given represent the deflection of the spot of light of the galvanometer, in scale-divisions.

The sign + prefixed to a figure indicates that the current passed through the galvanometer *down* the line-wire to Fort-William. The opposite direction is indicated by a − sign. The sign ± indicates that the current was variable in direction. ±0 indicates that the current was extremely faint, the spot of light oscillating about the zero-point. The sign ∞ indicates that the spot of light was driven off the scale altogether. Where the current was very unsteady, the figures are in old style type.

September 20.—Ridge of high pressure between two cyclones, one lying to south-west and one to north-east. Centre of former advancing towards Denmark in afternoon.

21.—Decided change of wind from north-easterly to westerly at 12 hours. Barometer rising all day, with temporary dip, accompanied by southerly wind, from 18 to 20 hours.

22.—Depression with centre well out to north-west at 8 hours, passed to northwards in afternoon. Anticyclone to south-east. Rain in morning, diminishing from 11 hours to 13 hours, when wind shifted slightly; heavy rain at 17 hours. Wind backing till 18 hours, when it blew from south by west. Barometer fell till 14 hours, steady till 17 hours, after which fall continued till 22 hours. Temperature rising at night.

23.—Cyclone, centre to north-west going eastwards. Anticyclone to south-east, moving over Italy. Wind shifted more to north at 4 hours, and rain stopped, with temperature falling rapidly. Shower between 8 hours and 9 hours. Mist clearing at 10 hours—on again after 13 hours. A little snow, with shift of wind to easterly, at 16 hours. Wind changed to south-westerly, followed by snow, after 22 hours.

24.—Cyclone to north-east off coast of Norway—centre travelling eastwards along 70th parallel N. lat. Centre of anticyclone shifted to south-west of Ireland since 8 hours of previous day. Snow fell till 8 hours and after 11 hours. Currents and meteorological condi-

Table of Currents.

	Date.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
September 1885, .	20	...	...	...	...	− 6	− 68	− 87	−128	− 62	−150	−110	− 28	+ 80	− 15	+109	+125	+ 39	+ 37	− 69	+ 22	− 88	− 49	− 92	− 38
,, ,, .	21	− 30	+ 29	− 49	+ 55	− 51	− 51	− 30	− 92	− 92	− 90	− 56	+ 18	+ 93	+ 80	+190	± 5	− 55	+ 83	+ 60	+ 29	−107	−107	− 33	− 5
,, ,, .	22	+ 58	− 53	− 20	± 87	+ 99	− 80	−126	−144	−190	−142	+ 45	+ 41	± 13	− 39	+276	−266	−304	−190	+ 74	− 19	−178	− 61	− 58	− 37
,, ,, .	23	− 89	−121	− 36	−245	+ 66	−263	−114	− 54	− 72	−315	+ 21	− 94	± 45	−111	+175	± 24	+190	−181	+126	− ∞	− 22	− ∞	+ 22	− 98
,, ,, .	24	+120	+ 47	+118	+113	+ 29	+ 30	+ 13	− 89	− 44	− 35	−125	− 8	− 13	− 6	+ 39	+ 46	+ 33	+ 21	+ 13	± 0	− 55	−109	−193	−124
,, ,, .	25	± 0	−229	+ 98	+ 25	+139	− 38	+168	− 50	−116	−100	−187	± 20	− 55	− 45	+ 77	+ 86	+243	− 16	+ 30	− 50	− 95	− 79	− 92	− 95
,, ,, .	26	−161	−146	− 20	+ 57	± 24	−102	+ 15	−114	− 97	−143	−168	...	−188	+ 6	+107	− ∞	− 58	+ 78	+ 38	− 25	− 31	− 90	−131	− 41
,, ,, .	27	− 14	− 39	− 4	− 8	+ 86	+ 85	− 35	−100	−240	+ 14	− 91	+ 14	− 48	+ 29	− 51	+164	+458	−311	− 80	− 73	− 72	+ ∞	− 30	−197
,, ,, .	28	− 91	− 40	+ 8	+ 17	+ 22	+ 30	+ 88	+ 7	− 74	− 52	− 97	− 40	+ 50	+ 24	+ 89	+103	+ 20	+ 39	+ 70	+129	− ∞	−296	− 31	−207
,, ,, .	29	− 77	− 28	− 15	− 20	+ 42	+ 44	+ 40	± 7	− 62	− 72	− 13	− 35	− 17	− 45	+105	+ 25	+ 9	− 18	+ 75	+ 12	− 7	− 86	− 67	−192
,, ,, .	30	−161	−113	− 56	+ 95	...	...	...	...	− 25	−144	−185	−117	+ 71	+ 29	+ 30	+ 51	+124	− 93	+ 19	+ 49	+ 9	− 34	− 13	− 48
October ,, .	1	− 65	− 71	− 34	−156	− 70	− 21	+ 59	+ 60	−123	−100	− 88	−102	− 10	− 11	+ 17	+ 6	+ 85	+ 55	17	± 35	+ 14	+ 60	+ 40	+ 57
,, ,, .	2	−230	− 77	− 53	− 48	+ 62	− 71	− 44	−131	+ 13	+ 36	+ 35	+ 51	− 42	− 29	+ 44	− 32	± 0	+ 22	− 11	+ 5	+ 9	+ 10	− 13	+ 34
,, ,, .	3	+ 37	−112	− 35	+ 57	− 34	+ 6	+ 41	+ 55	− 65	− 51	− 42	− 5	− 21	− 95	+ 24	− 15	− 96	− 26	− 10	− 45	− 67	− 24	− 87	+ 62
,, ,, .	4	+ 8	− 22	− 24	− 23	− 3	− 46	− 39	− 72	− 73	− 16	− 64	− 22	+ 18	+ 57	+ 63	+ 40	+ 7	− 15	+ 1	−110	− 84	−133	− 76	− 15
		− 50	− 70	− 16	− 6	+ 26	− 32	− 4	− 61	− 88	− 91	− 75	− 23	− 5	− 11	+ 86	− 11	+ 46	− 34	+ 21	− 38	− 85	− 66	− 57	− 63

tions generally very steady from 6 hours to 12 hours. Wind north-east by east.

25.—Centre of cyclone further eastwards and of anticyclone further westwards. Snow in intermittent showers all day. Fog clearing off at 5 hours, on again at 7 hours; clear from noon till 15 hours and after 23 hours.

26.—Centre of anticyclone further north—off west coast of British Isles. Cyclone advancing southwards and shallower. Fog very thin, clearing occasionally till 3 hours. Top clear from 12 hours till 18 hours, then fog occasionally till 21 hours. Sky cloudless at 22 hours. Snow in forenoon, ceasing at 16 hours. Scud passing at 23 hours.

27.—Anticyclone over south-west of Ireland, and giving way. Cyclone also giving way. Tending towards more uniform distribution of pressure. Rapid rise of temperature after 7 hours. Fog after 14 hours, except at 17 hours, when top cleared. Snow began to fall at 22 hours.

28.—Cyclones lying to north-west of Scotland and over Gulf of Bothnia. Anticyclone over Bay of Biscay. Wind backed till 7 hours, with drizzling rain, changing to heavy rain at 12 hours and sleet after 19 hours, with snow at 22 hours, followed by drizzling rain. Sudden dip of temperature at 21 hours.

29.—Cyclones to north of Shetlands and off north coast of Spain. Very deep depression approaching at night. Snow at 7 hours, with top clear for a short time. Top clear again at midnight.

30.—Galvanometer unworkable from 5 hours to 9 hours, owing to shaking of house by wind. Centre of storm passed at 9 hours.

October 1.—Brush discharge on lightning conductor at 5 hours 5 minutes, and at 14 hours. Cyclone passing off in morning. Another depression approaching from westwards.

2.—Cyclone advancing from westwards. Wind backed till 17 hours; minimum barometer at 18 hours. Very heavy rainfall.

3.—Cyclone passing off in forenoon. Another approaching; barometer began to fall at midnight. Snow all day.

4.—Maximum temperature at 12 hours. Wind backed and increased till 13 hours, veering and diminishing afterwards. Barometer continued falling.

3. On the Partition of Energy among Groups of Colliding Spheres. By Prof. Tait.

(*Abstract.*)

The second, only, of two short papers which I communicated to the Society a month ago, on points connected with the Kinetic Theory of gases, took account of the greater probability of collision between two particles as their *relative* speed is larger. I propose now to calculate the effect of this consideration on the results of my first paper.

The question resolves itself into finding the mean value of the expression

$$\mathrm{Pu}^2 - \mathrm{Qv}^2 - (\mathrm{P}-\mathrm{Q})\mathrm{uv} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

of that paper, in terms of the mean square speeds in the two systems; because, only when this is zero, does kinetic equilibrium set in.

We are here concerned only with collisions between particles belonging one to each system.

In my *Note on the Mean Free Path* (*anté*, p. 397) it is shown that the fraction of a group of particles, having speed v perpendicular to a layer of thickness δx, which collide, at angles from β to $\beta+\delta\beta$, with particles in that layer whose speed is v_1, is proportional to

$$\frac{\delta x}{v}\sqrt{v^2+v_1^2-2vv_1\cos\beta}\,.\sin\beta d\beta\,.$$

Hence, in a given time, the number of such collisions is proportional to

$$\sqrt{v^2+v_1^2-2vv_1\cos\beta}\,.\sin\beta d\beta = \bar{v}\sin\beta d\beta,\ \text{suppose.}$$

Let V, V_1 be the projections of v, v_1 on the unit sphere, C that of the line of centres at collision. Then $\mathrm{VV}_1=\beta$. Let also $\mathrm{VC}=\alpha$, $\mathrm{CVV}_1=\phi$. Finally, let n, n_1, represent the proportionate numbers of particles in the separate systems which have speeds v to $v+\delta v$, v_1 to $v_1+\delta v_1$, respectively. Thus

$$n = \frac{4}{\sqrt{\pi}\,.\,a^3}\varepsilon^{-pv^2}v^2dv\,,$$

$$n_1 = \frac{4}{\sqrt{\pi}\,.\,\beta^3}\varepsilon^{-qv_1^2}v_1^2dv_1\,;$$

where, for simplicity, p is put for $1/a^2$ and q for $1/\beta^2$ in the exponentials. Then, for a v and a v_1, colliding, the mean value of u², the square of the speed of the v in the line of centres, is

$$\frac{\int nn_1\bar{v}\sin\beta d\beta\,.\,v^2\cos^2\alpha\,.\,\sin\alpha d\alpha d\phi}{\int nn_1\bar{v}\sin\beta d\beta\sin\alpha d\alpha d\phi}.$$

Here the limits of α ought to be restricted to a hemisphere of which the direction of relative motion is the axis. But, by extending them to the whole sphere, we merely double each integral, while we avoid some complex relations. We may compensate for this by taking ϕ from 0 to π only. [The same remark applies to the other integrals of this kind with which we have presently to deal.] The above fraction then takes the value

$$\frac{\frac{1}{3}\int nn_1\bar{v}\sin\beta d\beta v^2}{\int nn_1\bar{v}\sin\beta d\beta.}$$

Since $$\bar{v}^2 = v^2 + v_1^2 - 2vv_1\cos\beta,$$
this becomes

$$\frac{\frac{1}{3}\int nn_1\bar{v}^2 d\bar{v}\, v/v_1}{\int nn_1\bar{v}^2 d\bar{v}/vv_1}.$$

In further integrating this, we must remember that the limits of $\bar{v}$ are $v - v_1$ and $v + v_1$, while $v > v_1$, but $v_1 - v$ and $v_1 + v$ while $v < v_1$. Thus the denominator (being symmetrical) consists of two parts, which differ from one another only by the interchange of p and q. The value of the numerator can be found from that of the denominator by differentiation with regard to p and change of sign. When this is done we have for the mean value of u²

$$\frac{3p+4q}{6p(p+q)}$$

This shows how the first and, by parity of reasoning, the second terms of (1) are affected by the new consideration. We might have directly verified this for the second term by evaluating

$$\frac{\int nn_1\bar{v}\sin\beta d\beta\,.\,v_1^2(\cos\alpha\cos\beta+\sin\alpha\sin\beta\cos\phi)^2\,.\,\sin\alpha d\alpha d\phi}{\int nn_1\bar{v}\sin\beta d\beta\sin\alpha d\alpha d\phi},$$

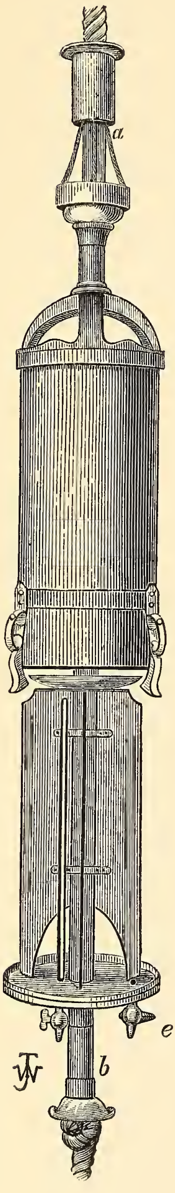


FIG. 1.

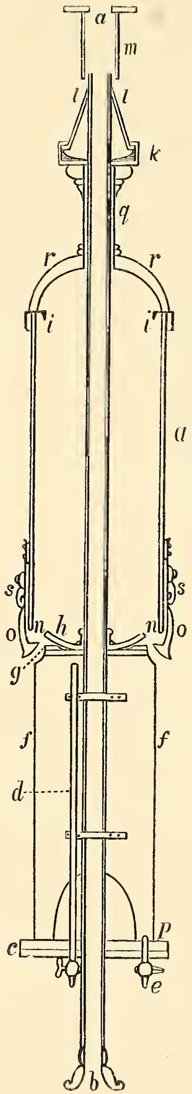


FIG. 2.

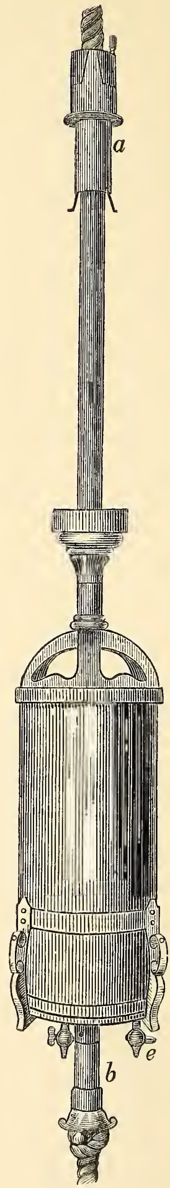


FIG. 3.

[After integration as to a and to ϕ, the part in brackets becomes a multiple of $\cos^2\beta + \sin^2\beta$.]

The average value of the product of the velocity-components along the line of centres (uv of (1)) is

$$\frac{\int nn_1\bar{v}\sin\beta d\beta \, . \, vv_1\cos a(\cos a\cos\beta + \sin a\sin\beta\cos\phi) \, . \, \sin a da d\phi}{\int nn_1\bar{v}\sin\beta d\beta\sin a da d\phi},$$

which is easily by the foregoing process reduced to

$$-1/6(p+q).$$

Thus it appears that the average value of (1), written in the form

$$P(u^2 - uv) - Q(v^2 - uv)$$

is, term for term,

$$2P/3p - 2Q/3q,$$

or, in the usual notation,

$$\frac{2}{3}\left(Pa^2 - Q\beta^2\right),$$

so that Maxwell's Theorem is proved.

[*March* 15, 1886.—There is an error here, due to a wrong assumption as to the probabilities of various positions of the line of centres. It does not vitiate the proof, as it introduces a mere numerical factor of the whole quantity. See p. 644.]

4. On Water-Bottles, with the Description of a new form of Slip Water-Bottle. By Hugh Robert Mill, D.Sc., Scottish Marine Station. (Plate XX.)

The various forms of apparatus employed for procuring samples of water from beneath the surface are either designed to take up as a sample a mixture of the water in a certain vertical range, or to secure their entire charge at one definite position. The former description of water-bottle has been used almost invariably in deep-sea work; the latter is necessary only in shallow water.

The most common type, on the principle of the force-pump, appears to have been originated by Hooke* two hundred and twenty years ago. A box provided with a valve above and one below, both opening upwards, is lowered by a weight; the water runs

* Described and figured, *Phil. Trans.*, ii. (1667), p. 442.

through it easily, keeping the valves open; when it is pulled up the pressure of the water closes the valves, and if the upward motion is uninterrupted keeps them shut. A specimen of water is thus secured from nearly the greatest depth to which the apparatus has been sent.

This form has been worked out in many modifications; arrangements have been added for locking the bottle when it is full, and also for closing it by other means than changing the direction of motion.

In Marcet's machine for obtaining bottom samples,* the upper and lower valves were connected together, and during the descent of the instrument they were kept open by a cord and weight, which, ceasing to act on touching the bottom, allowed a spring to close and lock the valves. There was thus no risk of the contents changing during the upward journey. In a modification for obtaining intermediate samples the valves (in this case cones fitted on a rigid rod) were held up by a catch which could be withdrawn by a lever actuated by a weight slipped down the sounding line. The valves then closed, and were locked by a catch.

Wille's† water-bottle and Sigsbee's ‡ water-cup are the most approved modern developments of Hooke's apparatus. Wille's apparatus raised 5 litres of water, Sigsbee's only 8 ounces. Both are locked by the action of the current in the ascent on small screw propellers, which form part of the instrument. Tennant before 1819 devised a water-bottle § which was closed by the action of the water on "a small fly-wheel during its ascent." The arrangement consisted of a large water-tight snuff-box, the lid of which was held open against a powerful spring by a small wedge that was pulled out by the revolving fly-wheel.

Sir Robert Christison's cistern thermometer || is a water-bottle on Hooke's principle, with unvalved holes below, and carefully adjusted ball and cone valves above.

The water-bottles¶ employed on the "Porcupine" and "Lightning" expeditions were valved instruments without a locking

* Described and figured, *Phil. Trans.*, cix. (1819), p. 208, pl. xi.

† Described and figured, *Norske Nordhavs Expedition*, iv. pt. 2, p. 17; and Tornoe's *Chemi* (1880), p. 13.

‡ Described and figured in Sigsbee's *Deep-Sea Sounding and Dredging* (1880), p. 91.

§ Described, *Phil. Trans.*, cix. (1819), p. 209.

|| *Proc. Roy. Soc. Edin.*, vii. (1872), p. 570, and xii. (1885), p. 31.

¶ *Depth of the Sea* (2nd ed., 1874), p. 500.

arrangement. Their inadequacy for the work led to the construction of entirely novel forms for the "Challenger."* The stop-cock water-bottle is a cylinder with a large stop-cock at each end, the levers of which are connected by an outside bar carrying a plate so arranged that it becomes horizontal when the line is hauled in, closes the stop-cocks by its resistance, then falls and hangs freely.

In the water-bottles already described water traverses the apparatus while it is being lowered, and as the openings are smaller than the diameter of the cylinders, the water enclosed at any time is a mixture derived from the few fathoms just passed through. This is no objection in deep-sea work, provided an adequate locking arrangement is employed. When a simple valved cylinder is used the results are untrustworthy, because any check on the line opens the valves and allows the water to get mixed.

The oldest method of getting water from a definite depth was by sinking a corked bottle full of air. It was sent down 100 fathoms or so, and when hauled up it was found still corked, but full of water. This is accounted for by two theories; the water either filters through the cork, or, at a certain depth, the pressure suffices to drive the cork in, the bottle instantly fills, and as it is drawn up, the contained water being relieved from pressure, expands and fixes the cork firmly in its place. This method of collecting water has been employed by many chemists, by Forchhammer† and Von Bibra‡ in particular; but it is very unsatisfactory.

Sir Humphry Davy invented, for Sir John Ross's Arctic voyage of 1818, a water-bottle§ which was found to be uncertain in its working.|| It was a strong pear-shaped copper vessel, with a stop-cock at the upper end, which was opened, and, after the bottle filled, closed again by levers actuated by a piston working in an air-tight side-tube, and capable of adjustment enabling it to act at any depth from 5 to 80 fathoms. The arrangement was entirely automatic, and as the pressure at the required depth opened and closed the bottle it was even unnecessary to measure the line as it was payed out.

* Described and figured, *Chall. Rep. Narrative*, i. (1884), pt. 2, p. 3.

† *Phil. Trans.*, clv. (1865), p. 203.

‡ Liebig's *Annalen*, lxxvii. (1851), p. 90.

§ Described and figured, *Jour. Scien. and the Arts*, v. (1818), p. 231.

|| Voyage of Discovery in H.M. ships "Isabella" and "Alexander," 1819, Appendix.

In very shallow water a bottle provided with a glass stopper may be sunk, and the stopper pulled out by a second line when at the proper depth. Stevenson's hydrophore (1813) * is an improvement on this. It is a metallic bottle closed by a plug, which may be removed and replaced at any depth, in order to fill the vessel and to secure the sample unchanged. Stevenson's deep-sea hydrophore † resembles one of Marcet's forms. It is a spindle-shaped vessel, fitted with two conical valves on a very heavy axis, which projects beneath the apparatus and keeps it shut during descent by its weight. When it strikes the bottom the valves are forced up, the air escapes, and water enters. On raising, the valves fall back into their places, and do not tend to open.

Jacobsen ‡ employed, during the cruise of the "Pommerania," in 1872, a glass cylinder adequately protected and provided with weighted valves which hang open during descent; at the required depth it is inverted by a second line, and the weights pressing on the valves serve to secure them. The difficulty of employing a double line is so great, when the sea is rough or when currents are rapid, that apparatus requiring such fitting is very inconvenient.

The Commission at Kiel, for the physical, chemical, and biological examination of the German seas, has devised many methods of collecting water.§ When the analysis of the dissolved gases in the sample was contemplated, an india-rubber bag containing a little mercury and squeezed free from air, was sunk and opened at the proper position.

On the French "Travailleur" expedition of 1881, a water-bottle combining the peculiarities of the stop-cock and valved forms was employed.|| On the "Talisman" expeditions a strong glass globe was exhausted by an air-pump, and its capillary opening sealed; it was fixed to the line below the Negretti-and-Zambra thermometer, which when reversed broke the tip of the capillary tube and water entered the globe. When the globe was received on deck the water sample was permanently secured by sealing off the broken capillary. No other process of collecting and preserving samples of water is so perfect theoretically as this,

* Described and figured, David Stevenson's *Canal and River Engineering* (1872), p. 125.

† Described and figured *ibid.*, p. 128.

‡ Liebig's *Annalen*, clxvii. (1873), p. 1.

§ See their annual *Berichte*, *passim.*

|| *La Nature*, 1882, i. 53.

provided the depth is not too great for the resistance of the vacuous globe to pressure.

Rung has an ingenious water-bottle in the shape of a large syringe * with a weighted handle (inside which there is a reversing thermometer); it is sunk with the nozzle downwards, the handle being looped up to a spring hook, which disengages it when a weight is slipped down the line from the ship. The syringe is then inverted, the heavy handle draws out the piston, and water enters through the small hole of the nozzle.

The water-bottles most usually employed during the last fifteen years are made on a principle altogether different from any of those enumerated above. Ekman's apparatus was used for work in shallow water by the Norwegian North Atlantic Expedition. It consisted † of a framework like the stand for an hour-glass, the bottom being a brass plate with an india-rubber ring let into it. A cylinder, open below and provided with a flanged opening above, was suspended by a catch to the upper part of the frame, and the whole was lowered over the side. On striking the water the catch fell back, but the rush of water kept the cylinder at the upper part of the frame work; as soon as the line was checked the cylinder fell, its base rested on the india-rubber ring, against which it was pressed by a spring catch.

H. A. Meyer's slip water-bottle ‡ was used on the German North Sea Expedition of 1872, and bottles of identical character, at least so far as regards their main features, were constructed for the "Challenger." § This form is practically Marcet's inverted. Instead of consisting of a cylinder with a rod bearing two conical valves hung by a spring above it, it consists of a rod with two conical valves and a cylinder hung above them. In Meyer's arrangement the slip cylinder was hung by a cord to a tumbler, developed from that of Brooke's sounding-rod, and the inner edges at each end of

* Described and figured, *Dentekniske Forenings Tidskrift*, 1883.

† Described and figured, *Norske Nordhavs Expedition*, iv. (1880), pt. ii. p. 17.

‡ Described and figured, *Exped. zur phys.-chem. und biol. Untersuch. der Nordsee im Sommer* 1872 (1875), p. 4.

§ For full particulars and figures of the "Challenger" water-bottles, with Mr Buchanan's more recent improvements, and of Mr Buchanan's combined sounding-rod and water-bottle, see *Challenger Rep. Narrative*, vol. i. pt. i. p. 111.

it were ground to fit on the conical edges of the base plate and the upper plate. Strong metal guides fixed to the shank supporting the base plate ensured that the cylinder should slip fairly on its fittings. On striking the bottom the tumbler threw off the slip, and the bottle closed. The "Challenger" instrument worked in the same way. To slip the cylinder at intermediate depths the "Challenger" investigators used a plate resembling that employed for closing the stop-cock bottle, and Meyer adopted a device better adapted for working in shallow water. He suspended the slip-cylinder by a cord and two hooks to two horizontal pins fixed to the upper part of the apparatus. A split wedge attached by rods to a ring surrounding the sounding-line rode on each pin; when a weight was let down the line from the ship it depressed the ring, which lowered the wedges and pushed the hooks off the pins, so closing the apparatus.

The superiority of slip water-bottles lies in their being adapted to take water from a perfectly definite position. In fact, a slip water-bottle, when it acts properly, cuts out of the layer in which it closes a cylinder of water, the parts of which retain their relative positions until the water-bottle is emptied.

In Buchanan's small slip water-bottle * the cylinder is allowed to run down the line from the ship. Its defects are its aptness to indent the edge by striking on the brass hemisphere, and its being too light to press sufficiently on the rubber to ensure that its contents are unmixed. It cannot, of course, be used on the same line with thermometers. This instrument was at first used in the work carried on by the Scottish Marine Station on the Firth of Forth, where water samples have to be obtained at all depths from 2 fathoms to 40, sometimes in a strong current, sometimes in a rather rough sea, and sometimes in a narrow channel, where there is considerable traffic, and where the instruments cannot be left down for many minutes. It was not very well suited for this work; for which it was found desirable to have a water-bottle fulfilling the following conditions:—

1. To be light enough to work by hand when necessary.
2. To contain about 2 litres of water.
3. To be used on the same line with thermometers.

* Described and figured, *Proc. Roy. Soc. Edin.*, xiii. (1885), p. 32.

4. To be closed at pleasure at any depth, or to be hauled up open if required.

5. To hold its charge perfectly secure.

6. To let the observer know when it closes.

When it was decided to have such an instrument made, I was not acquainted with the description of Meyer's water-bottle, or any other approximately answering the requirements; as I had not then time to search out the scattered papers on the subject, and as no list of references could be got, the water-bottle shown to the meeting was devised, and by many experiments, with the advice of Mr Buchanan, and the assistance of Mr Frazer, who made the instrument, it was brought to a satisfactory condition.

The water-bottle is represented in figs. 1 to 3, Plate XX. Fig. 1 gives its general appearance when open and ready for use; fig. 2 is a vertical section; fig. 3 shows it closed; fig. 4 is the plan of the base-plate. The material of the whole is brass, with the exception of an india-rubber ring and washer. The axis *ab* (see Plate XX.) is a strong tube which supports all the fittings, and through which the sounding-line passes. The funnel-shaped end of the tube *b* rests either on a knot, or on a short bar spliced into the rope. The base-plate C is provided with a ring *p*, of peculiarly soft rubber, specially prepared for the purpose. It is perforated by the stop-cock *e*, which opens by a key to run off the water when the bottle is full, and by the tube *d*, also terminating in a stop-cock, and intended to let in air when the bottle is being emptied. Three light radial wings *ff* serve as guides to the slip cylinder. The top plate *g* has a saucer-shaped india-rubber washer *h* fixed on it by a screw. The slip cylinder has its lower edge *nn* lightly grooved, so as to grip the rubber ring, and a flange with a blunt knife-edge *ii* projects from the upper part. Three strong curved strips *rr* terminate above in a tube *q*, sliding very easily on the central rod. The upper part of *q* is widened, and is provided with an internal groove *k*, in which the bent extremities of three springs *ll* catch, and so support the slip. These springs are bent outwards, and when the bottle is to be

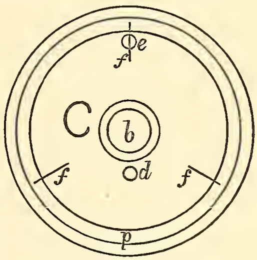


Fig. 4.

closed, a weight slipped down the line strikes the wide tube *m*, and drives it down over the springs *ll*, drawing them in and releasing the slip. The knife-edge *ii* strikes the rubber washer *h* at the same moment as the lower edge *n* strikes and indents the rubber ring *p*. At the same instant the three springs *oo* are forced over the base-plate, and clasp it tightly, clamping the two together before the elasticity of the india-rubber has time to assert itself. An extremely tightly-fitting joint is the result. The spring *o* is supplemented by an additional spring *s*, the action of which enables more flexible metal to be used for the catches. It requires a little practice to enable one to set the water-bottle again, but this is soon acquired.

This water-bottle is believed to possess certain advantages over other forms. It can be used in conjunction with the reversing thermometers of Messrs Negretti and Zambra, when these are fitted with the Scottish frame,* and by a very easy adjustment any number of thermometers and water-bottles can be used simultaneously on one line, thus enabling samples of water and temperature observations to be obtained from several positions at once. The impact of the messenger on the top of the water-bottle, and the locking of the springs below, can be felt distinctly through nearly 100 fathoms of line, and so the moment when it shuts is known. The locking arrangement is very satisfactory, and so simple that any accident, such as the distortion of a spring, can be put right at once. The same holds good of the detaching gear.

The water-bottle shown has been in constant use for a year, both on board the "Medusa," where it is worked by steam-power, and on fishing-boats, where it was managed by hand.

5. On a Repetition of Berthelot's Experiment on the Tenacity of Water and its Adhesion to Glass. By H. Creelman. Communicated by Professor Tait.

* *Proc. Roy. Soc. Edin.*, xii. (1884), p. 627; xiii. p. 33.

Monday, 1st February 1886.

JOHN MURRAY, Esq., Ph.D., Vice-President, in the Chair.

The following Communications were read :—

1. The Theory of Determinants in the Historical Order of its Development. By Thomas Muir, M.A., LL.D.

PART I.—*Determinants in General* (1693–1779).

In October 1881 I published in the *Quarterly Journal of Mathematics* (xviii. pp. 110–149) a "List of Writings on Determinants," which contained the titles of all the books, pamphlets, memoirs, magazine articles, &c., which were then known to me to exist on the subject of the Theory of Determinants. The list consisted of 489 entries arranged in chronological order, the first date being 1693, and the last 1880. During the three years which have elapsed since it was published, I have been steadily making manuscript additions to it, not merely in the way of continuation for the purpose of keeping it up to date, but also by the intercalation of omitted titles unearthed in the course of my own researches, or brought to my notice by obliging correspondents.

The continuation of the list from 1880 forwards is comparatively an easy matter: it is not by any means easy to render equally complete that portion of the list which pertains to the eighteenth century. In the early history of a scientific subject, before the nomenclature has become fixed, the mere *titles* of writings are insufficient guides: the searcher's work is, consequently, minute and laborious, and he never can be quite sure that his labours are at an end. As far, however, as Determinants are concerned, I am inclined now to think that the writings which are unknown cannot be of much importance, and that the time has come for using the collected material in the production of a detailed history of the subject.

The plan proposed to be followed is not to give one connected history of determinants as a whole, but to give separately the history of each of the sections into which the subject has been divided, viz., to deal with determinants in general, and thereafter in order with the various special forms. This will not only tend to smoothness in the narrative by doing away with the necessity of frequent harkings back, but it will also be of material importance to investigators who may wish to find out what has already been done in advancing any particular department of the subject. To this end, also, each new result as it appears will be numbered in Roman figures; and if the same result be obtained in a different way, or be generalised, by a subsequent worker, it will be marked among the contributions of the latter with the same Roman figures, followed by an Arabic numeral. Thus the theorem regarding the effect of the transposition of two rows of a determinant will be found under Vandermonde, marked with the number xi., and the information intended thus to be conveyed is that in the order of discovery the said theorem was the *eleventh* noteworthy result obtained: while the mark XI. 2, which occurs under Laplace, is meant to show that the theorem was not then heard of for the first time, but that Laplace contributed something additional to our knowledge of it. In this way any reader who will take the trouble to look up the sequence XI., XI. 2, XI. 3, &c., may be certain, it is hoped, of obtaining the full history of the theorem in question.

The early foreshadowings of a new domain of science, and tentative gropings at a theory of it, are so difficult for the historian to represent without either conveying too much or too little, that the only satisfactory way of dealing with a subject in its earliest stages seems to be to reproduce the exact words of the authors where essential parts of the theory are concerned. This I have resolved to do, although to some it may have the effect of rendering the account at the commencement somewhat dry and forbidding.

No author, so far as I am aware, has preceded me in the task I have chosen. Sketches of the history have appeared in a number of text-books of the subject, notably in Günther's *Lehrbuch der Determinanten-Theorie für Studirende* (2te Aufl. xii. 209 pp., Erlangen, 1877), which contains a considerable quantity of detail. The *early* history has been very carefully dealt with by F. J. Studnička, in a memoir published in the *Abhandlungen der königl. böhm. Gesellschaft der Wissenschaften*, 6 Folge, viii. 40 pp. (24th March 1876), and entitled "A. L. Cauchy als formaler Begründer der Determinanten-Theorie. Eine literarisch-historische Studie." There is also an academic thesis (*Teorin för Determinant-Kalkylen*, 121 pp., Helsingfors, 1st March 1876), by E. J. Mellberg, which treats somewhat at length of the early authorities. The existence of these two latter writings has not, however, induced me to curtail to any extent the corresponding part of my work.

LEIBNITZ (1693).

[Leibnizen's mathematische Schriften, herausg. v. C. I. Gerhardt. 1 Abth. ii. pp. 229, 238–240, 245, Berlin, 1850.]

In the fourth letter of the published correspondence between Leibnitz and De L'Hospital, the former incidentally mentions that in his algebraical investigations he occasionally uses numbers instead of letters, treating the numbers however as if they were letters. De L'Hospital, in his reply, refers to this, stating that he has some difficulty in believing that numbers can be as convenient or give as general results as letters. Thereupon Leibnitz, in his next letter (28th April 1693), proceeds with an explanation :—

"Puisque vous dites que vous avés de la peine à croire qu'il soit aussi general et aussi commode de se servir des nombres que des lettres, il faut que je ne me sois pas bien expliqué. On ne sçauroit douter de la generalité en considerant qu'il est permis de se servir de 2, 3, etc., comme d' *a* ou de *b*, pour veu qu'on considere que ce ne sont pas de nombres veritables. Ainsi 2.3 ne signifie point 6 mais autant qu' *ab*. Pour ce qui est de la commodité, il y en a des très grandes, ce qui fait que je m'en sers souvent, sur tout dans les calculs longs et difficiles ou il est aisé de se tromper. Car outre la commodité de l'épreuve par des nombres, et même par l'abjection du novenaire, j' y trouve un tres grand avantage même pour l'avancement de l'Analyse. Comme c'est une ouverture assez extraordinaire, je n'en ay pas encor parlé à d'autres, mais voicy ce que c'est. Lorsqu'on a besoin de beaucoup de lettres, n'est il pas vray que ces lettres n'expriment point les rapports qu'il y a entre les grandeurs qu'elles signifient, au lieu qu'en me servant des nombres je puis exprimer ce rapport. Par exemple soyent proposées trois equations simples pour deux inconnues à dessein d'oster ces deux inconnues, et cela par un canon general. Je suppose

$$\begin{array}{lll} & 10+11x+12y=0 & (1) \\ \text{et} & 20+21x+22y=0 & (2) \\ \text{et} & 30+31x+32y=0 & (3) \end{array}$$

ou le nombre feint estant de deux characteres, le premier me marque de quelle equation il est, le second me marque à quelle lettre il appartient. Ainsi en calculant on trouve par tout des harmonies qui non seulement nous servent de garans, mais encor nous font entrevoir d'abord des regles ou theoremes. Par exemple ostant premierement y par la premiere et la seconde equation, nous aurons:

$$\left.\begin{array}{l} +10.22+11.22x \\ -12.20-12.21.. \end{array}\right. = 0 \qquad (4)^*$$

et par la premiere et troisieme nous aurons:

$$\left.\begin{array}{l} +10.32+11.32x \\ -12.30-12.31.. \end{array}\right. = 0 \qquad (5)$$

ou il est aise de connoistre que ces deux equations ne different qu'en ce que le charactere antecedent 2 est changé au charactere antecedent 3. Du reste, dans un même terme d'une même equation les characteres antecedens sont les mêmes, et les characteres posterieurs font une même somme. Il reste maintenant d'oster la lettre x par la quatrieme et cinquieme equation, et pour cet effect nous aurons †

$$\begin{array}{ccc} 1_0 . 2_1 . 3_2 & & 1_0 . 2_2 . 3_1 \\ 1_1 . 2_2 . 3_0 & = & 1_1 . 2_0 . 3_2 \\ 1_2 . 2_0 . 3_1 & & 1_2 . 2_1 . 3_0 \end{array}$$

qui est la derniere equation delivrée des deux inconnues qu'on vouloit oster, et qui porte sa preuve avec soy par les harmonies qui se remarquent par tout, et qu'on auroit bien de la peine à decouvrir en employant des lettres a, b, c, sur tout

* This is written shortly for

$$\left.\begin{array}{l} +10.22+11.22x=0 \\ -12.20-12.21x=0 \end{array}\right\}$$

† The author here slightly changes his notation. What is meant to be indicated is

$$10.21.32+11.22.30+12.20.31=10.22.31+11.20.32+12.21.30.$$

lors que le nombre des lettres et des equations est grand. Une partie du secret de l'analyse consiste dans la caracteristique, c'est à dire dans l'art de bien employer les notes dont on se sert, et vous voyés, Monsieur, par ce petit echantillon, que Viete et des Cartes n'en ont pas encor connu tous les mysteres. En poursuivant tant soit peu ce calcul on viendra à un *theoreme general* pour quelque nombre de lettres et d'equations simples qu'on puisse prendre. Le voicy comme je l'ay trouvé autres fois :

"*Datis aequationibus quotcunque sufficientibus ad tollendas quantitates, quae simplicem gradum non egrediuntur, pro aequatione prodeunte, primo sumendae sunt omnes combinationes possibiles, quas ingreditur una tantum coefficiens uniuscujusque aequationis: secundo, eae combinationes opposita habent signa, si in eodem aequationis prodeuntis latere ponantur, quae habent tot coefficientes communes, quot sunt unitates in numero quantitatum tollendarum unitate minuto: caeterae habent eadem signa.*

"J'avoue que dans ce cas des degrés simples on auroit peut estre decouvert le même theoreme en ne se servant que de lettres à l'ordinaire, mais non pas si aisement, et ces adresses sont encor bien plus necessaires pour decouvrir des theoremes qui servent à oster les inconnues montées à des degrés plus hauts. Par exemple, ... "

It will be seen that what this amounts to is *the formation of a rule for writing out the resultant of a set of linear equations.* When the problem is presented of eliminating x and y from the equations

$$a+bx+cy=0\,, \qquad d+ex+fy=0\,, \qquad g+hx+ky=0,$$

Leibnitz in effect says that first of all he prefers to write 10 for a, 11 for b, and so on; that, having done this, he can all the more readily take the next step, viz., forming every possible product whose factors are one coefficient from each equation,* the result being

$$10\,.\,21\,.\,32\,, \quad 10\,.\,22\,.\,31\,, \quad 11\,.\,20\,.\,32\,,$$
$$11\,.\,22\,.\,30\,, \quad 12\,.\,20\,.\,31\,, \quad 12\,.\,21\,.\,30\,;$$

and that, then, *one* being the number which is less by one than the

* Of course, this is not exactly what Leibnitz meant to say.

number of unknowns, he makes those terms different in sign which have only *one* factor in common.

The contributions, therefore, which Leibnitz here makes to algebra may be looked upon as three in number :—

(1) A *new notation*, numerical in character and appearance, for individual members of an arranged group of magnitudes; the two numbers which constitute the notation being like the Cartesian co-ordinates of a point in that they denote any one of the said magnitudes by indicating its position in the group, . . . (I.)

(2) A rule for *forming the terms* of the expression which equated to zero is the result of eliminating the unknowns from a set of simple equations, ... (II.)

(3) A rule for *determining the signs* of the terms in the said result. . . . . (III.)

The last of these is manifestly the least satisfactory. In the first place, part of it is awkwardly stated. Making those terms different in sign *which have only as many factors alike as is indicated by the number which is less by one than the number of unknown quantities* is exactly the same as making those terms different in sign *which have only two factors different.* Secondly, in form it is very unpractical. The only methodical way of putting it in use is to select a term and make it positive; then seek out a second term, having all its factors except two the same as those of the first term, and make this second term negative; then seek out a third term, having all its factors except two the same as those of the second term, and make this third term positive; and so on.

Although there is evidence that Leibnitz continued, in his analytical work, to use his new notation for the coefficients of an equation (see Letters xi., xii., xiii. of the said correspondence), and that he thought highly of it (see Letter viii. "chez moi c'est une des meilleures ouvertures en Analyse"), it does not appear that by using it in connection with sets of linear equations, or by any other means, he went further on the way towards the subject with which we are concerned. Moreover, it must be remembered that the little he did effect had no influence on succeeding workers. So far as is known, the passage above quoted from his correspondence with De L'Hospital was not published until 1850. Even for some little time after the date of Gerhardt's publication it escaped observation, Lejeune Dirichlet being the first to note its historical importance. It is true that during his own lifetime, Leibnitz's *use of numbers in place of letters* was made known to the world in the *Acta Eruditorum* of Leipzig for the year 1700 (*Responsio ad Dn. Nic. Fatii Duillerii imputationes*, pp. 189–208); but the particular application of the new symbols which brings them into connection with determinants was not there given.

CRAMER (1750).

[Introduction a l'Analyse des Lignes Courbes algébriques, par Gabriel Cramer, pp. 59, 60, 656–659. Génève, 1750.]

The third chapter of Cramer's famous treatise deals with the different *orders* (degrees) of curves, and one of the earliest theorems of the chapter is the well-known one that the equation of a curve of the nth degree is determinable when $\frac{1}{2}n(n+3)$ points of the curve are known. In illustration of this theorem he deals (p. 59) with the case of finding the equation of the curve of the *second* degree which passes through *five* given points. The equation is taken in the form

$$A + By + Cx + Dyy + Exy + xx = 0\,;$$

the five equations for the determination of A, B, C, D, E are written down; and it is pointed out that all that is necessary is the solution of the set of five equations, and the substitution of the values of A, B, C, D, E thus found. "Le calcul véritablement en seroit assez long," he says; but in a footnote there is the remark that it is to algebra we must look for the means of shortening the process, and we are directed to the appendix for a convenient general rule which he had discovered for obtaining the solution of a set of equations of this kind. The following is the essential part of the passage in which the rule occurs:—

"Soient plusieurs inconnues z, y, x, v, &c., et autant d'équations

$$A^1 = Z^1z + Y^1y + X^1x + V^1v + \&c.$$
$$A^2 = Z^2z + Y^2y + X^2x + V^2v + \&c.$$
$$A^3 = Z^3z + Y^3y + X^3x + V^3v + \&c.$$
$$A^4 = Z^4z + Y^4y + X^4x + V^4v + \&c.$$
$$\&c.$$

où les lettres A^1, A^2, A^3, A^4, &c., ne marquent, pas comme à l'ordinaire, les puissances d' A, mais le prémier membre, supposé connu, de la prémiére, seconde, troisiéme, quatriéme, &c. équation."

[Here the solutions of the cases of 1, 2, and 3 unknowns are given, and he then proceeds.]

"L'examen de ces Formules fournit cette Règle générale. Le nombre des équations et des inconnues étant n, on trouvera la valeur de chaque inconnue en formant n fractions dont le dénominateur commun à autant de termes qu'il y a de divers arrangements de n choses différentes. Chaque terme est composé des lettres ZYXV, &c., toujours écrites dans le même ordre, mais auxquelles on distribue, comme exposants, les n prémiers chiffres rangés en toutes les maniéres possibles. Ainsi, lorsqu'on a trois inconnues, le dénominateur a $[1 \times 2 \times 3 =]$ 6 termes, composés des trois lettres ZYX, qui recoivent successivement les exposants 123, 132, 213, 231, 312, 321. On donne à ces termes les signes + ou −, selon la Règle suivante. Quand un exposant est suivi dans le même terme, médiatement ou immédiatement, d'un exposant plus petit que lui, j'appellerai cela un *dérangement.* Qu'on compte, pour chaque terme, le nombre des dérangements : s'il est pair ou nul, le terme aura le signe +; s'il est impair, le terme aura le signe −. Par ex. dans le terme $Z^1Y^2V^3$ il n'y a aucun dérangement; ce terme aura donc le signe +. Le terme $Z^3Y^1X^2$ a aussi le signe +, parce qu'il a deux dérangements, 3 avant 1 et 3 avant 2. Mais le terme $Z^3Y^2X^1$, qui a trois dérangements, 3 avant 2, 3 avant 1, et 2 avant 1, aura le signe −.

"Le dénominateur commun étant ainsi formé, on aura la valeur de z en donnant à ce dénominateur le numérateur qui se forme en changeant, dans tous ces termes, Z en A. Et la valeur d' y est la fraction qui a le même dénominateur et pour numérateur la quantité qui résulte quand on change Y en A, dans tous les termes du dénominateur. Et on trouve d'une maniére semblable la valeur des autres inconnues."

It is evident at once that the new results here given are—

(1) A rule for *forming the terms* of the common denominator of

the fractions which express the values of the unknowns in a set of linear equations, ... (IV.)

(2) A rule for *determining the sign* of any individual term in the said common denominator (and, included in the rule, the notion of a "dérangement"), ... (III. 2)

(3) A rule for *obtaining the numerators* from the expression for common denominator, ... (V.)

The problem which Cramer set himself at this point in his book was exactly that which Leibnitz had solved, viz., the elimination of n quantities from a set of $n+1$ linear equations. The solution which Cramer obtained, and which, be it remarked, was the solution best adapted for his purpose, was quite distinct in character from that of Leibnitz. Leibnitz gave a rule for writing out the final result of the elimination; what Cramer gives is a rule for writing out the values of the n unknowns as determined from n of the $n+1$ equations, after which we have got to substitute these values in the remaining $(n+1)$th equation. The notable point in regard to the two solutions is, that Cramer's rule for writing the *common denominator* of the values of the n unknowns (an expression of the nth degree in the coefficients) is exactly Leibnitz's rule for writing the *final result*, which is an expression of the $(n+1)$th degree. Had either discoverer been aware that the same rule sufficed for obtaining both of these expressions, he could not have failed, one would think, to note the *recurrent* law of formation of them. The result of eliminating w, x, y, z from the equations,

$$a_r w + b_r x + c_r y + d_r z = e_r \quad (r = 1, 2, 3, 4, 5)$$

is, according to Leibnitz, if we embody his rule in a later symbolism,

$$| a_1 b_2 c_3 d_4 e_5 | = 0\,;$$

whereas, according to Cramer, it is—

$$a_1 \frac{|e_2 b_3 c_4 d_5|}{|a_2 b_3 c_4 d_5|} + b_1 \frac{|a_2 e_3 c_4 d_5|}{|a_2 b_3 c_4 d_5|} + c_1 \frac{|a_2 b_3 e_4 d_5|}{|a_2 b_3 c_4 d_5|} + d_1 \frac{|a_2 b_3 c_4 e_5|}{|a_2 b_3 c_4 d_5|} = e_1,$$

and from the collocation of these the one natural step is to the identity

$$-|a_1 b_2 c_3 d_4 e_5| = a_1|e_2 b_3 c_4 d_5| + b_1|a_2 e_3 c_4 d_5| + \ldots\ldots - e_1|a_2 b_3 c_4 d_5|\,.$$

The fate of Cramer's rule was very different from that of Leibnitz.

It was soon taken up, and after a time found its way into the schools, where it continued for many years to be taught as the nutshell form of the theory of the solution of simultaneous linear equations. Indeed Gergonne is reported* to have said, "Cette methode était tellement en faveur, que les examens aux écoles des services publics ne roulaient, pour ainsi dire, que sur elle ; on était admis ou rejeté suivant qu'on la possedait bien ou mal."

Finally, the exact difference between Cramer's notation for the coefficients of the unknowns and the notation of Leibnitz should be noted, and in connection therewith the fact that when dealing with the subject of elimination between two equations of the mth and nth degrees in x Cramer uses a notation closely resembling that which Leibnitz employed, viz. $[1^2]$ $[1^3]$, &c.

BÉZOUT (1764).

[Recherches sur le degré des équations résultantes de l'évanouissement des inconnues, et sur les moyens qu'il convient d'employer pour trouver ces équations.—*Hist. de l'Acad. Roy. des Sciences*, Ann. 1764 (pp. 288–338), pp. 291–295.]

The object of Bézout's memoir is sufficiently apparent from the title; we may therefore at once give those portions of it which directly concern our subject. On p. 291 is the commencement of the following passage:—

"M. Cramer a donné une règle générale pour les exprimer toutes débarrassées de ce facteur: j'aurois pu m'en tenir à cette règle; mais l'usage m'a fait connoître que quoiqu'elle soit assez simple, quant aux lettres, elle ne l'est pas de même à l'égard des signes lorsqu'on a au-delà d'un certain nombre d'inconnues à calculer; . . . .

Lemme I.

"Si l'on a un nombre n d'équations du premier degré qui renferment chacune un pareil nombre d'inconnues, sans aucun terme absolument connu, on trouvera par la règle suivante la relation que doivent avoir les coëfficiens de ces inconnues pour que toutes ces équations aient lieu.

* By Studnička.

"Soient a, b, c, d, &c., les coëfficiens de ces inconnues dans la première équation.
a', b', c', d', &c., les coëfficiens des mêmes inconnues dans la seconde équation.
a'', b'', c'', d'', &c., ceux de la troisième & ainsi de suite.

"Formez les deux permutations ab & ba & écrivez $ab - ba$; avec ces deux permutations & la lettre c formez toutes les permutations possibles, en observant de changez de signe toutes les fois que c changera de place dans ab & la même chose à l'égard de ba; vous aurez

$$abc - acb + cab - bac + bca - cba\,.$$

Avec ces six permutations & la lettre d, formez toutes les permutations possibles, en observant de changer de signe à chaque fois que d changera de place dans un même terme; vous aurez

$$\begin{aligned} &abcd - abdc + adbc - dabc - acbd + acdb - adcb + dacb \\ &+ cabd - cadb + cdab - dcab - bacd + badc - bdac + dbac \\ &+ bcad - bcda + bdca - dbca - cbad + cbda - cdba + dcba \end{aligned}$$

& ainsi de suite jusqu'à ce que vous ayez épuisé tous les coëfficiens de la première equation.

" Alors conservez les lettres qui occupent la première place; donnez à celles qui occupent la seconde, la même marque qu'elles ont dans la seconde équation; à celles qui occupent la troisième, la même marque qu'elles ont dans la troisième équation, & ainsi de suite; égalez enfin le tout à zéro et vous aurez l'équation de condition cherchée.

" Ainsi si vous avez deux équations et deux inconnues comme

$$\begin{aligned} ax + by &= 0 \\ a'x + b'y &= 0 \end{aligned}$$

l'équation de condition sera $ab' - ba' = 0$ ou $ab' - a'b = 0 \ldots$."

In the same way the next two cases are given; then—

" . . . . mais comme ces équations de condition doivent servir de formules pour l'élimination dans les équations de différens degrés, il convient de leur donner une forme qui rende les substitutions le moins pénibles qu'il se pourra ; pour cet effet, je les mets sous cette forme :

$$ab' - a'b = 0$$

$$(ab' - a'b)c'' + (a''b - ab'')c' + (a'b'' - a''b')c = 0$$

$$\begin{aligned}&[(ab' - a'b)c'' + (a''b - ab'')c' + (a'b'' - a''b')c\,]d'''\\ +&[(a'b - ab')c''' + (ab''' - a'''b)c' + (a'''b' - a'b''')c\,]d''\\ +&[(a'''b - ab''')c'' + (ab'' - a''b)c''' + (a''b''' - a'''b'')c]d'\\ +&[(a'b''' - a'''b')c'' + (a'''b'' - a''b''')c' + (a''b' - a'b'')c''']d = 0.\end{aligned}$$

Cette nouvelle forme a deux avantages : le premier, de rendre les substitutions à venir, plus commodes ; le deuxième, c'est d'offrir une règle encore plus simple pour la formation de ces formules.

" En effet, il est facile de remarquer 1°, que le premier terme de l'une quelconque de ces équations, est formé du premier membre de l'équation précédente, multiplié par la première des lettres qu'elle ne renferme point, cette lettre étant affectée de la marque qui suit immédiatement la plus haute de celles qui entrent dans ce même membre.

" 2°. Le deuxième terme se forme du premier, en changeant dans celui-ci la plus haute marque en celle qui est immédiatement au-dessous & réciproquement, and de plus en changeant les signes.

" 3°. Le troisième, se forme du premier, en changeant dans celui-ci la plus haute marque en celle de deux numéros au-dessous & réciproquement, & de plus en changeant les signes.

" 4°. Le quatrième, se forme du premier, en changeant dans celui-ci la plus haute marque en celle de trois numéros au-dessous & réciproquement, & changeant les signes, & toujours de même pour les suivans.

" Par exemple, ...

" D'après ces observations, il sera facile de voir que l'équation de condition pour cinq inconnues et cinq équations, sera

. . . ."

The latter part of this we are drawn to at once, as it enunciates quite clearly the Recurrent Law of Formation to which attention has above been directed as a natural deduction from the work of Leibnitz and Cramer.

The notable point in regard to the earlier portion is, that Bézout throws his rule of term-formation and his rule of signs into one. In the case of finding the resultant of

$$a_r x + b_r y + c_r z = 0 \qquad (r = 1, 2, 3)$$

his process consists of four steps, viz. :—

(1) $a.$

(2) $a\,b \;\vdots - b\,a$

(3) $a\,b\,c \;-a\,c\,b \;+c\,a\,b \vdots - b\,a\,c \;+ b\,c\,a \;- c\,b\,a\,.$

(4) $a_1b_2c_3 - a_1c_2b_3 + c_1a_2b_3 - b_1a_2c_3 + b_1c_2a_3 - c_1b_2a_3\,.$

The first term of (2) is got from (1) by affixing b, and the second is got from the first by advancing the b one place and changing the sign. The first term of (3) is got from the first term of (2) by affixing c, the second term is got from the first by advancing c a place and changing the sign, and the third is got from the second by advancing c a place and changing the sign; the last three are got from the second term of (2) in the same way as the first three are got from the first term of (2).

It will thus be seen that while Leibnitz and Cramer direct us to find the permutations in any way whatever, and thereafter to fix the sign of each in accordance with a rule, Bézout requires the permutations to be found by a particular process, and attention given to the question of sign throughout all this process, so that when the terms have been found their signs have likewise been determined.

Bézout's contributions to the subject thus are —

(1) A combined rule of term-formation and rule of signs, ... } (II. 2) + (III. 3)

(2) The recurrent law of formation of the new functions, (VI.)

VANDERMONDE (1771).

[Mémoire sur l'élimination. *Hist. de l'Acad. Roy. des Sciences.* Ann. 1772, 2^e partie (pp. 516–532).]

This important memoir of Vandermonde and that of Laplace, which is dealt with immediately afterwards, both appear in the

History of the French Academy of Sciences for 1772, Laplace's memoir occupying pp. 267–376, and Vandermonde's pp. 516–532. There is, however, a footnote to the latter, which states that it was read for the first time to the Academy on 12th January 1771.

The part of it which concerns us is the first article, which treats of elimination in the case of equations of the first degree. Vandermonde here writes :—

"Je suppose que l'on représente par $\overset{1}{1}, \overset{2}{1}, \overset{3}{1},$ &c., $\overset{1}{2}, \overset{2}{2}, \overset{3}{2},$ &c., $\overset{1}{3}, \overset{2}{3}, \overset{3}{3},$ &c., &c., autant de différentes quantités générales, dont l'une quelconque soit $\overset{\alpha}{a},$ une autre quelconque soit $\overset{\beta}{b},$ &c., & que le produit des deux soit désigné à l'ordinaire par $\overset{\alpha}{a}.\overset{\beta}{b}.$

"Des deux nombres ordinaux α & a, le premier, par exemple, désignera de quelle équation est pris le coëfficient $\overset{\alpha}{a},$ & le second désignera le rang que tient ce coëfficient dans l'équation, comme on le verra ci-après.

"Je suppose encore le système suivant d'abréviations, & que l'on fasse

$$\frac{\alpha\,|\,\beta}{a\,|\,b} = \overset{\alpha}{a}.\overset{\beta}{b} - \overset{\alpha}{b}.\overset{\beta}{a},$$

$$\frac{\alpha\,|\,\beta\,|\,\gamma}{a\,|\,b\,|\,c} = \overset{\alpha}{a}.\frac{\beta\,|\,\gamma}{b\,|\,c} + \overset{\alpha}{b}.\frac{\beta\,|\,\gamma}{c\,|\,a} + \overset{\alpha}{c}.\frac{\beta\,|\,\gamma}{a\,|\,b},$$

$$\frac{\alpha\,|\,\beta\,|\,\gamma\,|\,\delta}{a\,|\,b\,|\,c\,|\,d} = \overset{\alpha}{a}.\frac{\beta\,|\,\gamma\,|\,\delta}{b\,|\,c\,|\,d} - \overset{\alpha}{b}.\frac{\beta\,|\,\gamma\,|\,\delta}{c\,|\,d\,|\,a} + \overset{\alpha}{c}.\frac{\beta\,|\,\gamma\,|\,\delta}{d\,|\,a\,|\,b} - \overset{\alpha}{d}\cdot\frac{\beta\,|\,\gamma\,|\,\delta}{a\,|\,b\,|\,c}$$

$$\frac{\alpha\,|\,\beta\,|\,\gamma\,|\,\delta\,|\,\epsilon\,|}{a\,|\,b\,|\,c\,|\,d\,|\,e\,|} = \overset{\alpha}{a}.\frac{\beta\,|\,\gamma\,|\,\delta\,|\,\epsilon}{b\,|\,c\,|\,d\,|\,e} + \cdot\;\cdot\;\cdot\;\cdot\;\cdot$$

. . . .

"Le symbole $\frac{\;|\;|\;}{\;|\;|\;}$ sert ici de caractéristique. Les seules choses à observer sont l'ordre des signes, et la loi des permutations entre les lettres a, b, c, d, &c., qui me paroissent suffisamment indiquées ci-dessus.

"Au lieu de transposer les lettres a, b, c, d, &c., on pouvoit les laisser dans l'ordre alphabétique, & transposer au contraire les lettres α, β, γ, δ, &c., les résultats auroient été parfaitement les mêmes; ce qui a lieu aussi par rapport aux conclusions suivantes.

"Premièrement, il est clair que $\frac{\alpha \mid \beta}{a \mid b}$ représente deux termes différens, l'un positif, & l'autre négatif, résultans d'autant de permutations possibles de a & b; que $\frac{\alpha \mid \beta \mid \gamma}{a \mid b \mid c}$ en représente six, trois positifs & trois négatifs, résultans d'autant de permutations possibles de a, b, & c; que $\frac{\alpha \mid \beta \mid \gamma \mid \delta}{a \mid b \mid c \mid d}$ . . . .

"Mais de plus, la formation de ces quantités est telle que l'unique changement que puisse résulter d'une permutation, quelle qu'elle soit, faite entre les lettres du même alphabet, dans l'une de ces abréviations, sera un changement dans le signe de la première valeur.

"La démonstration de cette vérité & la recherche du signe résultant d'une permutation déterminée, dépendent généralement de deux propositions qui peuvent être énoncées ainsi qu'il suit, en se servant de nombres pour indiquer le rang des lettres.

"La première est que

$$\frac{1 \mid 2 \mid 3 \mid \ldots \mid m \mid m+1 \mid \ldots n}{1 \mid 2 \mid 3 \mid \ldots\ m \mid m+1 \mid \ldots n}$$

$$= \pm \frac{1 \mid 2 \mid 3 \mid \ldots \mid n-m+1 \mid n-m+2 \mid n-m+3 \mid \ldots \mid n}{m \mid m+1 \mid m+2 \mid \ldots \mid n \mid 1 \mid 2 \mid \ldots \mid m-1}$$

le signe − n'ayant lieu que dans le cas où n & m sont l'un & l'autre des nombres pairs.

"La seconde est que

$$\frac{1 \mid 2 \mid 3 \mid \ldots \mid m \mid m+1 \mid \ldots \mid n}{1 \mid 2 \mid 3 \mid \ldots \mid m \mid m+1 \mid \ldots \mid n}$$

$$= -\frac{1 \mid 2 \mid 3 \mid \ldots \mid m-1 \mid m \mid m+1 \mid m+2 \mid \ldots \mid n}{1 \mid 2 \mid 3 \mid \ldots \mid m-1 \mid m+1 \mid m \mid m+2 \mid \ldots \mid n}.$$

"Il sera facile de voir que, la première équation supposée, celle-ci n'a besoin d'être prouvée que pour un seul cas, comme, par exemple, celui de $m=n-1$, c'est-à-dire, celui où les deux lettres transposées sont les deux dernières.

" Au lieu de démontrer généralement ces deux équations, ce qui exigeroit un calcul embarrassant plutôt que difficile, je me contenterai de développer les exemples les plus simples : cela suffira pour saisir l'esprit de la démonstration.

. . . ."

($2\frac{1}{2}$ pages are occupied with verifications for the case of

$$\frac{\alpha|\beta}{a|b}, \quad \text{of} \quad \frac{\alpha|\beta|\gamma}{a|b|c}, \quad \text{and of} \quad \frac{\alpha|\beta|\gamma|\delta}{a|b|c|d}.)$$

" On verra qu'en général la démonstration de notre seconde équation pour le cas $n=a$, dépend de cette même équation pour le cas $n=a-1$, quel que soit a : d'où il suit que puisque $\frac{1|2}{1|2}=-\frac{1|2}{2|1}$, elle est généralement vraie.

. . . .

" De ce que nous avons dit jusqu'ici *il suit que*

$$\frac{\alpha|\beta|\gamma|\delta|\ldots\ldots}{a|b|c|d|\ldots\ldots}=0,$$

si deux lettres quelconques du même alphabet sont égales entr'elles ; car quelque part que soient les deux lettres égales, on peut les transposer aux deux dernières places de leur rang, ce qui ne fera au plus que changer le signe de la valeur ; alors, de leur permutation particulière, il ne peut, d'une part, résulter aucun changement, puisqu'elles sont égales ; d'autre part, selon notre seconde équation ci-dessus, il doit en résulter un changement de signe ; cette contradiction ne peut être levée qu'en supposant la valeur zéro. . . . . . .

" Tout cela posé ; puisque l'on a identiquement,

$$\frac{1|1|2}{1|2|3}=\frac{1}{1}.\frac{1|2}{2|3}+\frac{1}{2}.\frac{1|2}{3|1}+\frac{1}{3}.\frac{1|2}{1|2}=0,$$

$$\frac{2|1|2}{1|2|3}=\frac{2}{1}.\frac{1|2}{2|3}+\frac{2}{2}.\frac{1|2}{3|1}+\frac{2}{3}.\frac{1|2}{1|2}=0,$$

si l'on propose de trouver les valeurs de $\xi 1$ et de $\xi 2$ qui satisfont aux deux équations

$$\overset{1}{1}\,.\,\xi 1 + \overset{2}{2}\,.\,\xi 2 + \overset{1}{3} = 0$$

$$\overset{2}{1}\,.\,\xi 1 + \overset{2}{2}\,.\,\xi 2 + \overset{2}{3} = 0,$$

on pourra comparer, & l'on aura

$$\xi 1 = \frac{\dfrac{1\,|\,2}{2\,|\,3}}{\dfrac{1\,|\,2}{1\;\;2}}, \quad \xi 2 = \frac{\dfrac{1\,|\,2}{3\,|\,1}}{\dfrac{1\,|\,2}{1\,|\,2}}.$$

. . . ."

(Three equations with three unknowns similarly dealt with.)

" Il est clair que ces valeurs n'ont point de facteurs inutiles: mais pour les rendre aussi commodes qu'il est possible dans les applications, and particulièrement dans celles où l'on veut faire usage des logarithmes, il sera bon d'y employer le plus qu'il se pourra, la multiplication des facteurs complexes. J'observe donc 1° que si l'on substitue dans le développement de $\frac{\alpha\,|\,\beta\,|\,\gamma\,|\,\delta}{a\,|\,b\,|\,c\,|\,d}$, les valeurs des $\frac{\alpha\,|\,\beta\,|\,\gamma}{a\,|\,b\,|\,c}$ en $\frac{\alpha\,|\,\beta}{a\,|\,b}$, on aura, en réduisant & ordonnant, d'après les observations ci-dessus,

$$\frac{\alpha\,|\,\beta\,|\,\gamma\,|\,\delta}{a\,|\,b\,|\,c\,|\,d} = \left\{ \begin{array}{l} \dfrac{\alpha\,|\,\beta}{a\,|\,b}\cdot\dfrac{\gamma\,|\,\delta}{c\,|\,d} - \dfrac{\alpha\,|\,\beta}{a\,|\,c}\cdot\dfrac{\gamma\,|\,\beta}{b\,|\,d} + \dfrac{\alpha\,|\,\beta}{a\,|\,d}\cdot\dfrac{\gamma\,|\,\delta}{b\,|\,c} \\ + \dfrac{\alpha\,|\,\beta}{b\,|\,c}\cdot\dfrac{\gamma\,|\,\delta}{a\,|\,d} - \dfrac{\alpha\,|\,\beta}{b\,|\,d}\cdot\dfrac{\gamma\,|\,\delta}{a\,|\,c} \\ + \dfrac{\alpha\,|\,\beta}{c\,|\,d}\cdot\dfrac{\gamma\,|\,\delta}{a\,|\,b} \end{array} \right.$$

si de même on substitue dans le développement des $\frac{\alpha\,|\,\beta\,|\,\gamma\,|\,\delta\,|\,\epsilon\,|\,\zeta}{a\,|\,b\,|\,c\,|\,d\,|\,e\,|\,f}$, les valeurs des $\frac{\alpha\,|\,\beta\,|\,\gamma\,|\,\delta\,|\,\epsilon}{a\,|\,b\,|\,c\,|\,d\,|\,e}$ en $\frac{\alpha\,|\,\beta\,|\,\gamma\,|\,\delta}{a\,|\,b\,|\,c\,|\,d}$, on aura, en réduisant & ordonnant, d'après les observations ci-dessus,

$$\frac{\alpha|\beta|\gamma|\delta|\epsilon|\zeta}{a|b|c|d|e|f}=\left\{\begin{aligned}
&\frac{\alpha|\beta}{a|b}\cdot\frac{\gamma|\delta|\epsilon|\zeta}{c|d|e|f}-\frac{\alpha|\beta}{a|c}\cdot\frac{\gamma|\delta|\epsilon|\zeta}{b|d|e|f}+\frac{\mid}{a|d}\cdot\frac{\mid\mid\mid}{b|c|e|f}\\
&+\frac{\alpha|\beta}{b|c}\cdot\frac{\gamma|\delta|\epsilon|\zeta}{a|d|e|f}-\frac{\mid}{b|d}\cdot\frac{\mid\mid\mid}{a|c|e|f}+\frac{\mid}{b|e}\cdot\frac{\mid\mid\mid}{a|c|d|f}\\
&+\frac{\mid}{c|d}\cdot\frac{\mid\mid\mid}{a|b|e|f}-\frac{\mid}{c|e}\cdot\frac{\mid\mid\mid}{a|b|d|f}+\frac{\mid}{c|f}\cdot\frac{\mid\mid\mid}{a|b|d|e}\\
&+\frac{\mid}{d|e}\cdot\frac{\mid\mid\mid}{a|b|c|f}-\frac{\mid}{d|f}\cdot\frac{\mid\mid\mid}{a|b|c|e}\\
&+\frac{\mid}{e|f}\cdot\frac{\mid\mid\mid}{a|b|c|d}\\
&\qquad\qquad\qquad-\frac{\mid}{a|e}\cdot\frac{\mid\mid\mid}{b|c|d|f}+\frac{\mid}{a|f}\cdot\frac{\mid\mid\mid}{b|c|d|e}\\
&\qquad\qquad\qquad-\frac{\mid}{b|f}\cdot\frac{\mid\mid\mid}{a|c|d|e}
\end{aligned}\right.$$

"La loi des permutations & des signes est assez manifeste dans ces exemples, pour qu'on en puisse conclure des développemens pareils pour les cas de huit & dix lettres, &c., du même alphabet; alors, en employant les premiers développemens pour les cas d'un nombre impair de ces lettres, on aura les formules d'élimination du premier degré, sous la forme la plus concise qu'il soit possible.

"Si l'on veut exprimer ces formules, généralement pour un nombre n d'équations

$$\overset{1}{1}.\xi 1+\overset{1}{2}.\xi 2+\overset{1}{3}.\xi 3+\ldots+\overset{1}{m}.\xi m+\ldots+\overset{1}{n}.\xi n+(\overset{1}{n+1})=0$$

$$\overset{2}{1}.\xi 1+\overset{2}{2}.\xi 2+\overset{2}{3}.\xi 3+\ldots+\overset{2}{m}.\xi m+\ldots+\overset{2}{n}.\xi n+(\overset{2}{n+1})=0$$

&c.

la valeur de l'inconnue quelconque ξm, sera renfermée dans l'équation suivante, à une seule inconnue

$$\frac{1\mid 2\mid 3\mid\ldots\mid n}{1\mid 2\mid 3\mid\ldots\mid n}.\,\xi m$$

$$\pm\frac{1\mid 2\mid 3\mid\ldots\ldots\ldots\mid n-m\mid n-m+1\mid n-m+2\mid n-m+3\mid\ldots\mid n}{m+1\mid m+2\mid m+3\mid\ldots\ldots\ldots\mid n\mid n+1\mid 1\mid 2\mid\mid m-1}=0$$

le signe + ayant lieu seulement dans le cas où m & n sont impairs l'un & l'autre."

Taking this up in order, we observe first that Vandermonde proposes for coefficients a positional notation essentially the same as that of Leibnitz, writing $\frac{1}{2}$ where Leibnitz wrote 12 or 1_2.

Then he defines a certain class of functions by means of their recurrent law of formation—a law and class of functions at once seen to be identical with those of Bézout. A special symbolism is used for the first time to denote the functions; thus, the expression

$$1_0.2_1.3_2 + 1_1.2_2.3_0 + 1_2.2_0.3_1 - 1_0.2_2.3_1 - 1_1.2_0.3_2 - 1_2.2_1.3_0\,,$$

which occurs in Leibnitz's letter, Vandermonde would have denoted by

$$\frac{1 \mid 2 \mid 3}{1 \mid 2 \mid 3},$$

and the result of eliminating x, y, z, w from the set of equations

$$1_r x + 2_r y + 3_r y + 4_r w = 0 \quad (r = 1, 2, 3, 4)$$

by

$$\frac{1 \mid 2 \mid 3 \mid 4}{1 \mid 2 \mid 3 \mid 4}.$$

It is next pointed out that permutation of the under row of indices produces the same result as permutation of the upper row, that the number of terms is the same as the number of permutations of either row of indices, and that half of the terms are positive and half negative.

The part which follows this is a little curious. The proposition is brought forward that if in the symbolism for one of the functions a transposition of indices takes place in either row, the same function is still denoted, the only change thereby possible being a change of sign. The demonstration is affirmed to be dependent on two theorems, neither of which is proved, as the proofs are said to be troublesome to set forth. Now it will be seen that the second of these theorems is to the effect that the transposition of any two consecutive indices causes a change of sign, and that consequently this alone is sufficient for the required demonstration. The first of the auxiliary theorems, in fact, is an immediate deduction from the second, the particular permutation which it concerns being produced by $(n - m + 1)(m - 1)$ transpositions of pairs of consecutive indices.

Passing over the illustrations of these propositions, we come next to the theorem that if any two indices of either row be equal the function vanishes identically, and we note particularly that the basis of the proof is that the interchange of the two indices in question changes the sign of the function, and yet leaves the function unaltered.

Upon this theorem the solution of a set of simultaneous linear equations is then with much neatness made to depend. In more modern notation Vandermonde's process is as follows:—It is known that

$$a_1 \,|\, b_1c_2 \,|\, + \, b_1 \,|\, c_1a_2 \,|\, + \, c_1 \,|\, a_1b_2 \,|\, = \,|\, a_1b_1c_2 \,|\, = 0\,,$$

and

$$a_2 \,|\, b_1c_2 \,|\, + \, b_2 \,|\, c_1a_2 \,|\, + \, c_2 \,|\, a_1b_2 \,|\, = \,|\, a_2b_1c_2 \,|\, = 0\,,$$

$$\therefore \quad \left.\begin{aligned} a_1\frac{|\,b_1c_2\,|}{|\,a_1b_2\,|} + b_1\frac{|\,c_1a_2\,|}{|\,a_1b_2\,|} + c_1 &= 0 \\ \text{and} \quad a_2\frac{|\,b_1c_2\,|}{|\,a_1b_2\,|} + b_2\frac{|\,c_1a_2\,|}{|\,a_1b_2\,|} + c_2 &= 0 \end{aligned}\right\}$$

hence, if the equations

$$\left.\begin{aligned} a_1x + b_1y + c_1 &= 0 \\ a_2x + b_2y + c_2 &= 0 \end{aligned}\right\}$$

be given us, we know that

$$x = \frac{|\,b_1c_2\,|}{|\,a_1b_2\,|}, \quad y = \frac{|\,c_1a_2\,|}{|\,a_1b_2\,|}$$

is a solution.

This result, moreover, is generalised; the solution of

$$r_1x_1 + r_2x_2 + \ldots + r_nx_n + r_{n+1} = 0 \qquad (r = 1, 2, \ldots, n)$$

being fully and accurately expressed in symbols, although the numerators of the values of $x_1, x_2, \ldots, x_n$ are not in so simple a form as Cramer's rule for obtaining the numerator from the denominator might have suggested.

Lastly, and almost incidentally, Vandermonde makes known a case of the widely general theorem now-a-days described as the theorem for expressing a determinant as an aggregate of products of complementary minors. His case is that in which the given determinant is of the order $2m$, and one factor of each of the products is of order 2.

Summing up, therefore, we must put the statement of our indebtedness to Vandermonde as follows:—

(1) A simple and appropriate notation for the new functions, *e.g.*,

$\frac{1\,|\,2\,|\,3}{1\,|\,2\,|\,3}$, ... (VII.)

(2) A new mode of defining the functions, viz., using Bézout's recurring law of formation, ... (VIII.)

(3) The remark that the ordinary algebraical expression of any of the functions is obtainable by permutation of *either* series of indices, ... (IX.)

(4) The remark that the positive and negative terms are equal in number, ... (X.)

(5) The theorem regarding the effect of interchanging two consecutive indices, ... (XI.)

(6) The theorem (with proof) regarding the effect of equality of two indices belonging to the same series, ... (XII.)

(7) A reasoned-out solution of a set of n simultaneous linear equations, by means of the new functions as above defined, . (XIII.)

(8) Expression of any of the new functions of order $2m$ as an aggregate of products of like functions of orders 2 and $2m-2$, ... (XIV.)

In addition to this, we must view Vandermonde's work as a whole, and note that he is the first to give a connected exposition of the theory, defining the functions apart from their connections with other matter, assigning them a notation, and thereafter logically developing their properties. After Vandermonde there could be no absolute necessity for a renovation or reconstruction on a new basis: his successors had only to extend what he had done, and, it might be, to perfect certain points of detail. Of the mathematicians whose work has thus far been passed in review, the only one fit to be viewed as the founder of the theory of determinants is Vandermonde.

LAPLACE (1772).

[Recherches sur le calcul intégral et sur le système du monde. *Hist. de l'Acad. Roy. des Sciences, Ann.* 1772, 2[e] *partie* (pp. 267–376) pp. 294–304].

In the course of his work Laplace arrives at a set of linear equations from which n quantities have to be eliminated. This he says can be accomplished by means of rules which mathematicians have given:—

"Mais comme elles ne me paroissent avoir été jusqu'ici démontrées que par induction, et que d'ailleurs elles sont impracticables, pour peu que le nombre des équations soit considérable; je vais reprendre de nouveau cette matière, et donner quelques procédés plus simples que ceux qui sont déjà connus, pour éliminer entre un nombre quelconque d'équations du premier degré."

Taking n homogeneous linear equations with the coefficients

$$\begin{array}{llll} {}^1a, & {}^1b, & {}^1c, & \ldots . \\ {}^2a, & {}^2b, & {}^2c, & \ldots . \\ \ldots & \ldots & \ldots & \ldots \end{array}$$

he first gives Cramer's rule for writing out what he, Laplace, calls the *Resultant*, using in the course of the rule the term *variation* instead of Cramer's term "*dérangement.*" Then he gives the "perhaps simpler" rule of Bézout, and shows that of necessity it will lead to the same result as Cramer's.

The theorem in regard to the effect of transposing two letters is next enunciated, and the blank left by Vandermonde is filled, for a proof of the theorem is given. The exact words of the enunciation and proof are—

"Si au lieu de combiner d'abord la lettre a avec la lettre b, ensuite ces deux-ci avec la lettre c, et ainsi de suite; c'est-à-dire, si au lieu de combiner les lettres a, b, c, d, e, &c., dans l'ordre a, b, c, d, e, &c., on les eût combinées dans l'ordre a, c, b, d, e, &c., ou a, d, b, c, e, &c., ou a, e, b, c, d, &c., ou &c., je dis qu'on auroit toujours eu la même quantité à la différence des signes près.

"Pour démontrer ce Théorème nommons en genéral, *resultante*, la quantité qui résulte de l'une quelconque de ces combinaisons, en sorte que la *première résultante* soit celle qui vient de la combinaison suivant l'ordre a, b, c, d, e, &c., que la *seconde résultante* soit celle qui vient de la combinaison suivant l'ordre a, c, b, d, e, &c., que la *troisième résultante* soit celle qui vient de la combinaison suivant l'ordre a, d, b, c, e, &c., et ainsi de suite; cela posé, il est clair que toutes ces résultantes renferment le même nombre de termes, et précisément les mêmes, puisqu'elles renferment tous les termes qui peuvent résulter de la combinaison des n lettres a, b, c, d, e, &c., disposées entre elles de toutes les manières possibles; il ne peut donc y avoir de différence entre deux résultantes, que dans les signes de chacun de leurs termes; or, il est visible que la première résultante donne la seconde, si l'on change dans la première b en c, et réciproquement c en b; mais ce changement augmente ou diminue d'une unité le nombre des variations de chaque terme; d'ou il suit que dans la seconde résultante, tous les termes dont le nombre des variations est impair, auront le signe +, et les autres le signe −; partant, cette seconde résultante n'est que la première, prise négativement.

"Il est visible pareillement que . . . ." &c.

The proof is thus seen to consist in establishing (1) that the terms of the one "resultant" must, apart from sign, be the same as those of the other; and (2) that the terms of the one resultant are either all affected with the same sign as the like terms of the other, or are all affected with the opposite sign, the comparison of sign being made by comparing the number of variations.

After this, the theorem that when two letters are alike the resultant vanishes is established in a way different from Vandermonde's, but not more satisfactory, viz., by considering what Bézout's rule would lead to in that case.

Application is then made to the problem of elimination, and to the solution of a set of linear simultaneous equations, the mode of treatment being again different from Vandermonde's, but this time with better cause. He says—

"Je suppose maintenant que l'on ait les trois équations

$$0 = {}^1a.\mu + {}^1b.\mu' + {}^1c.\mu'',$$
$$0 = {}^2a.\mu + {}^2b.\mu' + {}^2c.\mu'',$$
$$0 = {}^3a.\mu + {}^3b.\mu' + {}^3c.\mu'',$$

je forme d'abord la résultante des trois lettres a, b, c, suivant l'ordre a, b, c, ce qui donne,

$${}^1a.{}^2b.{}^3c - {}^1a.{}^2c.{}^3b + {}^1c.{}^2a.{}^3b - {}^1b.{}^2a.{}^3c + {}^1b.{}^2c.{}^3a - {}^1c.{}^2b.{}^3a.$$

ou

$${}^1a.[{}^2b.{}^3c - {}^2c.{}^3b] + {}^2a.[{}^1c.{}^3b - {}^1b.{}^3c] + {}^3a.[{}^1b.{}^2c - {}^1c.{}^2b];$$

je multiplie ensuite la première des équations précédentes par ${}^2b.{}^3c - {}^2c.{}^3b$, la seconde par ${}^1c.{}^3b - {}^1b.{}^3c$, la troisième par ${}^1b.{}^2c - {}^1c.{}^2b$, et je les ajoute ensemble, ce qui donne,

$$\begin{aligned}0 = {} & \mu.[{}^1a.({}^2b.{}^3c - {}^2c.{}^3b) + {}^2a.({}^1c.{}^3b - {}^1b.{}^3c) + {}^3a({}^1b.{}^2c - {}^1c.{}^2b)] \\ & + \mu'.[{}^1b.({}^2b.{}^3c - {}^2c.{}^3b) + {}^2b.({}^1c.{}^3b - {}^1b.{}^3c) + {}^3b({}^1b.{}^2c - {}^1c.{}^2b)] \\ & + \mu''.[{}^1c.({}^2b.{}^3c - {}^2c.{}^3b) + {}^2c.({}^1c.{}^3b - {}^1b.{}^3c) + {}^3c({}^1b.{}^2c - {}^1c.{}^2b)]\,;\end{aligned}$$

or, il suit de ce que nous venons de voir, que les coëfficiens de μ' et μ'', sont identiquement nuls, puisqu'ils ne sont que la résultante des trois lettres a, b, c, dans laquelle on écrit b, ou c, par-tout où est a; donc, on aura pour l'équation de condition demandée,

$$0 = {}^1a.({}^2b.{}^3c - {}^2c.{}^3b) + {}^2a.({}^1c.{}^3b - {}^1b.{}^3c) + {}^3a.({}^1b.{}^2c - {}^1c.{}^2b)\,;$$

c'est-à-dire, la résultante de la combinaison des trois lettres a, b, c égalée à zéro. On démontreroit la même chose, quel que soit le nombre des équations."

"Pour montrer l'analogie de cette matière, avec l'élimination des équations du premier degré, je suppose que l'on ait les trois équations,

$$\begin{aligned}{}^1p &= {}^1a.\mu + {}^1b.\mu' + {}^1c.\mu'', \\ {}^2p &= {}^2a.\mu + {}^2b.\mu' + {}^2c.\mu'', \\ {}^3p &= {}^3a.\mu + {}^3b.\mu' + {}^3c.\mu''.\end{aligned}$$

Je multiplie, comme ci-devant, la première par $({}^2b.{}^3c - {}^2c.{}^3b)$, la seconde par $({}^1c.{}^3b - {}^1b.{}^3c)$, et la troisième par $({}^1b.{}^2c - {}^1c.{}^2b)$, je les ajoute ensemble, et j'observe que les coëfficiens de μ' et de μ'', sont identiquement nuls dans l'équation qui en résulte; d'où je conclus,

$$\mu = \frac{{}^1p.({}^2b.{}^3c - {}^2c.{}^3b) + {}^2p.({}^1c.{}^3b - {}^1b.{}^3c) + {}^3p.({}^1b.{}^2c - {}^1c.{}^2b)}{{}^1a({}^2b.{}^3c - {}^2c.{}^3b) + {}^2a({}^1c.{}^3b - {}^1b.{}^3c) + {}^3a({}^1b.{}^2c - {}^1c.{}^2b)}\,;$$

on voit donc que le numérateur de l'expression de μ, se forme du dénominateur, en y changeant a en p; on aura ensuite μ' ou μ'', en changeant dans l'expression de μ," &c.

This mode of treatment leaves nothing to be desired. It is that which is most commonly employed in the text-books of the present day.

The next point taken up is the most important in the memoir, and requires special attention. It is introduced as "a very simple process for considerably abridging the calculation of the equation of condition between *a*, *b*, *c*," &c.—that is to say, the calculation of a resultant. It is, however, something of much more value than this, involving as it does a widely general expansion-theorem to which Laplace's name has been attached, but of which we have already seen special cases stated by Vandermonde. The theorem may be described as giving an expansion of a resultant in the form of an aggregate of terms each of which is a product of resultants of lower degree. Laplace's exposition is as follows:—

"Je suppose que vous ayez deux équations,

$$0 = {}^1a.\mu + {}^1b.\mu' \; ; \quad 0 = {}^2a.\mu + {}^2b.\mu' \; ;$$

écrivez $+ab$, et donnez l'indice 1 à la première lettre, et l'indice 2 à la seconde; l'équation de condition demandée sera $+{}^1a.{}^2b - {}^1b.{}^2a = 0$.

"Je suppose que vous ayez trois équations; écrivez $+ab$, combinez ce terme avec la lettre c de toutes les manières possibles, en changeant le signe de chaque terme chaque fois que c change de place, vous aurez ainsi $+abc - acb + cab$; donnez dans chaque terme l'indice 1 à la première lettre, l'indice 2 à la seconde, l'indice 3 à la troisième, et vous aurez $+ {}^1a.{}^2b.{}^3c - {}^1a.{}^2c.{}^3b + {}^1c.{}^2a.{}^3b$; cela posé, au lieu de $+{}^1a.{}^2b.{}^3c$ écrivez $+({}^1a.{}^2b - {}^1b.{}^2a).{}^3c$; au lieu de $+{}^1a.{}^2c.{}^3b$ écrivez $-({}^1a.{}^3b - {}^1b.{}^3a).{}^2c$; et au lieu de $+{}^1c.{}^2a.{}^3b$ écrivez $+({}^2a.{}^3b - {}^2b.{}^3a).{}^1c$; l'équation de condition demandée sera

$$0 = ({}^1a.{}^2b - {}^1b.{}^2a).{}^3c - ({}^1a.{}^3b - {}^1b.{}^3a).{}^2c + ({}^2a.{}^3b - {}^2b.{}^3a).{}^1c.$$

"Je suppose que vous ayez quatre équations, écrivez $+abc - acb + cab$, et combinez ces trois termes avec la lettre d, en observant 1° de n'admettre que les termes dans lesquels c précède d; 2° de changer de signe dans chaque terme toutes les fois que d change de place, et vous aurez

$$+ abcd - acbd + acdb + cabd - cadb + cdab \; ;$$

donnez ensuite l'indice 1 à la première lettre, l'indice 2 à la seconde, &c., et vous aurez

$$+ {}^1a.{}^2b.{}^3c.{}^4d - {}^1a.{}^2c.{}^3b.{}^4d + {}^1a.{}^2c.{}^3d.{}^4b$$
$$+ {}^1c.{}^2a.{}^3b.{}^4d - {}^1c.{}^2a.{}^3d.{}^4b + {}^1c.{}^2d.{}^3a.{}^4b \; ;$$

cela posé, au lieu de $+\,{}^1a.{}^2b.{}^3c.{}^4d$ écrivez

$$+\,({}^1a.{}^2b\,-\,{}^1b.{}^2a).({}^3c.{}^4d\,-\,{}^3d.{}^4c)\,,$$

et ainsi des autres termes, et l'équation de condition sera

$$\begin{aligned}0 = &({}^1a.{}^2b - {}^1b.{}^2a).({}^3c.{}^4d - {}^3d.{}^4c) - ({}^1a.{}^3b - {}^1b.{}^3a).({}^2c.{}^4d - {}^2d.{}^4c)\\ &+ ({}^1a.{}^4b - {}^1b.{}^4a).({}^2c.{}^3d - {}^2d.{}^3c) + ({}^2a.{}^3b - {}^2b.{}^3a).({}^1c.{}^4d - {}^1d.{}^4c)\\ &- ({}^2a.{}^4b - {}^2b.{}^4a).({}^1c.{}^3d - {}^1d.{}^3c) + ({}^3a.{}^4b - {}^3b.{}^4a).({}^1c.{}^2d - {}^1d.{}^2c)\,.\end{aligned}$$

"Je suppose que vous ayez cinq équations, écrivez les six termes $+abcd-acbd+\ldots$ relatifs à quatre équations, et combinez-les avec la lettre e de toutes les manières possibles, en observant de changer de signe chaque fois que e change de place; donnez ensuite l'indice 1, &c., &c., ... ; au lieu du terme $+\,{}^1a.{}^2c.{}^3b.{}^4e.{}^5d$ écrivez $({}^1a.{}^3b\,-\,{}^1b.{}^3a).({}^2c.{}^5d\,-\,{}^2d.{}^5c).{}^4e$, &c. . . . . . .

"Lorsqu'on aura six équations, on combinera les termes $+abcde-abced+$ &c., relatifs à cinq équations avec la lettre f, en observant 1° de n'admettre que les termes dans lesquels e précède f; 2° de changer de signe lorsque f change de place: on transformera ensuite, par la règle précédente, ..."

Notwithstanding the multiplicity of instances, the rule here illustrated is not made altogether clear. This is due to two causes,—first, the linking of one case to the case before it; and, second, the want of explicit notification that the letters b, d, f . . . are combined in one way, and the intervening letters $c, e,$ . . . in another. For the sake of additional clearness, let us see all the steps necessary in the case of the resultant of the five equations

$$a_rx_1 + b_rx_2 + c_rx_3 + d_rx_4 + e_rx_5 = 0 \qquad (r = 1, 2, 3, 4, 5)\,,$$

and supposing, as we ought to do, that the case of four equations has not been already dealt with. These steps are—

1°. Combining b with a subject to the condition that a precede b: result—

$$ab\,.$$

2°. Combining c with this *in every possible way*, the sign being &c.: result—

$$abc - acb + cab\,.$$

3°. Combining d with each of these terms subject to the condition that c precede d: result—

$$abcd - acbd + acdb + cabd - cadb + cdab.$$

4°. Combining e with each of these terms *in every possible way:* result—

$$abcde - abced + abecd - aebcd + eabcd$$
$$- acbde + acbed - \dots\dots\dots$$
$$\dots\dots\dots\dots\dots\dots$$

5°. Appending indices: result—

$$a_1b_2c_3d_4e_5 - a_1b_2c_3e_4d_5 + \dots\dots$$
$$\dots\dots\dots\dots\dots\dots$$

6°. Changing a_mb_n into $(a_mb_n - b_ma_n)$, c_rd_s into $(c_rd_s - d_rc_s)$, &c.: result—

$$(a_1b_2 - b_1a_2)(c_3d_4 - d_3c_4)e_5 - (a_1b_2 - b_1a_2)(c_3d_5 - d_3c_5)e_4 + \dots$$

This is the required resultant in the required form.

It is of the utmost importance to notice that what is accomplished in 1°, 2°, 3°, 4° is simply (a) *the finding of the arrangements of* a, b, c, d, e *subject to the conditions that* a *precede* b, *and* c *precede* d, *and obtaining each arrangement with the sign which it ought to have in accordance with Cramer's rule.* The number of necessary directions might thus be reduced to three, viz., (a), (5), (6), in which case (1), (2), (3), (4) would take their proper places as successive steps of a methodic and expeditious way of accomplishing (a).

Laplace appends a demonstration of the accuracy of this development of the resultant of the nth degree, the line taken being that if the multiplications were performed the terms found would be exactly the 1.2.3.....n terms of the resultant, and would bear the signs proper to them as such.

He then goes on to deal with a rule for obtaining a like development in which as many as possible of the factors of the terms are resultants of the *third* degree.

To do so succinctly he is obliged to introduce a *notation* for resultants. On this point his words are—

"Je désigne par (abc) la quantité

$$abc - acb + cab - bac + bca - cba,$$

et par (ab) la quantité $ab - ba$, et ainsi de suite; par $({}^1a.{}^2b.{}^3c)$ j'indiquerai la quantité (abc), dans les termes de laquelle on donne 1 pour indice à la première lettre, 2 à la seconde, et 3 à la troisième; par $({}^1a.{}^2b)$, je désignerai la quantité (ab) dans les termes de laquelle on donne 1 pour indice à la première lettre, et 2 à la seconde; et ainsi de suite."

We can but remark that here again he leaves little room for improvement: his symbolism is essentially that which is still in common use.

The exposition of the rule is as follows:—

"Je suppose maintenant que vous ayez trois équations, l'équation de condition sera

$$0 = ({}^1a.{}^2b.{}^3c).$$

"Je suppose que vous ayez quatre équations; écrivez $+abc$, et combinez ce terme de toutes les manières possibles avec la lettre d, en observant de changer de signe lorsque d change de place, ce qui donne $+abcd - abdc + adbc - dabc$; donnez l'indice 1 à la première lettre, l'indice 2 à la seconde, &c., et vous aurez

$$+ {}^1a.{}^2b.{}^3c.{}^4d - {}^1a.{}^2b.{}^3d.{}^4c + {}^1a.{}^2d.{}^3b.{}^4c - {}^1d.{}^2a.{}^3b.{}^4c;$$

au lieu du terme $+{}^1a.{}^2b.{}^3c.{}^4d$, écrivez $+({}^1a.{}^2b.{}^3c).{}^4d$; au lieu de $-{}^1a.{}^2b.{}^3d.{}^4c$, écrivez $-({}^1a.{}^2b.{}^4c).{}^3d$, et ainsi de suite, et vous formerez l'équation de condition

$$0 = ({}^1a.{}^2b.{}^3c).{}^4d - ({}^1a.{}^2b.{}^4c).{}^3d + ({}^1a.{}^3b.{}^4c).{}^2d - ({}^2a.{}^3b.{}^4c).{}^1d.$$

"Je suppose que vous ayez cinq équations, combinez les termes $+abcd - abdc + \&c.$, relatifs à quatre équations avec la lettre e en observant 1° de n'admettre que les termes dans lesquels d précède e; 2° de changer de signe lorsque e change de place, et vous aurez

$$+ abcde - abdce + abdec + \&c.$$

donnez l'indice 1 à la première lettre, l'indice 2 à la seconde, &c., et vous aurez

$$+ {}^1a.{}^2b.{}^3c.{}^4d.{}^5e - {}^1a.{}^2b.{}^3d.{}^4c.{}^5e + {}^1a.{}^2b.{}^3d.{}^4e.{}^5c + \&c.;$$

ensuite, au lieu de $+{}^1a.{}^2b.{}^3c.{}^4d.{}^5e$, écrivez $+({}^1a.{}^2b.{}^3c).({}^4d.{}^5e)$; au lieu de $-{}^1a.{}^2b.{}^3d.{}^4c.{}^5e$, écrivez $-({}^1a.{}^2b.{}^4c).({}^3d.{}^5e)$, et ainsi de suite; et en égalant à zero la somme de tous ces termes, vous formerez l'équation de condition demandée.

"Je suppose que vous ayez six équations, combinez les termes $+abcde-$&c., relatifs à cinq équations avec la lettre *f*, en observant 1° de n'admettre que les termes où *e* précède *f*; 2° de changer de signe lorsque *f* change de place: donnez ensuite 1 pour indice à la première lettre, ...

"Si vous avez sept équations, combinez les termes $+abcdef$ $-$&c. relatifs à six équations avec la lettre *g* de toutes les manières possibles; pour huit équations, combinez les termes relatifs à sept avec la lettre *h*, en n'admettant que les termes dans lesquels *g* précède *h*, et ainsi du reste."

The really important point in all this is in regard to the manner in which the letters are brought into combination. It will be seen that the set begun with is *abc*, consequently *a* precedes *b*, and *b* precedes *c* throughout: then *d* is combined in every possible way with this: *e* is combined subject to the condition that *d* precede *e*; *f* is combined subject to the condition that *e* precede *f*: *g* is combined in every way possible: *h* is combined subject to the condition that *g* precede *h*: and so on. It would appear therefore that the letters which are to be combined in every possible way are *d* and *every third one afterwards*, and that each of the other letters is conditioned to be preceded by the letter which immediately precedes it in the original arrangement *abcdefghi*. . . . Condensing these directions after the manner of the former case, we should draft the rule as follows:—

(*a*) Find every possible arrangement of *abcdefghi* . . . subject to the conditions that in each arrangement we must have *a*, *b*, *c* in their natural order; *d*, *e*, *f* in their natural order; *g*, *h*, *i* in their natural order; and so on.

(*b*) Prefix to each arrangement its proper sign in accordance with Cramer's rule.

(*c*) Append in order the indices 1, 2, 3 . . . . to the letters of each arrangement.

(*d*) Change $a_m b_n c_r$ into $(a_m.b_n.c_r)$, $d_s e_x f_y$ into $(d_s.e_x.f_y)$, &c.

Without saying anything as to the verification of the developments thus obtained, Laplace concludes as follows:—

> "On décomposeroit de la même manière l'équation R en termes composés de facteurs de 4, de 5, &c., dimensions."

To show how this could be effected would have been a tedious matter, if the method of exposition used in the previous cases had been followed, viz., multiplying instances with wearisome iteration of language until the laws for the combination of the letters could with tolerable certainty be guessed. On the other hand, had Laplace condensed his directions in the way we have indicated, the rule for the case in which as many as possible of the factors are of the 4th degree could have been stated as simply as that for either of the two cases he has dealt with. The only changes necessary, in fact, are in parts (1) and (4), and merely amount to writing the letters in consecutive sets of *four* instead of *two* or *three*.

Further, when the rule is condensed in this way, the problem of finding the number of terms in any one of the new developments—a problem which Laplace solves in one case by considering how many terms of the final development each such term gives rise to—is transformed into finding the number of possible arrangements referred to in part (1) of the rule. Where the highest degree of the factors of each term is 2 and the resultant which we wish to develop is of the 2nd degree (which is the case Laplace takes), the number of such arrangements is evidently $(1.2.3 \ldots . n)/(1.2)^s$, s being the highest integer in $n/2$; if the highest degree of the factors is 3, the number of arrangements is

$$\frac{1.2.3 \ldots\ldots n}{(1.2.3)^s\,(1.2)^t},$$

where s is the highest integer in $n/3$ and t the highest integer in $(n-3s)/2$; and so on.

The facts in reduction of the claim which Laplace has to the expansion-theorem now bearing his name are thus seen to be (1) that the case in which as many as possible of the factors of the terms of the expansion are of the 2nd degree had already been given by Vandermonde; (2) that Laplace did not give a statement of his rule in a form suitable for application to all possible cases, and, indeed, was not sufficiently explicit in the statement of it for the first two cases to enable one readily to see what change would be necessary in applying it to the next case. Notwithstanding these drawbacks, however, there can be no doubt that if any *one* name is to be attached to the theorem it should be that of Laplace.

The sum of his contributions may be put as follows :—

(1) A proof of the theorem regarding the effect of the transposition of two adjacent letters in any of the new functions. (XII. 2)

(2) A mode of arriving at the known solution of a set of simultaneous linear equations. (XIII. 2)

(3) The name *resultant* for the new functions. (XV.)

(4) A notation for a resultant, *e.g.* $({}^1a.{}^2b.{}^3c)$. (VII. 2)

(5) A rule for expressing a resultant as an aggregate of terms composed of factors which are themselves resultants. (XIV. 2)

(6) A mode of finding the number of terms in this aggregate. (XVI.)

LAGRANGE (1773).

[Nouvelle solution du problème du mouvement de rotation d'un corps de figure quelconque qui n'est animé par aucune force accélératrice. *Nouv. Mém. de l'Acad. Roy.* . . . . (*de Berlin*). *Ann.* 1773 (pp. 85–120).]

The position of Lagrange in regard to the advancement of the subject is quite different from that of any of the preceding mathematicians. All of those were explicitly dealing with the problem of elimination, and therefore directly with the functions afterwards known as determinants. Lagrange's work, on the other hand, consists of a number of incidentally obtained algebraical identities which we now-a-days with more or less readiness recognise as relations between functions of the kind referred to, but which unfortunately Lagrange himself did not view in this light, and consequently left behind him as isolated instances. With him x, y, z and x', y', z' and x'', y'', z'' occur primarily as co-ordinates of points in space, and not as coefficients in a triad of linear equations; so that

$$(xy'z''+yz'x''+zx'y''-xz'y''-yx'z''-zy'x''),$$

when it does make its appearance, comes as representing six times the bulk of a triangular pyramid and not as the result of an elimination. In days when space of four dimensions was less attempted to be thought about than at present, this circumstance might possibly account for no advance being made to like identities involving four sets of four letters x, y, z, w; x', y', z', w'; &c.

In this first memoir the algebraical identities are brought together and stated at the outset as follows :—

"Lemme.

"1. Soient neuf quantités quelconques

$$x, y, z, x', y', z', x'', y'', z''$$

je dis qu'on aura cette équation identique

$$\begin{aligned}(xy'z'' + yz'x'' + zx'y'' - xz'y'' - yx'z'' - zy'x''^2)\\ = (x^2+y^2+z^2)(x'^2+y'^2+z'^2)(x''^2+y''^2+z'')^2\\ + 2(xx'+yy'+zz')(xx''+yy''+zz'')(x'x''+y'y''+z'z'')\\ - (x^2+y^2+z^2)(x'x''+y'y''+z'z'')^2\\ - (x'^2+y'^2+z'^2)(xx''+yy''+zz'')^2\\ - (x''^2+y''^2+z''^2)(xx'+yy'+zz')^2 .\end{aligned}$$

"Corollaire 1.

"2. Donc si l'on a entre les neuf quantités précédentes ces six équations

$$\begin{array}{ll} x^2+y^2+z^2=a & x'x''+y'y''+z'z''=b, \\ x'^2+y'^2+z^2=a' & xx''+yy''+zz''=b', \\ x''^2+y''^2+z''^2=a'' & xx'+yy'+zz'=b'', \end{array}$$

et qu'on fasse pour abréger

$$\xi = y'z'' - z'y'', \quad \eta = z'x'' - x'z'', \quad \zeta = x'y'' - y'x'',$$

$$\beta = \surd(aa'a'' + 2bb'b'' - ab^2 - a'b'^2 - a''b''^2);$$

on aura

$$x\xi + y\eta + z\zeta = \beta .$$

On aura de plus les équations identiques suivantes

$$x'\xi + y'\eta + z'\zeta = 0, \quad x''\xi + y''\eta + z''\zeta = 0$$

$$\xi^2 + \eta^2 + \zeta^2 = a'a'' - b^2,$$

$$\begin{array}{ll} y'\zeta - z'\eta = bx' - a'x'', & y''\zeta - z''\eta = a''x' - bx'', \\ z'\xi - x'\zeta = by' - a'y'', & z''\xi - x''\zeta = a''y' - by'', \\ x'\eta - y'\xi = bz' - a'z'', & x''\eta - y''\xi = a''z' - bz'', \end{array}$$

qui sont très faciles à vérifier par le calcul.

" Corollaire 2.

" 3. Si on prend les trois équations

$$x\xi + y\eta + z\zeta = \beta,$$
$$xx' + yy' + zz' = b'',$$
$$xx'' + yy'' + zz'' = b',$$

et qu'on en tire les valeurs des quantités x, y, z, on aura par les formules connues

$$x = \frac{\beta(y'z'' - z'y'') + b'(\eta z' - \zeta y') + b''(\zeta y'' - \eta z'')}{\xi(y'z'' - z'y'') + \eta(z'x'' - x'z'') + \zeta(x'y'' - y'x'')}$$

$$y = \frac{\beta(z'x'' - x'z'') + b'(\zeta x' - \xi z') + b''(\xi z'' - \zeta x'')}{\xi(y'z'' - z'y'') + \eta(z'x'' - x'z'') + \zeta(x'y'' - y'x'')},$$

$$z = \frac{\beta(x'y'' - y'x'') + b'(\xi y' - \eta x') + b''(\eta x'' - \xi y'')}{\xi(y'z'' - z'y'') + \eta(z'x'' - x'z'') + \zeta(x'y'' - y'x'')};$$

donc faisant les substitutions de l'Art. préc. et supposant pour abréger

$$a = a'a'' - b^2$$

on aura

$$x = \frac{\beta\xi + (a''b'' - bb')x' + (a'b' - bb'')x''}{a},$$

$$y = \frac{\beta\eta + (a''b'' - bb')y' + (a'b' - bb'')y''}{a},$$

$$z = \frac{\beta\zeta + (a''b'' - bb')z' + (a'b' - bb'')z''}{a}."$$

In regard to the first identity here (the so-called lemma), the important and notable point is that the right-hand member is the same kind of function of the nine quantities $x^2+y^2+z^2$, $xx'+yy'+zz'$, $xx''+yy''+zz''$, $xx'+yy'+zz'$, $x'^2+y'^2+z'^2$, $x'x''+y'y''+z'z''$, $xx''+yy''+zz''$, $x'x''+y'y''+z'z''$, $x''^2+y''^2+z''^2$ as the left-hand member is of the nine x, y, z, x', y', z', x'', y'', z''. Indeed, without this distinguishing characteristic, the identity would have been to us of comparatively little moment. Possibly Lagrange was aware of it; but, if so, it is remarkable that he did not draw attention to the fact. It is quite true that Lagrange's identity and the modern-looking identity

$$\begin{vmatrix} x & y & z \\ x' & y' & z' \\ x'' & y'' & z'' \end{vmatrix}^2 = \begin{vmatrix} x^2+y^2+z^2 & xx'+yy'+zz' & xx''+yy''+zz'' \\ xx'+yy'+zz' & x'^2+y'^2+z'^2 & x'x''+y'y''+z'z'' \\ xx''+yy''+zz'' & x'x''+y'y''+z'z'' & x''^2+y''^2+z''^2 \end{vmatrix}$$

are essentially the same; but no one can deny that the latter contains on the face of it an all-important fact which is hid in the former, and which in Lagrange's time could be made known only by an additional statement in words.

The second identity

$$x'\xi + y'\eta + z'\zeta = 0$$

is a simple case of one of Vandermonde's, viz., that regarding the vanishing of his functions when two of the letters involved were the same.

The third identity

$$\xi^2 + \eta^2 + \zeta^2 = a'a'' - b^2$$

is in modern notation

$$\begin{vmatrix} y' & y'' \\ z' & z'' \end{vmatrix}^2 + \begin{vmatrix} z' & z'' \\ x' & x'' \end{vmatrix}^2 + \begin{vmatrix} x' & x'' \\ y' & y'' \end{vmatrix}^2 = \begin{vmatrix} x'^2 + y'^2 + z'^2 & x'x'' + y'y'' + z'z'' \\ x'x'' + y'y'' + z'z'' & x''^2 + y''^2 + z''^2 \end{vmatrix}$$

and is thus seen to be a simple special instance of a very important theorem afterwards discovered.

The fourth identity

$$y'\zeta - z'\eta = bx' - a'x'',$$

may be expressed in modern notation as follows:—

$$\begin{Vmatrix} y' & z' \\ |z'x''| & |x'y''| \end{Vmatrix} = \begin{vmatrix} x'x'' + y'y'' + z'z'' & x'' \\ x'^2 + y'^2 + z'^2 & x' \end{vmatrix},$$

and, quite probably, has also ere this been generalised in the like notation.

The fifth identity

$$x = \frac{\beta\xi + (a''b'' - bb')x' + (a'b' - bb'')x''}{\alpha},$$

is not so readily transformable, the determinantal theorem which it involves being indeed completely buried. Multiplying both sides by α; then doing away with α, which seems perversely introduced "pour abréger" when no like symbol of abridgment takes the place of $a''b'' - bb'$ or of $a'b' - bb''$; and transposing, we have

$$\begin{aligned} \beta\xi &= x(a'a'' - b^2) - x'(a''b'' - bb') + x''(bb'' - a'b') \\ &= \begin{vmatrix} x & b'' & b' \\ x' & a' & b \\ x'' & b & a'' \end{vmatrix}; \end{aligned}$$

that is, finally,

$$|xy'z''| \, . \, |y'z''| = \begin{vmatrix} x & xx' + yy' + zz' & xx'' + yy'' + zz'' \\ x' & x'^2 + y'^2 + z'^2 & x'x'' + y'y'' + z'z'' \\ x'' & x'x'' + y'y'' + z'z'' & x''^2 + y''^2 + z''^2 \end{vmatrix},$$

which we recognise as an instance of the multiplication-theorem on putting

$$\begin{vmatrix} x & y & z \\ x' & y' & z' \\ x'' & y'' & z'' \end{vmatrix} \times \begin{vmatrix} 1 & x' & x'' \\ 0 & y' & y'' \\ 0 & z' & z'' \end{vmatrix}$$

for the left-hand member.

LAGRANGE (1773).

[Solutions analytiques de quelques problèmes sur les pyramides triangulaires. *Nouv. Mém. de l'Acad. Roy.* . . . . (*de Berlin*) *Ann.* 1773 (pp. 149–176).]

In this memoir also there is a preparatory algebraical portion, the subject being the same as before, and the author's standpoint unchanged. Indeed the two introductions differ only in that the second is a rounding off and slight natural development of the first.

In addition to ξ, η, ζ, we have now $\xi', \eta', \zeta', \xi'', \eta'', \zeta''$ used as abbreviations for $zy'' - yz''$, $xz'' - zx''$, ... ; in addition to α, we have $\alpha', \alpha'', \beta, \beta', \beta''$, standing for $aa'' - b'^2$, $aa' - b''^2$, $b'b'' - ab$, $bb'' - a'b'$, $bb' - a''b''$; and X, Y, Z, X′, Y′, ..., A, A′, . . . are introduced, having the same relation to $\xi, \eta, \zeta, \xi', \eta'$, ... α, α', . . . as these latter have to x, y, z, x', y', ..., a, a', ... Lagrange then proceeds:—

"3. Or en substituant les valeurs de ξ, ξ', &c., en x, x', &c., et faisant pour abréger

$$\Delta = xy'z'' + yz'x'' + zx'y'' - xz'y'' - yx'z'' - zy'x'',$$

on trouve

$$\begin{array}{lll} X = \Delta x, & Y = \Delta y, & Z = \Delta z, \\ X' = \Delta x', & Y' = \Delta y', & Z' = \Delta z', \\ X'' = \Delta x'', & Y'' = \Delta y'', & Z'' = \Delta z'', \end{array}$$

donc mettant ces valeurs dans les dernières équations ci-dessus, on aura en vertu des six équations supposées dans l' Art. 1.

$$\begin{aligned} A &= \Delta^2 a, & B &= \Delta^2 b, \\ A' &= \Delta^2 a', & B' &= \Delta^2 b', \\ A'' &= \Delta^2 a'', & B'' &= \Delta^2 b'', \end{aligned}$$

et de là il est facile de tirer la valeur de Δ^2 en a, a', a'', b, &c. ; car on aura d'abord

$$\Delta^2 = \frac{A}{a} = \frac{\alpha'\alpha'' - \beta^2}{a}$$

et substituant les valeurs de α', α'' et β en a, a', &c. (Art. 1).

$$\Delta^2 = aa'a'' + 2bb'b'' - ab^2 - a'b'^2 - a''b''^2 ;$$

on trouvera la même valeur de Δ^2 par les autres équations. Si on remet dans cette équation les quantités x, y, z, x', &c., on aura la même équation identique que nous avons donnée dans le Lemme ci-dessus (p. 86).

" 4. Il est bon de remarquer que la valeur de Δ^2 peut aussi se mettre sous cette forme

$$\Delta^2 = \frac{a\alpha + a'\alpha' + a''\alpha'' + 2(\beta b + \beta' b' + \beta'' b'')}{3} ;$$

or si on multiplie cette équation par Δ^2 et qu'on y substitue ensuite A à la place de $\Delta^2 a$, A' à la place de $\Delta^2 a'$ et ainsi de suite (Art. préc.) on aura

$$\Delta^4 = \frac{A\alpha + A'\alpha' + A''\alpha'' + 2(B\beta + B'\beta' + B''\beta'')}{3} ;$$

ou bien en mettant pour A, A', &c., leurs valeurs en α, α', &c. (Art. 2).

$$\Delta^4 = \alpha\alpha'\alpha'' + 2\beta\beta'\beta'' - \alpha\beta^2 - \alpha'\beta'^2 - \alpha''\beta''^2 ;$$

d'où l'on voit que la quantité Δ^2 et son carré Δ^4 sont des fonctions semblables, l'une de a, a', a'', b, b', b'', l'autre de α, α', α'', β, β', β''.

" 5. De plus, comme l'on a (Art. 3)

$$\begin{aligned} &xy'z'' + yz'x'' + zx'y'' - xz'y'' - yx'z'' - zy'x'' \\ &= \sqrt{(aa'a'' + 2bb'b'' - ab^2 - a'b'^2 - a''b''^2)} \quad = \Delta, \end{aligned}$$

et qu'il y a entre les quantités x, y, z, x', &c., et a, a', a'', b,

&c., les mêmes relations qu'entre les quantités ξ, η, ζ, ξ', &c., et a, a', a'', β, &c. (Art. 1), on aura donc aussi

$$\xi\eta'\zeta'' + \eta\zeta'\xi'' + \zeta\xi'\eta'' - \xi\zeta'\eta'' - \eta\xi'\zeta'' - \zeta\eta'\xi''$$
$$= \sqrt{(aa'a'' + 2\beta\beta'\beta'' - a\beta^2 - a'\beta'^2 - a''\beta''^2)} = \Delta^2.$$

Donc on aura cette équation identique et très remarquable

$$\xi\eta'\zeta'' + \eta\zeta'\xi'' + \zeta\xi'\eta'' - \xi\zeta'\eta'' - \eta\xi'\zeta'' - \zeta\eta'\xi''$$
$$= (xy'z'' + yz'x'' + zx'y'' - xz'y'' - yx'z'' - zy'x'')^2."$$

The remaining portion is of little importance; its main contents are four sets of nine identities each, viz. :—

1. $x\xi + x'\xi' + x''\xi'' = \Delta\,, \qquad y\xi + y'\xi' + x''\xi'' = 0$, &c.
2. $x\xi + y\eta + z\zeta = \Delta\,, \qquad x'\xi + y'\eta + z'\zeta = 0$, &c.
3. $\xi = \dfrac{ax + \beta''x' + \beta'x''}{\Delta}$, &c.
4. $x = \dfrac{a\xi + b''\xi' + b'\xi''}{\Delta}$, &c.

Besides the fact that Art. 3 contains a proof of the Lemma of the previous memoir, we have to note the new identity

$$X = \Delta x,$$

which in modern determinantal notation is

$$\begin{Vmatrix} |xz''| & |yx''| \\ |zx'| & |xy'| \end{Vmatrix} = x\,|xy'z''|\,,$$

—a simple special instance of the theorem regarding what is now-a-days known as "a minor of the determinant adjugate to another determinant."

The last two lines of Art. 4 by implication make it almost certain that Lagrange did not look upon

$$xy'z'' + yz'x'' + zx'y'' - xz'y'' - yx'z'' - zy'x''$$
$$\text{and} \quad aa'a'' + 2bb'b'' - ab^2 - a'b'^2 - a''b''^2$$

as functions of the same kind.

The new theorem in Art. 5, which Lagrange justly characterises as "very remarkable," is in modern determinantal notation

$$\begin{Vmatrix} |y'z''| & |z'x''| & |x'y''| \\ |zy''| & |xz''| & |yx''| \\ |yz'| & |zx'| & |xy'| \end{Vmatrix} = \begin{vmatrix} x & y & z \\ x' & y' & z' \\ x'' & y'' & z'' \end{vmatrix}^2$$

—a simple instance of the theorem which gives the relation, as we now say, "between a determinant and its adjugate."

In regard to the remaining identities which we have numbered (1), (2), (3), (4), we note that (1) and (3) are not new, although (3) is here given almost in the form desiderated above (pp. 580–1); (2) involves the fact that Δ is the same function of $x, x', x'', y, y', y'', z, z', z''$, as it is of $x, y, z, x', y', z', x'', y'', z''$; and (4) may be transformed as follows:—

$$x\Delta = a\xi + b''\xi' + b'\xi'',$$

$$= \begin{vmatrix} a & y & z \\ b'' & y' & z' \\ b' & y'' & z'' \end{vmatrix},$$

$$= \begin{vmatrix} x^2 + y^2 + z^2 & y & z \\ xx' + yy' + zz' & y' & z' \\ xx'' + yy'' + zz'' & y'' & z'' \end{vmatrix};$$

so that it may be considered as another disguised instance of the multiplication-theorem, the determinant just reached being equal to

$$\begin{vmatrix} x & y & z \\ x' & y' & z' \\ x'' & y'' & z'' \end{vmatrix} \times \begin{vmatrix} x & 0 & 0 \\ y & 1 & 0 \\ z & 0 & 1 \end{vmatrix}.$$

LAGRANGE (1773).

[Recherches d'Arithmétique. *Nouv. Mém. de l'Acad. Roy. . . . (de Berlin) Ann.* 1773 (pp. 265–312).]

This is an extensive memoir on the numbers "qui peuvent être représentées par la formule $Bt^2 + Ctu + Du^2$". At p. 285 the expression

$$py^2 + 2qyz + rz^2$$

is transformed into

$$Ps^2 + 2Qsx + Rx^2$$

by putting $$y = Ms + Nx,$$

and $$z = ms + nx,$$

and Lagrange says—

> ". . . . je substitue dans la quantité $PR - Q^2$ les valeurs de P, Q et R, et je trouve en effaçant ce qui se détruit
>
> $$PR - Q^2 = (pr - q^2)(Mn - Nm)^2; \ . \ . \ . \ ."$$

which we at once recognise as the simplest case of the theorem connecting (as we now say) the discriminant of any quantic with the discriminant of the result of transforming the quantic by a linear substitution.

Putting now in compact form all the identities obtained from the three preceding memoirs of Lagrange, we have—

(1) $(xy'z''+yz'x''+zx'y''-xz'y''-yx'z''-zy'x'')^2$
$= aa'a''+2bb'b''-ab^2-a'b'^2-a''b''^2,$ (XVII.)
where $a=x^2+y^2+z^2, \quad a'=.....$

(2) $\xi^2+\eta^2+\zeta^2=a'a''-b^2$, where $\xi=y'z''-z'y''$, $\eta=....$ (XVIII.)

(3) $y'\zeta-z\eta=bx'-a'x''$. (XIX.)

(4) $\xi\Delta=\alpha x+\beta''x'+\beta'x''$, where $\alpha=a'a''-b^2$, $\beta''=.....$,
and $\Delta=xy'z''+yz'x''+zx'y''-xz'y''-yx'z''-zy'x''$. (XVII. 2)

(5) $X=\Delta x$, where $X=\eta'\zeta''-\zeta'\eta''$. (XX.)

(6) $(xy'z''+yz'x''+zx'y''-xz'y''-yx'z''-zy'x'')^2$
$=\xi\eta'\zeta''+\eta\zeta'\xi''+\zeta\xi'\eta''-\xi\zeta'\eta''-\eta\xi'\zeta''-\zeta\eta'\xi''$. (XXI.)

(7) $PR-Q^2=(pr-q^2)(Mn-Nm)^2$, (XXII.)
if $p(Ms+Nx)^2+2q(Ms+Nx)(ms+nx)+r(ms+nx)^2$
$=Ps^2+2Qsx+Rx^2$ identically.

BÉZOUT (1779).

[Théorie Générale des Equations Algébriques, §§ 195–223, pp. 171–187; §§ 252–270, pp. 208–223. Paris.]

In his extensive treatise on algebraical equations Bézout was bound, as a matter of course, to take up the question of elimination; and, as he had dealt with the subject in a separate memoir in 1764, one might not unreasonably expect to find the treatise giving merely a reproduction of the contents of the memoir in a form suited to a didactic work. Such, however, is far from being the case. He merely mentions the necessary references to the work of Cramer, himself, Vandermonde, and Laplace; and then adds—

"Mais lorsqu'il a été question d'appliquer ces différentes méthodes au problème de l'élimination, envisagé dans toute son étendue, je me suis bientôt apperçu qu'ils laissoient tous encore beaucoup à desirer du côté de la pratique."

His main objection to the said methods is that when one has to deal with a set of equations of no great generality, with coefficients, it may be, expressed in figures—

"Il faut construire ces formules dans toute la generalité dont les équations sont susceptibles, et faire par conséquent le même travail que si les équations avoient toute cette généralité.

. . . .

(197). Au lieu donc de nous proposer pour but seulement, de donner des formules générales d'élimination dans les équations du premier degré, nous nous proposons de donner une règle qui soit indifféremment et également applicable aux équations prises dans toute leur généralité, et aux équations considerées avec les simplifications qu'elles pourront offrir: une règle dont la marche soit la même pour les unes que pour les autres, mais qui ne fasse calculer que ce qui est absolument indispensable pour avoir la valeur des inconnues que l'on cherche: une règle qui s'applique indifféremment aux équations numériques et aux équations littérales, sans obliger de recourir à aucune formule. Telle est, si je ne me trompe, la règle suivante.

"*Règle générale pour calculer, toutes à la fois, ou séparément, les valeurs des inconnues dans les équations du premier degré, soit littérales soit numériques.*

"(198). Soient u, x, y, z, &c., des inconnues dont le nombre soit n, ainsi que celui des équations.

"Soient a, b, c, d, &c., les coëfficiens respectifs de ces inconnues dans la première équation.

"a', b', c', d', &c., les coëfficiens des mêmes inconnues dans la seconde équation.

"a'', b'', c'', d'', &c., les coëfficiens des mêmes inconnues dans la troisième équation: et ainsi de suite.

"Supposez tacitement que le terme tout connu de chaque équation soit affecté aussi d'une inconnue que je représente par t.

"Formez le produit $uxyzt$ de toutes ces inconnues écrites dans tel ordre que vous voudrez d'abord; mais cet ordre une fois admis, conservez-le jusqu'à la fin de l'opération.

"Echangez successivement, chaque inconnue, contre son coëfficient dans la première équation, en observant de changer le signe à chaque échange pair: ce résultat sera, ce que j'appelle, une *première ligne.*

"Echangez dans cette *première ligne*, chaque inconnue, contre son coëfficient dans la seconde équation, en observant, comme ci-devant, de changer le signe à chaque échange pair: et vous aurez une *seconde ligne.*

"Echangez dans cette *seconde ligne*, chaque inconnue, contre son coëfficient dans la troisième équation, en observant de changer le signe à chaque échange pair: et vous aurez une *troisième ligne.*

"Continuez de la même manière jusqu'à la dernière équation inclusivement; et la dernière *ligne* que vous obtiendrez, vous donnera les valeurs des inconnues de la manière suivante.

"Chaque inconnue aura pour valeur une fraction dont le numérateur sera le coëfficient de cette même inconnue dans la dernière ou n^e *ligne*, et qui aura constamment pour dénominateur le coëfficient que l'inconnue introduite t se trouvera avoir dans cette même n^e *ligne.*"

The application of this very curious rule is illustrated by a considerable number of varied examples, of which we select the second—

"(200). Soient les trois équations suivantes

$$\begin{aligned} ax + by + cz + d &= 0\,, \\ a'x + b'y + c'z + d' &= 0\,, \\ a''x + b''y + c''z + d'' &= 0\,. \end{aligned}$$

"Je les écris ainsi

$$\begin{aligned} ax + by + cz + dt &= 0\,, \\ a'x + b'y + c'z + d't &= 0\,, \\ a''x + b''y + c''z + d''t &= 0\,. \end{aligned}$$

Je forme le produit $xyzt$.

Je change successivement x en a, y en b, z en c, t en d, et observant la règle des signes, j'ai pour première ligne

$$ayzt - bxzt + cxyt - dxyz\,.$$

Je change successivement x en a', y en b', z en c', t en d', et observant la règle des signes, j'ai pour seconde ligne

$$\begin{aligned}&(ab' - a'b)zt - (ac' - a'c)yt + (ad' - a'd)yz \\ &+ (bc' - b'c)xt - (bd' - b'd)xz + (cd' - c'd)xy.\end{aligned}$$

Je change successivement x en a'', y en b'', z en c'', t en d'', et observant la règle des signes j'ai pour troisième ligne

$$\begin{aligned}&[(ab' - a'b)c'' - (ac' - a'c)b'' + (bc' - b'c)a'']t \\ &- [(ab' - a'b)d'' - (ad' - a'd)b'' + (bd' - b'd)a'']z \\ &+ [(ac' - a'c)d'' - (ad' - a'd)c'' + (cd' - c'd)a'']y \\ &- [(bc' - b'c)d'' - (bd' - b'd)c'' + (cd' - c'd)b'']x.\end{aligned}$$

D'où (198) je tire

$$x = \frac{-[(bc' - b'c)d'' - (bd' - b'd)c'' + (cd' - c'd)b'']}{(ab' - a'b)c'' - (ac' - a'c)b'' + (bc' - b'c)a''},$$

$$y = \frac{+[(ac' - a'c)d'' - (ad' - a'd)c'' + (cd' - c'd)a'']}{(ab' - a'b)c'' - (ac' - a'c)b'' + (bc' - b'c)a''},$$

$$z = \frac{-[(ab' - a'b)d'' - (ad' - a'd)b'' + (bd' - b'd)a'']}{(ab' - a'b)c'' - (ac' - a'c)b'' + (bc' - b'c)a''}.$$

Among the other examples are included (1) one in which the coefficients in the set of equations are given in figures; (2) one in which some of the coefficients are zero; (3) one showing the simplification possible when the value of only one unknown is wanted; (4) one showing the signification of the vanishing of one of the "*lignes*"; (5) one showing the signification of the absence of one of the unknowns from the last "*ligne*"; and (6) one or two concerned with the allied problem of elimination.

Bézout nowhere gives any reason for his rule; it is used throughout as a pure rule-of-thumb: its effectiveness being manifest, he leaves on the reader the full burden of its arbitrariness. The unreal product *xyzt* at the very outset must have been a sore puzzle to students, and none the less so because of the certainty which many of them must have felt that a real entity underlay it.

To throw light upon the process, let us compare the above solution of a set of three linear equations with the following solution, which from one point of view may be looked upon as an improvement on the ordinary determinantal modes of solution as presented to modern readers.

The set of equations being

$$\left.\begin{array}{l} ax\ +by\ +cx\ +d\ =0 \\ a'x\ +b'y\ +c'x\ +d'\ =0 \\ a''x+b''y+c''x+d''=0 \end{array}\right\}$$

we know that the numerator of the values of x, y, z, and the common denominator are

$$-\begin{vmatrix} b & c & d \\ b' & c' & d' \\ b'' & c'' & d'' \end{vmatrix}, \quad +\begin{vmatrix} a & c & d \\ a' & c' & d' \\ a'' & c'' & d'' \end{vmatrix}, \quad -\begin{vmatrix} a & b & d \\ a' & b' & d' \\ a'' & b'' & d'' \end{vmatrix}, \quad +\begin{vmatrix} a & b & c \\ a' & b' & c' \\ a'' & b'' & c'' \end{vmatrix}.$$

They are therefore the coefficients of x, y, z, t in the determinant

$$\begin{vmatrix} a & b & c & d \\ a' & b' & c' & d' \\ a'' & b'' & c'' & d'' \\ x & y & z & t \end{vmatrix}, \text{ or } \Delta \text{ say.}$$

Thus the problem of solving the set of equations is transformed into finding the development of this determinant. In doing so let us use $[xyz]$ to stand for the determinant of which x, y, z is the last row, and whose other rows are the two rows immediately above x, y, z in Δ: similarly let $[zt]$ stand for the determinant of which z, t is the last row, and its other row the row c'', d'' immediately above z, t in Δ; and so on in all possible cases, including even $[xyzt]$, which of course is Δ itself.

Then clearly we have

$$[xyzt]=a[yzt]-b[xzt]+c[xyt]-d[xyz] \quad . \quad . \quad . \quad . \quad (1)$$

Developing in the same way the four determinants here on the right side, we have as our next step

$$\begin{aligned} [xyzt] = \quad & a(b'[zt]-c'[yt]+d'[yz]) \\ & -b(a'[zt]-c'[xt]+d'[xz]) \\ & +c(a'[yt]-b'[xt]+d'[xy]) \\ & -d(a'[yz]-b'[xz]+c'[xy]), \\ = \quad & (ab'-a'b)[zt]-(ac'-a'c)[yt]+(ad'-a'd)[yz] \\ & +(bc'-b'c)[xt]-(bd'-b'd)[xz]+(cd'-c'd)[xy]. \end{aligned}$$

Again, developing the six determinants $[zt]$, $[yt]$, ... in the same way, and rearranging the terms, we have finally

$$\begin{aligned}[xyzt] = &\{(ab' - a'b)c'' - (ac' - a'c)b'' + (bc' - b'c)a''\}t \\ &- \{(ab' - a'b)d'' - (ad' - a'd)b'' + (bd' - b'd)a''\}z \\ &+ \{(ac' - a'c)d'' - (ad' - a'd)c'' + (cd' - c'd)a''\}y \\ &- \{(bc' - b'c)d'' - (bd' - b'd)c'' + (cd' - c'd)b''\}x .\end{aligned}$$

But the coefficients of x, y, z, t in $[x\,y\,z\,t]$ were seen on starting to be the numerators and the common denominator of the values of x, y, z in the given set of equations: hence

$$x = \frac{-\{(bc' - b'c)d'' - (bd' - b'd)c'' + (cd' - c'd)b''\}}{\{(ab' - a'b)c'' - (ac' - a'c)b'' + (bc' - b'c)a''\}}$$

$$y = \;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.$$

$$z = \;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.$$

2. The Formation of the Germinal Layers in Teleostei. By George Brook, F.L.S., Lecturer on Comparative Embryology in the University of Edinburgh.

(*Abstract.*)

The majority of recent investigations have concluded that the thickening of the rim of the blastoderm, and the new layer which is derived from it, is brought about by a true invagination of the *segmented* blastoderm. On the other hand, Klein and Kupffer hold that the newly formed layer is not derived from the segmented blastoderm (archiblast), but is mainly produced from an *unsegmented* portion of the blastoderm (parablast), which is intermediate in position between the archiblast and the yolk.

A little over a year ago I was led to conclude, from a study of the development of *Trachinus*, that the so-called "invaginated layer," the primitive hypoblast, was in great part, if not entirely, built up from the margin inwards of cells budded off from the parablast. More recently I have studied the question in other forms, particularly the herring, and am now enabled to bring forward more important evidence as to the origin and morphological significance of the parablast, and also of the part which this layer plays in the economy of the embryo.

The first two furrows in the herring are vertical in direction, and at right angles to one another. They are not pushed down to the base of the germinal mound, but cease some distance before reaching the yolk. Four segmentation spheres are thus formed, which are imperfectly separated from the lower pole of the ovum. The third furrow takes an equatorial direction, and simply completes the bases of the first four segmentation spheres. The upper portion goes on segmenting, and constitutes the archiblast. The lower pole consists of a central mass of yolk, around which is a layer of protoplasm, which constitutes the parablast. With the formation of the first equatorial furrow we have a division of the ovum into an animal and a vegetative pole, as in the amphibian ovum.

The archiblast represents the animal pole, and the parablast, with its enclosed yolk, the vegetative. The segmentation cavity appears between them. The primitive hypoblast is formed from the vegetative pole by a budding off of cells from the margin of the parablast, as has already been described. Cell formation takes place in the parablast of the herring ovum earlier than I have observed it in other forms, and two batches of cells are added to the animal pole by this means before the pseudo-invagination begins. In the herring the archiblast, together with the cells which have been derived from the parablast prior to the formation of the segmentation cavity, gives rise to the ectoderm. The primitive hypoblast, which is almost entirely derived from the vegetative pole, gives rise to the mesoderm and notochord, and the true entoderm remains as a single row of cells in connection with the parablast.

If this account should prove to be correct, several interesting relations will be established between Teleostei and other forms. The primitive hypoblast, as I have here described it, is precisely homologous with that of Amphioxus, and both give rise to mesoderm, notochord, and entoderm.

Again the derivatives of the animal and vegetative pole in the herring are practically the same as in the frog. In Teleosteans, however, the vegetative pole consists at first of one cell instead of four, this arrangement being brought about by the greater bulk and different arrangement of the yolk.

Quite recently Dr Ruckert, who has investigated the question in Elasmobranchs, has come to very similar conclusions.

3. Account of a Preliminary Experiment on the Thermal Conductivity of Ice. By A. Crichton Mitchell. Communicated by Professor Tait. (Plate XXI.)

The following paper is an account of a preliminary experiment performed in the Edinburgh University Physical Laboratory, with the view of determining the thermal conductivity of ice.

The method employed was that of Angström, which consists in heating and cooling alternately, to a definite amount and for definite periods of time, one end of a block or bar of the substance whose conductivity is required. The thermal changes produced in this manner are transmitted throughout the substance in a species of wave. Taking two points in the substance in a line perpendicular to the surface which is being heated and cooled, these changes are produced until the temperature indications at the two successive points have become periodic. The conductivity can then be calculated from the ratio of the amplitudes of the temperature indications per unit length along the line joining the two points, and from the interval in time between the maximum temperatures per unit length.

Obviously, the ranges of temperature we must work with in the case of ice lie below 0° cent.; and accordingly, the periodic cooling and heating were effected by successive applications of a freezing mixture and exposure to the surrounding air, which was throughout the experiment never above 1° cent. To carry this out, a tinned iron box, with open top, had two thermo-electric junctions of iron-German silver—inserted through india-rubber corks, fitted into circular holes, in opposite sides of the box; one hole being so much above the other as to separate the junctions by a distance of 1·27 centimetres from each other, in a line perpendicular to the bottom of the box. The cube was then filled with water, previously boiled to expel dissolved air, and placed on the roof of the College for forty-eight hours during frost. The ice formed in this manner, with the thermo-electric junctions in its interior, was free from cracks and air particles, and was evidently quite homogeneous.

It was at first attempted to cool and heat the surface of the ice by simply laying on it a freezing mixture of snow and salt for a definite period of time, and subsequently flooding the surface of the

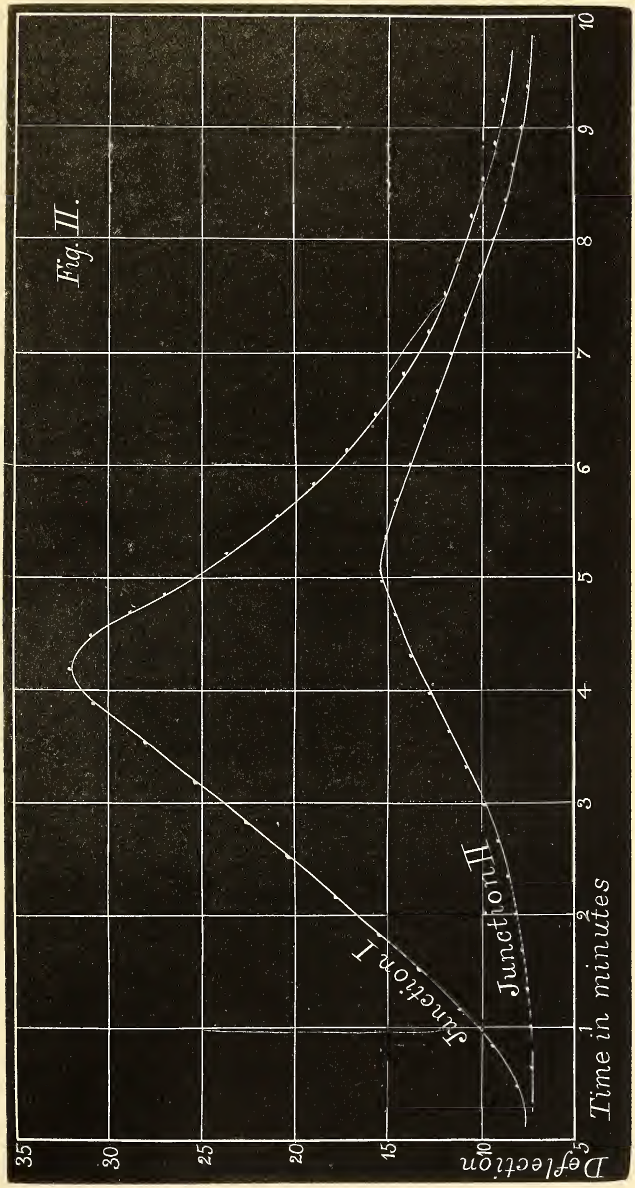
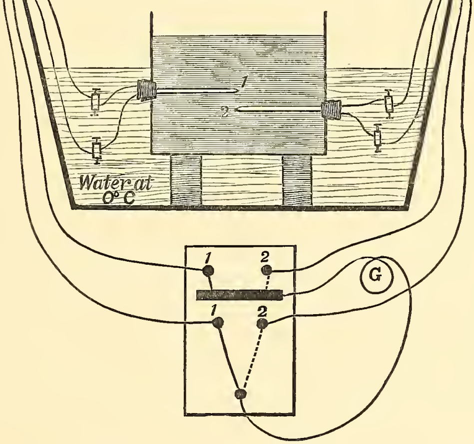


Fig. II.
Junction I
Junction II
Time in minutes
Deflection
35
30
25
20
15
10
5
1
2
3
4
5
6
7
8
9
10

ice with ice-cold water for the same time. But the first of these two operations was found to melt the ice on its surface; while during the second, the ice-cold water froze on the surface of the previously cooled ice. To obviate this difficulty, a thin sheet of tinfoil was placed on the suface of the ice; on this was laid for five minutes the freezing mixture of pounded ice and salt; and during the next five minutes the surface of the ice was simply exposed to the air. This alternation of cooling and heating was then regularly carried on until the thermal changes at the thermo-electric junctions

Fig.I.



were observed to be periodic; after which readings were taken at equal intervals of time, viz., 20 seconds.

The metal-box, containing the cube of ice, was placed in a bath of ice and water, which provided a steady temperature for one of the junctions in each of the two thermo-electric circuits. By means of a commutator, one junction (in the ice) at a time was placed in circuit with a Thomson's dead-beat galvanometer (resistance 1·5 ohms at 9°·4 cent.); the circuit was so changed as to include the two junctions alternately. In this manner it was found possible to take readings every ten seconds.

It was found difficult to attain a strictly periodic change in the temperature at each of the junctions. This may be due partly to the fact that freezing mixtures themselves undergo sudden changes of temperature, and partly to the circumstance that the completeness of contact between the intervening sheet of tinfoil and the surface of the ice may not have been the same during two successive periods.

J_1	J_2	J_1	J_2	J_1	J_2	J_1	J_2
27·7		42·7		40·8		3·00	
	27·4		29·6		34·4		28·9
28·3		45·1		38·8		30·0	
	27·4		30·5		33·7		28·8
29·6		48·1		37·1		29·4	
	27·3		31·5		33·1		28·2
31·5		50·6		35·7		29·2	
	27·3		32·4		32·4		27·85
33·7		51·9		33·5		28·8	
	27·5		33·6		31·2		27·6
35·8		50·7		32·7		28·65	
	27·9		34·4		30·5		27·3
38·0		47·1		31·8		28·5	
	28·5		35·1		30·0		27·1
40·2		43·5		31·1		28·5	
	29·0		34·8		29·4		27·05

Galvanometer zero, 29·0.

Detailed above are a set of readings taken during one period—one of the few in which the changes were practically periodic. The junctions are numbered in order, beginning with that nearer the surface. The interval between two readings of the same junction is 20 seconds, and they were taken alternately.

Plotting these readings (which express differences of temperature) against time, a curve is obtained, the equation to which is

$$\begin{aligned} f(\theta) = A_0 + A_1 \cos\theta + A_2 \cos 2\theta + A_3 \cos 3\theta + \ldots . \\ + B_1 \sin\theta + B_2 \sin 2\theta + B_3 \sin 3\theta + \ldots . \end{aligned}$$

where θ is an angle which increases in proportion to the time, and where A_0, A_1, A_2, B_1, B_2, . . . &c., are unknown coefficients. By taking six values of $f(\theta)$ we may determine the coefficients A_0, A_1, A_2, A_3, B_1, B_2, B_3. Subtracting from each value of $f(\theta)$, A_0, the mean value of the function, we get

$$\begin{aligned} \eta = A_1 \cos\theta + \ldots \\ + B_1 \sin\theta + \ldots \end{aligned}$$ Then putting $P_1 = \sqrt{A_1^2 + B_1^2}$,

this may be written

$$\eta = P_1 \left(\frac{A}{P_1}\cos\theta + \frac{B_1}{P_1}\sin\theta\right) + \ldots\ldots \&c.$$

Evidently $\frac{A_1}{P_1}$ and $\frac{B_1}{P_1}$ are respectively the cosine and sine of some angle. Let it be α. Then we have

$$\eta = P_1 \cos(\theta - \alpha_1) + P_2 \cos 2(\theta - \alpha_2) + \ldots\ldots$$

Having determined P_1 and α_1 for the first junction, P_1' and α_1' are determined in the same way for the second.

Then $$\frac{P_1'}{P_1} = \epsilon^{-px} \text{ and } \alpha_1' - \alpha_1 = qx,$$

where x is the distance between the junctions. Having calculated p and q, the conductivity κ may be found by the formula

$$\frac{\kappa}{c\rho} pq = \frac{\pi}{T},$$

where c = specific heat,

ρ = density,

T = length of period.

Detailed below is the full working out for the period during which the readings above given were taken :—

Junction I. *corrected for* A_0

η_0	=	7·7	=	− 9·01
η_1	=	15·8	=	− 0·91
η_2	=	28·15	=	+ 11·44
η_3	=	23·5	=	+ 6·89
η_4	=	14·5	=	− 2·21
η_5	=	10·6	=	− 6·11
6		100·25		

$\therefore A_0 = 16·71$

$6A_1' = 2(\eta_0 - \eta_3) + (\eta_1 - \eta_2) - (\eta_4 - \eta_5)$

$= -31·8 - 12·35 - 3·9 = -48·05$

$\therefore A_1 = -\ 8·01$

$2\sqrt{3}B_1 = (\eta_1 - \eta_5) + (\eta_2 - \eta_4)$

$= 5·2 + 13·65 = 18·85$

$\therefore \sqrt{3}B_1 = 9·43 \quad \therefore B_1 - 5·48$

$\therefore P_1 = 9·706$ and $\alpha_1 = 145° \ 37'$

Junction II. *as above.*

η_0	=	7·6	=	− 2·85
η_1	=	7·7	=	− 2·75
η_2	=	11·0	=	+ 0·55
η_3	=	15·05	=	+ 5·60
η_4	=	12·2	=	+ 1·75
η_5	=	9·15	=	− 1·30
6		62·7		

$\therefore A_0 = 10·45$

$6A_1' = -23·15$

$\therefore A_1 = -\ 3·86$

$2\sqrt{3}B_1' = -\ 2·65$

$\therefore B_1' = -\ ·768$

$\therefore P_1' = 3·936, \quad \alpha_1' = 191° \ 19'.$

$\log \frac{P_1}{P_1'} = px + \log \epsilon. \quad \therefore p = ·708. \quad \alpha_1' - \alpha_1 = qx \quad \therefore q = ·625$

$\frac{\kappa}{c\rho} pq = \frac{\pi}{T} \qquad \therefore \kappa = ·005.$

(in C. G. S. units).

This experiment was performed on Saturday, January 9, 1886, and the period for which readings have been given, and from which the determination $\kappa = \cdot 005$ has been obtained, occurred between 11 A.M. and mid-day of that date. It was attempted again in the evening, beginning at 5.30 P.M. Shortly after 6 P.M. the galvanometer was seen to give irregular deflections, even when not included in one of the thermo-electric circuits. These deflections continued to increase to such an extent that the directing magnet had to be shifted to keep the light-spot on the scale. These phenomena were found to be due to the disturbed state of the earth's magnetism at the time, for from 7.30 P.M. till 8.30 P.M. on that evening a brilliant auroral display took place. Some readings taken at 8.20 P.M. showed a deflection of the needle through 2° 15′—this even when the disturbance was passing off.

The ratio of the intensity of the magnetic field due to the earth *alone*, to that due to the earth *and* magnet has since been tested, and found to be $\frac{1735}{1600}$, the arrangement being such that, superposed on the field due to the earth alone was another, almost double but opposite.

In all probability the readings, taken immediately before this disturbance was noticed, were affected by it; for, on taking the readings from the last two periods in the evening's work (about 6.15 P.M.), and calculating the conductivity therefrom, I find it to be ·011 and ·010 respectively.

As already stated, the period from which the determination $\kappa = \cdot 005$ was obtained occurred about mid-day, and there is no reason to believe that the readings during that period were vitiated by the cause which rendered those taken in the evening untrustworthy.

PRIVATE BUSINESS.

The Right Hon. J. H. A. Macdonald, Professor Frederick O. Bower, Mr Robert Irvine, Dr G. Sims Woodhead, Mr Arthur W. Hare, Mr George Fosbery Lyster, Dr D. Noel Paton, the Rev. George Laing, and Mr William Macdonald were balloted for, and declared duly elected.

Monday, 15th February 1886.

ROBERT GRAY, Esq., Vice-President, in the Chair.

The following Communications were read :—

1. Chemical Affinity and Solution. By W. Durham, Esq.

2. On the Reproductive Elements in *Myxine glutinosa*, L. By J. T. Cunningham, B.A.

(*Abstract.*)

The mature Ovum of Myxine.—The earliest description of the mature ovum is that given by Allen Thomson, in the article "Ovum" in Todd's *Cyclopædia of Anatomy and Physiology*, vol. v., published in the year 1859. He says :—"I have found that in the *Myxine glutinosa* the globular yolk is enclosed in a horny capsule of similar consistence and structure (to that of Elasmobranchs), but of a simple elongated ellipsoidal shape; and in place of four terminal angular tubes there are a number of trumpet-shaped tubular processes projecting from the middle of the two ends, which probably serve the same purpose as the differently shaped appendages of the ova of the shark and skate." He gives a figure in woodcut of the ovum, and of one of the threads magnified. The figures are correct with this exception: in the representation of the entire ovum the yolk is represented in outline as though seen through the envelope, and is globular, like the yolk of Elasmobranchs. In the Myxine ovum the yolk fills the cavity of the ellipsoidal envelope. It is not true that the terminal processes are tubular. I have examined them, and found them solid, and, as far as can be seen with a low power, homogeneous. I have not been able to ascertain from what specimen or specimens the description of Thomson is taken, but there is a single specimen of the ripe ovum in Professor Turner's museum which may have been examined by Thomson. This specimen was brought to the museum in the time of Professor Goodsir, but it is not possible now to ascertain whether it was dredged from the sea-bottom or taken from a pregnant female.

In 1863 Professor Steenstrup,* of Copenhagen, published a

* *Oversigt Dansk. Vidensk. Forhandlenger*, 1863.

description of some ripe ova found in a female Myxine sent to the Copenhagen Museum in the month of September 1862. He also compares the envelope of the ovum with its polar threads to the capsule of the deposited ovum in Elasmobranchs. The ova were lying at the edge of the ovary, to which they were only connected by the entangling of the threads. In the woodcut to Steenstrup's paper one of the eggs has the polar portion of the capsule at one end detached like an operculum.

I have recently, by cutting sections of very large ovarian eggs of Myxine, ascertained that the envelope of the deposited egg is developed entirely within the follicle. It is usual to distinguish primary egg membranes as chorion or vitelline membrane, according as they are developed by secretion from the follicular epithelium, or from the ovum. I am inclined to think that in this sense the envelope of the Myxine egg is a chorion, but I have not yet completely examined the question of the development of the membrane in all details. The important point is that the envelope is a primary egg membrane, and that the threads are solid processes from it. In sections of the polar region of ovarian eggs about 19 mm. in length, the ovum is surrounded by three distinct layers, corresponding to those universally found in vertebrate ovaries. The most external is the connective tissue layer, which is of considerable thickness, and is continuous with the thin mesoarium. Next to this is the follicular epithelium, composed of several layers of elongated cells, arranged with their long axes perpendicular to the surface of the ovum. Next is the egg-membrane, which is homogeneous, and forms the sole envelope of the deposited ovum. At one pole is found a cellular process projecting from the follicular epithelium, and penetrating through the chorion. Thus a canal is formed in the latter, constituting the micropyle. But this aperture is not at this stage open internally; the micropyle penetrates nearly, but not quite, to the inner surface of the chorion.

In the vitellus, close beneath the inner end of the micropyle, is seen the germinal vesicle, which is globular, large, and distinct. In my preparations nucleoli could not be made out, but from its appearance the vesicle did not seem to have undergone much change from its original condition.

In older eggs, about 21 mm. long, the beginning of the formation of the polar threads may be seen. In sections of the polar region of such eggs, the plane of the sections being parallel to the longer axis of the egg, deep pits are seen in the follicular epithelium. These pits are expanded at the bottom, and reach nearly to the connective tissue layer of the follicle, only a thin layer of epithelium separating the cavity of the pit from the inner surface of the connective tissue. Corresponding to these pits are seen processes from the chorion; there can be no doubt that in the fresh living condition the processes entirely fill up the pits. The chorion itself is much thicker than in the stage previously described, the processes are directly continuous with it, and like it are, at least as seen with ordinary magnifying powers, homogeneous. The processes are quite solid, and the inner surface of the chorion turned towards the vitellus is as even as in the earlier stage. The micropyle is seen again at one pole of the egg, but its condition is a little different. It is open externally, but closed by a thin portion of the chorion internally. It still contains a cellular thread, but this thread is shrunken in size, and has now no connection with the follicular epithelium, the surface of which is unbroken above the micropyle.

Without further evidence, I concluded that the further development of the egg consisted in the thickening of the chorion and the elongation of the threads, these processes being due apparently to the secretory activity of the follicular epithelium. The probability of this being the case is shown by the fact that both epithelium and chorion are much thicker at the poles than at the equatorial region of the ovarian eggs. I had no doubt that the follicle burst and allowed the escape of the egg enclosed in its chorion with the threads at the poles. But I was unable from the above facts to ascertain exactly how the follicle opened. I had seen bodies in the ovary of some specimens of Myxine which looked like aborted eggs, and had surmised that these were corpora lutea, but they were too degenerate to afford any evidence of the exact manner in which the ovum had escaped. But in December and January I found a female specimen of Myxine in the ovary of which were no large eggs, but a number of collapsed follicles, from which the ripe ova had evidently escaped quite recently; examining these follicles I found that each possessed a slit-like aperture at one end, and thus the question of the escape of the ovum with its threads is elucidated.

I have also recently obtained a female specimen of Myxine in which all the large eggs in the ovary had a slight projection at each end, and in these knobs the ends of the threads could be seen through the connective tissue. In these eggs the polar threads were half way or more towards their complete development.

In January I obtained two or three other specimens in which the eggs were nearly as ripe, the projections formed by the development of the threads being visible, but not quite so prominent. In sections of the ripest eggs above described it is seen that the follicular epithelium at the poles of the egg has become greatly thickened, while the connective tissue layer has become thinner. The threads are contained in deep cylindrical sacs formed by the epithelium; the distal ends of these sacs project deeply into the connective tissue layer, which is very thin over their terminations. The epithelium is thick all round these sacs, and it is quite evident that the threads and the layer from which they project are formed by the epithelium. The micropyle in these ripest eggs is in the same condition as before, and is still closed by a thin layer of chorion at its inner end. I have not yet found the germinal vesicle in the eggs at this stage. The question whether a vitelline membrane exists internal to the chorion I have not yet decided.

Development of the Ova.—The ovary of Myxine differs from that of other vertebrata, or craniata, in consisting of an extremely thin fold instead of a somewhat solid mass. It is impossible to define the boundary between ovary and mesoarium. The mesoarium extends the whole length of the body on the right side only (in two specimens I have found it developed on the left side only), and is attached at the angle between the mesentery and intestine. The eggs originate at the free edge of the ovary, which is only slightly thickened, and as they grow large pass inwards, the largest eggs being always nearest to the attached border of the mesoarium. There is no transition in thickness between the membranous mesoarium and the thick connective-tissue layer of the follicle, but the former passes abruptly into the latter. The line of attachment of the mesoarium passes round the longest circumference of the ellipsoidal follicle. When the eggs are large they stretch the mesoarium and hang down beyond the edge of the ovary, but the relations pointed out are never altered, not even when the egg escapes. The very young eggs are transparent and spherical, and show a distinct germinal vesicle in the fresh condition. As the eggs elongate the germinal vesicle passes to one end, but the yolk soon develops and conceals that structure from view.

Male Elements of Reproduction.—Professor Steenstrup, in the paper above mentioned, says that no one seems to have seen a male Myxine. This is not quite correct, for Johannes Müller, in the last volume of his *Verglerichende Anatomie der Myxinoiden*, published in 1845, describes the testis of Myxine in a somewhat vague manner, but in such a way that, from my own experience, I have no doubt that he really had a young male specimen under his hands. The males are very rare; out of all the specimens which I have examined only ten have been males, and these are all immature. It is extremely difficult to distinguish between a male and a very immature female; in most cases I have only been able to do so by microscopic examination of the generative organ. The testis is similar in general structure to the ovary, but the free border is slightly more thickened than in the latter organ, and has the gelatinous appearance characteristic of testicular tissue. When examined with a low power the thickened edge is seen to contain a number of more or less spherical capsules, and these on compression are seen to be filled with rounded polygonal cells. When the capsule is burst the cells escape, and are then seen to be spherical, extremely transparent, and provided with a large nucleus. It is easy to conclude that these cells give rise to spermatozoa. The spermatozoa of Myxine hitherto have never been seen or described.

Hermaphrodite Specimens.—After identifying the immature males, I found that in nearly every specimen in which the eggs were very immature the posterior end of the sexual organ was similar in structure to the testis. The testicular portion is usually much smaller than the ovarian, and occupies about 2 inches of the posterior end, but sometimes extends further forward. These hermaphrodites are almost as common as the females. The most curious fact about the hermaphrodite forms is, that in two of them I have found the early stages of the development of spermatozoa, although in the males I never found anything but the spherical cells above described. In one of these two specimens I found spermatozoa within the testicular capsules, but these spermatozoa were few in number and not in motion. I have not yet been able to work out completely the process of spermatogenesis, but it seems that the cells of the testicular capsules send off processes, each of which becomes a spermatozoon. Only two or three of these processes are formed at a time, and the spermatoblast seems to develop a number of spermatozoa in succession, instead of, as in nearly all other cases, simultaneously. The spermatozoa have a pear-shaped head, and a long tail, which is attached to the obtuse end of the head.

I venture to suggest the hypothesis in explanation of the above facts, that the males are nothing more than supplementary males, and that the Myxine in its young state is nearly always, if not always, hermaphrodite. It is evident that, as the spermatozoa are developing in the hermaphrodites while the eggs are still very small, self-fertilisation is impossible; but it seems extremely probable that the hermaphrodites while young act as males, and that most eggs are fertilised by them. The females with large eggs are never hermaphrodite, and it may be inferred that as the eggs develop the testicular portion of the reproductive organ disappears. There may be some females which never possess a testicular portion, as there are perfect males, but of this I cannot be certain. If the above hypothesis be correct, it would account for the extreme rarity of perfect males. Another fact, which is partially accounted for by my investigations, is the extreme rarity of female specimens with ripe eggs. The eggs are certainly deposited in winter, and eggs approaching maturity are not to be found in the summer months. But even now the specimens with eggs nearly ripe bear a very small proportion to the total number obtained, and it is probable that the animals, when just preparing to shed their sexual products, cease to feed, and therefore cannot be allured by bait to either hook or trap, which are the only known methods of capturing them. One thing deserves to be mentioned with reference to the male elements. In the hermaphrodites, in which spermatozoa were being developed, the total size of the testicular portion of the generative organ was extremely small, compared to that of the testis in all other vertebrates, and the quantity of milt shed, unless a sudden development takes place at the last moment, must be extremely small. This fact seems to indicate that fertilisation does not take place in the open water, and it is possible that the eggs and milt are shed in the mud in which the animal lives.

3. The Life-History of the Micro-organisms associated with Variola and Vaccinia. An Abstract of Results obtained from a Study of Small-Pox and Vaccination in the Surgical Laboratory of the University of Edinburgh. By J. B. Buist, M.D., F.R.C.P., Edinburgh.

"Go to the quality of the active principle; abstract it from the material, and contemplate it by itself. Then determine the time; how long, at furthest, this thing, of this particular quality, can naturally subsist."—*Marc. Aurel.*, Book ix. sect. 25.

Origin of Inquiry.

The following investigations were undertaken with the view of ascertaining the nature and cause of opacity in vaccine lymph. According to the authorities on the subject, clear fresh lymph is a perfect material for vaccination, while opaque lymph, fresh or stored, is an imperfect material, but hitherto the nature of the difference between them has not been explained satisfactorily. It has been maintained by many that opaque lymph is a satisfactory material for the purpose of vaccination, but this view is not endorsed by the National Vaccine Establishment. In April, last year, Professor Chiene suggested to me that the cause of opacity in lymph was to be found in a "germ," and he cordially assented to my request for assistance in making the necessary cultivations in order to determine its nature. The cultivations detailed were made by his assistant Mr Hare, whose intimate acquaintance with modern methods of bacteriological research has saved much time and labour. The responsibility of the observations recorded rests upon me entirely.

A preliminary microsopic examination of clear and opaque vaccine lymph led to no definite result, as the appearances observed could not be explained, It was therefore decided to examine—

I. Empty Commercial Vaccine Tubes for "germs."

II. Cultivations of Vaccine Lymph.

a, By the naked-eye; *b*, by the microscope.

III. Cultivations of Variolous Lymph.

a, By the naked-eye; *b*, by the microscope.

IV. Clear and Opaque Vaccine and Variolous Lymph.

V. The Results of Experimental Vaccination.

I. Examination of Empty Commercial Vaccine Tubes.

The problem to be solved was whether such tubes contain germinal matter. To determine this, two series of experiments were undertaken.

1. Sealed commercial tubes were introduced with aseptic precautions into beakers containing sterile nutrient fluid. Continued sterility of the fluid was proved by subsequent incubation at 35° C. The tubes were then broken with aseptic precautions. Subsequent incubation showed that more than half of the beakers containing broken tubes became cloudy.

Where the sealed tubes were left unbroken, but where the fluid had merely been stirred with a sterile glass rod, one out of six only became cloudy.

2. Commercial and sterilised vaccine tubes were charged with sterile and non-sterile fluid, with and without spray, in imitation of the conditions under which vaccine lymph might be stored. The result showed that sterility of the tube and of the fluid and the use of the spray were necessary to prevent the occurrence of opacity. Where these conditions were absent opacity occurred in every tube.

The fact that a large proportion of the beakers containing broken tubes showed no change in the fluid, led to the conclusion that the amount of germinal matter in commercial tubes was very small. Besides, the amount of opacity in the fluid in the second series of experiments was very much less than that observed in vaccine lymph. It was therefore concluded, that the contents of the tubes had very little to do with the production of opacity in vaccine lymph. This conclusion is concurred in by Mr Farn, of the National Vaccine Establishment.

II. Examination of Cultivations of Vaccine Lymph.

All the cultivations were made by Mr Hare with aseptic precautions. The material was transferred directly from the vesicles to the cultivating medium. All the successful cultivations were got from clear lymph. None were got from opaque lymph. The appearances were noted in each cultivation on three separate occasions.

1. Table *showing the Naked-Eye Appearances of Cultivations of Vaccine Lymph.*

No.	Name of Tube.	4th Day.	8th Day.	Subsequently.
1	I.A, agar.	White.	Faint yellow.	Yellow.
2	I.B, ,,	,,	,,	,,
3	II.A, ,,	,,	Yellowish green.	Strong yellow.
4	II.B, ,,	,,	,,	,,
5	I. ,,	No report.	No report.	Grey and orange.
6	II. ,,	,,	,,	White and yellow.
7	I.A, jelly.	No reaction.	,,	,,
8	I.B, ,,	No report.	White,yellow,orange.	Orange.
9	II.A, ,,	,,	White and yellow.	Yellow.
10	II.B, ,,	,,	,,	Yellow "cocoons."
11	II. ,,	,,	No report.	,,
12	I.A′, agar.	Secondary	cultivation.	Dull orange
13	II.B′, ,,	,,	,,	White & yel. "cocoons."
14	I.B′, jelly.	,,	,,	Bright orange.
15	II.A′, ,,	,,	,,	White and yellow.
16	I. jelly, yellow.	Secondary, 11th day.	Orange.	Orange.
17	I. jelly, white.	,,	,,	,,
18	III.B, agar, 477.	White.	Grey and dull orange.	Dull orange.
19	III.A, ,,	Faint white.	White in cloud.	White.
20	III.A, jelly, 477.	No reaction.	No reaction.	No reaction.
21	III.B, ,,	,,	,,	,,
22	IV.A, agar, 480.	From opaque	lymph.	,,
23	IV.B, ,,	,,	,,	,,
24	IV.A, jelly, 480.	,,	,,	,,
25	IV.B, ,,	,,	,,	,,
26	V.A, agar, 478.	White.	White.	White "cocoons."
27	V.B, ,,	,,	,,	,,
28	V.A, jelly, 478.	No report.	No report.	White & yel. "cocoons."
29	V.B, ,,	,,	,,	,,
30	VI.A, agar, 475.	Greyish blue.	Greyish white.	Thick white growth.
31	VI.B, ,,	,,	,,	,,
32	VI.A, jelly, 475.	White "cocoons."	White.	Jelly liquefied.
33	VI.B, ,,	,,	,,	Yellow.
34	VII.A, jelly, 479.	,,	White "cocoons."	White.
35	VII.B, agar, 479.	White.	Dull orange.	Dull orange and brown.
36	VIII.A, agar, 483.	White&dull orange.	White.	Strong white growth.
37	VIII.B, agar, 483.	,,	Dull orange.	Dull orange.
38	IX.A, jelly, 481.	White.	White and yellow.	White and yellow.
39	IX.B, agar, 481.	,,	White.	Yellow.
40	X.A, agar, 485.	,,	,,	White and yellow.
41	X.B, ,,	,,	White and dull ochre.	,,
42	XI. agar, 487.	,,	White.	White, yellow, & brown.

An analysis of the preceding table shows that in primary cultivations the colour of the growth, with scarcely any exception, was white on the fourth day. Primary cultivations in Koch's jelly were invariably white in the form of "cocoons." On the eighth day yellow and orange colour appeared in a certain proportion, but the prevailing colour was still white. After this the principal colours were white and yellow, only one cultivation being of an orange colour. We had thus three distinct growths, white, yellow and orange, as described by other observers. Secondary cultivations were made from certain of the tubes which had been opened for microscopic examination. In only one case out of six were the same colours reproduced. Change of colour in the growth was thus observed to take place both in primary and secondary cultivations. It is difficult to explain how this can take place on the supposition that we have three different organisms to deal with.

2. *Histological Examination of Vaccine Cultivations.*

A. Orange cultivation showed swarms of minute spherical "micrococci" without definite arrangement.

B. White cultivations showed single, double, and triple micrococci, and in one case a sarcina form. The micrococci were larger in cultivations which had been incubated.

C. Yellow cultivations showed dumb-bell and sarcina form micrococci. Here also the incubated cultivations showed larger torula-form micrococci.

We could not explain these different appearances. It was supposed that we had three different organisms, any one of which might be the immediate cause of vaccinia. Other preparations of vaccine lymph, clear and opaque, were now made.

In clear lymph certain minute badly stained spherical bodies were recognised similar to those of the orange vaccine cultivation, but I am indebted to Dr Francis Troup for the first clear demonstration of them in vaccine lymph. I then saw that the "micrococci" in clear lymph and orange "vaccine" are identical. Opaque lymph after being kept some time showed large spherical transparent bodies like oil drops, but their nature was a mystery. Even after examining vaccine cultivations, we were as far off as ever from being able to explain the nature and cause of opacity in lymph. I therefore suggested that we should cultivate variola.

III. Examination of Cultivations of Variolous Lymph.

As there were no cases of small-pox in Edinburgh suitable for our purpose, it became necessary to visit the Hospital Ships at Purfleet, on the Thames, to obtain variolous cultivations. I have to acknowledge the readiness with which Dr Birdwood placed the material at his disposal at our service, and also the able assistance given by Messrs Bott and Clatworthy, the resident physicians.

The variolous cultivations may be conveniently divided into three classes : —

1. Where no reaction or growth occurred.
2. Where growth occurred without liquefaction.
3. Where growth was accompanied by liquefaction.

1. The first class is of value as showing the care with which contamination of the media was prevented. The third class was excluded from present comparison with vaccine cultivations, by the occurrence of liquefaction of the media. The second class may fairly be compared with vaccine cultivations. But we had found that the most definite and easily recognised form of growth was the "cocoon" in Koch's jelly. Our series is therefore reduced to cultivations of variola, showing this distinct mode of growth. Nos. 11, 12, and 39 only showed a large definite "cocoon" growth without liquefaction. These were selected as parallel, and probably identical, with vaccine cultivations of the same appearance. The questions to be decided were, as to their histological appearances, physiological action, and contagiousness.

2. *Histological Investigation of Variolous Cultivations.*

A. White "variola" showed single, double, and triple micrococci, identical with white "vaccine."

B. Clear variolous lymph showed minute spherical bodies, similar if not identical with those of clear vaccine lymph and orange "vaccine."

C. Opaque variolous lymph showed large torula-looking "micrococci," as well as smaller forms.

IV. Examination of Clear and Opaque Vaccine and Variolous Lymph.

On comparing clear and opaque variolous lymph with clear and opaque vaccine lymph, the micro-organisms in each appeared identical. My observations are thus in accordance with the description given by Cohn, quoted by Burdon Sanderson in his Report on the Intimate Pathology of Contagion. Cohn was unable to say whether there was any connection between the bodies in clear and opaque lymph; but Zopf, in his work *Die Spaltpilze*, 1885, states that the opacity "consists in cell rows and masses resulting from the continuous division of the cocci." He recognises no other modes of development.

TABLE *showing the General Naked-Eye Appearances of Cultivations of Variolous Lymph in Solid Media.*

Source.	No.	Name of Tube.	8th day.	13th day.	Result.
Early pustular or pustular.	1	Aa, jelly.	No reaction.	No reaction.	No reaction.
	2	Ab, ,,	"	"	"
	3	Ac, ,,	"	"	"
	4	Ad, ,,	"	"	"
	5	Ae, agar.	"	"	"
	6	Af, ,,	"	"	"
	7	Ag, ,,	"	"	Trace of white.
	8	Ah, ,,	"	"	"
	9	Ai, serum.	White riband.	White.	White.
	10	Aj, ,,	No reaction.	Trace of white.	Trace of white.
Blood, papulo-vesicular.	11	Ba, jelly.	White "cocoon."	White "cocoon."	Larger, pure white.
	12	Bb, ,,	"	"	"
	13	Bc, ,,	No reaction.	No reaction.	No reaction.
	14	Bd, agar.	White cloud.	White cloud.	White cloud.
	15	Be, ,,	"	"	"
	16	Bf, ,,	No reaction.	No reaction.	No reaction.
	17	Bg, serum.	"	"	"
	18	Bh, ,,	"	"	"
Vesicular.	19	Ca, agar.	White zone.	White zone.	White zone.
	20	Cb, ,,	White cloud.	White cloud.	White cloud.
	21	Cc, ,,	White zone.	White zone.	White zone.
	22	Cd, serum.	White cloud.	White cloud.	White cloud.
	23	Ce, ,,	"	"	"
Papulo-vesicular.	24	Da, jelly.	White "cocoons."	White "cocoons"	White "cocoons."
	25	Db, ,,	Liquefaction, and	white p.p. at bottom of	liquid.
	26	Dc, ,,	No reaction.	No reaction.	No reaction.
	27	Dd, agar.	White.	White.	Faint white.
	28	De, ,,	No reaction.	"	White.
	29	Df, ,,	"	No reaction.	No reaction.
	30	Dg, serum.	"	"	"
	31	Dh, ,,	White riband.	White.	White.
Vesicular.	32	Ea, jelly.	No reaction.	No reaction.	No reaction.
	33	Eb, ,,	White "cocoon."	White "cocoon."	White.
	34	Ec, ,,	"	"	Liquefying.
	35	Ed, ,,	"	Large white, liquefying	with white p.p.
	36	Ee, ,,	"	White.	White.
	37	Ef, ,,	"Cocoons" and	liquefying globe, with	white p.p.
	38	Eg, ,,	"	"	"
	39	Eh, ,,	White cocoon.	Larger white.	Pure white "cocoon."
	40	Ei, ,,	No reaction.	Small "cocoon."	White.
	41	Ej, ,,	White "cocoon."	Globe of liquefaction,	with orange p.p.
	42	Ek, ,,	"	White.	Faint white.
	43	El, ,,	"Cocoons."	Globe of liquefaction,	with yellow p.p.
	44	Em, agar.	White cloud.	White cloud.	White cloud.
	45	En, ,,	White zone.	Thick white zone.	White.
	46	Eo, ,,	Liquefying.	Liquefying.	Liquefying.
	47	Ep, ,,	White cloud.	White.	White.
	48	Eq, ,,	"	"	"
	49	Er, ,,	Liquefying?	Liquefying?	Solid white.
	50	Es, ,,	White cloud.	White cloud.	Wh., with orange patch.
	51	Et, ,,	No reaction.	No reaction.	No reaction.
	52	Eu, serum.	White.	White.	White riband.
	53	Ev, ,,	No reaction.	No reaction.	No reaction.

Table—*Cultivations of Variolous Lymph*—continued.

Source.	No.	Name of Tube.	8th day.	13th day.	Result.
Papulo-vesicular.	54	Fa, jelly.	Faint White.	White.	Faint white.
	55	Fb, "	White cocoons.	"	"
	56	Fc, "	"	"	White "cocoons."
	57	Fd, "	No reaction.	No reaction.	No reaction.
	58	Fe, "	White.	White.	Liquef. and white p.p.
	59	Ff, "	"	"	Faint growth.
	60	Fg, agar.	"	Thick white.	White cloud.
	61	Fh, "	"	"	"
	62	Fi, "	"	"	"
	63	Fj, "	No reaction.	No reaction.	No reaction.
	64	Fk, "	"	"	"
	65	Fl, serum.	White riband.	White riband.	White riband.
	66	Fm, "	"	"	"
Bullæ.	67	Ga, jelly.	Funnel-shaped	liquefaction, with	white p.p.
	68	Gb, "	"	"	"
	69	Gc, "	"	"	"
	70	Gd, "	"	"	"
	71	Ge, agar.	Orange or ochre.	Cocoons solid.	Ochre cocoons.
	72	Gf, "	"	"	"
	73	Gg, "	"	"	"
	74	Gh, "	White cloud.	White cloud.	White cloud.
	75	Gi, "	White and orange.	White and ochre.	White and orange.

V. Experimental Vaccination.

We divide the experiments into four series—

I. Vaccination of Calves.

II. Vaccination of Guinea Pigs.

III. Vaccination of Monkeys.

IV. Contagion Experiment.

Ten experiments were performed, as is shown by the following table :—

No.	Vaccine Material.	Vaccinifer.	Result.
I.	White, yellow, and orange "vaccine."	Calf.	Pustular eruption on head.
II.	Opaque variolous lymph.	Calf.	Pustular eruption on back.
III.	Vesicular variolous lymph.	Calf I.	Protected by "vaccine" I.
IV.	Pustular variolous lymph.	Calf II.	Protected by variolation II.
V.	Orange "vaccine."	Guinea pig.	Local scab.
VI.	White "vaccine."	Guinea pig.	No local result. Constitutional ?
VII.	Yellow "vaccine."	Guinea pig.	No local result. Constitutional ?
VIII.	Clear vaccine lymph.	Monkey.	Four typical vaccine vesicles.
IX.	White variolous "cocoon."	Monkey.	Eight pocks. No local result.
X.	Modified variola IX.	Monkey.	Not contagious.

An analysis of this table shows that orange "vaccine" produces a local scab in a guinea pig, and that clear vaccine lymph produces typical vaccination in monkeys. Vaccine cultivations and opaque variolous lymph produce an eruptive fever in calves, when inoculated. No local result is produced. White variolous cultivation produces a mild variolous eruption in a monkey, which does not appear to be contagious to another monkey. No local result is produced at the points of inoculation. Protection is afforded from the poison of variola by previous variolation and vaccination with "vaccine" cultivations. White and yellow "vaccine" produce no local result in guinea pigs. They probably produce a mild constitutional result. The experiments appear to show that different vaccine materials possess different degrees of potency.

Classification of Micro-organisms.

In attempting to trace the life-history of the vaccine and variolous organisms from the preceding observations we are confronted by a preliminary difficulty. At present the fission-fungi are undergoing the most minute investigation, and the result has been attempts to improve upon the classifications of Cohn and Naegeli. Naegeli held that the bacteria were allied to yeasts, and should therefore be included in the class of fungi. The difficulty in accepting this view arose from the fact that fungi were supposed to be destitute of colouring matter. Owing to this, Cohn placed them among algæ, but the tendency now is to amalgamate the colourless fungi (bacteria) and the colour-producing algæ (bacteria) into one group, the thallophytes (Sachs). The latest classifications of Flügge, 1883, and Zopf, 1885, appear to me to be unsatisfactory, and I prefer to follow the classification of Cohn into four tribes, including six genera. He believes that the form or shape characteristic of each tribe is adhered to throughout the life of the organism. Thus, a micrococcus cannot be transformed into a bacterium or bacillus, but retains its spherical shape. We have only to do at present with Cohn's first group, the Sphærobacteria, comprising one genus, the micrococci. While, however, Cohn has settled the main lines upon which the classification of Schizomycetes should be based, he admits that his classification of the genera into species is defective. This is due to deficient knowledge of their physiological action and modes of reproduction. Thus, micrococci having the same appearance may have different effects. Cohn divides his genus, Micrococcus, into three physiological species—(1) Chromogenic, (2) Zymogenic, (3) Pathogenic. He places the Micrococcus Vaccinæ among the pathogenic micrococci, but the record of the cultivations just detailed shows that the vaccine organism is also chromogenic, so that it might equally well be classed among these coloured micrococci. At the same time, he admits that differences in arrangement and size are unreliable data upon which to found the classification of species. A necessity, therefore, arises for the acceptance to some extent of the theory of pleomorphism (Tulasne), *i.e.*, that the same plant can occur under two or more forms, as well with respect to the organs of vegetation as to those of reproduction. Applying this theory to the bacteria, we find that a single species may show various forms in the course of its life-cycle. This has been shown by the researches of De Bary, Zopf, Dallinger, Douglas Cunningham, Ewart and Geddes, and others.

The propagation of fungi takes place asexually in three ways—1 By free cell formation (asci, thecæ, spore-pouches). 2. Constriction (basidians). 3. By cell-fission or gemmation. Spores are the chief means of the spread of fungi (Wagner).

Surrounding media modify the form and mode of fructification of fungi, some increasing and others diminishing spore-formation, or we may have the fungus dividing into yeast forms. Schwann, Pasteur, and others consider the yeast fungi as organisms *sui generis*, arising in fermentable liquids from their own specific germs.

Hallier, Hoffmann, and others consider that they are only conditions, especially of mould fungi occurring in fermentable liquids, particularly the spore forms, which fructify in the atmosphere in other forms. They originate likewise from spores or from yeast cells themselves when they reach a liquid. Hoffmann thinks that the genera of Schizomycetes, described by Ehrenberg, Pasteur, &c., pass into one another, peculiarities which are to be held as characteristic of the species, and which change in the course of development according to the change in the external conditions of life (Wagner). As we have seen, Cohn maintains that such genera are distinct throughout life. Species may show various sizes and different pigments besides differing in their effects. Zopf is a warm supporter of the theory of pleomorphism. Crookshank (*Bacteriology*, 1886), who adopts Zopf's classification, says that in classifying species of bacteria, we must take into account—1. Microscopical appearances in various nutrient media. 2. Character of their colonies under a low power, in plate cultivations. 3. Microscopical appearances of the organisms themselves. 4. Their physiological action. These desiderata, however, scarcely satisfy the requirements of the case, and I beg leave to add, 5. The study of their modes of development and reproduction in each species.

In this way we may be able to make out the life-history of an organism. Recent observations by Lister, Neelsen, Zopf, Van Tieghem, Klein, and Hauser, are said (Crookshank) to show that the orders of Cohn pass into one another. It is due to Lister to say, however, that he retracted his first opinion with regard to the bacillus of black milk, and expressed a doubt as to whether he had not got a mixture of organisms. If this were true, of course, Cohn's classification of genera would fall to the ground. Cohn's strong point is that he opposes change of shape in genera. He admits differences in size and arrangement and colour, as well as physiological action, in the different species of each genus. The truth appears to be, that while the various genera retain their globular, oval, rod-shaped or spiral form throughout life, the different species described as cocci, rods, threads, and spirals may be merely stages of growth of a single organism. At the same time these various forms may produce different physiological effects. We find so-called "cocci" described as growing into torulæ or rods. But we find that rods are spore-bearing, so that it appears rather a misnomer to call such spores cocci. Should they not be called spores of bacilli? It is evident that a gap has to be filled up between the higher torula-form and the spore. The researches of Dr Douglas Cunningham upon the micro-organisms found in the intestinal canal show that they have an active and a resting stage. In suitable media, the "zoospores" multiply till the material for their growth is exhausted, when the medium is acid, and the micro-organisms cannot develop further. When transferred to an alkaline medium they at once become active.

The mode of reproduction of bacterium termo has been well described by the Rev. W. H. Dallinger, in a remarkable paper communicated to the Royal Society of London in 1878 by Professor

Huxley. He finds that the bacterium grows to an ovoid body, of very delicate nature, which bursts and gradually collapses, scattering very minute spores. By continuous observation, he has seen the spore grow again into the ovoid body, which was seen to burst again as before. Mr Dallinger worked with very high powers, × 3000. Similar observations with regard to the life-history of bacteria have been made by Professor Cossar Ewart, but he does not emphasise the resting stage. Mr P. Geddes points out that this occurs in many instances in the cycle of cell-life.

TABLE *showing the Histological Appearances of the Vaccine Organism in Solid and Fluid Media*, (× 700).

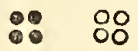
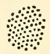
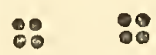
No.	Medium.	Material.	Forms.	Corresponding Forms.
1	Fluid.	Clear lymph.		Burdon Sanderson's "microzyme." Cohn's spheroidal corpuscle.
2	,,	,,		Cohn's simple corpuscle or M. Vaccinæ.
3	Solid.	White in jelly.		Cohn's "pairs of corpuscles."
4	,,	White in agar.		Cohn's "groups" or "clumps."
5	,,	Yellow in jelly.		Cohn's "groups resembling sarcinæ."
6	,,	Yellow in agar.		Cohn's "larger aggregations" or "clumps."
7	Fluid.	Opaque lymph.		Burdon Sanderson's "semifluid material" or "oil-drops." Cohn's "refractive cells resembling oil-drops."
8	Solid.	Orange, 8th day.		Burdon Sanderson's "microzyme." Cohn's "minute spheroidal corpuscle."

TABLE *showing Appearances of Variolous Organisn in Solid and Fluid Media, (after Cohn)*, (× 700).

No.	Medium.	Material.	Forms.	Corresponding Forms.
1	Fluid.	Clear lymph.		Cohn's minute sphere.
2	,,	,,		Cohn's simple corpuscle.
3	Solid.	White in jelly.		Cohn's pairs of corpuscles.
4	,,	,,		Cohn's "groups" or "clumps."
5	Fluid.	Opaque lymph.		Cohn's "groups resembling sarcinæ."
6	,,	,,		Cohn's "larger aggregations."
7	,,	,,		Cohn's "refractive cells resembling oil-drops."
8				

Life History of the Vaccine Organism.

In tracing this I shall follow the method recommended above by Crookshank, as my observations fall naturally under his headings.

1. *Macroscopical Appearances of Vaccine Cultivations.*—We found that the best medium for making observations was Koch's jelly. Here we obtained three definite coloured growths. The colours on the surface of the jelly were white, yellow, and orange. Below the surface they were white and yellow. No orange colour appeared below the surface. The shape of the colonies was oval or like a cocoon. Sometimes these were aggregated together, and irregular on the surface. They grow from inoculations of clear lymph only.

2. The "colonies" have been well described by Cohn, in 1872, in preserved lymph. He saw the minute spherical corpuscle of fresh clear lymph succeeded by "simple corpuscles, double corpuscles, rows and heaps or masses of corpuscles." He saw the corpuscles become larger until at last the lymph contained separate large globular homogeneous transparent bodies like oil-drops. I can confirm these observations as correct, and I agree with Zopf (1885) in thinking that they can only proceed from continuous division and growth of the organisms in clear lymph. Opacity of lymph is produced in this way. I observed, however, that the large torula-looking bodies disappeared from fresh preparations within twelve hours, and next day both stained and unstained preparations showed large masses, which had apparently grown from them by budding. I think that this appearance is produced by the bursting of the globules, but I have not seen this take place. I think that these large cells contain spores, and that they are developed from the organisms in clear lymph. If these bodies originated in accidental contamination of the lymph, it is difficult to see why they should be of constant occurrence in stored lymph, and not only so, but also in opaque lymph within the vesicles. Then they did not appear in the other nutrient fluid used to imitate vaccine lymph in the tube experiments. The stages of growth between the embryonic and the mature form have been accurately traced by Cohn, both in vaccine and variolous lymph. The larger forms are never found in fresh clear lymph.

With regard to the colonies in solid media, the first appearance is white, even when the growth is of some size. The change of colour takes place gradually, and it remains yellow. Spore formation, as shown by the bright orange colour, is seldom seen in solid media. I am unable to explain this, except that the environment is unfavourable to the production of spores, while it is favourable to the ordinary vegetative growth. Then, when secondary cultivations were made, the same colour was only once reproduced. If change occurred, it was in the direction of more distinctness in the colour, apparently showing that the change of medium was more favourable for spore production. It would be interesting to know whether coloured growths of vaccine lymph are alkaline or acid in reaction. If the orange growth is composed of spores, it should correspond to the alkaline clear lymph. At the same time, the white and yellow should show an acid reaction similar to that given by opaque lymph. We may suppose the yellow colour to be produced by a mixture of vegetative and spore growth, *i.e.*, white and orange.

3. *Microscopic Appearances of the Organisms.*—My observations show that the size of the organisms increases with the age of the cultivations. Incubation has also some effect, and one medium may be more suitable than another for its growth. Thus in Koch's jelly the micrococci were smaller than those in agar after incubation. As the material was the same, this could only be explained by more rapid growth. Thus we find that the same organism derived from the same source, presents different appearances according to the environment and other favourable circumstances. It does not follow, however, that the same forms will produce the same effects. Nor does it follow that different-sized organisms will not produce similar physiological effects. The truth seems to be that the larger organism is the more powerful. The embryonic form is milder in action.

4. *Physiological Action.*—The results of experiments, although few in number, appear to show that the embryonic form is milder in action than the more mature form of organism. Thus clear vaccine lymph and orange vaccine, both containing minute organisms, produced only a local result. Opaque variolous lymph and white and yellow vaccine cultivations and white variolous cultivations, containing larger organisms not found in clear lymph, produce an

eruptive fever. They appear to be more powerful in action. If the organisms do not grow from the minute spheres in clear lymph, where do they come from? Are there several kinds of minute spheres in clear lymph? Even if so, according to the opposite view, they could not change their size and arrangement by cultivation only.

5. *Mode of Development and Reproduction.*—My observations appear to confirm Cohn's opinion that genera of bacteria retain their shape throughout their life-history. Micrococci remain micrococci, but they may present variations in size, arrangement, and colour, and their physiological action may become more powerful. Definite production of bright colours appears to be associated with spore-formation. The large transparent delicate torula found in fluid media, represents the organism in its resting stage, as described by Dallinger and Douglas Cunningham. The active stage commences when this mature organism is transplanted to a suitable medium. Then spore production immediately becomes complete, and a fresh cycle of growth commences. I cannot say where these spore-bearing cells originate, but it is possible that they come from yeasts or moulds.

Summary of Results.

The following conclusions appear to be warranted by the results of the inquiry just detailed. Bacteriologists are still at variance as to whether bacteria spring from higher forms, and grow into them again. So far as the globular or sphæro-bacteria are concerned, the only mode of reproduction at present recognised is fission occurring in one or more directions. Different morphological appearances and colours are held to be distinctive of different species of micrococci, but it appears probable that a careful study of the physiological action and mode of reproduction is required before a satisfactory classification can be obtained. Continuous observation of each organism from its embryonic to its mature form is necessary. Cultivation of the organisms, in both solid and fluid media, also appears to be imperative. It is also necessary to distinguish between local and constitutional results of experimental inoculation with cultivations.

We conclude, then,

1. That commercial vaccine tubes contain germinal matter, but in small amount, and that it assists in the production of opacity in lymph.

2. Clear vaccine lymph, clear variolous lymph, and orange

"vaccine" contain probably, not micrococci, but the spores of micrococci. Inoculation with these materials produces local irritation by the growth of the "spore" into a more mature form of organism.

3. Opaque vaccine lymph and opaque variolous lymph contain larger, more refractive bodies of various sizes, which are probably developed from the spores in clear lymph. They increase in size and number in proportion to the length of time the lymph has been kept. After a few months large torulæ crowd the field in microscopic preparations. Such lymph has an acid reaction, and when inoculated it produces either violent local action, *i.e.*, accelerated vaccination, or we may have no local action, but secondary eruption in some other part of the body. This is probably due to rapid spore-production by the torulæ. The spores are probably absorbed into the blood, and rapidly grow there, until they are arrested in the capillaries, where they continue to grow and set up irritation ending in the production of vesicles or pustules. From these secondary foci may again be produced. This would account for the appearance of periodic secondary eruptions after vaccination. The growth from the spore to the torula explains the occurrence of opacity in lymph. Drying the lymph prevents this growth, and also deterioration of the true vaccine material.

4. White, yellow, and dull ochre or orange cultivation of vaccine lymph in solid media, appear to represent stages of growth between the spore and the torula. They correspond to the refractive corpuscles and cells described by Cohn in vaccine lymph. When inoculated, they produce in calves eruptive fever. They do not produce a local result.

5. White variolous cultivations in solid media appear to represent stages of growth between the spore in clear variolous lymph and the torula in opaque variolous material. When inoculated, a mild eruptive fever was produced in a monkey. This was not contagious to another monkey. The organisms correspond to the refractive corpuscles of Cohn. Cultivations of variola and vaccinia in solid media appear to produce mild eruptive fever. They do not produce a local result.

6. Inoculation with vaccine and variolous cultivations protects from a subsequent attack of variola in calves.

7. The best or perfect material for vaccination appears to be that which contains spores only. This is probably due to the small quantity of the virus, and to its slower rate of increase.

8. Inferior or imperfect materials for vaccination are more powerful in their action. Thus opaque vaccine and variolous lymph not unfrequently produced eruptions, with a modified imperfect local effect. Cultivation of clear lymph in solid media appears to increase its potency, as shown by its production of an eruptive fever in a calf. Cultivation of vesicular variolous lymph in solid media does not appear to differ in potency from vaccine cultivations, as shown by the effect of inoculation on a monkey. The action of the material containing spores is probably milder.

9. Vaccination probably protects from small-pox, by producing a mild form of fermentation in the blood. The process probably takes place slowly, as the ferment is growing in unsuitable soil.

10. When the spores or mature forms are inhaled they probably grow in the air-passages with extreme rapidity, and thus get into the blood, where they multiply during the incubative period.

11. My observations appear to show that what is called "attenuation of a virus" may be explained by spore-production. Are not the perfect vaccine materials for infective diseases to be found in the spores of the micro-organisms which are their exciting causes?

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4. On the probable Heats of Formation of Zinc-Copper Alloys. By A. P. Laurie, Esq.

5. On the Mean Free Paths in a mixture of Two Systems of Spheres. By Professor Tait.

6. On Two Shrunk Human Heads from South America. By Professor Duns, D.D.

The Indians, to whom the preparation of these heads is traced, are scattered over a wide tract of country on the eastern side of the Andes. They are known under the general designation Macas, the name of the region they inhabit—a designation which includes the Jivaros, Pastazas, Mendes, Tumbas, and more than twenty other tribes. Early brought into contact with the first Spanish invaders, they suffered much at their hands. Many references to them occur in the history of the Spanish settlers. Their appearance, social habits, and superstitious practices have much prominence given to them in the recent literature of South American travel. At present I limit my remarks mainly to the specimens of "shrunk" or reduced heads now before us. They are from several points of view remarkable, and raise several questions of great ethnological interest, but trustworthy references to them are comparatively few. Indeed, the only sources of information worth mentioning are a communication by Mr William Bollaert, F.R.G.S., to the Ethnological Society of London, 1860, and another, by Sir John Lubbock, to the Anthropological Institute of Great Britain in 1873. The former is entitled "On the Idol Human Head of the Jivaro Indians in Ecuador;" the latter, "Note on the Macas Indians." In Mr Bollaert's paper special attention is given to a specimen obtained by M. José Felix Barriero, of the Secretariat of the Provincial Government, Quito, and sent by him to Don R. de Silva Ferro, Chilian Consul, London. This specimen was placed in the Ecuador Court of the International Exhibition, 1862. Sir John Lubbock's paper is devoted chiefly to a general description of the Macas Indians.

The red specimen of shrunk head now exhibited was sent to my friend Dr H. Gunning of Palmeiros, Rio de Janeiro, a Fellow of this Society, by the Manager of the Amazon Steamboat Company, whom it had reached from the upper waters of that great river. It is styled by the sender a *Cabeza reduzida*—reduced head. Dr Alfred Pullar, owner of the black specimen, has kindly permitted me to show it to the Society. The former was obtained from the Pastaza tribe of Macas Indians, the latter from the Jivaro tribe. In a note accompanying the head, Dr Pullar says:—"Through the kindness of a friend in South America, I have lately received the curious war trophy of the Jivaros, who inhabit a remote district on the eastern side of Ecuador. It would appear that very few of these objects have been brought to Europe, their rarity being explained by the fact that their preparation is a religious custom of these Indians. Dr Duns, therefore, suggested to me that this trophy would be interesting to the Fellows of the Society in relation to a somewhat similar specimen which forms the subject of his paper. This curious preparation is a human head, which by some process, known only to the Indians, has been dried and reduced in bulk to its present condition. It consists of the entire scalp and face-skin, the features being perfectly preserved, the eyes closed, and eyebrows remaining intact. There is an aperture at the base of the head, through which the bones and other structures have been removed, leaving only the dried and shrunken integuments. The hair is of a deep black colour, very thick, soft and glossy, and about 20 inches in length. The measurements of the head are as follows:—From roots of hair or forehead to nose, $1\frac{1}{4}$ inches; nose to chin, 2 inches; from ear to ear, across nose, $4\frac{1}{2}$ inches; length of ear, $1\frac{2}{8}$ inches. The lips are sewn together, and a number of strings hang from them, the use of which is not apparent."

There is considerable difference between the red specimen and that thus described by Dr Pullar, both in measurement and other respects. I have brought them together for comparison, with the view of indicating features of which we have no record in the papers referred to above. While, of course, the accuracy of craniometric characterisations is not attainable and not sought here, yet the leading lines of skull measurement may be followed with regard to the integument, which still retains much of the shape it had before the bones were removed. In view of this explanation, I give the following, it being understood that the terms used are intended simply to indicate roughly the directions of the measurements :—

	Pastaza.	Jivaro.
Alveolo-condylian plane (Broca), . .	$3\frac{3}{8}$ inches	$4\frac{1}{8}$ inches
Vertical, or basilo-bregmatic diameter (Broca), .	$3\frac{1}{8}$,,	$3\frac{2}{8}$,,
Glabello-lambdoidean plane, or antero-posterior diameter, ...	3 ,,	4 ,,
Parietal diameter, ...	$2\frac{3}{8}$,,	$2\frac{4}{8}$,,
Nares, ...	$\frac{5}{8}$,,	$\frac{6}{8}$,,
Hair, ...	21 ,,	20 ,,

In the Pastaza specimen the septum of the nose and the eyebrows are awanting—the former evidently by injury after the head was prepared. In the Jivaro specimen the integument, at a point answering to about the middle of the coronal suture, has been squeezed together as if between the forefinger and thumb, thereby increasing the height of the forehead. In the other the compression is in the skin which covered the spot where the coronal and temporal sutures meet, thereby giving an aspect of greater breadth to the brow. The ears of the Pastaza specimen are smaller than those of the Jivaro, and in the ear lobes of both are holes, which show that large ear ornaments had been worn. The hair of both is thick, strong, tending to lanky, and of a glossy, deep black colour. Both have an exaggerated prognathous appearance. Does the difference of colour point to a tribal difference?

Artificial deformation of the head has long been noticed by ethnologists. It is widespread. Anciently it was not unknown in Europe, and it can now be traced in Polynesia, Asia, Africa, and both Americas. It was the expression of conventional ideas of beauty, as among the ancient Peruvians, and also among the still extant tribe of Flat-heads in North America; while, as regards the cutis, it is also met with among the Maories of New Zealand. It is practised on the dead as a mark of devotion to the memory of relatives among the Andaman Islanders; and, as a proof of success in war among the Dyaks of Borneo, the Jivaros and Pastaza's of Ecuador, and the Mundurucús of the Upper Amazon—facts which raise questions of much importance to ethnology, as bearing on the geographical distribution of tribes, and the import of the existence of identical customs and superstitions among nations far remote from each other. It is also worthy of notice that the Mundurucús should differ widely from their comparatively near neighbours, the Macas tribes, in the preparation of the head, and yet agree with the Bornean families. The Mundurucú does not attempt to remove the bones, or to reduce the natural size of the head. His effort is to preserve the natural likeness and the usual ornamentation. This is shown in the photograph on the table.

As regards the Ecuador specimens, it is impossible as yet to account for the fact, that we have so little information as to their meaning and the modes of preparing them, while so much has been recorded touching the several habits and industrial art of the tribes among whom they occur. In the reference to the Macas head, by Sir John Lubbock, the following passage occurs :—"The process of preparation, according to the account given me by Mr Buckley, is very simple. The head is removed, and, after being boiled for some time with an infusion of herbs, the bones, &c., are removed through the neck. Heated stones are then put into the hollow, and as they cool are continually replaced by others; the heat thus applied dries and contracts the skin. It will be seen that Mr Buckley's account confirms that of M. Barriero. A string is then run through the head, which is suspended in the hut, and solemnly abused by the owner, who is answered by the priest speaking for the head, after which the mouth is sewn up to prevent any chance of reply." But Sir John leaves out an important sentence in M. Barriero's account, who says :—"This is how I understood the matter; however, I may not have well understood the process." This theory of desiccation by the application of heated stones is not satisfactory. It is more likely the explanation will be found in connection with "the boiling for some time with a ninfusion of herbs." Rapid shrinkage might, perhaps, be thus obtained equal all over, and without folding, especially if accompanied by quick drying. And I may put a question in this connection which, however, I feel wholly unqualified to answer. Does what we know of the drying powers of the acid in certain vegetable oils, and of the action of tannic acid on skin, warrant a guess that there may be properties in the herbs used in these preparations which, being set free by boiling, might produce the result? The finger and thumb marks already referred to might be accounted for by the hypothesis that the heads were held over heated stones after being taken from the infusion of herbs. There is room enough to speculate. I think, however, the speculation is warranted by (may it not be said) the attainments of some of the Upper Amazon tribes in organic chemistry! How otherwise can we account for their skill to separate, by a complex process, the starch in the tubers of the manioc plant (*Janipha manihet*) from the strong narcotic poison they contain, and to give to the people the former as a nutritious bread—*farinha* or cassava—the "Bread of Brazil?" Or, even, how otherwise could they prepare from other plants the arrow poison, or *woorare?* It would not be a great surprise to learn that, having gouged the bones from scalp and face-skin, their skill as herbalists, aided by a little careful manipulation, enabled them to realise these shrunk heads. As regards their meaning, it seems to me we have information enough on this point to warrant the inference that they were used by the native priests as oracles, and that the strings, with their blood-red marks, were connected with this use.

Monday, 1st March 1886.

PROFESSOR DOUGLAS MACLAGAN, Vice-President, in the Chair.

The following Communications were read:—

1. On the Magnitude of the Mutual Attraction between two pieces of matter at distances of less than ten micro-millimetres. By Sir William Thomson, Hon. V.P.

2. On a Theorem in the Science of Situation. By Professor Tait.

3. On Radiation from Snow. By John Aitken, Esq.

4. Comparison of the Volumes of Saline Solutions with the Sums of the Volumes of the Constituents. By J. Holms Pollok, Chemical Laboratory, Glasgow University. Communicated by Sir William Thomson. (Plate XXII.)

My attention was first drawn to the change of volume which takes place when a salt is dissolved in different quantities of water, by an experiment shown by Sir William Thomson in his class at the Glasgow University. He took a wide glass tube, about 3 feet long, sealed at one end, and having a narrow tube attached to the other end. The lower half of this tube he filled with a saturated solution of common salt, and on the top of that he placed a layer of water, which just reached a mark about the middle of the small tube. He then corked the open end, and mixed up the water and brine by inverting the tube two or three times, when it was seen that the solution had contracted.

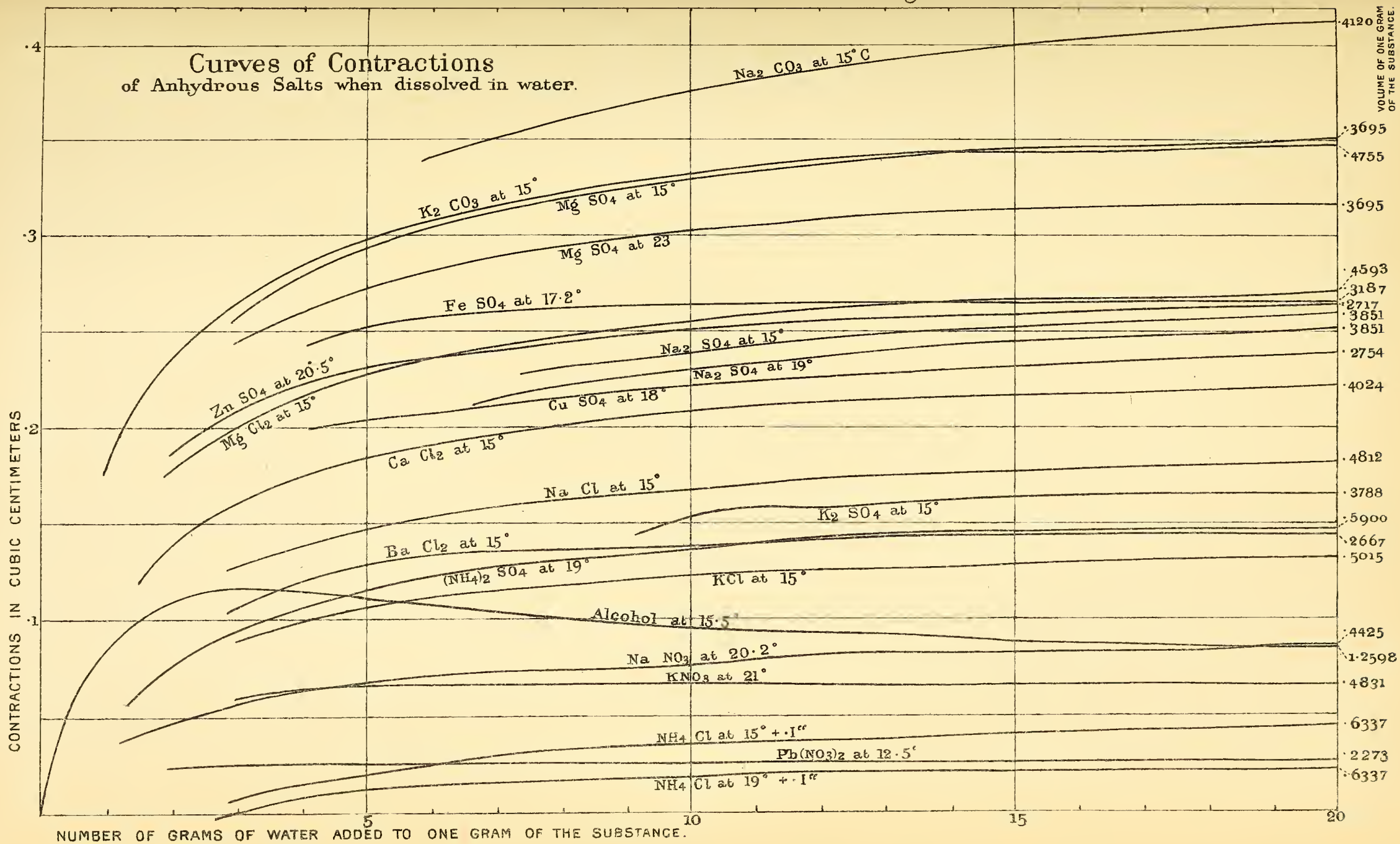
After seeing this experiment, I determined to find the amount of contraction that takes place; but, instead of taking a saturated solution, I took 1 gramme of the anhydrous salt, and ascertained the amount of contraction that takes place on dissolving it in any quantity of water from 1 gramme to 20.

These results I calculated from the tables of specific gravities of solutions of salts, given in Storer's *Dictionary of Solubilities.* Those for the curves at 15° were obtained by Gerlach, with the exception of those for alcohol, which were taken by Fownes; the specific gravities for the others were obtained by Schiff, with the exception of those for lead nitrate, which were by Hassinfratz. The contractions were found by means of the formula

$$C=\frac{A}{a}+\frac{B}{b}-\frac{A+B}{r},$$

where C is the contraction in cubic centimetres, A the number of grammes of the substance taken, B the number of grammes of water added, and a, b, and r the specific gravities of the substance, the water, and the resultant solution, all referred to 4° C.

Thus, I find by calculation in the case of magnesium sulphate at 15° C., that taking 1 gramme of $MgSO_4$, and adding to it 2·961


Curves of Contractions
of Anhydrous Salts when dissolved in water.
Na2 CO3 at 15° C
K2 CO3 at 15°
Mg SO4 at 15°
Mg SO4 at 23
Fe SO4 at 17·2°
Na2 SO4 at 15°
Na2 SO4 at 19°
Zn SO4 at 20·5°
Mg Cl2 at 15°
Cu SO4 at 18°
Ca Cl2 at 15°
Na Cl at 15°
K2 SO4 at 15°
Ba Cl2 at 15°
(NH4)2 SO4 at 19°
KCl at 15°
Alcohol at 15·5
Na NO3 at 20·2°
KNO3 at 21°
NH4 Cl at 15° + ·1cc
Pb(NO3)2 at 12·5°
NH4 Cl at 19° + ·1cc
·4
·3
·2
·1
CONTRACTIONS IN CUBIC CENTIMETERS
5
10
15
20
NUMBER OF GRAMS OF WATER ADDED TO ONE GRAM OF THE SUBSTANCE.
VOLUME OF ONE GRAM OF THE SUBSTANCE.
·4120
·3695
·4755
·3695
·4593
·3187
·2717
·3851
·3851
·2754
·4024
·4812
·3788
·5900
·2667
·5015
·4425
1·2598
·4831
·6337
·2273
·6337

grammes of water which gives a saturated solution, the contraction which takes place amounts to ·255 c.c., on adding sufficient water to make this 3 grammes the contraction increased to ·256 c.c., and on adding another gramme it increased to ·278 c.c., and so on until 20 grammes of water were added, when the contraction amounted to ·350 c.c. These results I have represented by curves, the ordinates giving the contractions in cubic centims., and the abscissas the number of grammes of water added to produce those contractions; the curves start at the point of saturation of the solutions, and the height of this point above the line of abscissas represents the amount of contraction that takes place when 1 gramme of the substance is dissolved in as small a quantity of water as possible. It will be noticed that there is contraction in every case with the exception of ammonium chloride, which gives an expansion on dissolving, but as water is added the amount of this expansion diminishes—that is, a solution when diluted contracts. In order to bring the curves for ammonium chloride into the diagram, I have added ·1 c.c. to each of them, which must therefore be subtracted in order to obtain the true change of volume.

From the appearance of the curves and by trial, I find that they are portions of equilateral hyperbolas having asymptotes parallel to x and y, and may be represented by the general equation

$$y = b - \frac{C}{a + x},$$

where y is the contraction in cubic centims., x the number of grammes of water added, a the distance from y of the asymptote parallel to y, and b the distance from x of the asymptote parallel to x, and C the constant $(a+x)(b-y)$; thus,

for $MgSO_4$ $a = 1{\cdot}429$ $b = {\cdot}374$ and $C = {\cdot}500$,
for $MgCl_2$ $a = 1{\cdot}645$ $b = {\cdot}290$ and $C = {\cdot}408$,
for $CaCl_2$ $a = 1{\cdot}857$ $b = {\cdot}240$ and $C = {\cdot}391$,
for K_2CO_3 $a = 1{\cdot}644$ $b = {\cdot}374$ and $C = {\cdot}501$.

Although the curves of contractions for all salts appear to be portions of equilateral hyperbolas, other substances give very different curves. Thus alcohol contracts until you have added 3 parts of water, and then the amount of contraction begins to diminish;

therefore, if we take a mixture of 3 parts of water and 1 part of alcohol and add water to it, we get an expansion. In cases where I have drawn the curves for two different temperatures, the effect of increase of temperature is to diminish the amount of contraction.

On the right hand side of the diagram the volume of 1 gramme of the salt in cubic centims is placed at the extremity of each of the curves, and if it be desired to obtain the increase of volume of a given weight of water on adding to it 1 gramme of a salt, it is only necessary to subtract the contraction from this number, and you get the increase of volume. From this it will be observed that Dalton's theorem—that the volume of water was not increased by dissolving in it an anhydrous salt capable of taking up water of crystallisation —does not hold good in any of the cases taken, except that of sodium carbonate; and there it only holds good provided the salt be dissolved in not less than twenty times its own weight of water.

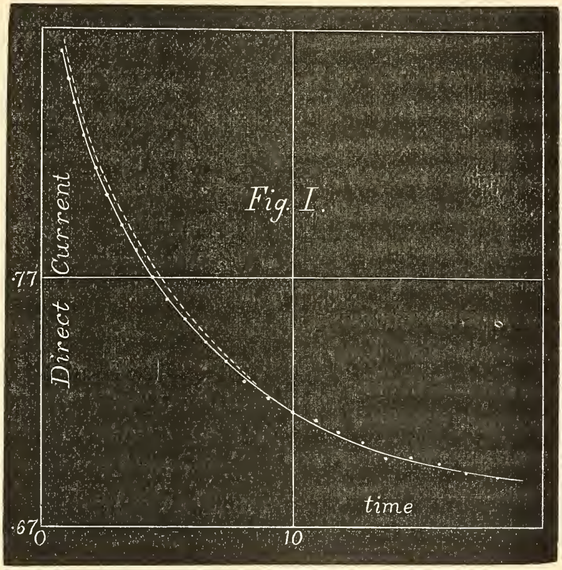
P.S.—Since writing the above I find that in 1846 a paper was published by John Joseph Griffin, on the "Constitution of Aqueous Solutions of Acids and Alkalies," in which he points out that the volume occupied by a substance in solution varies with the quantity of water in which it is dissolved, thus controverting Dalton's theorem. In this paper he gives contractions of the common acids and alkalies, and also of K_2CO_3, Na_2CO_3, NH_4Cl, and $MgSO_4 + 7H_2O$ (*Memoirs of the Chemical Society*, vol. iii. p. 155).

5. On the Increase of Electrolytic Polarisation with Time. By Mr W. Peddie.

The law of variation of the electromotive force of polarisation with current-density has been very thoroughly investigated. It is found that it may be represented by an equation of the form

$$F = a - b\varepsilon^{-cx},$$

where x is the current-density, and a, b, c are constants. So for very feeble direct currents the reverse polarisation current is proportional to the current-density; but for strong currents it cannot be expressed by an algebraical formula as a function of the current-density in a finite series of terms. The above formula gives the *maximum* value of the polarisation current. So far as I know, no observations have been made regarding its variation with time from its commencement until the maximum is reached. This question is of interest chiefly from a theoretical point of view. The object of this note is to describe the result of some experiments made on this subject. Platinum electrodes, heated to redness before each experiment, were used. The electrolyte was a 5 per cent. aqueous solution of sulphuric acid. A Helmholtz galvanometer was placed in circuit with the electrolytic cell and the battery. The reading of the galvanometer was taken every minute from the time of starting the current until it apparently reached the stationary value. The results of two of these experiments are shown graphically by the subjoined curves. The ordinates are proportional to the current-strength, and the abscissæ represent time. These curves closely resemble the logarithmic curve in form. To test how close the correspondence is, we may assume the equation



$$j = a - b\varepsilon^{-ct}$$

to be true, when j is the polarisation current, t is the time, and a, b, c are constants. In fig. 1, I have taken the point (·85, 1) as the origin, and reckoned j downwards to the curve from a line drawn parallel to the axis of time through this point. The value of the constants may be got from three points $(j_1, t_1) \ldots (j_3, t_3)$, where $t_1 \ldots t_3$ are in arithmetical progression, by means of the following equations:—

$$a = \frac{j_1 j_3 - j_2^2}{j_1 + j_3 - 2j_2}$$

$$\log b = \frac{t_2 \log (a - j_1) - t_1 \log (a - j_2)}{t_2 - t_1}$$

$$c = \frac{\log (a - j_1) - \log (a - j_2)}{(t_2 - t_1) \log \varepsilon} .$$

For the curve in fig. 1, I obtain the following equation by means of points between $t = 10$ and $t = 19$—

$$j = \cdot 162 - \cdot 165 \varepsilon^{-\cdot 19 t}.$$

The position of this curve is shown in the figure by means of the dotted line.

Fig. 2 shows the results of another experiment, in which the current-density was different. Here the point (·37, 0) is taken as origin. The equation to this curve calculated from the points corresponding to $t = 5$, $t = 7$, ... on the assumption that it is a logarithmic curve, is

$$j = \cdot 116 - \cdot 101 \varepsilon^{-\cdot 218 t}.$$

It will be seen that this curve coincides with that obtained by experiment except near the origin. I find that the observed points lie very accurately on a curve whose equation is of the form

$$j = a - b \varepsilon^{-ct + d\varepsilon^{-et}}.$$

This curve practically coincides with the former for values of t greater than 5, so that we may assume a, b, and c to have the same values in both. To determine d and e we have the equations

$$\log \frac{b}{a - j} = ct$$

$$\log \frac{b}{a - j'} = ct - d\varepsilon^{-et} ,$$

where j and j' correspond respectively to points on the logarithmic curve, and on the curve representing the results of observation for the same value of the time. Hence

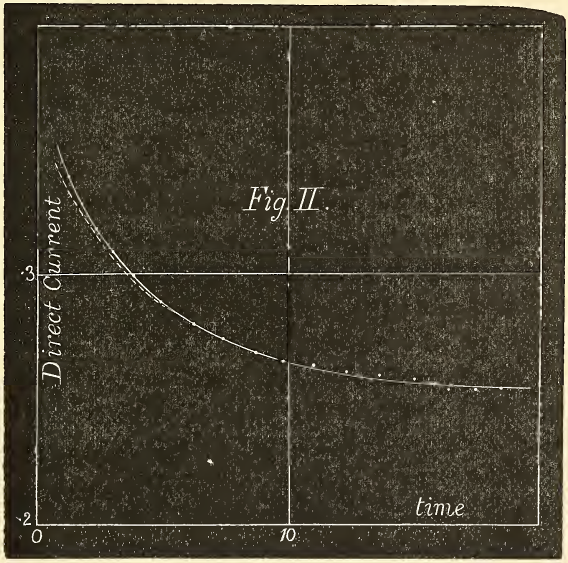
$$e=\frac{1}{t'-t}\log.\ \log\left(\frac{a-j'}{a-j}\right)_t\left(\frac{a-j}{a-j'}\right)_{t'},$$

$$d=\frac{\log\left(\frac{a-j}{a-j}\right)_t}{\varepsilon^{-ct}}.$$

For the curve of fig. 2 we get the equation

$$j=\cdot116-\cdot101\varepsilon^{-\cdot218t+\cdot131\varepsilon^{-\cdot53t}}.$$

This curve is practically indistinguishable from that of fig. 2. The sign of d will determine whether the logarithmic curve lies above the actual curve or not. But all the curves I have obtained lie above the logarithmic curve with the exception of that in fig. 1; so that, especially since the curves in that figure are apparently again approaching each other, I believe that this apparent exception is really due to an error in drawing the curve through the observed points where t is large, which would affect the constants.



It would seem, then, that the polarisation current can be expressed as a function of the time by means of a formula of the form

$$j=a-b\varepsilon^{-ct+d\varepsilon^{-et}},$$

where d is always positive.

My thanks are due to Messrs Moffat and Callender, students in the University Physical Laboratory, who have conducted the experiments for me.

Added June 23.—Further experiments made with larger electrodes show that the above empirical formula closely represents the results of observation; but they also show that the curves are symmetrical about an axis, and are probably hyperbolas. I am at present engaged in investigating the point.

6. On Thermometer Screens. By John Aitken, Esq. (Plate XXIII.)

Part III.

In my previous communications to the Society on this subject* some different forms of thermometer screens are described, and the results are given of a number of trials made with them during trying conditions of weather. The result of these tests showed that all the screens gave readings a little too high when there was much radiation, and that the thermometer in the fan apparatus also indicated too high a temperature, the readings of a fine-bulbed thermometer in a polished silver case being taken as our standard of temperature in these trials. The reasons are given for the thermometer in the draught screens indicating too high temperature, and the ineffectual attempts made at the time to check these errors are described.

Confining our attention for a moment to the draught screen, fig. 3, and the fan apparatus, figs. 5 and 6, of previous papers. The reasons for the thermometer in screen fig. 3 reading too high are—1st, the outside of the case being heated by the sun, part of this heat is conveyed inwards to the thermometer, being conducted through the concentric tubes, and radiated from tube to tube, the air passing over the surface of the tubes not being able completely to check this transference of heat; 2nd, the too high readings given by this screen are also in part due to the heat radiated and reflected from the ground, and entering the lower end of the tube. The introduction of small screens into the tube below the thermometer to check the entrance of radiant heat, while admitting a free passage of the air, was not found to improve the correctness of the readings given by this screen. The entering air seemed to be heated as much by the screens as the bulb was by direct radiation.

* *Proc. Roy. Soc. Edin.*, No. 117, 1883–84.

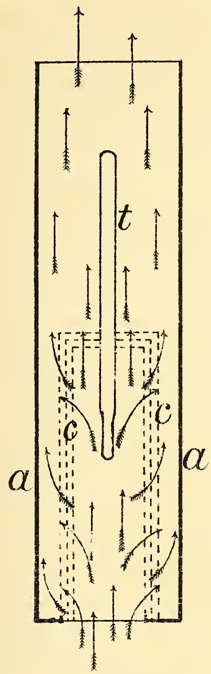


Fig 1

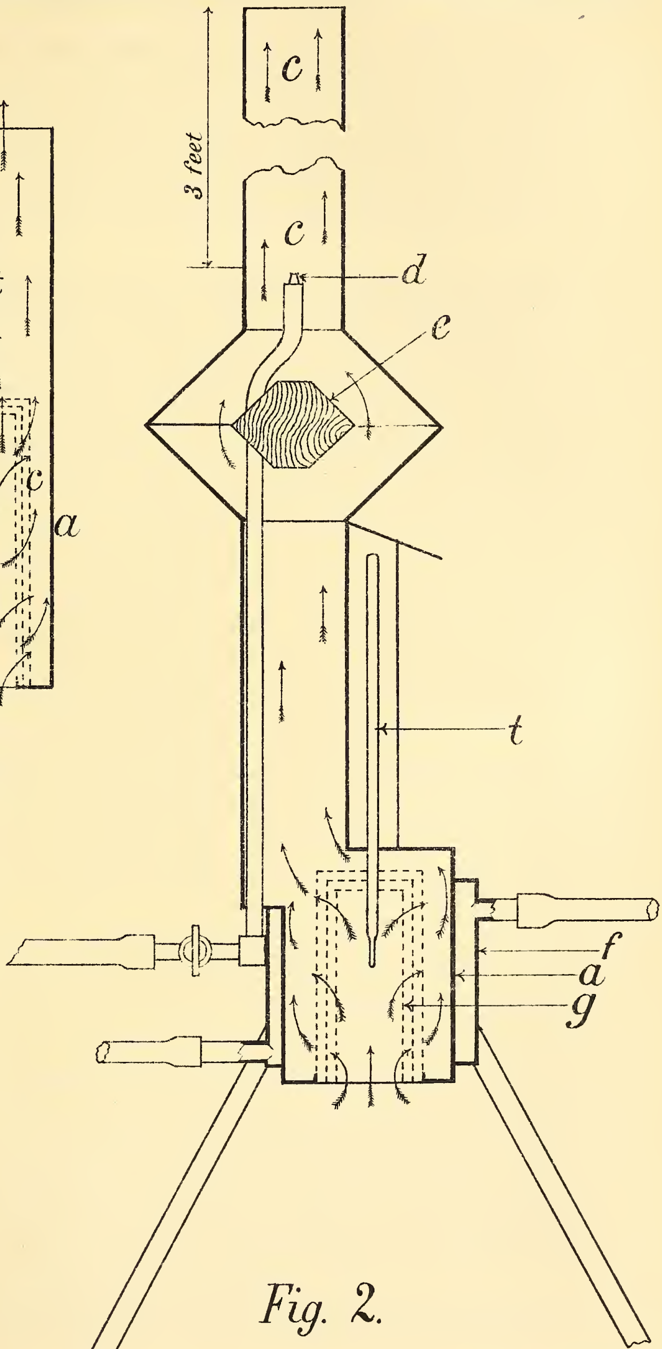


Fig. 2.

A third reason of the too high readings is that some of the air heated on the outside of the case is driven by air currents past the annular openings and enters the central tube. The too high readings given by the fan apparatus would be principally due to the heat conducted through the walls of the air passage and radiated to the thermometer, and very little of it to heat radiated by outside objects entering by the air passage.

In the attempts to devise arrangements to correct these errors, I have been guided very much by two conclusions arrived at in a previous part of this investigation. The one conclusion was, that if we wish a body to acquire the temperature of the air it must be infinitely small, and in practice it should be as small as possible; the smaller it is the nearer will its temperature be to that of the air. The other conclusion was, that all radiant heat must be prevented from falling on the bulb of the thermometer, because the radiant heat is absorbed, not only at the surface, but also internally, by the glass walls of the bulb, and the passing air carries away heat only from the outside of the bulb, which explains the reason why, in practice, it was not found possible to check the heating effect of a very small amount of radiation by any velocity of air current that could be made to pass over the bulb.

This investigation thus naturally divides itself into two parts. The first, how best to check the heat absorbed by the outside of the case, and prevent it getting to the thermometer; the second, how best to check the entrance of radiant heat at the opening by which the air enters.

Taking these two points in their order, we shall confine for the present our attention to the question how best to prevent the thermometer being heated by the hot case by which it is surrounded. In the screen shown in fig. 3 of the previous paper, the transference of heat was checked by the non-conducting concentric tubes and air passages. The cooling effect of the air in this arrangement cannot, however, be perfect, on account of the length of the surface over which it flows in an even stream; only the lower edges, where the air first touches these tubes, will be cooled to near the temperature of the air, the upper parts being warmer and warmer the further they are away from the entrance.

Guided by the principle already referred to, it appeared that the best method of causing the walls of the tube to acquire the temperature of the air, and at the same time prevent heat passing from the outer case to the thermometer, would be to surround the bulb with a tube of some open or porous material, such as cloth, through which the air could be made to pass, and to cause the air to enter one end of this tube, and to pass radially through its walls in the manner shown in Plate XXIII. fig. 1, where *a* is the outside case heated by radiation, *t* the thermometer, and *c* a tube of some porous material surrounding the thermometer and placed inside the draught tube as shown. The arrows in the figure show the direction of the air currents in the draught tube under these conditions, from which it will be seen that the air currents are made to flow in a direction the opposite of that in which the heat tends to move; and it was expected that the outward-moving air currents would check the inward movement of the heat, and prevent it arriving at the thermometer; also that the passing air would cause the inside surface of the tube rapidly to acquire the temperature of the air, and to follow its changes quickly.

The trials with this arrangement were quite successful. The advance of heat was so perfectly held in check by it that the thermometer kept at the temperature of the air, even when the surrounding tube was highly heated. As these experiments may have some interest, I shall give somewhat in detail the results of some experiments made with some different materials used for this purpose. As it was winter, and no experiments of this kind were possible in the open air, a draught screen was prepared for making the trials in the laboratory. This apparatus is shown in fig. 2: *a* is the case surrounding the thermometer *t*; *c* is the draught tube, heated by a gas jet *d*, for promoting a circulation of air; *e* is a screen placed below the gas flame to prevent heat being radiated downwards to the thermometer case. The air enters the lower end of the case, and is drawn upwards by means of the column of heated air in the draught tube *c*. As it was necessary to put this method of protecting the thermometer to as severe a trial as possible, the outer case *a*, surrounding the thermometer, was jacketed by the case *f*, which could be kept hot with steam. The thermometer could be thus exposed to radiation from a surface all round it having a temperature of 100° C.

In experimenting on this method of protecting the thermometer, different materials were used for making the porous tube; the results will be here given of the trials with muslin, wire-cloth, and cotton wool. The material under trial was rolled up in the shape of a tube and placed inside the case of the draught tube, as shown at *g*, and the protecting power of one, and of a number of thicknesses of the different materials was measured.

As the question to be determined was, how much the thermometer surrounded by the hot case was heated above the temperature of the air when protected in this manner by the different materials, it was necessary that the temperature of the air should be very accurately determined. In conducting the investigation, it soon became evident that a thermometer hung up in the room could not be relied upon for this purpose, as it was too much affected by radiation, from the fire, from gas flames, and from the body of the observer; for the amount of difference required to be measured was not degrees, but fractions of a degree. Another draught screen was therefore prepared, and a thermometer placed in it. The thermometer in this screen was well protected by concentric tubes; a gas flame placed close to the case had no effect on it, and all radiation from below was easily checked. The draught was kept up in this screen, as in the other, by means of a jet of gas in the upper part of the tube. The temperature of the air as given by this screen could be relied upon to a small fraction of a degree. In the trials, the two draught screens were placed as near each other as convenient, generally about one-third of a metre apart.

The thermometers used in these trials were graduated to Centigrade degrees. The scale of both of them was very wide, and each degree was divided into tenths—the scale of the one showing the temperature of the air was 4·2 mm. to the degree, and the other 5·5 mm. to the degree. The thermometers were carefully compared with each other in water, and corrections made for difference.

In experimenting with this arrangement of apparatus, the gas was lighted in both draught tubes to produce a circulation of the air. In the screen under trial a No. 1 jet was used turned down to one quarter of full flame, and kept as constant as possible during the trials. The first trials were made with the thermometer case as it came from the work, but without polishing the inside surface that radiated heat to the thermometer. A number of trials were made with it in this condition, of which it is unnecessary to give the detailed results. It may, however, be mentioned, that with the usual draught and with no protection between the thermometer and the walls of the case—that is, with the bulb exposed all round to radiation from bright tin at 100°—the thermometer rose to 18°, the temperature of the air being 12°; that is, it was heated 6° above the temperature of the air. When one thickness of wire-cloth and two thicknesses of muslin were placed between the bulb and the case, the radiation was almost entirely checked, and the thermometer rose only about 0°·2 above the temperature of the air.

As it could not be expected that the inside of the case would keep bright after being long in use, it was thought advisable to make the tests under the most disadvantageous conditions possible. The inside of the case was therefore painted black. When this was done, a great increase in the heating effect on the thermometer was produced, as was to be expected.

In the following tables are given the results of some experiments made with the inside of the case blackened, and with fine cloth as the protecting material. The protection effected by different numbers of thicknesses was tried, and the results are given. The cloth used in these trials was book-muslin, about 56 meshes to the inch.

Muslin.

1. Air.	2. Case.	3. Difference.	4. Protection.
13°·4	31°·6	18°·2	None
13°·4	20°·9	7°·5	1 Thickness
13°·4	17°·4	4°·0	2 ,,
13°·25	13°·6	0°·35	4 ,,
13°·3	13°·3	0°·0	12 ,,

In the above table, in column 1 is given the temperature of the air of the room; in column 2 the reading of the thermometer surrounded by the case heated to 100°; in column 3 the difference between the thermometers, and shows the amount of heating produced by the warm case; and in column 4 the protection placed between the thermometer and the hot case.

It will be observed that when there was no protection between the thermometer and the case, the thermometer got heated 18°·2 above the temperature of the air, or three times more than it was before the radiating surface was painted black. It will be noticed that a single thickness of muslin placed between the thermometer and the case greatly checked the radiation; that as the number of thicknesses was increased, the heating effect rapidly diminished; and when twelve folds or thicknesses were between the two, not the slightest effect could be detected. This test has been repeated a number of times with the same result. To check the results, readings were taken with the steam off and the case cold. Steam was then turned on, the case heated, and readings taken. Steam then cut off, and cold water circulated through the jacket, but not the slightest difference could be detected under the two conditions, showing that the thermometer was thoroughly protected by twelve thicknesses of muslin. The protection was of course perfect only under the condition of the experiment. If the draught was reduced by shutting off the gas, and the air heated only by the small amount it got in its passage through the case, then the thermometer rose a very little above the temperature of the air.

No comparative trials were made with black and white muslin, as it was not possible to get two muslins similar in every respect except colour; but as we are here dealing with dark heat, it does not seem likely that this would have any effect.

The next two tables give the results of tests made with two different kinds of wire-cloth as the protecting material. In the first table are given the results obtained with wire-cloth made with No. 35 iron wire and 36 meshes to the inch; in the second table the results obtained with No. 38 brass wire and 70 meshes to the inch.

The contents of the different columns in these two tables are arranged as in the last one. It will be observed that the results with wire-cloth are not so good as with the muslin; this will be due partly to the conducting power of the wire, and also probably in part to heat reflected by the polished surface of the wires. These tables show very little difference in the protecting powers of the two wire-cloths. The tables must not, however, be compared too closely, as the conditions do not admit of very exact results. It may be noticed, for instance, that while the two tables agree

Iron Wire-Cloth.

No. 35 wire and 36 meshes to the inch.

1. Air.	2. Case.	3. Difference.	4. Protection.
15°·7	34°·4	18°·7	None.
15°·4	25°·7	10°·3	1 Thickness.
15°·3	22°·5	7°·2	2 ,,
13°·6	16°·3	2°·7	4 ,,
13°·4	14°·0	0°·6	8 ,,
15°·0	15°·05	0°·05	12 ,,
15°·2	15°·2	0°·00	16 ,,

Brass Wire-Cloth.

No. 38 wire and 70 meshes to the inch.

1. Air.	2. Case.	3. Difference.	4. Protection.
15°·6	34°·5	18°·9	None.
16°	26°·6	10°·6	1 Thickness.
16°·4	22°·8	6°·4	2 ,,
16°·3	18°·8	2°·5	4 ,,
16°·4	16°·8	0°·4	8 ,,
16°·1	16°·15	0°·05	12 ,,
16°·2	16°·2	0°·00	16 ,,

fairly well at the two ends, they do not agree at intermediate points. This disagreement at the intermediate points will probably be the result of the more or less perfect overlapping of the meshes, and of the greater or less degree of contact between the folds of the cloth. Neither of these have any existence when only one thickness is used; they are averaged when there are many thicknesses, and it is only at the intermediate points that they have a disturbing influence.

Cotton Wool, Medium Quality.

1. Air.	2. Case.	3. Difference.	4. Protection.
14°·0	32°·6	18°·6	None.
13°·8	13°·8	0°·0	1 Thickness.

The above table shows the result with cotton wool. The kind known as medium quality was used, the sheets of which are not so thick as those of a finer kind. For supporting the cotton wool in its place inside the case, a wire-cloth cage was used, its inside being lined with one thickness of the wool from which the *skin* had been previously removed. This extremely feeble-looking protection, as will be seen from the table, acted perfectly; the thermometer when protected by it was quite unaffected by the hot case. A number of readings were taken when the case was heated to 100°, and when cooled with water, but not the slightest difference could be detected. Without any gas to assist the draught, the temperature rose 0°·2 above the temperature of the air.

It will be noticed that a very thin covering of cotton wool or muslin, when employed in the manner here described, is quite sufficient to stop the advance of all heat from the warm walls of the case surrounding the thermometer; and further, it is interesting to notice that the amount of muslin and cotton wool that stops all heat is far from being able to stop all light. A good deal of light can come through a sheet of cotton wool, or twelve thicknesses of muslin. This peculiar action reminds us of the somewhat similar action of glass and other substances, which pass the rays of one end of the spectrum, while they stop those of the other.

When we consider the action of muslin used in this manner to check radiation, we see it is one that has been long well known. Gardeners are well acquainted with the fact that any cloth, however thin, spread over plants, is a great protection to them on frosty nights. The action of the cloth on these occasions is exactly the same as in the thermometer case; the thin cloth checks radiation, and prevents the heat from passing into space. The cloth itself is but little cooled by radiation, as it is constantly receiving heat from the air passing through its meshes, the air on these occasions being always hotter than the exposed surfaces of bodies. The plant therefore makes its heat-exchanges with a surface but little cooled by radiation instead of with the cold of space, as tempered by our atmosphere. We see from this that the protection afforded by these cloths on frosty nights is efficient only on what are called radiation frosts; the cloth has no power to heat the air. Further, we see that the efficiency of the cloth will be a good deal affected by the amount of wind; the better the air circulation the warmer the cloth will be—that is, the less it will be cooled by radiation. It may also be observed that an open cloth may be under certain conditions a better protection than a close covering. From the experiments with muslin in the draught tube it was seen that one thickness of this material reduced the radiation effect to less than half. From experiments made at night with one radiation thermometer, protected by a piece of muslin stretched horizontally at a little distance above it, while another was freely exposed to the sky, I found that one thickness of the same muslin reduced the cooling effect of radiation to almost exactly one half, the less circulation of the air at the time accounting for the difference.

It is now long since Dr Joule first laid down certain imaginary conditions under which it might be possible to get the true temperature of the air. The method proposed by him was to place the thermometer in a long vertical tube, open at both ends, but with a cap by which the lower end could be closed. This tube was to be surrounded with a jacket by means of which it could be heated to any desired temperature. The temperature of this tube was to be carefully adjusted, so that the air inside of it tended neither to ascend nor to descend when the cap was taken off. When this condition of matters was arrived at, the air inside the tube would evidently have the same temperature as the air outside of it, and the thermometer would be at the true temperature of the air, as the radiating surfaces all round it would have the same temperature as the air. It is needless to say these conditions could not be carried into practice, for taking observations except where the temperature was nearly constant, and the air free from currents; in the open air, winds and the constant changes of temperature there taking place would make it quite impracticable.

By the method here described we do seem to have a practical way of surrounding the thermometer with the air to be tested, and of causing the surrounding tube to take up and follow the changes in the temperature of the air. By means of muslin, cotton wool, or wire-cloth, through which the air is made to circulate, it does seem possible to surround the thermometer with a tube at the temperature of the air, and to protect it from all radiation from surrounding objects. Under the conditions existing in the open air, where the case is never very highly heated, the error, when the thermometer is protected in this manner, need never amount to more than 0°·01, or less than a readable amount on all thermometers in general use.

But though we can by the above means surround the thermometer with air at the correct temperature, and with a tube at the temperature of the air, yet our difficulties are far from being at an end. We unfortunately cannot get the air into and out of the tube without openings, and these openings either allow radiant heat to fall on the thermometer, or if we place screens to check the radiation, then these screens heat the air in its passage over them; the air and the inside walls of the tube get thereby heated, and the thermometer gives too high a reading.

The investigation has, therefore, been continued in this direction, and some preliminary experiments made on different methods of checking the entrance of radiant heat; it is unnecessary, however, to give here more than a brief outline of the results. For making experiments on this radiation effect, the lower end of the draught tube was placed horizontally with its opening in front of a large gas flame, which was allowed to radiate freely to the thermometer, the upper part of the draught tube being, as before, vertical, to produce the required draught. With the draught produced by a small jet of gas, the error due to heating by radiation from the flame was 0°·45. Screens were then placed inside the case, like louvre boards, to prevent the radiation falling on the bulb, but their presence was found to increase the error. The effect of a strong draught of air produced by a fan was then tried, the screens being removed and the flame allowed to radiate direct to the bulb, but the effect of the powerful blast was only to reduce the error from 0°·45 to 0°·35; that is, the strong draught only gave a reduction of $\frac{1}{10}$th of a degree more than the slow draught of the gas jet. This inability of a strong draught of air to check the effects of radiation has been noticed in a previous part of this investigation. With the screens replaced in the tube in front of the thermometer and fan draught the error was 0°·3.

As the introduction of screens between the source of the radiation and the thermometer bulb produced very little improvement even with a strong draught, probably because the entering air got as much heat on the warmed screens as the bulb did by direct radiation, an arrangement was devised in which all air that had touched the screens, or sides of the case, was drawn through side passages, and only the central core of the entering air allowed to pass to the thermometer. When this arrangement of apparatus was tried, the error with gas draught was reduced to 0°·15, and with fan draught to only about 0°·05.

PRIVATE BUSINESS.

Mr Hugh Miller, Mr John Richard Brittle, the Right Hon. the Lord Provost, Professor Armstrong, Professor Wallace, Dr Arthur Anderson, C.B., Mr Alexander Gibson, Advocate, Colonel R. Murdoch Smith, R.E., and the Right Hon. the Earl of Haddington were balloted for, and declared duly elected Fellows of the Society.

Monday, 15th March 1886.

SHERIFF FORBES IRVINE, Vice-President, in the Chair.

The following Communications were read:—

1. The Volumetric Estimation of Inorganic Nitrites. By G. Armstrong Atkinson, M.B., C.M., Assistant to the Professor of Materia Medica in the University of Edinburgh.

The ever-increasing importance of nitrites in medicine, owing to their power as therapeutical agents, and to the scientific work which has been and is being done to elucidate their pharmacology, renders a knowledge as to the precise amount of nitrite a commercial specimen contains of high importance. For while to most patients a dose of five or six grains of pure, or nearly pure, nitrite of sodium is as large a quantity as they can conveniently bear, we read* of twenty and thirty grains of so-called nitrite of sodium having been administered without dangerous or very unpleasant results. In such cases we cannot but conclude the drug was impure, and MacEwan † has shown that samples of nitrite of sodium were met with in commerce containing but a decimal percentage of the salt. Many papers ‡ have recently appeared on the estimation of nitrite of ethyl in the spirit of nitrous ether, but in this contribution I desire only to consider those methods suitable for the estimation of nitrous acid in its inorganic compounds. While many methods are employed for this purpose, that chiefly followed in pharmaceutical chemistry is one or other of the modifications of the permanganate process, a process first applied to the volumetric estimation of inorganic nitrites by Feldhaus.§ He presumably obtained the idea from Forchhammer of Copenhagen, who in 1850 described a process for the estimation of organic matter in potable waters by permanganate of potassium. The process, as applied to nitrites, depends upon the power of permanganate of potassium, especially in the presence of free acid (preferably sulphuric), to oxidise nitrous to nitric acid, as may thus be expressed in the case of nitrite of sodium:—

$$4H_2SO_4 + 2KMnO_4 + 5NaNO_2 = 2MnSO_4 + 2KHSO_4 + 5NaNO_3 + 3H_2O.$$

Taking the same example, it is obvious that to estimate the percentage of actual nitrite in commercial nitrite of sodium, all we require is to ascertain the amount of permanganate (representing a certain quantity of oxygen) which a given quantity of the commercial nitrite can decolorise, and compare it with the quantity which would be decolorised by an absolutely pure nitrite. This latter quantity is readily enough ascertained from the atomic weights of the elements. The simplest method of estimating the amount of

* See especially the *Practitioner*, vol. xxx. p. 109.

† *Pharmaceutical Journal*, 3rd series, vol. xiii. p. 121.

‡ Consult papers by Dott, MacEwan, Eykman, and Allen, in *Pharmaceutical Journal*, 1882–85.

§ *Archiv der Pharmacie*, April 1860.

permanganate, and therefore of oxygen required, is to follow such a process as Feldhaus describes in a later paper * than that I have referred to. He recommends the nitrite to be dissolved in very slightly acidulated water, and permanganate of potassium to be added until the oxidation of the nitrous acid is nearly completed, when the solution is to be made strongly acid, and permanganate run in until a permanent light red coloration is obtained. Now, as Fresenius † points out, and as very little experience teaches us, nitrous acid, owing to its great tendency to decompose in watery solution with the formation of nitric acid and nitric oxide, requires in such an estimation as that we are considering to be present in the amount of not more than 1 in 5000 of water, and even with this, and a much greater degree of dilution, decomposition slowly proceeds. Furthermore, we must remember anhydrous nitrous acid (N_2O_3)—we cannot speak of the hydrated acid (HNO_2), as it is not known in the pure state—has a boiling point of about $-10°$ C., ‡ so that the risk is incurred of the estimation being vitiated not only by decomposition, but by decomposition and volatilisation combined. After numerous experiments with this method of Feldhaus, I have not obtained satisfactory results. The slowness of oxidation which occurs when the feebly acidulated solution contains but little permanganate, gives time for those evils—volatilisation and decomposition—of which I have just spoken, to occur. Moreover, since there is some difficulty in knowing when the reaction is almost, and even more when it is quite, completed, I have been led to look for a modification of the permanganate process—a modification which will allow very rapid oxidation of the nitrous to nitric acid. To add some excess of permanganate, and estimate that excess by a reducing agent, has been frequently described, but I obtain the most satisfactory results by using a large excess of permanganate, and titrating back with some suitable reducing agent. Such an agent may be found in oxalic acid, as suggested by Kinnicult and Nef,§ or in ammonio-ferrous sulphate, as employed by Feldhausen and Kubel.||

* *Zeitschrift für analytische Chemie*, vol. i. p. 426.

† *Anleitung zur quantitativen chemischen Analyse*, 6th edit., vol. i. p. 390.

‡ Dittmar, *Chemical Analysis*, p. 224.

§ *American Chemical Journal*, vol. v. p. 388.

|| Classen, *Quantitative Analyse*, p. 222.

Or we may, as Tidy * recommends in a process for the estimation of organic matter in potable waters, add iodide of potassium, and estimate the liberated iodine with hyposulphite (thiosulphate) of sodium, adding starch solution to indicate the exact point at which to stop. Muter † uses a very similar method for the estimation of the nitrite in spirit of nitrous ether. I have carefully compared all these methods, and unhesitatingly give preference to that in which ammonio-ferrous sulphate is the reagent used, as it, while quite as accurate, is more easily employed than either of the other two Assuming a temperature of 60° F. to be taken as granted, the process, as I use it, requires the following solutions, the most convenient strengths of which have been fixed after repeated trials with solutions containing varying amounts :—

1. *Solution of Permanganate of Potassium*—one gram in the litre.—This solution, although recrystallised permanganate is usually almost pure, must have its exact strength calculated by titration in one or other of the ordinary ways,—preferably, I think, against metallic iron or a ferrous salt, although oxalic acid has a powerful advocate in Berthelot.‡

2. *Solution of Ammonio-ferrous Sulphate.*—It is most convenient that this solution be of such a strength that 1 c.c. will be peroxidised by, and will therefore decolorise 1 c.c. of the permanganate solution. To do this we require roughly 12·5 grammes of the iron salt in the litre (12·4339 precisely). The mere watery solution soon decomposes, but I find the addition of 1 c.c. of pure sulphuric acid for each gramme of the salt employed (that is, I add 12·5 c.c. of acid for each litre of the solution) keeps the solution well, and also furnishes acid to assist the acid already added in decomposing the permanganate, and in converting the ferrous into the ferric salt. Each day the solution is used it must, however, be titrated against the permanganate, a process which occupies only a few minutes.

3. *Diluted Sulphuric Acid.*—That of the British Pharmacopœia does quite well,—it is almost 1 in 12, but I am in the habit of using a 10 per cent. solution of pure acid. It is very necessary to be certain that the solution will not itself decolorise some permanganate, as impure sulphuric acid so generally does.

* *Journal of the Chemical Society*, vol. xxxv. (new series), p. 46–106.

† *Pharmaceutical Journal*, vol. x. (3rd series), p. 94.

‡ Dingler's *Polytechnisches Journal*, ccxii. p. 354.

4. *A one per mille Solution of the Nitrite to be investigated.*—In the case of such nitrites as nitrite of silver, where the metal has a high atomic weight (Ag = 108), it is advisable to use 2 per mille. But as usually nitrite of sodium or potassium is the nitrite in question, 1 in 1000 is the most suitable strength. Now, as we are dealing with the action of reducing agents on permanganate of potassium, a question first started, so far as I know, by Jones,* comes under consideration. He states that the action of oxalic acid, of ferrous sulphate, and of some other substances with which he has experimented on permanganate of potassium, in strong or in dilute solution, and with or without the presence of sulphuric acid, is accompanied by the evolution of oxygen, and, as he mentions, such a statement has an important bearing on the use of permanganate in volumetric analysis. I have repeated some of Jones's experiments, and while agreeing with him that in strong solution such an evolution of oxygen does occur, I am quite unable to find any evidence of the evolution of this gas with the dilute solutions I have mentioned. Moreover, the check experiments I shall shortly allude to confirm me in my opinion that no such fallacy can arise in this modification of the permanganate process. But if no oxygen be given off during the reduction of the permanganate, is none given off when one adds the sulphuric acid to the potassium salt (the permanganate)? I have estimated the amount of oxidising power possessed by a mixture of the permanganate and sulphuric acid solutions after standing for periods varying from a few seconds to 30 minutes, the reducing agent being a solution of ammonio-ferrous sulphate, and have found no diminution in strength. After boiling for some time a mixed solution of permanganate and sulphuric acid, and then estimating the oxidising power, there is certainly a marked but not very great diminution:—to 200 c.c. of distilled water, 50 c.c. of permanganate solution (1 per 1000) and 10 c.c. diluted sulphuric acid (1 in 10) were added, and the mixed solutions at once titrated against ferrous-ammonium sulphate solution, of which 53·25 c.c. were used. A similar mixture was gently boiled in a glass flask for three hours, when only 50·34 c.c. of the reducing agent were required to effect complete decoloration. Repetitions of the experiment gave very similar results. Further, in connection with the possibility of oxygen

* *Journal of the Chemical Society*, vol. xxxiii. (new series), pp. 95–101.

being given off during oxidation of the substance used to reduce the permanganate, the solutions of permanganate and of ferrous-ammonium sulphate were separately poured into long glass tubes, which having been completely filled and closed with the thumb, were opened under water. The liquids gradually mixed by diffusion, but no evolution of gas could be detected. Oxygen, however, being somewhat soluble in water (roughly 3 volumes in 100 volumes of water), it may be questioned whether, in this last experiment especially, oxygen might not be given off, and be dissolved by the water. The permanganate and ammonio-ferrous solutions were separately shaken up with pure air, and after standing for some little time were mixed as before, and as before gave negative results.

The next point I wish to discuss is in what order should the various solutions be added? In all my experiments in reference to this question I have employed sufficient distilled water to dilute the the nitrous acid in the nitrite, to the extent of at least 1 in 5000, and in all the same bulk of water and the same solution of the nitrite—nitrite of sodium—were employed.

In this series, therefore—(1) I have added the nitrite first, then the acid, and immediately followed this by the permanganate; or (2) I have run in permanganate before the acid, and added this latter (*a*) slowly and (*b*) rapidly; and (3) finally, I have added the nitrite last, both (*a*) rapidly and (*b*) slowly. All these methods give fairly approximate results, but all (with one exception) allow some slight decomposition of the nitrous acid, evidenced by the odour of nitric peroxide, and by the amount of permanganate decolorised; this decomposition, judging from the odour and the results of the analysis, being especially marked where the sulphuric acid preceded the permanganate, the nitrite of sodium having been added first. The one exception was where the nitrite was slowly added, in a way I shall afterwards mention, to the previously acidified permanganate (3, *a*).

Again, as anhydrous nitrous acid decomposes ammonia into nitrogen and water according to the well-known equation,

$$2NH_3 + N_2O_3 = 2N_2 + 3H_2O,$$

does the presence of ammonia or its compounds give fallacious results with this permanganate process? Two beakers, each containing 50 c.c. of the permanganate and 10 c.c. of the sulphuric acid solutions, were taken—to one a considerable amount of sulphate of ammonium was added (as, of course, any ammonia or ammonium salt present would assume this form), and then to both an equal amount of nitrite of sodium solution. In each case precisely the same amount of ferrous ammonium sulphate was reduced. Moreover, solutions of nitrite of ammonium gave concordant results, and results which indicated that no secondary decomposition had occurred. Besides any nitrogen given off would almost certainly have been manifested by bubbles of gas.

These questions having been considered, we may now look to the details of the method. A tentative experiment, by the simple addition of sulphuric acid and permanganate solutions in Feldhaus' original way,* is done to roughly ascertain how much permanganate solution is required to oxidise the nitrous acid in 50 c.c. of the nitrite solution under examination, or the amount which would be required, were the nitrite pure, is calculated, which is the simpler plan, and one proceeds as follows:—Into a beaker of not less than 500 c.c. capacity, 200 c.c. or so of distilled water is poured. The required number of c.c. of permanganate for 50 c.c. nitrite solution being approximately known, twice or thereabouts that number is run into the beaker, and then 10 c.c. of the 10 per cent. sulphuric acid (or 12 c.c. of the pharmacopœial diluted acid) is mixed with this. Now *slowly* add 50 c.c. of the nitrite solution, the addition extending over about one minute, and the nozzle of the pipette being passed well below the surface of the liquid, and moved round so as to agitate the contents of the beaker. The nozzle is drawn above the surface when almost empty, and a little distilled water run over its exterior to wash off any adhering fluid from the beaker. After waiting two or three minutes (less time is really sufficient, as I find after one minute no trace of nitrite, but it is, as a matter of precaution, well to wait about three minutes) titrate back with the ammonio-ferrous solution to ascertain the amount of unchanged permanganate. The exact point of decolorisation is best obtained by zig-zag titration, a method of obtaining the end-point used with excellent results by Dittmar for his "Challenger" reports.† Now

* *Vide supra.*

† "Challenger" Reports, "Physics and Chemistry," vol. i. pt. i. p. 4.

convert the quantity of ammonio-ferrous solution used into its equivalent in c.c. of permanganate, and in the ordinary way calculate the percentage of nitrite the sample contains.

To test the method, nitrite of silver was precipitated from a moderately strong solution of nitrite of potassium by nitrate of silver, and two grammes of the recrystallised nitrite dissolved in lukewarm water were made up to one litre. As this nitrite is not very stable, the amount of silver was estimated by chloride of sodium, and calculating from this basis it was computed that every 50 c.c. of the solution contained ·02465 gram of anhydrous nitrous acid. The following six consecutive estimations show the quantities actually found :—

1. ·02464
2. ·02465
3. ·02463
4. ·02464
5. ·02465
6. ·02466.

The more commonly employed inorganic nitrites being that of those alkalies, I may here note that I find commercial specimens of nitrite of sodium, either in rods or crystals, usually contain nitrous acid equal to 94–95 per cent. of nitrite; specimens of nitrite of potassium an amount equal to from 86–88 per cent. of the salt; whilst nitrite of ammonium, being very deliquescent, is consequently sold in solution which generally contains, when not old, about 12 per cent. of actual nitrite.

In this paper, therefore, I have endeavoured to show—

1. That the permanganate process as ordinarily employed for the estimation of inorganic nitrites, viz., by gradually adding permanganate to the acidified solution of the nitrite, is unsatisfactory.

2. That it is desirable to use a large excess of permanganate, and titrate back with a reducing agent.

3. That very accurate results are obtained by using comparatively weak solutions of permanganate and of the reducing agent.

4. That the most suitable reducing agent is ammonio-ferrous sulphate, and that both it and the permanganate must not be in strong solution.

5. That the nitrite must be slowly added to the acidified permanganate.

6. That with the solutions recommended no fallacy is introduced by evolution of oxygen, or by secondary decomposition between ammonia or ammonium compounds and nitrous acid.

2. The Absolute Determination of the Strength of an Electric Current by means of the Balance. By Professor James Blyth, M.A.

The object of this paper is to describe a method of determining the strength of an electric current in absolute measure by measuring, in grammes weight, the repulsion between two circuits each carrying the same current.

For convenience of calculation, the circuits are made circles of equal radius, and are placed with their planes horizontal.

The construction of the instrument is as follows:—A delicate chemical balance is provided, with the scale pans replaced by two suspended coils of wire. Each of these coils is made of a single turn of moderately fine copper wire bent round a disc of glass of the requisite diameter. The ends of the wire, after being firmly tied together for a considerable length with a thin layer of insulating material between, are bent so as to lie radially along the upper surface of the disc. This disc is cemented concentrically to a similar disc of slightly larger radius, so that the wire is firmly fixed in the step formed by the two discs. The double disc has a round hole through its centre, by means of which it is attached to the end of a wooden cylinder. At opposite sides of this cylinder are fixed two vertical rods of brass of equal length, and terminating at the top in small platinum cups for holding mercury or dilute acid. To the lower ends of these rods, one to each, are soldered the ends of the copper wires which pass radially across the disc. The whole is suspended by a suitable hook from one end of the balance beam, and is so adjusted that the cups are in line with the knife edge at the end of the beam, and have their upper edges just a little above its level. A precisely similar coil is suspended from the other end of the beam, and the lengths and weights of both are so adjusted that, when the index of the balance is at zero, the coils hang with their planes exactly in the same horizontal plane. In order that the weighing may be at all exact it is necessary that the electrical connections, by means of which the current is led through the suspended coils, be so made as to interfere as little as possible with the sensibility of the balance. This is affected in the following manner:—An insulated copper wire, having its ends tipped with short lengths of platinum wire, is run along the lower edge of the beam, being firmly lashed to it by well-rosined silk thread. The ends of this wire, bent twice at right angles, are so placed that their platinum tips dip vertically into one of each pair of the platinum cups which are attached to the vertical rods of the suspended coils. From the other cup of each pair proceed two similarly tipped copper wires which run along the upper edge of the beam, and are also firmly tied to it. These wires only proceed as far as the middle of the beam, where they are bent first outwards, one on each side of the beam at right angles to it, and then downwards, so that the platinum tips are vertical. These latter dip into a pair of platinum cups attached to two vertical rods which spring from the base board of the balance. These rods are placed at equal distances on each side of the beam, and are of such length that the platinum cups are in line with the central knife edge of the beam, and with their edges just a little higher than its level. There are thus in all six cups and six dipping wires. Three of these are in line on one side of the beam and three on the other. Also the line joining the points of each pair of dipping wires is made to coincide with the corresponding knife edge; and further, the edges of all the cups are in the same plane when the balance is in equilibrium.

The fixed coils are made precisely in the same way as the suspended ones, with this exception, that the wooden cylinder with its vertical rods is removed. One of these is placed below one of the suspended coils (the right hand one usually), and the other, having a large central opening for the reception of the supporting cylinder and rods of the suspended coil, is placed above the other. Each is supported from the base board of the balance by three levelling screws, which also serve for adjusting the vertical distance between the fixed and suspended coils. This is done by means of three distance pieces of brass carefully worked so as to have the required length as determined by a screw gauge. To enable the respective pairs of coils to be placed concentric with each other, circles of equal radius are scratched on each glass disc, and the adjustment is made by looking from above downwards upon both discs from holes in the top of the balance case. The ends of the wires proceeding from the fixed coils dip into mercury pools formed in the base board of the balance, which also serve for making connections with the battery and the vertical rods which convey the current into the suspended coils. The connections are so arranged that the current circulates in opposite directions in each fixed and corresponding suspended coil. In this way repulsion is always produced, no matter how the current enters and leaves the entire circuit. The repulsion is measured by the number of grammes required to restore the balance to exact equilibrium.

From the above description it will be obvious that any motion of the beam in the act of weighing causes only a very slight motion of the platinum wires which dip into the fluid contained in the cups. In this way the resistance due to the viscosity of the fluid is very small, even in the case of mercury, and much smaller when dilute acid is used. In point of fact, the diminution of sensibility due to this cause is less than in the case of determining the specific gravities of solids by weighing in water in the ordinary way. With mercury it is quite easy to weigh accurately to a milligramme.

The repulsion between each pair of coils can be calculated from the formula given by Neuman for the action between two current elements.

Let a = radius of each coil.
x = the distance between their planes.
θ = the angle between the directions of an element ds of the one circuit, and in element ds' of the other.
r = the distance between these elements.

Then, if M denote the potential energy due to the mutual action of the two circuits when each carries unit current, we have

$$M = \int_0^{2\pi}\int_0^{2\pi} \frac{\cos\theta ds ds'}{r}.$$

Now $ds = a d\theta\,,\ ds' = a d\theta'\,,\ r = \sqrt{x^2 + 4a^2 \sin^2 \tfrac{1}{2}\theta}$

$$\therefore\ M = \int_0^{2\pi}\int_0^{2\pi} \frac{a^2 \cos\theta\, d\theta\, d\theta'}{\sqrt{x^2 + 4a^2 \sin^2 \tfrac{1}{2}\theta}}$$

$$M = 2\pi a^2 \int_0^{2\pi} \frac{\cos\theta\, d\theta}{\sqrt{4a^2 + x^2 - 4a^2 \cos^2 \tfrac{1}{2}\theta}}$$

$$= \pi a k \int_0^{2\pi} \frac{\cos\theta\, d\theta}{\sqrt{1 - k^2 \cos^2 \tfrac{1}{2}\theta}}\,.$$

If $$k^2 = \frac{4a^2}{4a^2 + x^2} = \sin^2\gamma \text{ (say)}$$

$$= 2\pi a k \int_0^{2\pi} \frac{(2\cos^2 \tfrac{1}{2}\theta - 1)\,.\,d\,.\,\frac{\theta}{2}}{\sqrt{1 - k^2 \cos^2 \tfrac{1}{2}\theta}}$$

$$= 4\pi a k \int_0^{\frac{\pi}{2}} \frac{(1 - 2\sin^2 \tfrac{1}{2}\varphi)\,d\,.\,\frac{\varphi}{2}}{\sqrt{1 - k^2 \sin^2 \frac{\varphi}{2}}}$$

If $$\theta + \varphi = \pi\,.$$

$$= 4\pi a k \int_0^{\frac{\pi}{2}} \frac{\left\{1 + \frac{2}{k^2}\left(1 - k^2 \sin^2 \frac{\varphi}{2} - 1\right)\right\} d\frac{\phi}{2}}{\sqrt{1 - k^2 \sin^2 \frac{\varphi}{2}}}$$

$$4\pi a k \left[\int_0^{\frac{\pi}{2}} \frac{d\,.\,\frac{\varphi}{2}}{\sqrt{1 - k^2 \sin^2 \frac{\varphi}{2}}} - \frac{2}{k^2}\int_0^{\frac{\pi}{2}} \frac{d\,.\,\frac{\varphi}{2}}{\sqrt{1 - k^2 \sin^2 \frac{\varphi}{2}}} + \frac{2}{k}\int_0^{\frac{\pi}{2}} \sqrt{1 - k^2 \sin^2 \frac{\phi}{2}}\,.\,\frac{da}{2}\right]$$

$$= 4\pi a k \left\{ Fk - \frac{2}{k^2} F + \frac{2}{k^2} E \right\}$$

$$= 4\pi a \left\{ \left(k - \frac{2}{k}\right) F + \frac{2}{k} E \right\}.$$

When F and E are the first and second complete elliptic integrals to modulus k.

To obtain the repulsion we must differentiate M with respect to x. This gives

$$\text{since} \quad \frac{dk}{dx} = -\frac{k^3x}{4a^2}$$

$$\text{and} \quad \frac{dF}{dk} = \frac{1}{k(1-k^2)}\left\{E-(1-k^2)F\right\}$$

$$\text{and} \quad \frac{dE}{dk} = \frac{1}{k}(E-F)$$

$$\frac{dM}{dx} = \frac{\pi}{a}\cdot\frac{kx}{1-k^2}\left\{(2-k^2)E-(2-2k^2)F\right\}.$$

By substituting $\sin^2\gamma$ for k^2 this becomes

$$\frac{dM}{dx} = 2\pi\cos\gamma\left\{(1+\sec^2\gamma)E-2F\right\}.$$

One of the instruments exhibited has two pairs of coils. In it

$$a = 10 \text{ centimetres.}$$
$$x = 1{\cdot}048 \quad \text{,,}$$

$$\therefore k = \sin\gamma = \sin 87^\circ.$$

$$E = 1{\cdot}005258587$$
$$F = 4{\cdot}338653976$$
$$\cos\gamma = {\cdot}0523360$$
$$\sec\gamma = 19{\cdot}107323$$

$$\text{let } 2\frac{dM}{dx}\cdot\frac{1}{g} = G$$

$$\therefore \log G = \bar{1}.3818437 \quad \therefore G = {\cdot}24090.$$

The other instrument has only one pair of coils. In it

$$a = 15{\cdot}3008812$$
$$x = 1.$$

The value of G is calculated in the same way.

3. On the Pelvic Girdle of Birds and Reptiles. By Professor D'Arcy Thomson.

4. On Sulphines. By Orme Masson, D.Sc.

5. On the Nature of the Relationship of Urea-Formation of Bile Secretion. By D. Noël-Paton, M.B., C.M.*

6. Note on the Collisions of Elastic Spheres. By Professor Tait.

(*Abstract.*)

In my paper of January 18th (*anté*, p 537) I had assumed all directions of the line of centres at impact to be equally probable. The introduction of the true condition affects the average value of

$$u^2 - uv$$

by a numerical factor only; so that the proof of Maxwell's Theorem remains valid. The expressions for the separate average values of u^2 and of uv, however, are altered more profoundly.

PRIVATE BUSINESS.

Sir William Thomson gave notice of the following Motion, to be considered as part of the Private Business on the evening of 19th April:—"That henceforth the Meetings of the Royal Society be held in the Afternoon instead of at 8 P.M."

Mr John Murray gave notice of an Amendment to the Motion of Sir William Thomson, in the terms, "That the First Meeting in each Month take place at 4 P.M."

* This paper appears in full in the *Journal of Anatomy and Physiology*, vol. xx. p. 520, 1886.

PROCEEDINGS

OF THE

ROYAL SOCIETY OF EDINBURGH.

VOL. XIII. 1885-86. No. 122.

Monday, 5th April 1886.

ROBERT GRAY, Esq., Vice-President, in the Chair.

The following Communications were read:—

1. Obituary Notices of—

(*a*) MORRISON WATSON, M.D., F.R.C.P. By Professor A. YOUNG.

(*b*) Rev. F. REDFORD, M.A. By H. BARNES, M.D.

2. The names of the following were proposed for election as Honorary Fellows in terms of the Laws:—

The Right Hon. Lord RAYLEIGH, M.A., Sec. F.R.S.
M. ALPHONSE MILNE-EDWARDS, Paris.
M. L'ABBÉ RENARD, Brussels.
Professor H. A. NEWTON, Yale College, U.S.
Professor H. A. THALÈN, Upsala.

3. On some Variations in the Structure of Wool and other Allied Fibres. By F. H. Bowman, D.Sc., F.R.S.E., F.L.S., F.C.S., &c. (Plate XXIV.)

The structure of all animal hairs is very complicated, and presents many difficulties, both to the scientific observer and to those who require to manipulate these fibres in the various processes of textile and other manufactures.

As appendages of the skin they are liable, like all the epidermal growths, to great variation in structure, which is seen in its extreme form in the feathers of birds, and in the horns, hoofs, nails, and claws of the higher mammals.

Apart however from these great variations, there are a number of smaller modifications, which, while they do not present the same structural interest, are of considerable value, as indicating differences in the breed of varieties of the same species, and are often of great industrial importance.

Many of these smaller variations having come prominently under my notice, especially in the case of wool, in a series of researches extending over many years, in regard to the industrial classification and use of these fibres, I thought it might be of interest to the Fellows of the Royal Society, if I communicated a short record of the more important variations which I have noticed.

Notwithstanding the many researches which have been made in this country, and especially in Germany, on the structure of animal fibres, they have hitherto been mainly directed to the variation existing between fibres and hairs in *general* rather than in particular; that is to say, to the variation in structure occurring between the hairs and wools of different species of animals, rather than those differences which are found to obtain between hairs on animals of the same species and on the same individual.

It is to these specific differences in the individual hairs and wool fibres of sheep and other allied animals that I wish to call your attention.

The observations have for the most part been made on the fibres of wool which have a commercial value, and were undertaken originally for technical purposes, but they have also a special scientific significance, as indicating the constant tendency in nature to a reversion to a more primitive type, and in exhibiting that wide variation which is produced by environment and artificial selection in breeding.

The difference in structure existing between wool and hair is one which is exceedingly difficult to define scientifically, and although in industrial practice amongst experts the distinction is well known, it depends upon such slight modifications that it is very difficult to determine where the characteristics of true hair cease, and those of wool commence, and *vice versâ*.

The difference between wool and hair is rather one of *degree* than of *kind*, and all the wool-bearing animals have the tendency when their cultivation is neglected to produce hair rather than wool, in the same way that cultivated cotton when neglected reverts to the original type of wild cotton, and the fibres lose their spiral character, which is of such value in the process of spinning. This tendency also always manifests itself whenever the conditions of soil and climate are unfavourable to the fullest development of the animal, and many sheep and other allied animals therefore produce both wool and hair; the fine hair in many animals being very like wool, and the coarse wool in others closely resembling hair.

The true difference does not consist, as is generally supposed, in the fact, that wool possesses a waved or curled structure in the fibre which is absent in the case of many hairs, but in the method of attachment of the epidermal scales which form the external covering of the fibre.

The curled locks of the negro consist of true hair and not wool, and there are many cases in the lower animals where the structure of the fibre is that of a true wool, while the straightness and want of curl usually associated with the hair is still retained.

The general structural peculiarities which distinguish them from other epidermal growths, are however the same both in wool and hair, and the method of generation is the same in both cases, so that a description of the one will also serve for the other, with such variation as will be pointed out later on.

Hairs are true appendages of the skin, being outgrowths of the epidermis. When attached to the animal each hair is implanted in a cutaneous depression, which is an involution of the skin, forming the hair follicle. In structure the walls of this follicle consist of layers, derived from the epidermis and from the cutis vera. The hair is fixed into this follicle and attached to the bottom by a dilation called the knob or bulb of the hair which encloses the papilla, or pulp, and is in living connection with the fibrous sheath of the follicle. The papilla or pulp belongs to the follicle rather than the hair, and corresponds to a papilla of the skin. It is rounded or oval in shape, consisting of distinctly fibrous areolar tissue, with nuclei and fat granules, but without any cellular structure, and is attached to the fibrous coat of the base of the follicle by a cylindrical portion or stalk.

That part of the hair which is contained within the follicle, and thus imbedded in the skin, forms the root of the hair. The hair decreases in diameter towards the mouth of the follicle. The free portion of the hair, or that which projects beyond the mouth of the follicle and outside the skin, is termed the shaft or stem, and forms the true hair. The shaft is usually round or oval, in section becoming smaller in diameter towards the unattached extremity, where it terminates when uncut in a point of more or less fineness.

Occasionally there are two or more points. The hairs vary very much both in length and diameter in different parts of the body both of man and the lower animals. The whole surface of the hair is covered over with a cuticle or coating of fine imbricated scales, the free margins of which are always towards the point of the hair, and these upwardly projecting edges give rise to a series of waved or serrated transverse lines, which can be distinctly seen under the microscope, especially after reagents have been used. The form of these scales is very diverse, and the distinctions very marked between different classes of animals and even between those of the same class. Within this scaly covering is a fibrous substance termed the cortical portion of the hair, and which in many hairs forms nearly the whole of the stem, but which in others is replaced, so far as the central portion of the hair is concerned, by a substance of a more distinctly cellular structure which forms a medulla or pith. Upon the cortical portion of the hair, its firmness, strength, and elasticity depends. In coloured hairs the cortex presents numerous longitudinal striæ or interrupted dark lines and dots, but in colourless hairs these are not easily detected, and are only visible as areas of unequal transparency. This portion of the hair when broken up by the use of suitable reagents, reveals elongated spindle-shaped cells with uneven surfaces, and a flattened and irregular angular section, often curved from their mutual pressure resulting from aggregation within the shaft of the hair. These ultimate cells vary in every dimension very much in every kind of hair, and often present distinct nuclei and irregular cavities which are filled with air. The medulla or pith when it exists in any hair, is also formed of clusters of cells; but in place of being spindle-shaped like those in the cortex, they are usually more rounded in form, although frequently angular in shape, and relatively of a larger size than the cells forming the cortical substance. The medulla always occupies the centre of the shaft, but the diameter of this portion relative to that of the hair varies very much in different hairs. The medulla seldom exists continuously throughout the whole length of the hair, being unusually absent at the point and interrupted at parts for a greater or less extent. In the latter case, the axis of the stem at the interruptions may be fibrous, like the surrounding cortical part, or these intervals may be occupied by a granular or a clear colourless matter. In some cases the medulla presents the appearance of a canal running along the axis, and filled with a more or less transparent homogeneous substance or a coloured or white opaque granular matter. In both cases there are frequently considerable air cavities.

Variations in the structure of the hair may occur in any of the parts of which it is composed, and those who know how very wide this variation is in the different hairs found in the animal kingdom, will not be surprised at its extensive occurrence within the narrower limits of any of the species.

The hair or wool of the sheep (*Ovis aries*) has a distinct individuality of its own, when in its highest state of development, but the the tendency to run into varieties, which is so marked in this class of animals, is also true of the fibrous covering. Purity of breed and cultivation tend to check variation in every direction, and the greatest uniformity in the likeness of individual fibres is always found in the most cultivated sheep, such as the merinos (*Ovis Hispaniam*), where the departure from the structure of true hair, as distinguished from true wool, is most marked. A classification of wool may indeed be based upon the variation from the structure of hair, which will embrace all the varieties of wool which are found either in wild or domestic sheep. To understand this classification, we must notice the difference in structure between the widest extremes of hair and wool.

In hair the scales of its cuticle are firmly attached to the cortical substance throughout the greater part of their length, and only reveal themselves when examined under the microscope as fine irregular transverse and anastomosing lines on the surface and by a slight denticulation at the edge of the hair when viewed by transmitted light. A typical illustration of this surface structure may be seen in Plate XXIV. fig. 1, which represents the appearance of a coarse hair taken from the fleece of a Cheviot sheep.

Along with this external structure there is, in true hair, usually associated an internal arrangement of the cells composing the cortical substance in which there is a tolerably distinct medullary axis with large and well-formed nucleated cells. Such a structure is represented in Plate XXIV. fig. 2, which is a longitudinal section of the same hair given in fig. 1.

Sometimes, however, the medullary axis has a different structure even where the external likeness is very similar. This structure is is seen in Plate XXIV. fig. 3, and was drawn from a section of a coarse hair taken from the fleece of a Pacpathian sheep. In this fibre the cells are much smaller and more numerous, and in some parts having a distinct granular pigmented appearance and non-nucleated.

In most cases the cells composing the cortical substance of hair are distinctly nucleated, but they vary very much in this respect. The shaft of the hair is usually firm and straight, and the epidermal scales are horny and dense.

In wool the epidermal scales are attached to the cortical substance much less firmly than in the case of hair, and their free margin is more prominent, so that the edges of the scales are much more distinctly seen and the denticulation at the edge of the fibre is more marked. The contour of the free margin of the scales is also generally less rounded than in those of the hair, and in the finest classes of wool is frequently serrated in a more or less irregular manner. The scales are also less horny and dense than those of hair, and possess a transparent or translucent appearance like wax or gelatine. A typical illustration of a wool fibre is given in Plate XXIV. fig. 4, which represents a fibre taken from a fine merino sheep. In this fibre the looseness of the attachment of the scales and the well-marked serration of their free margins are distinctly seen. The looseness of the attachment of the epidermal scales are in some classes of wool even more marked than in the merino fibre. Plate XXIV. fig. 5 represents a fibre taken from the Chinese sheep (*Morvant de la Chine*). In this fibre the scales are large and well defined, with a horny structure more approaching to that of true hair, but with such a small attachment to the stem of the fibre


Fig. 1. × 150.


2. × 150.


3. × 200.


4. × 250.


5. × 150.


6. × 150.


7. × 150.


8. × 150.


9. × 400.


10. × 400.


11. × 400.


12. × 150.


13. × 200.


14. × 200.


15. × 100.


16. × 160.


17. × 250.


18. × 250.


19. × 200.

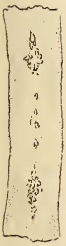

20. × 500.


21. × 250.


22. × 250.


23. × 250.


24. × 250.


25. × 150


26. × 300.


27. × 300.


28. × 300.


29. × 300.


30. × 300.

McFarlane & Erskine, Lithrs, Edinr.

that they assume a form resembling a series of cups or crowns inserted one within the other. Each scale is continuous round the whole circumference of the fibre.

The internal structure of the wool fibre is usually much less easily distinguished than in the case of hair, because the cells forming the cortical substance are much smaller and more transparent. They seldom exhibit any traces of neuclei, and it is only in special fibres that any medullary axis is visible, and in most cases where this is revealed there are external indications of reversion to the character of hair. Plate XXIV. fig. 6 represents the longitudinal section of a coarse fibre of Lincoln wool, which may be compared with the similar section of Cheviot hair given in fig. 2, when the distinction will be easily seen. In the Lincoln wool the medullary cells are larger, but less distinctly marked, and they exhibit hardly any trace of neuclei.

In examining the variations from this typical structure of wool, we cannot do better than commence with the surface configuration of this fibre of Lincoln wool, the section of which is given in Plate XXIV. fig. 6, and the external appearance in fig. 7. The scales are large and distinct, with well-defined and denticulated margins, and standing out from the general surface of the fibre, so as to present a strongly serrated edge when seen against a dark background.

This fibre was taken from the coarsest part of the fleece, on the flanks of the sheep, and treated with caustic alkali after washing with a mixture of alcohol and water. Even when a fibre was drawn from the shoulder of this sheep, where the best wool is always found, the same characteristics were exhibited, although in a less marked degree, but there was no trace of any medulla. This fibre from the shoulder is figured in Plate XXIV. fig. 8, so that the relative fineness in diameter of the two fibres can readily be determined.

These fibres may be taken as representatives of those which are found on all the long-woolled breeds of English sheep, such as those of Leicester, Yorkshire, and Nottingham. They are all distinguished for the brightness and high lustre of the cuticular scales, which are always large and distinct.

Closely allied to these bright-haired wools are the fibres derived from the alpaca goat (*Auchenia Paco*) and the Angora goat (*Capra Angora*), which is known commercially as mohair. The fibre from the alpaca goat is very closely allied to true hair, and exhibits many of its characteristics. It is most like hair in its external structure, while it resembles wool in the arrangement of its cortical cells. Mohair, although usually called hair, is far more like wool than alpaca, but it never possesses the same curl and suppleness in the fibre which is exhibited by true wool.

When the fibres of alpaca are examined under the microscope their close relationship to true hair is easily seen, and this relationship extends to the internal as well as the external structure. Many of the fibres show a distinct medullary axis with large nucleated cells, which frequently contain large quantities of pigment. In some cases, where this is not distinctly manifested, there is an enlargement of the cells in the central axis, although they do not differ in any other respect from the remainder of the cortical part. Plate XXIV. fig. 9 is taken from a coarse fibre of Chala alpaca. The epidermal scales are well marked with rounded edges, and, like all alpaca fibres, possess a very high lustre. Some of the fibres, when perfectly clean and seen by reflected light, have the appearance of burnished silver. Plate XXIV. fig. 10 gives the same fibre when viewed with transmitted light, in which the large medullary cells are distinctly seen, while the cortical part has a fine granular appearance, without any cellular structure being visible.

The fibres from the Angora goat have a close resemblance to those of alpaca, but there is always in them a greater looseness of the cuticular scales; and while they retain the high surface lustre, there is a greater tendency to the dispersion of light when seen with reflected light. The scales are also more transparent, and of a less horny nature. The distinguishing feature, however, is that the free margins of the scales are not so smooth and rounded at the edges, but show signs of the same denticulation which is so prominent a feature in true wool; so much so that many of the fibres in the better qualities of mohair can only with difficulty be distinguished from the bright-haired English wools, such as Lincoln or Leicester, except that the scales are rather smaller and more regular, and that there is less tendency to curl. Plate XXIV. fig. 11 is taken from a fibre of mohair, and may be compared with the alpaca fibre given in fig. 9, and the finer fibre of Lincoln wool given in fig. 8, when the distinction already noticed will be easily seen.

Closely allied to alpaca and mohair in their structure are the wools which are derived from all the semi-wild sheep of the mountainous regions of Central Asia and the plains of Tartary and Siberia, but the fleeces of these sheep are generally more defaced by the prevalence of long coarse hairs than is the case with alpaca or mohair. In some of these wools, such as grey Vicaneer, dark Bagdad, and yellow Pacpathian, we have several distinct classes of fibres side by side in the same fleece. The fleeces of these sheep indeed exhibit a greater variation in the structure of individual fibres than any others which have come under observation. These fibres may in the same fleece, and often in the same lock of wool, be roughly divided into three different classes—

(*a*) Those which have all the characteristics of true hair in their most marked degree.
(*b*) Those which resemble alpaca and mohair fibres.
(*c*) Those which are true wool.

In the first of these divisions (*a*) there are several distinct variations in the form of the hair structure. We have already seen in Plate XXIV. fig. 3, the internal structure of one of these fibres taken from a Pacpathian sheep, and its resemblance to a hair. The external appearance of many of these fibres is remarkable for the very great regularity in the arrangement of the external scales, and by their pointed extremities, which gives them almost the appearance of the stem of a palm tree. Plate XXIV. fig. 12 gives an illustration of one of these fibres, which was taken from a lock of Bagdad wool. Occasionally this great regularity in the epidermal scales is found in the hairs of more cultivated sheep, as may be noticed in Plate XXIV. fig. 13, which is sketched from the surface of a coarse hair taken from the fleece of a Cheviot sheep. Sometimes the construction of the cuticular layer of these coarse hairs tends to the production of larger scales than those which are usually found on other associated fibres. These scales present an appearance as though the larger scales had been formed within the follicle by the coalescence of several smaller scales into one, and it is specially noticed that in cases where this occurs there is a tendency in the free edge or margin of the large scale to follow the same contour as the smaller ones. Sometimes there are slight surface markings or depressions on the larger scales, which seem to indicate the margins of the smaller ones out of which they were formed.' The union is, however, so complete that it is impossible, except in a very few instances, to separate the larger into the smaller scales, even by the use of reagents. Plate XXIV. fig. 14 is sketched from a coarse hair of Pacpathian wool, in which the surface markings of many of the large scales show the configuration of the smaller scales out of which they were formed.

Occasionally the whole epidermal tissue of these coarse hairs assumes an entirely different appearance, in which the usual scaly structure is replaced by a series of interrupted longitudinal channels, which give the fibre the appearance of a vegetable rather than an animal structure. One of these fibres, taken from a lock of Jora wool, is given in Plate XXIV. fig. 15, in which the cuticular envelope resembles a fluted column, and where any transverse lines are present to mark the free margins of the scales, they not inaptly supply the semblance of joints in the masonry. In all cases where this peculiar structure is visible in the cuticular layer, there is associated along with it an equally distinctive cortical and medullary formation. The cortex exhibits a coarse texture of spindle-shaped cells with longitudinal striæ, while the medulla is composed of large and distinct rounded cells with well-marked nuclei. The whole arrangement is indicative of a loose formation, with considerable air spaces existing both in the medulla and cortex. Plate XXIV. fig. 16 represents the internal structure of the fibre, whose external surface is given in fig. 15. Probably this extreme variation from the normal type may have arisen from the shrinking up of the loosely-packed cells in the cortical part, which by their attachment to the epidermal layer, which seems to be thinner than is usual in hairs of this diameter, have drawn them inwards, and thus formed corrugations at the intervals between successive bundles of the elongated cells.

The second class of fibres (*b*) have a very close resemblance to those of alpaca and mohair, but they are usually softer and more pliant, with less lustre and a greater tendency to variation in the formation of individual scales in the cuticular layer. One of these fibres, taken from a lock of Pacpathian wool, is given in Plate XXIV. fig. 17, and cannot be distinguished from a fibre of alpaca, such as that given in Plate XXIV. fig. 9, except by its association with other fibres which never occur in the fleece of the alpaca goat. Other fibres, however, approach very closely to the appearance of true wool, but with a greater variation in the regularity of the individual scales than is usual in the more cultivated sheep. Plate XXIV. fig. 18 is an illustration of one of these fibres, taken also from a Pacpathian fleece, which may be compared with the merino fibre given in Plate XXIV. fig. 4. Amongst these fibres we also notice the first indication of a surface formation, which is a very common variation from the typical form in the more cultivated wools. This consists in a tendency to form rings of scales, in which we have the single scale continuous round the whole circumference of the fibre, similar to those characteristic of Chinese wool given in Plate XXIV. fig. 5, except that the free margin of the scales are not so marked or the scales so solid and horny, while the attachment of the epidermal scales to the cortical part is more continuous. Such a fibre is given in Plate XXIV. fig. 19, taken from a Pacpathian fleece.

The third class of fibres (*c*) are those of true wool, and possess all its highest characteristics. They are always much shorter than the others, and form an undergrowth of fine fibres which fill in the spaces between the coarser hairs, and in many cases are as fine and delicate in structure, with as great a tendency to curl, as the most beautiful fibres taken from the fleeces of the most cultivated sheep.

Plate XXIV. fig. 20 is taken from a fibre drawn from the fleece of an Afghan sheep (*Ovis cagia*). The specimen of wool from this sheep was a most extraordinary mixture of the very coarsest hair and fibre with the very finest wool, so much so that it almost seemed impossible that such diverse fibres could grow at any rate on the same portion of the skin. Most of the coarse hairs resembled fig. 12 and fig. 15, were deeply coloured by dark black, brown, and yellow pigment, and possessed a hard horny structure. The fine fibres were perfectly colourless and transparent, and closely resembled the wool of the English Southdown or the Australian merino. Except that there was a larger variation in the structure of the scales in many of the individual fibres than is usually noticed in the most cultivated wools, they could not be distinguished from them. When we come to look at the wool of the more cultivated races of sheep, such as the common domestic sheep (*Ovis rusticus*), we find much less variation in the individual fibres than is usual in the less cultivated races, but the difference in structure between one fibre and another is nevertheless frequently very marked.

If we examine a number of fibres from a Lincoln sheep, there is in the finer fibres a close resemblance to those which are found in all the long-woolled breed, but along with these there are fibres which are distinctive of the Lincoln breed alone. In the latter there occur more or less rounded scales along with the usual serrated ones, as though there was a tendency to revert to the more distinct form of scales which we have seen on some of the coarser hairs, such as given in Plate XXIV. fig. 13, from a Cheviot sheep, or the alpaca fibre given in Plate XXIV. fig. 9. A fibre of Lincoln wool, drawn from the fleece of a Lincoln wether, which exhibits this peculiar formation is given in Plate XXIV. fig. 21. Many parts of this fibre bear a distinct resemblance to the Lincoln fibre already given in Plate XXIV. fig. 7, except that the scales are not so distinctly marked nor so freely imbricated at the margins, and at irregular intervals this imbrication entirely ceases, and we have smooth rounded edges taking their place. When looking at the second class of fibres found in the coarse Asiatic wools, we noticed a formation represented in Plate XXIV. fig. 19, where the scales lose their foliated characted and tend to form continuous rings. This peculiarity in the formation and attachment of the cuticular scales is also frequently found amongst the fibres of the more cultivated wools.

It is indeed of very frequent occurrence in most of the long-woolled breeds, such as the Lincoln, and may be seen in Plate XXIV. fig. 22, which represents the appearance of a fine fibre, taken from a fine Lincoln wether fleece. Where this formation obtains, the scales are always more horny in their substance than those of the fibres possessing the normal structure which are associated with them. In many cases these fibres are associated in clusters in the lock of wool, as though a special area of the skin possessed the power of producing them, but they are also frequently found separately, and sometimes only parts, even of the same fibre, exhibit this peculiarity. They are also usually confined to certain parts of the animal, and occur specially at those parts where the wool tails off into short hair, as at the junction of wool and hair on the face and limbs.

In Plate XXIV. fig. 23 we have a fibre which displays both the characteristic scales of the true wool and the larger and more ring-like formations. This was sketched from a fibre taken from a Leicester sheep. In this fibre it will be noticed that one of the ring-like scales is of great length when compared with the diameter of the fibre, or the relative length of the other scales above and below. When this fibre was examined with transmitted light, so as to render its internal structure visible, a peculiarity was noticed which is of very great importance from an industrial or technical point of view. At that part of the fibre where the surface was covered by the large smooth scale, the internal structure exhibits no sign of any definite cells, either in the medullary or cortical parts. Up to the extremity of the imbricated and wool-like scales, indications of cell structure are visible, both in the cortical and medullary parts, but beyond that point they cease to exist in either, and the whole fibre assumes an ivory-like density. This change in structure does not occur all at once, but seems to commence in the central part of the fibre, and gradually to extend outwards until it constitutes the formation of the whole fibre. This will be seen in Plate XXIV. fig. 24, which exhibits a section of the same fibre as Plate XXIV. fig. 23. Beyond the point to which the ring-like scale extends, this solid structure again tails off, and the fibre assumes its usual appearance. This peculiarity is not of very great importance when the area over which it extends is small, but when it becomes the general characteristic of the fibre it introduces serious difficulties in the way of the manufacturer, because the solid portion of the fibre ceases to be elastic and pliable, and easily breaks when subjected to flexure. In addition to this all these fibres resist, or are incapable of that felting action which is so important a feature in the true wool, and which depends upon the facility with which the scales of the one fibre interlock into those of others when in juxtaposition. These solid fibres also resist the entrance of all dyeing or colouring matter into their interior, and will only receive a surface colouring, which is readily removed by either chemical or mechanical means. In some cases the outer continuity of the scales is not accompanied by a change of internal structure, and when examined by transmitted light the cortical and even medullary cells are distinctly visible. Such fibres are usually known as flat kemps, because they generally possess an oval section in which the major axis is very large in comparison to the minor axis. In this case the fibres will receive the dye, but they will not felt.

Kempy fibres are always most numerous in the fleeces of wild and uncultivated sheep, but they also occur in those of the most cultivated races. In the former case they are generally distributed throughout the whole of the fleece, but in the latter they are usually confined to certain localities as already mentioned, and are almost certain indications of want of trueness in the breed of the sheep. These kempy fibres are in most cases larger in diameter and shorter in length than the wool fibres with which they are associated. Plate XXIV. fig. 25, represents a section of a coarse kemp taken from a Highland sheep.

In the fibres taken from the fleeces of middle-classed wools, such as the Southdown and half-bred sheep, we have considerable uniformity in the general structure of the fibres and the surface configuration of the scales, but with frequent indications in many of the fibres of a return or reversion to the typical structure of the fibres of the original stocks out of which these artificial races have been produced. Plate XXIV. figs. 26 and 27 are illustrations of two fibres taken from the same lock of wool drawn from a Leicester-Botany fleece. The first exhibits all the characteristic features of the fibres found in a pure Leicester sheep, and the latter closely resembles the pure Australian merino fibres. These two fibres must, from their position in the lock of wool from which they were taken, have been generated within follicles which were imbedded side by side in the skin. They may be compared with Plate XXIV. figs. 4 and 8.

In the perfectly pure races of sheep, such as the best English Southdowns, or the Spanish, German, and Australian merinos, in which we find the greatest perfection of the fleece and fibre in all the most desirable characteristics of wool, and where every care and attention has been paid to the health and comfort of the sheep, we also find the least tendency to any variation in the individual fibres. Even here, however, we find differences in the structure of fibres which have grown in close continuity with each other. This difference can only be explained by considering some of the arrangements of the epidermal scales as undoubted cases of reversion to the type of fibre characteristic of the original stock from which these varieties were obtained in the remote past. Several of these more important variations are given in Plate XXIV. figs. 28, 29, and 30. These fibres are all sketched from pure Australian merino fibres. In fig. 28 the arrangement of the epidermal scales in the upper and lower part of the fibre closely resembles that exhibited in the Cheviot fibres given in Plate XXIV. fig. 13, while the central portion is covered with scales which are similar to those on the Pacpathian fibre, given in Plate XXIV. fig. 13. The fibre given in fig. 29 closely resembles Plate XXIV. fig. 22, taken from a Lincoln sheep in which the same ring-like scales appear at intervals. Fig. 30 shows a kempy development, which, however, in the finest merino wool, is very rare, with short intervals in which the true wool appears. As a rule, when kemps occur in the merinos, the whole fibre partakes of this character, and the fibres are flat ovals in section, with a clear transparent structure. In some of these kempy fibres the usual curled or waved character of the true wool is replaced by a twisting of the whole fibre round its axis, so as to give the fibre the appearance of a corkscrew, with a comparatively wide pitch, or like the twist in a fibre of cotton.

These variations from the normal structure of wool and other allied fibres might be very much increased if we include those which are evidently the result of malformations arising from the various diseases to which sheep are subject, or to the existence of more than one fibre within the same follicle, which frequently produces fibres of singular configuration; but those which have already been named and figured show the principal variations which are presented in the fibres under ordinary conditions.

It is singular that most of these variations, indeed all of them, are formed in the fibres from the same sheep in the various races which inhabit Central Asia; while in most of the sheep inhabiting other parts of the world, the usual variations from the normal types are less distinctive in their character, and confined within narrower limits. This seems to point to the mountainous regions of Central Asia as the district from which the present domestic sheep has spread over the other countries of the world. If the study of these variations will throw any light on the cause which produces them, and thus enable those who are engaged in the culture of the sheep to secure still greater uniformity in the character of the fleece, it will undoubtedly render great service to those who require to use wool for the higher branches of textile manufacture.

4. On the Comparison of the Intensity of Gravity at different Stations. By Professor Tait.

5. On the Reproductive Organs in the Genus *Eudrilus*, E.P. By Frank E. Beddard, M.A., F.Z.S., Prosector to the Zoological Society of London. (Plate XXV.)

Among the many interesting genera of earthworms described by M. Perrier, the most interesting and remarkable in many ways is *Eudrilus.* This genus is unique among earthworms, by reason of the peculiar structure of its generative organs. In all earthworms at present known, with this exception,* the ovaries are situated in a distinct segment of their own, into which opens the funnel of the oviduct, which is quite independent of the ovary; the oviducts generally pass through the mesentery which bounds posteriorly the segment (usually the 13th) containing the ovaries, and open on to the exterior of the body in the ventral surface of the following segment.

M. Perrier has described these organs in *Eudrilus* in the following words (*Nouv. Arch. d. Mus.*, t. viii., 1872, p. 74) :—"L'appareil femelle n'est pas moins étrange. Il est situé dans le quatorzième anneau et son orifice extérieure n'est pas autre chose que l'orifice porté par cet anneau en avant de la paire supérieure de soies. On voit partir de cet orifice un tube qui se recourbe plusieurs fois, en se dirigeant en arrière, se renfle finalement en une poche allongée à parois plus ou moins distendues et dont l'extrémité en cul-de-sac se dirige en avant. Greffés sur ce tube avant sa dilatation en poche on voit d'abord un tube plus petit entortillé de façons diverses, et juste en face de lui une sphère assez peu volumineuse, quelquefois deux, qui présentent alors un aspect un peu différent. Je n'ai pu examiner ce dernier corps que sur deux individus conservés dans l'alcohol, ... mais cette examen ne peut laisser aucun doute; ce sont là des ovaires dans lesquels il est encore

* *Moniligaster* appears to be somewhat abnormal in the size and position of the ovaries; but there is no fundamental difference from other Oligochæta.

Fig. 1. × 2.

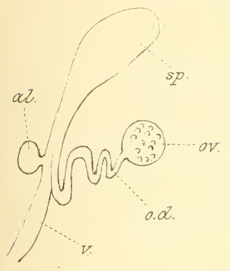


Fig. 2. × 2.

Fig. 4.

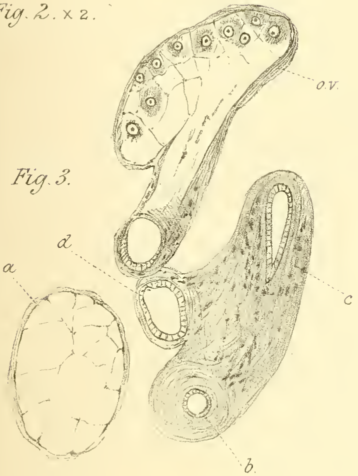


Fig. 3.

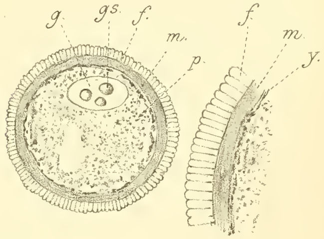


Fig. 5.

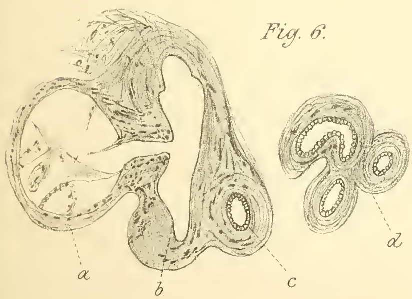


Fig. 6.

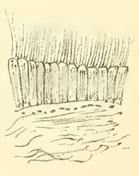


Fig. 7.

possible reconnaître des œufs avec tous leur éléments caractéristiques." I presume from this account, and from the figure (*loc. cit.*, pl. ii. fig. 26, *o*) which illustrates it, that M. Perrier means to imply that in this earthworm the ovary is not only fixed on to the spermatheca, but that it actually communicates with the exterior through its lumen; that the spermatheca, in fact, serves not merely as a receptacle for the semen, but also as an oviduct. This is not stated in so many words by Perrier, and writers of text-books have not quoted this fact in describing the female generative organs of the Annelida. I find, however, that M. Perrier's statements are in a way correct, and as the matter is one of importance, from the general point of view of the morphology of the generative organs and their ducts in Annelids, I think it worth while to enter more fully into the subject.

The opportunity to do so has been afforded by the kindness of Mr E. L. Layard, H.B.M. Consul at Noumea. Among a number of earthworms sent to me from New Caledonia, were several specimens of a species of *Eudrilus*, which appears to be not far removed from Perrier's *E. peregrinus*. As this species and one other are natives of the West Indies, while the third species is from Rio Janeiro, the genus being thus a New World genus, I am inclined to think that the New Caledonian species has been imported, and is not indigenous to that island.*

By comparing together a complete series of sections, and checking the results by help of a careful dissection under a lens, I have been able to make out the relations of the different parts of the female generative apparatus. Plate XXV. fig. 1, illustrates these organs as seen under a lens previous to any dissection; in fig. 2 the different parts are separated from each other, and are seen to consist—(1) of a thick-walled muscular vagina (*v*), which is continuous above with (2), a somewhat pear-shaped thin-walled pouch, the spermatheca; at the junction of the spermatheca with the vagina open two ducts, one on each side; (3) the long coiled oviduct *od*, terminating in (4) the ovary; on the other (5) a small rounded gland *al*, which is almost sessile upon the vagina, communicating with its lumen by a very short duct.

* Mr Layard, however, informs me that there is no direct communication between New Caledonia and South America.

The ovary is a rounded gland, somewhat flattened from above downwards; in transverse sections it has a reniform outline illustrated in figs. 3, 4; from the lower surface of the organ (fig. 3) arises the oviduct, which is at first (*d*) thin-walled with a wide lumen, and afterwards (*c*) acquires a thicker muscular coating; the oviduct is everywhere lined with a single layer of columnar epithelial cells. In the figures referred to (figs. 3, 4) it will be seen that *the oviduct is completely continuous with the ovary;* its lumen passes into the interior of that organ, and its muscular walls pass without a break into the muscular tunic of the ovary.

In fig. 4 I have sketched a highly magnified section of the ovary, in order to display its structure as fully as possible.

As already mentioned, M. Perrer has briefly described and figured the ovaries of *Eudrilus*, and has called attention to the fact that these structures cannot be interpreted in any other way, since they contain most unmistakable ova entirely like those of other Lumbricidæ.

In fig. 5 is represented an ovum with its germinal vesicle and germinal spot. The ovum is bounded externally by a very conspicuous and comparatively thick membrane, which in my preparations has been rendered more distinct by deep staining with borax carmine; the protoplasm of the ovum is uniformly granular, though occasionally I have observed cavities free from granules. The germinal vesicle is large, and distinctly limited by a membrane; it lies usually eccentrically, and is oval or more irregularly curved in form; the germinal vesicle appears to contain a fluid substance, and has usually a single, spherical, highly refracting, germinal spot; I have noted as many as three of these in some ova. In the figure which illustrates the ovum (fig. 5), the membrane which bounds it externally is represented as being homogeneous, it appears from my sections that there is only this vitelline membrane and no other. The protoplasm of the ovum forms a somewhat denser layer just beneath the membrane, which is better shown in fig. 5, A.

The mature ova were in every case surrounded by a very distinct columnar follicular epithelium, and the rest of the compartment was filled up with a mass of small rounded cells (fig. 4), some of which were larger than others, and appeared to be ova in course of development; the exact disposition of these masses of cells I am unable to give as they were much broken up, and had shrunk away from the walls.

There can, however, I should imagine, be no doubt whatever that the structures figured in figs. 3, 4, and 5 are ova, and that the body in whose cavities they were invariably found is the ovary.

The *oviduct* (fig. 2, *od*) is greatly coiled, and when stretched out is of considerable length; the distal region, that nearest to the ovary, can readily be distinguished in transverse sections by its wider lumen and thinner walls; this part is lettered *d* in fig. 3, the proximal section of the oviduct is lettered *c* in the same figure; *b* is the vagina. I have traced by means of sections the whole course of the oviduct from the aperture into the vagina up to its disappearance in the interior of the ovary, but I have not thought it worth while to figure a large series of sections in order to display the whole course of the oviduct. *The oviduct is lined by a columnar epithelium, which, at any rate in certain regions, is ciliated.* At the point where the oviduct opens into the vagina, but on the opposite side of the latter, is a small, spherical, yellowish-coloured, glandular body, which can readily be distinguished from the ovary by its yellowish colour (the ovary is white and translucent) and smaller size; an examination of its minute structure showed also that this body is not a second ovary, for it contained no traces of ova. The interior is divided up, however, like the ovary into numerous compartments by trabeculæ, and the walls of these compartments are everywhere lined by an epithelium. It appears to be a glandular organ, and it communicates (fig. 5) by a short, narrow duct with the vagina. This structure is possibly analogous to an albuminiparous gland. I could observe no traces of spermatozoa either in this glandular diverticulum or in the spermatheca, but it appears to be exceedingly probable, from the structure of these parts, that the ova are fertilised in the duct of the spermatheca which I have termed the vagina (fig. 2, *v*).

At the commencement of this paper I have given M. Perrier credit for having been the first to recognise the fact that the ovary opens into the duct of the spermatheca, and that its contents reach the exterior by this duct. M. Perrier's circumstantial account and the figure which he gives seems to favour such an interpretation; I find that Mr Benham, in a recently published memoir on earthworms, has arrived at a similar conclusion as to M. Perrier's results.* The facts, however, which I have detailed above seem to me to indicate that M. Perrier did not really absolutely prove any such connection between the ovary and the spermathecal duct; at the same time, I make these remarks with considerable hesitation, having had in the course of my own investigations into the structure of this group abundant evidence of the accuracy of M. Perrier's drawings and description. The species of *Eudrilus* which I have myself studied does not appear to me to differ markedly, either in external characters or in anatomical structures, from *Eudrilus peregrinus;* and I have already expressed doubts as to whether, for this reason, the species can be really indigenous to New Caledonia, whence it was sent to me. Whether or not the species is identical with *Eudrilus peregrinus*, there is little reason to suppose that the female generative organs would show any such differences in individuals, or closely allied forms, as would appear to be the case from a comparison of Perrier's with my own description; and I should mention that the facts brought forward in the present paper depend upon the examination of four ovaries and their ducts, two of which have been studied by simple dissection, and two by continuous series of transverse sections; these latter are complete series, not a single section having been lost, and I have naturally retained them for reference. M. Perrier distinctly speaks of the ovary in *Eudrilus peregrinus* as being sessile upon the spermatheca; in *E. Lacazii* there is a small spherical body in the same position, as also in *E. decipiens;* in neither of these latter species, however, does M. Perrier appear to have made out ova in the supposed ovaries, which may therefore be presumed with equal reason to represent the accessory glandular body of *E. peregrinus.* The figure illustrating the female generative apparatus is from *E. decipiens;* the most careful examination of my sections has revealed no structure which can possibly correspond to the diverticulum (petit tube entortillè) of the spermatheca, except the oviduct; nevertheless, the ovary appears, on a superficial view, to be sessile upon the duct of the spermatheca. This appearance may have misled M. Perrier, although the figure cited from his work appears to indicate that he made a dissection, and did not merely figure the various structures as they appear

* *Quart. Jour. Micr. Sci.*, 1886, p, 262.

when the body of the worm is opened. I am bound to conclude, therefore, that M. Perrier's remarks on the structure of the female generative apparatus in *Eudrilus* represent a lucky guess partly expressing the truth; in this case I may claim for myself the discovery of the true relations of the ovary to the oviduct in *Eudrilus*.

Another fact, which shows plainly that the structure which I have described as an oviduct is really so, and not a diverticulum of the spermatheca, is its ciliation; I cannot state positively that the oviduct is ciliated throughout, but in its distal portion nearest to the ovary the cilia were here and there extremely conspicuous; a few of these cells are drawn on fig. 7 of the Plate. I am not acquainted with any earthworm in which either the spermatheca or its diverticula are ciliated; and, indeed, the presence of cilia would be useless in a pouch which serves for the storage of the spermatozoa.

In fig. 76 of plate iv. of his memoir, M. Perrier has figured a portion of the ovary of *Eudrilus*. The figure illustrates the trabeculæ of muscular or connective tissue which bound the several compartments of which the organ is composed; the ova are represented as being surrounded by a granular mass, which entirely fills up the space separating the ovum or ova from the trabeculæ; this, as I have already stated, is not a homogeneous mass, but is evidently composed of small closely packed cells, some of which are young ova, while others form a definite single layered follicular epithelium immediately surrounding the ovum.

The female genital apparatus of *Eudrilus* differs, therefore, from that of other Oligochæta,—

(1) In the connection of the oviduct with the spermatheca;

(2) In the continuity of the ovary and its duct;

(3) In the complicated structure of the ovaries; and,

(4) In the presence of a definite columnar follicular epithelium surrounding the mature ovum.

A discussion of these several points naturally follows:—

(1) The connection of the oviduct with the spermatheca is a novelty in the group; but, at the same time, it must be remembered that the structure which I have identified with the spermatheca, following Perrier, may not really be the morphological equivalent of the spermatheca of *Lumbricus* or *Perichæta*. The position of

these organs behind the testes are against such an identification; at the same time, in *Microchæta*, Mr Benham* and myself † have described a number of small pouches, which may correspond to the spermatheca, and are in a similar position as far as the testes are concerned. Furthermore, the position of the conjoined oviduct and spermathecal apertures by the outer pair of setæ, while the male genital pores are placed on a level with the lowermost pair of setæ, suggests a practical difficulty in assigning to these pouches the function of seminal reservoirs. I have not succeeded in finding any trace of spermatozoa within the supposed spermatheca; but this failure does not count for much, considering the condition of the specimens. In my opinion, the nature of these so-called spermatheca must be left undecided for the present; they appear to be possibly new structures developed on the oviduct, but probably serve as spermathecæ.

(2) The absolute continuity between the ovary and its duct is not merely new to the *Oligochæta terricola*, but to the whole of the Chætopoda. In this group the generative ducts are more generally regarded ‡ as the slightly metamorphosed equivalent of nephridia; and, without insisting upon their homology with nephridia, it is at any rate clear that they are quite independent of the generative glands, both as regards origin and adult structure; in other groups of the invertebrata there is some dispute as to the nature of the genital ducts. Lang § speaks of the sexual products in the Platyhelminthes and Hirudineæ being carried off by special ducts, which are prolongations of the genital ducts themselves. Balfour || considers this view doubtful in the case of the Hirudineæ and Platyhelminthes, but is in favour of regarding the genital ducts of the Nematodes as being of this kind. In all these instances, as well as in the Crustacea and in some Mollusca (and, according to the Hertwigs,¶ in Bryozoa and Rotifera), the genital products are carried out of the body by ducts which, whether they are or are not modi-

* *Quart. Jour. Micr. Sci.*, March 1886.

† *Trans. Zool. Soc.*, vol. xii. part 3.

‡ Balfour, *Comparative Embryology*, vol. ii. p. 618; Gegenbaur, *Elements of Comparative Anatomy*§; Huxley, *Anatomy of Invertebrated Animals;* Lankester, *Ency. Brit.*, art. "Mollusca."

§ *Arch. d. Biol.*, vol. ii. (1881), p. 551.

|| *Comp. Embry.*, vol. ii. p. 619.

¶ *Cœlomtheorie*, p. 26 *et passim.*

fied nephridia, have at any rate acquired a close secondary connection with the generative glands; the anatomical difference between the generative ducts in the Leeches and Platyhelminthes on the one hand, and the Oligochæta on the other, is a fact worthy of note, even if it does not express a profound morphological difference. In *Eudrilus* the materials at my disposal do not enable me to make any statements respecting the morphology of the oviducts; but their continuity with the ovary, whether merely secondary or fundamental, is an important fact in their anatomy, and is comparable to the structure of the oviduct in *Hirudo** or in the *Platyhelminthes.* Indeed, the whole arrangement of the female generative apparatus, with the stout muscular vagina, the spermathecal pouch, and the accessory gland opening into the vagina, is by no means unlike the conditions met with in certain Gastropoda. Without wishing to push this latter comparison too far, I may insist upon the undoubted resemblance to the Hirudinea and Platyhelminthes, particularly to the former group.

The tendency of recent research has been rather against regarding the Hirudinea as Annelida, and their numerous points of affinity with the Platyhelminthes have been pointed out by Lang, Bourne, and others; it is, therefore, important to observe that, as far as the female generative organs are concerned, there is a decided resemblance between *Eudrilus* and *Hirudo*, and this fact keeps to bridge over the gap which separates the Leeches from the Chætopoda. It also follows that the structure of the genital glands and their ducts is not constant in the Oligochæta, as it is generally believed to be; and on this account it is not permissible to lay too great stress upon the relations between the genital glands and their ducts in classification (as also in the case of the Ganoid and Teleostean fish).

In every respect, with the exception of the ovaries and their ducts, *Eudrilus* conforms very closely to the structure of other earthworms; and in view of these striking resemblances of structure, the condition of the ovaries and oviducts can hardly be regarded as being of such importance as to separate *Eudrilus* from other Oligochæta. In *Lumbricus* the ovary terminates in a slender process, which was

* It has been recently shown by Nussbaum (*Zool. Anz.*, Bd. viii. p. 184) that the oviducts of the Leech are primitively independent of the ovary, and only later acquire a connection with it.

first described by d'Udekem,* the discoverer of these organs; this structure, which is a prolongation of the delicate cellular covering of the ovary, was erroneously regarded by d'Udekem as the oviduct; it may possibly represent morphologically the oviduct in *Eudrilus*, and be the last remnant of an oviduct continuous with the ovary, such as exists (?) in the unsegmented worms from which the Annelida must have originated.

(3) The minute structure of the ovary in *Eudrilus* is evidently different from that of other Oligochæta; in *Lumbricus* † these glands are little more than a specially thickened region of the peritoneal epithelium, enclosed in a thin capsule formed by the peripheral layer of cells. In *Eudrilus* the glands show a very considerable advance in structure; the details given above, although unfortunately very imperfect, seem to indicate that the ovaries may have originated, not from the epithelium lining the general body cavity, but that they may more nearly resemble the ovaries of the Platyhelminthes and Leeches, which belong to the "tubular" type. This question can, of course, only be settled by a study of their development. In the case of the Leeches, Balfour supposes, that "if, as seems probable, the true affinities of the Leeches are with the Chætopoda, the investment of the ovaries must be of a secondary nature." Very possibly this is also the case with *Eudrilus*, but in the meantime the structural resemblance to the Leech is a fact to be noted; in both cases the ovary is enclosed in a muscular coat. It might be objected to what I have already said, that in the ovaries and oviducts of *Eudrilus* there is a similarity to the testes and vesiculæ seminales of earthworms. These organs, as we know from the researches of Hering,‡ confirmed by Bourne,§ have the following structure:—There are two pairs of minute testes about the same size as, and occupying a similar position to, the ovaries. The contents of the testes are transferred, when in a more or less complete condition, to pouch-like structures, developed at the expense of the proximal ends of the vasa deferentia, or according to Bergh (*Zool. Anzeig.*, Bd. ix. p. 232) from the septa. These seminal vesicles are

* *Mem. cour. et mem. d. savants etrag.*, *Acad. Roy. d. Belgique*, t. xxvii. (1856), p. 20.

† Claparède, *Zeitschr. f. wiss. Zool.*, Bd. xix. (1869).

‡ *Zeitschr. f. wiss. Zool.*, (1852).

§ Quoted by Bloomfield, *Quart. Jour. Micr. Sci.*, vol. xx. (1880).

not mere hollow cavities filled with developing spermatozoa, but, as Bloomfield has shown, are divided up in a reticulate fashion by septa of connective tissue. There are therefore some reasons for supposing, that in *Eudrilus* the female generative apparatus is similar to the male generative apparatus; that the structures which I have described as ovaries correspond to the receptaculum ovorum described by Hering, Horst, and recently by Bergh (*Zool. Anzeig.*, Bd. ix. p. 232) in *Lumbricus*, and that, therefore, the true ovaries remain to be discovered. Such a similarity would be interesting, more especially because it would be a further development of the conditions met with in other Lumbricidæ; but I am inclined to think that it does not occur in this genus; the fact that the supposed ovaries contain not merely mature and immature ova, but that they consist of numerous tubules, evidently lined with a germinal epithelium, from which the ova arise, and the fact that these tubules converge and open into the oviduct, appears to me to show that they are the real ovaries.

(4) The formation of a columnar follicular epithelium surrounding the ova has not, to my knowledge, been observed in any earthworm. In the summary of observations on the ova in different groups, given in the first volume of Balfour's *Comparative Embryology*, there is no statement concerning the presence of a follicular epithelium, which, however, is known to occur in *Sipunculus* and in the Leeches. In the latter group it has been described by several writers, including Jijima* and Schneider,† but appears to form a continuous protoplasmic mass investing the ovum, and containing nuclei. In *Sipunculus* and the Echinodermata, and in Lumbricidæ there is a follicular epithelium which is formed of flattened cells. The follicle of *Eudrilus* appears, in fact, to resemble that of certain lower vertebrata more than any segmented worm; but in the absence of more extended information than we possess at present, I do not wish to be understood to insist upon this similarity.

The ovum, with its surrounding follicular epithelium, is displayed in fig. 5; the cells, as will be seen from that figure, are very small, and I was unable to detect a nucleus. The appearances illustrated

* See Isaa Jijima, "Egg Strings, &c., of Nephelis," *Quart. Jour. Micr. Sci.*, vol. xxii. (new series), p. 159.

† *Das Ei und seine Befruchtung.*

in that figure seem to me, however, unquestionably to indicate the presence of a definite follicular epithelium; I can hardly have confounded it with a zona radiata, for this latter membrane when present is *inside* the vitelline membrane, whereas the structure described by me in this paper as follicular epithelium is *outside* the vitelline membrane.

Explanation of Plate.

Fig. 1. Female generative apparatus of *Eudrilus* sketched *in situ.*

Fig. 2. Female generative apparatus of *Eudrilus* with the different parts separated by dissection. *sp*, spermatheca; *v*, its muscular duct; *al*, diverticulum; *ov*, ovary; *od*, oviduct.

Fig. 3. Transverse section through the female generative organs. *a*, glandular diverticulum of spermatheca; *b*, muscular duct of spermatheca; *c*, distal section of oviduct; *d*, proximal region of oviduct continuous with *ov*, ovary.

Fig. 4. Transverse section through ovary, and commencing oviduct more highly magnified. *a*, ovum surrounded by follicular epithelium; the compartment containing this ovum, as well as the next, are nearly filled by the germinal epithelium, among which a few conspicuous nuclei are to be observed, which are probably those of developing ova; *c*, commencing oviduct, its walls continuous with those of ovary.

Fig. 5. Ovum of *Eudrilus.* *g*, germinal vesicle; *gr*, germinal spots; on the right of the figure is another (A) representing a segment of the ovum more highly magnified; *f*, follicular epithelium; *m*, vitelline (?) membrane; *y*, peripheral layer of denser protoplasm.

Fig. 6. Transverse section through duct of spermatheca and its glandular diverticulum, to show opening of latter into former. *a*, diverticulum; *b*, duct of spermatheca; *c*, oviduct near to its opening into *b*; *d*, more distal region of coiled oviduct.

Fig. 7. A few cells from oviduct, to show their columnar form and ciliation.

PRIVATE BUSINESS.

The following Candidates were balloted for, and declared duly elected Fellows of the Society:—A. Beatson Bell, Chairman of Prison Commissioners, 130 George Street; J. P. B. Robertson, Q.C., M.P., 19 Drumsheugh Gardens; John Halliday Croom, M.D., 25 Charlotte Square; D. Bruce Peebles, Tay House, Bonnington; Leopold Field, F.C.S., Lambeth, London; Rev. J. MacGregor, D.D., 11 Cumin Place.

Monday, 19th April 1886.

Sir WILLIAM THOMSON, Hon. Vice-President, in the Chair.

The President laid before the Society a proposal for a Subscription to present a Medal to Professor van Beneden on the occasion of his Jubilee as Professor.

The President read a letter from the Committee of Organisation of the "Congrès International d'Hydrologie et de Climatologie de Biarritz," to be held at Biarritz on the 1st of October of the present year.

The President read a letter from the President of the Society of Antiquaries of London, calling the attention of the Society to a memorandum in reference to the preservation of the Court Rolls of the Manors of this country.

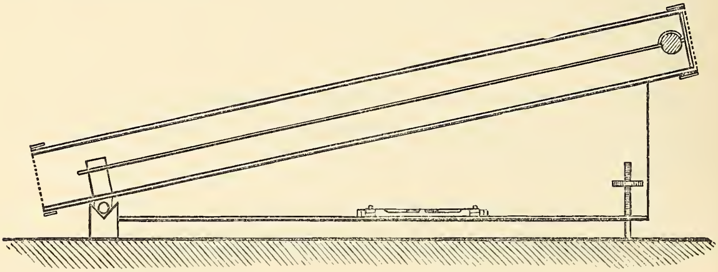
The following Communications were read :—

1. On a new form of Portable Spring Balance for the Measurement of Terrestrial Gravity. By Sir W. Thomson.

The design and construction of the instrument now to be described was undertaken on the suggestion of General Walker, of the East Indian Trigonometrical Survey. At the Aberdeen Meeting of the British Association in 1885, General Walker obtained the appointment of a committee to examine into the whole question of the present methods and instruments for the measurement of gravitational force, and to promote investigation, having for its object the production of gravitation measuring instruments of a more reliable and accurate character than those now in use.

The secretary of this committee, Professor Poynting, has already issued a circular note to the members of the committee (of whom the author is one), stating the conditions which must be fulfilled by any gravimeter laid before the committee for examination and report.

An instrument, constructed according to the following description, promises to fulfil all the conditions mentioned in Professor Poynting's circular. Its sensibility is amply up to the specified degree. It is, of necessity, largely influenced by temperature, and it is not certain that the allowance for temperature, or the means which may be worked out for bringing the instrument always to one temperature, may prove satisfactory. It is almost certain, although not quite certain, that the constancy of the latent zero of the spring will be sufficient, after the instrument has been kept for several weeks or months under the approximately constant stress under which it is to act in regular use.



Front elevation, with one-half of Tube removed.

The instrument consists of a thin flat plate of springy German silver of the kind known as "doctor," used for scraping the colour off the copper rollers in calico printing. The piece used was 75 centimetres long, and was cut to a breadth of about 2 centimetres. A brass weight of about 200 grammes was securely soldered to one end of it, and the spring was bent like the spring of a hanging bell, to such a shape that when held firmly by one end the spring stood out approximately in a straight line, having the weight at the other end. If the spring had no weight the curvature, when free from stress, must be in simple proportion to the distance along the curve from the end at which the weight is attached, in order that when held by one end it may be straightened by the weight fixed at the other end.

The weight is about 2 per cent. heavier than that which would keep the spring straight when horizontal; and the fixed end of it is so held that the spring stands, not horizontal, but inclined at a slope of about 1 in 5, with the weighted end above the level of the fixed end. In this position the equilibrium is very nearly unstable. A definite sighted position has been chosen for the weight, relatively to a mark rigidly connected to the fixed end of the spring, fulfilling the condition that in this position the equilibrium is stable at all the temperatures for which it has hitherto been tested; while the position of unstable equilibrium is only a few millimetres above it for the highest temperature for which the instrument has been tested, which is about 16° C.

The fixed end is rigidly attached to one end of a brass tube, about 8 centimetres diameter, surrounding the spring and weight, and closed by a glass plate at the upper end of the incline, through which the weight is viewed. The tube is fixed to the hypotenuse of a right-angled triangle of sheet brass, of which one leg, inclined to it at an angle of about $\frac{1}{5}$ radian, is approximately horizontal, and is supported by a transverse trunnion resting on fixed V-s under the lower end of the tube, and a micrometer screw under the short, approximately vertical, leg of the triangle.

The observation consists in finding the number of turns and parts of a turn of the micrometer screw, required to bring the instrument from the position at which the bubble of the spirit-level is between its proper marks, to the position which equilibrates the spring-borne weight, with a mark upon it exactly in line with a chosen divisional line on a little scale of 20 half-millimetres, fixed in this tube in the vertical plane perpendicular to its length.

The instrument is, as is to be expected, exceedingly sensitive to changes of temperature. An elevation of temperature of 1° C. diminishes the Young's modulus of the German silver so much, that about a turn and a half of the micrometer screw (lowering the upper end of the tube at the rate of 2/3 millimetre per turn) produced the requisite change of adjustment for the balanced position of the movable weight. About $1\frac{1}{8}$ turn of the screw corresponds to a difference of 1/5000 in the force of gravity, and the sensibility of the instrument is amply valid for 1/40 of this amount; that is to say, for 1/200,000 difference in the force of gravity. Hence it is not want of sensibility in the instrument that can prevent its measuring differences of gravity to the 1/100,000; but to attain this degree of minuteness it will be necessary to know the temperature of the spring to within 1/20° C. I do not see that there can be any great difficulty in achieving the thermal adjustment by the aid of a water jacket and a delicate thermometer. To facilitate the requisite thermal adjustment, I propose, in a new instrument of which I shall immediately commence the construction, to substitute for the brass tube a long double girder of copper (because of the high thermal conductivity of copper), by which sufficient uniformity of temperature along the spring throughout the mainly effective portion of its length and up to near the sighted end, shall be secured. The water jacket will secure a slight enough variation of temperature to allow the absolute temperature to be indicated by the thermometer with, I believe, the required accuracy.

2. Measurements of the Electro-Motive Force of a Constant Voltaic Cell with Moving Plates. By A. P. Laurie, B.Sc., B.A.

3. Note on the Formation of the Hectocotylus in Rossia. By W. E. Hoyle, M.A.

4. On some Definite Integrals. By Professor Tait.

5. On Alterations in the Electric Conducting Power of Alloys at their Melting Point. By Harry Rainy, M.A., and R. D. Clarkson, B.Sc. (Plate XXVI.)

The electric conductivity of metals has been observed to change very greatly at their melting point, the resistance being in many cases nearly doubled when the metal is fused. The experiments recorded in the following communication originated in an attempt to investigate more fully into this fact. The metals chosen for the first observations were tin and lead, both of which have their melting points at temperatures that can be readily obtained.

At first we endeavoured to take the resistance, at various temperatures, of a column of metal having a definite cross section and length, by means of a Wheatstone's bridge. For this purpose glass tubes were employed, which were placed horizontally in a hot-air bath, where they could be raised to a temperature considerably above

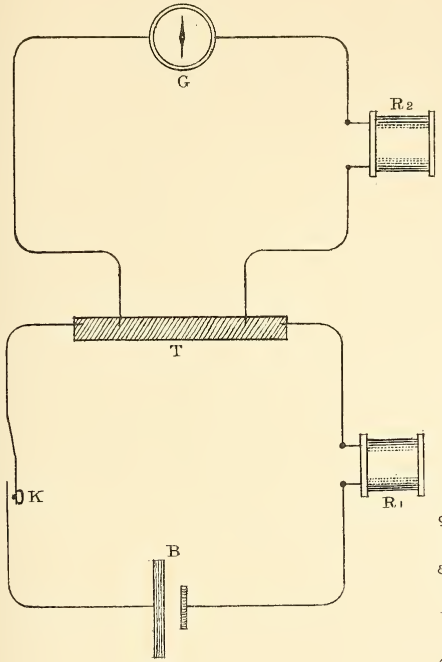


Fig. I.

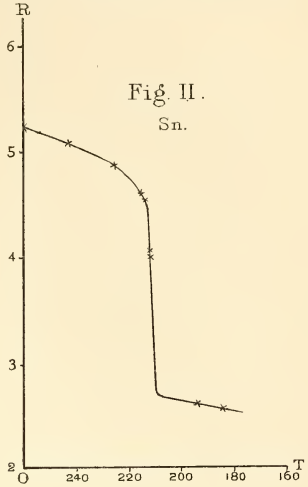


Fig. II.
Sn.

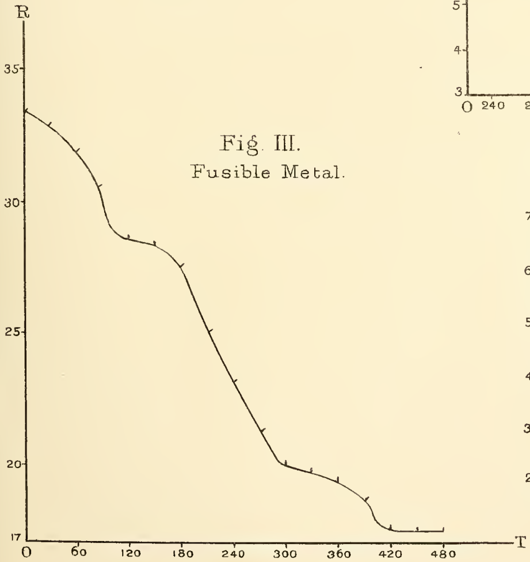


Fig. III.
Fusible Metal.

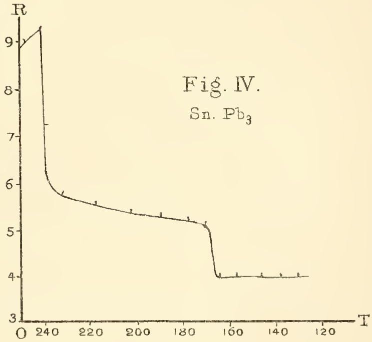


Fig. IV.
$Sn.\ Pb_3$

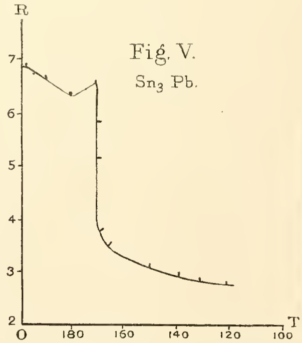


Fig. V.
$Sn_3\ Pb.$

M^cFarlane & Erskine, Lith^rs Edin^r

the melting point of the metals experimented upon. The length of these tubes was 60 cm., the diameter of the bore 3 mm., and the ends of the tubes which were bent upwards for a length of about 5 cm. terminated in small cups, into which the wires connecting the column of metal with the Wheatstone's bridge dipped.

When the tube had been raised to a temperature above that at which the metal melted, the latter was poured into it from a crucible in which it had been fused, and the resistance was observed from time to time as the whole gradually cooled down. The results thus obtained were, however, unsatisfactory, and varied from one experiment to another. It was found to be very difficult to keep a tube of the length employed heated equally at all points when the temperature was high, and in addition to this, the tubes could seldom be used for a second experiment, as they almost invariably cracked when an attempt was made to remelt the metal. After various modifications had been unsuccessfully tried, this form of apparatus was abandoned, and a new method was adopted, which has been employed in all the rest of the experiments.

A small trough of highly baked stoneware, 10 cm. long, 1 cm. broad, and 1 cm. deep, was placed on a sheet of thin iron plate and heated by a powerful gas flame. In this trough the metal was melted, and then wires were dipped into it,—one at each end. These wires were connected with a Leclanché cell, and thus the circuit was completed through the melted metal. A shunt circuit was formed by a wire whose ends dipped into the metal in the trough, so that the current was divided; part passing through the metal, and part through the shunt circuit, in which a reflecting galvanometer was placed. In the battery circuit a resistance of about 2·5 ohms was inserted, so that the melted metal formed a very small portion of the total resistance of this circuit. Hence the intensity of the current passing was practically the same whether the metal in the trough were melted or solid. The resistance of the shunt circuit, including the galvanometer, was somewhat more than 11 ohms; any change, therefore, of the resistance of this circuit, due to heating of the wires where they entered the trough, might be neglected as compared with the total resistance of the galvanometer circuit.

Under these conditions the resistance of the metal in the trough was proportional to the current in the shunt circuit.

The observations were made in the following manner:—A key was introduced into the battery circuit, and as the melted metal gradually cooled down, this key was depressed at regular intervals of thirty seconds, and the deflection of the galvanometer noted. In most of the experiments the temperature was taken at the same time by means of a copper-iron thermo-electric junction which had been previously tested, and of which one junction was inserted into the melted metal, while the other was kept at a constant temperature.

The results of experiments conducted in this manner on tin and lead are given in a table at the end of this communication, and indicate a very sudden and considerable alteration in the conductivity of these metals at their melting points. It may be mentioned that the tin employed in the experiments was commercial grain tin; the lead was in the form of assay foil.

Soon after commencing these experiments it occurred to us to employ Rose's fusible metal, in consequence of the ease with which it can be melted. The result which we obtained was, to us, quite unexpected; for the resistance, instead of becoming suddenly about half its former amount as the metal solidified, descended to its lower value by three successive falls. The experiment when repeated gave the same result.

We therefore resolved to investigate further into the matter, and proceeded to form alloys of lead and tin. To make sure that, if the same appearance should present itself in these alloys, it might be referred to some property of the alloy, the conductivity of specimens of the lead and tin used in making them up was tested; in every case the resistance altered by a single change from its one value to the other.

The alloys were made by melting the proper amounts of lead and tin in a ladle or in a crucible, sometimes a flux was added, and a considerable number of specimens of each alloy was made, that the results given by any one specimen might be checked by those obtained from the others. In the two alloys of tin and lead which were employed, the metals were fused together in quantities which were simple multiples of their atomic weights; but this is not necessarily the only manner in which the metals may be mixed in order to form an alloy. This is well brought out in a paper by

Professor F. Guthrie on Eutexia,* which appears to have important relations to the phenomena recorded in this communication.

The first alloy tested was $SnPb_3$. The change in resistance in this case took place by two distinct falls with a space between them where the resistance changed very much less rapidly. This experiment was repeated several times, and the same result was always obtained.

The next alloy tested was Sn_3Pb. In this case the change of resistance was effected by a single fall, as in the case of a simple metal; repeated experiments failed to show any break in the sudden alteration of conductivity.

The authors were led to employ these two alloys in consequence of some observations made by Rudberg,† who states that the alloy Sn_3Pb has one solidifying point, but that the others exhibit a higher one also, which in the case of $SnPb_3$ is very far above the lower one. The temperatures given by him do not exactly correspond with those at which the dips appear in the conductivity curves, but these temperatures do not profess to any great accuracy, for the object was in this case rather to determine the change of temperature from observation to observation, than to give the absolute temperature of the alloy at any observation.

One alloy of zinc and lead (ZnPb) has also been tried. It gives evidence of a break in the alteration of conductivity, but a sufficient number of observations has not been made upon it to justify any great dependence on this result.

The conclusion which these facts would seem to indicate, although it is premature as yet to adopt it as established, is that there is a definite alloy, corresponding to Professor Guthrie's "Eutectic Alloy," from which the other constituents separate out and solidify, giving rise to the first fall in resistance as the metal cools, and that afterwards, when the eutectic alloy itself solidifies, the second fall occurs. A point of great importance in this connection is brought out by a comparison of figs. 4 and 5. In the alloy $SnPb_3$ the second fall in resistance occurs at the same temperature as the whole fall in the (eutectic) alloy Sn_3Pb. The

* "On Eutexia," *Phil. Mag.*, vol. xvii. 5th series, 1884.

† Quoted in Gmelin's *Handbook of Chemistry*, vol. v. p. 180, Engl. transl. by Henry Watts, in the Cavendish Soc. Works.

first fall would then be naturally explained by the solidification of the excess of lead contained in this alloy over that required to form the eutectic alloy. This solidification of the lead takes place at a temperature lower than its ordinary melting point, a result doubtless in some way connected with its being mixed with the alloy. If three constituents are present, as in fusible metal, the whole of one and part of the remaining two may combine to form a tri-eutectic alloy, then all that remains of one of the two still free may form an eutectic alloy with part of the other metal; and lastly, there would be a residue of the final metal which was not wholly used up in these combinations. This would lead to a curve with three successive falls, which is exactly what we find in fusible metal. But, as we have already said, it is still premature to form a judgment upon the merits of this theory, especially as we hope, at no distant time, to be able to bring forward many additional facts, which may materially aid in the formation of a conclusion for or against the suggestions offered above.

It should, perhaps, be mentioned that Dr Matthiessen made experiments on fusible metal about twenty years ago,* but apparently failed to observe the nature of the alteration of resistance. This may have been due to the fact that the form of apparatus he employed was not so suitable for detecting the character of the alteration.

The authors, in concluding this account, desire to express their thanks to Mr D. Callander for his kind assistance in taking the temperature observations.

A few words may be added in explanation of the accompanying tables and diagrams.

In tables I. and II. are recorded the observations on lead and tin. Table III. gives observations on fusible metal, table IV. on the alloy $SnPb_3$, and table V. on Sn_3Pb.

In the experiments on lead and fusible metal the deflections and times alone are given, as the thermo-electric apparatus was not adjusted for reading temperatures so high and so low, respectively, as those at which these metals melt. In the other tables the first column records the time at which each observation was made, reckoned in seconds from the commencement of the experiment;

* *Phil. Mag.*, vol. xiii. 4th series, p. 90.

the next column gives the temperature of the alloy at that instant; and the last column gives the deflection reading on the scale of the galvanometer; which, as the angle was always very small, is approximately enough proportional to the current in the galvanometer circuit, and therefore to the resistance of the alloy.

At first the alloy was always somewhat above its melting point, and the observations were continued for a short time after the alloy appeared to be perfectly solid.

Fig. 1 is a diagram to illustrate the arrangement of the circuit in the experiments with the trough. B represents the Leclanché cell, R_1 the resistance inserted in the battery circuit, K the key in the same, T the trough, G the galvanometer inserted in the shunt circuit taken from two points in the trough, and R_2 the resistance inserted in this circuit.

Fig. 2 represents the relation between the resistance and temperature of tin as it solidifies. The resistances are measured along OR, and the temperatures along OT; these become lower as they recede from the point O.

Fig. 3 shows the same for fusible metal, except that in this case time, not temperature, is measured along OT.

Fig. 4 gives the curve for the alloy $SnPb_3$, and fig. 5 for Sn_3Pb, resistance being measured along OR, and *temperature* along OT.

The points on these curves at which observations were taken are marked by small crosses. As these observations were made at regular intervals of 30 seconds, the projection of these points on the temperature axis in figs. 2, 4, and 5, indicate the rate at which the temperature of the cooling alloy changed. The more closely these projections are crowded together the more slowly does the temperature change; and it will be observed that it is at the very points where the falls in resistance occur that this takes place. This gives additional corroboration to the accuracy of the observations.

These experiments have been performed in the Physical Laboratory of the Edinburgh University, through the kindness of Professor Tait, to whom, and to Professor Chrystal, at whose suggestion the subject was originally untertaken, the authors are deeply indebted for valuable advice.

Table I.—Lead.

Time in Seconds.	Deflection.
0	22·4
30	22·0
60	22·0
90	20·0
120	13·3
150	10·2
180	10·1
210	9·8
240	9·7
270	9·8

Table II.—Tin.

Time in Seconds.	Temperature.	Deflection.
0	260° C.	5·3
30	245°	5·1
60	226°	4·9
90	215°	4·6
120	214°	4·6
150	212°	4·0
180	211°	4·0
210	194°	2·7
240	184°	2·6

Table III.—Fusible Metal.

Time in Seconds.	Deflection.
0	33·5
30	33·0
60	32·0
90	30·5
120	28·7
150	28·5
180	27·5
210	25·0
240	23·5
270	21·5
300	20·0
330	19·8
360	19·4
390	18·8
420	17·5
450	17·5
480	17·5

Table IV.—Alloy $SnPb_3$.

Time in Seconds.	Temperature.	Deflection.
0	247° C.	8·9
30	242°	9·1
60	240°	7·3
90	232°	5·7
120	218°	5·7
150	203°	5·3
180	190°	5·2
210	176°	5·1
240	170°	5·0
270	164°	4·0
300	156°	4·1
330	146°	4·0
360	137°	4·1
390	130°	4·1

Table V.—Alloy Sn_3Pb.

Time in Seconds.	Temperature.	Deflection.
0	198° C.	6·8
30	188°	6·6
60	180°	6·3
90	170°	6·5
120	170°	5·8
150	168°	5·2
180	168°	3·7
210	165°	3·4
240	150°	3·1
270	140°	2·9
300	131°	2·8
330	121°	2·7

6. Examples upon the Reading of the Circle or Circles of a Knot. By the Rev. Thomas P. Kirkman, M.A., F.R.S.

How this reading is to be done is well known; but it may be useful to have more examples. Consider the two following circles of two unifilars each of fourteen crossings—

$$aFbdcAdbeGfEgcAfBDCaDBEgfeGC,$$
$$afbDcAdGeCfbgEAFBdCaDgEcFBCe,$$

which are the simplest possible that have their janal symmetries. I wish to show that the knots are completely given by their circles, as are also their symmetries.

In the circle of an unifilar every crossing is twice read, once in an odd and once in an even place, the thread passing alternately over and under itself at successive crossings. The only duads that occur twice are edges of 2-gons. The first knot has six 2-gons, *bd*, BD, *c*A, C*a*, *e*G, E*g*. At the 2-gon *bd* the thread F*bdc* passes over and under *ebd*A; and .. F*bdc* .. and .. *ebd*A .. are meshes collateral with the 2-gon *bd*. We take .. *ebd*A .. for a base on which to project the first knot, observing that as F*e* and F*b* are edges, F*be* is a triangle collateral with our base .. *ebd*A ... At the 2-gon *e*G, *be*G*f* passes over and under F*e*GC, and .. *be*G*f* .. is a mesh collateral with *e*G. As *be* cannot be in three meshes, our base is .. A*dbe*G*f* .., and since *f*A is an edge, this base is the 6-gon A*dbe*G*f*. The first circle is unaltered by exchanging throughout capital and small letters. There is then another 6-gon *a*DBE*g*F in the knot. Draw this within the base, *a* remote from A, D from *d*, &c., so that the meshes A*dbe*G*f* and *a*DBE*g*F are read in the same direction round; and make the 2-gons *db*, DB, E*g*, *e*G. There are two other 2-gons to construct. From *c* near A and C near *a*, between the 6-gons, draw 2-gons A*c* and *a*C. Our fourteen summits are properly projected, and we complete the projection by drawing the edges F*b*, *f*B, F*e*, *f*E, CG, *cg*, CD, *cd*.

It is evident that on this first knot in space every feature, edge, crossing or mesh, is diametrically opposite to a similar feature. There is no zonal trace, at every point of which the configurations on the right and left reflect each other; nor is there a diameter about which in revolution a configuration is repeated; that is, two opposite eyes in every diameter read round exactly the same asymmetric sequence; but this only when one reads with, and the other against, his watch. The opposite configurations are in every diameter asymmetric and *contrajanal*, and the knot is a *contrajanal anaxine* knot, on which a zonal trace is impossible. About a *janal* axis proper, zoned or zoneless, opposite observers read round like configurations when each reads with his watch. This first knot is a contrajanal anaxine *subsolid*, *i.e.*, one admitting section through no two points only, but through the crossings of a 2-gon. There are contrajanal anaxine *unsolids*, *i.e.*, admitting linear section not through the two crossings of a 2-gon, which have 12 or 10 crossings only.

The second knot has four 2-gons, *fb*, FB, G*e*, *g*E. At *fb* .. *afb*D .., .. C*fbg* .. are meshes collateral with it; and as *b*D and *g*D are edges, D*bg* is a triangle collateral with .. C*fbg* .. which we choose for our base. The 2-gon *g*E is collateral with .. *bg*E*a* .. and .. D*g*E*c* ... Since *bg* cannot be in three meshes, .. C*fbg* .. is .. *bg*E*a* .., and our base is .. C*fbg*E*a* ... As DC and D*a* are edges, this base is the 7-gon DC*fbg*E*a*. Inside this, with *d* remote from D, *c* from C, &c., we have to draw the heptagon *dc*FBG*e*A, and we complete the projection by the edges *af*, AF, *b*D, B*d*, *bg*, BG, *c*E, C*e*, *c*A, C*a*, and by making the 2-gons G*e*, *g*E, *fb*, FB. There is a zonal trace across the epizonal edges *bg* and BG, and the mid-points of the identical zoneless polar edges *ac* and AC, are the poles of a zoneless 2-ple contrajanal axis, about which in revolution there is a 2-ple repetition. We have constructed a 2-ple monaxine monozone subsolid knot. There are 2-ple monaxine monozone unsolid knots that have 12, 10, and 8 crossings only.

The 12-filar knot of 180 crossings, whose circles under written completely define it, has a zoneless symmetry of the highest possible complexity, and is the simplest knot of that symmetry that can be formed. Required its meshes and its symmetry.

$abca_1b_1cdefm_2n_2fghij_8k_8ijkla_{11}b_{11}lmnpa_3b_3p$,

$a_1b_1c_1abc_1d_1e_1f_1m_3n_3f_1g_1h_1i_1m_4n_4i_1j_1k_1l_1m_5n_5l_1m_1n_1p_1a_2b_2p_1$,

$a_2b_2c_2m_1n_1c_2d_2e_2f_2j_5k_5f_2g_2h_2i_2m_7n_7i_2j_2k_2l_2m_8n_8l_2m_2n_2p_2dep_2$,

$a_3b_3c_3mnc_3d_5e_3f_3m_{11}n_{11}f_3g_3h_3i_3m_9n_9i_3j_3k_3l_3a_4b_4l_3m_3n_3p_3d_1e_1p_3$,

$a_4b_4c_4j_3k_3c_4d_4e_4f_4j_9k_9f_4g_4h_4i_4a_6b_6i_4j_4k_4l_4a_5b_5l_4m_4n_4p_4g_1h_1p_4$,

$a_5b_5c_5j_4k_4c_5d_5e_5f_5m_6n_6f_5g_5h_5i_5a_7b_7i_5j_5k_5l_5d_2e_2l_5m_5n_5p_5j_1k_1p_5$,

$a_6b_6c_6g_4h_4c_6d_6e_6f_6g_9h_9f_6g_6h_6i_6d_{10}e_{10}i_6i_6k_6l_6d_7e_7lm_6n_6p_6d_5e_5p_6$,

$a_7b_7c_7g_5h_5c_7d_7e_7f_7j_6k_6f_7g_7h_7i_7a_{10}b_{10}i_7j_7k_7l_7a_8b_8l_7m_7n_7p_7g_2h_2p_7$,

$a_8b_8c_8j_7k_7c_8d_8e_8f_8m_{10}n_{10}f_8g_8h_8i_8d_{11}e_{11}i_8j_8k_8l_8ghl_8m_8n_8p_8j_2k_2p_8$,

$a_9b_9c_9j_{11}k_{11}c_9d_9e_9f_9g_{10}h_{10}f_9g_9h_9i_9d_6e_6i_9j_9k_9l_9d_4e_4l_9m_9n_9p_9g_3h_3p_9$,

$a_{10}b_{10}c_{10}g_7h_7c_{10}d_{10}e_{10}f_{10}g_6h_6f_{10}g_{10}h_{10}i_{10}d_9e_9i_{10}j_{10}k_{10}l_{10}g_{11}h_{11}l_{10}m_{10}n_{10}p_{10}d_8e_8p_{10}$,

$a_{11}b_{11}c_{11}jkc_{11}d_{11}e_{11}f_{11}g_8h_8f_{11}g_{11}h_{11}i_{11}j_{10}k_{10}i_{11}j_{11}k_{11}l_{11}a_9b_9l_{11}m_{11}n_{11}p_{11}d_3e_3p_{11}$.

No duad is found twice in the circles, except the pair of crossings of a 2-gon, which is read twice, as *ab*. Every crossing *s* occurs twice, either in one or in two circles, and is read central in two triplets $as\beta$, $\alpha' s\beta'$. The four angles about s are $as\alpha'$ opposite to $\beta s\beta'$, and $as\beta'$ opposite to $\beta s\alpha'$. The crossing n occurs in circles 1 and 4 in the triplets mnp and mnc_3: its angles are

$$mnm \text{ opposite } pnc_3, \text{ and } mnc_3 \text{ opposite } pnm,$$

where the edges mn in the triplets are the two edges of a 2-gon mn.

As mc_3 is an edge as well as mn and nc_3, c_3mn is a triangular mesh, and $K = \ldots mn \ldots$ is a mesh not triangular. Both are collateral with the 2-gon mn.

The crossing p is read in two triplets, npa_3 and b_3pa, of the first circle: its angles are

$$npb_3 \text{ opposite } a_3pa, \text{ and } npa \text{ opposite } b_3pa.$$

The angles c_3np (1) and npb_3 are in the mesh $\ldots c_3npb_3 \ldots = L$, which since b_3c_3 is an edge in circle 4, is the 4-gon $c_3npb_3 = L$. Also the angles mnp (1) and npa (2) are in the mesh $K = \ldots mnpa \ldots$, which is collateral with the 2-gon mn and with the 4-gon L.

The crossing a_3 occurs in the circles 1 and 4 in pa_3b_3 and $p_3a_3b_3$, where the two edges a_3b_3 are different. Its angles are

$$pa_3p_3 \text{ opposite } b_3a_3b_3 \text{ and } pa_3b_3 \text{ opposite } p_3a_3b_3.$$

Here pa_3p_3 and a_3pa (2) are angles of the mesh $M = \ldots apa_3p_3 \ldots$

At a in pab and bac_1 in circles 1 and 2 the angles are

$$pab \text{ opposite } bac_1 \text{ and } pac_1 \text{ opposite } bab.$$

Here c_1ap, apa_3 (3), and p_3ap_3 (3), are angles in $M = \ldots c_1apa_3p_3 \ldots$, which, since d_1c_1 and d_1p_3 are edges in circles 2 and 4, is the 6-gon $M = d_1c_1apa_3p_3$. The angle pab is in the face $K = \ldots mnpab \ldots$, which is collateral with the 2-gon mn, the 4-gon L, the 6-gon M, and the 2-gon ab.

If now we repeat at the four like-posited triplets of the first circle, ca_1d, fm_2g, ij_8j, $la_{11}m$, what we have done at the triplet pa_3a, we shall complete the demonstration that our 15-gonal base

$$K = abcdefghijklmnp$$

is collateral with five 2-gons, five 4-gons, and five 6-gons. And such a 15-gon will be found in the same way from each of the

12 circles. Each 15-gon is of zoneless 5-ple repetition, whose collaterals are the meshes 246 ... five times written, showing a zoneless repetition.

The knot must be the zoneless hexarchaxine $G = 15^{12}6^{20}4^{30}3^{60}2^{60}$, *i.e.*, of twelve 15-gons, twenty 6-gons, &c. It has six principal 5-ple axes, ten secondary 3-ple axes, and fifteen 2-ple tertiary axes, all the axes zoneless-janal. The triangles and 2-gons are all asymmetrical and all alike.

To construct the knot G. Cut away the summits of the hexarchaxine 5^{12}, and make what remains of the edges into thirty 2-gons. You have the zoned hexarchaxine knot $F = 10^{12}3^{20}2^{30}$. Each triangle *abc* of F is collateral with three 10-gons, A, B, and C. At *a* in A on the left of *b*, complete by the 2-gon $\beta\gamma$ the small triangle $a\beta\gamma$, and at *b* in B and *c* in C complete by 2-gons the triangles $b\gamma\alpha$ and $c\beta\alpha$. Do the like at each of the twenty triangles of F, operating in the same direction round each. Thus G is constructed.

It is easy in like manner to form upon the regular 20-edron hexarchaxine knots, both zoned and zoneless, on the 4-edron such tetrarchaxine, and on the cube or its reciprocal such triarchaxine knots.

The following examples of knot-symmetry, perhaps not yet noticed, may be found useful:—

1. $6^2 5^4 3^8 2^4$, 2-ple monaxine contrajanal, a bifilar of 16 crossings, whose circles are

1*fedf*54234896790*cbac*;
1*deoab*876532.

The contrajanal poles are the 6-gons 1248*bc*, and 90*ef*56, whose zoneless axis is the only contrajanal diameter.

2. $9^2 5^6 3^{12} 2^6$, 3-ple monaxine contrajanal, a bifilar of 24 crossings, with the circles

12*ijkif*3*hg*34*decd*05*ba*568978*l*1*mn*;
2*hgfec*4*ba*0976*mnljk*.

The 3-ple contrajanal poles are the 9-gons

12*h*34*b*56*m*, and 890*defigl*.

3. $9^2 6^3 4^6 3^6 2^9$, 3-ple monaxine monozone 6-filar of 24 crossings,

1*kj*1678*ih*8 ; 29*alma*3*pn*3 ; 5*ed*54*bcfgc* ;
*k*29*hij* ; *p*4*blmn* ; *e*679*fd*.

The zonal trace crosses 12 faces, 2446 2446 2446, and the contrajanal polar faces are zoneless 3-ple 9-gons.

4. $8^6 6^2 3^{12} 2^{12}$, 3-zoned monarchaxine homozone, a bifilar of 30 crossings, with the circles

12*gf*23*klmk*34*rq*45*suvs*567861*ecde* ;
*abdcbihfghijmljnpqrpntvuta*9879.

The 3-zoned poles are the 6-gons 123456, *abijnt*. Six like 2-ple 8-gons, 1*ecba*976, &c., terminate the three identical contrajanal axes.

5. $(12)^2 6^6 4^6 3^{12} 2^{12}$, 3-ple zoneless monarchaxine janal, of 36 crossings with the six circles,

12*r*1*bcdeβdpq* ; 2*rnpqnms*34*t*3 ; 4*tlmslku*56*v*5 ;
6*vjkujiw*78*x*7 ; 8*xhiwhgy*90*z*9 ; 0*zfgyfeβabcd*.

The principal poles are the 3-ple 12-gons, 1234567890*ab* and *defghijklmnp*.

The six secondary 2-ple janal axes, in a plane at right angles to the principal axis, have for alternate zoneless poles, six 6-gons and six 4-gons.

PRIVATE BUSINESS.

Sir William Thomson proposed the motion of which he had given notice, viz. :—"That henceforth the Meetings of the Royal Society be held in the afternoon instead of at 8 P.M."

A letter from Mr Murray was read by the Secretary. In this letter Mr Murray apologised for his absence, and recommended "That the Meetings should be held alternately at 4 o'clock and at 8 o'clock."

Mr T. H. Cockburn Hood proposed as a second amendment—"That the first Meeting in each month take place at 2 o'clock, an that Papers upon Geology, Meteorology, and Zoology be read at said Meetings."

On the suggestion of the Secretary, it was decided to remit to the

A MGANDA.

Council to ascertain the individual opinions of the Fellows of the Society on the whole question of the hour of meeting of the Society, and to communicate the result to the Annual Meeting.

Monday, 3rd May 1886.

ROBERT GRAY, Esq., Vice-President, in the Chair.

The following Communications were read:—

1. Notes on the Waganda Tribe of Central Africa. By Robert W. Felkin, M.D., F.R.G.S., Fellow of the Anthropological Societies of London and Berlin, &c. (Plate XXVII.)

The paper which I have the honour of presenting to you to-night is similar in construction to those I have previously brought under your notice on the For and Madi Tribes.

The Waganda are very different from the tribes further north, and a description of them will I think aptly illustrate the very marked contrasts presented by the various Central African Tribes.

As in the former papers, I have written from notes of my own observations made when in the country, and from information supplied to me by people of the tribe. While I do not give anything that has not formed the subject of my personal investigation, it is yet impossible to avoid mentioning matters and details which have been more or less touched on by other travellers.

Uganda occupies a position to the north, north-west, and west of the Victoria Nyanza. It is bounded on the north by the 1st degree of North latitude, on the south by the Kitangule River, on the east by the Nile, and on the west by the 31st degree of East longitude. The country is divided into three provinces—Uddu in the south, Singo in the west, and Changwe in the east; and to this latter province must be reckoned about 400 islands, called by the collective name of Sesse.

The western frontier of the country is very ill-defined, and may be found to extend considerably beyond the limit here assigned to it. The equator, as will be seen from a glance at the map, divides the country into two almost equal parts.

Physical Features of the Country.—The physical features of Uganda are very varied, and give a distinct character to the different districts. The country bordering the lake and for some distance inland is mountainous, especially in the north-west, where parallel low mountain chains are found. The general elevation of the hills above their valleys is about 400 feet, and in the marshy valleys between them sluggish streams make their way to the Nyanza. All the hills are covered with splendid timber and abundant underwood. Further inland the valleys widen and the hills gradually decrease in size, until at the northern border the country becomes a plain, intersected at long intervals by large rush drains, and covered with open forest or rank grass jungle. The eastern part of Uganda, between Rubaga and the Nile, consists of undulating country varied by deep narrow valleys.

Geology.—The formation of the rocks is volcanic or metamorphic. The upper strata of land, for the depth of 2 or 3 feet, is a rich black alluvial soil, under which is a bed of red sandy clay averaging about 30 feet in thickness, and lower still in many places is a layer of tolerably pure porcelain earth. Large masses of mica are found, and at the outcrop of the metamorphic rocks crystals may frequently be seen. Ironstone is also found in rather large quantities, but as far as is known no other metals are to be obtained.

Climate.—The climate is remarkably mild, and the temperature very uniform throughout the year. The extreme variations are 50° F. minimum (extremely rare) and 90° F. maximum. The rainfall is about 50 inches, and the atmosphere is very humid. There are two periods of maximum rainfall—March, April, and May, and September, October, and November. During these months rain falls nearly every day, often accompanied by thunder.

Population.—The total population of Uganda is about 5 millions. It is principally composed of the Waganda who inhabit the mainland north of the Victoria Nyanza, and the Wasesse who inhabit the islands. These two tribes are of the same stock, the difference in name only denoting the districts in which they dwell. They are pure negroes, of dark chocolate coloured skin (Broca's Table, No. 35–43). Colour of eyes, Broca's Table, 35. The men are tall, well-

	1.	2.	3.	4.	5.
1. Height from ground to vertex, . .	1610	1768	1682	1568	1620
2. Greatest length of head from glabella backwards, ...	188	189	195	194	194
3. Greatest breadth above ears, . . .	132	138	142	144	141
4. Length of face from root of nose to lower border of chin, ...	130	131	117	117	122
5. Breadth of face from one foremost lower edge of cheek-bone to the other, .	113	103	104	109	111
6. Breadth from one angle of lower jaw to the other, ...	93	100	93	105	100
7. Greatest breadth of zygomata, . .	114	118	140	129	134
8. Length of nose from root to the point where the septum joins the upper lip,	60	61	47	57½	53
9. Height of head from chin to vertex, .	226	229	225	233	216
10. Length of neck from upper edge of "Pomum Adami" to sternal notch, .	70	71	67	81	70
11. Length of body from sternal notch to upper edge of pubes, ...	540	547	560	486	546
12. Height of navel from ground, . .	959	1044	1080	902	966
13. Height of up. edge of pubes from ground,	794	886	839	798	784
14. Height of head from meatus auditorius to vertex, ...	131	142	124	124	125
15. Distance between the two ears (top of meatus auditorius), ...	131	127	133	125	121
16. Upper breadth of nose (from one canthus to the other), ...	32	28	35	32	33
17. Lower breadth of nose, ...	43	42	42	42	43
18. Length of nose from root to point, .	57	56	52½	52	56
19. Breadth of mouth, ...	52	54	56½	54	47
20. Distance of root of nose, middle line, to meatus auditorius, ...	118	121	129	115	126
21. Distance to junction of nose with lip from same place, ...	120	128	133	120	119
22. Distance to middle of upper lip from same place, ...	130	133	147	135	135
23. Distance of chin, middle line, lower edge, from same place, ...	116	130	132	123½	130
24. Greatest circumf. of head from glabella,	557	554	556	585	560
25. Arc from tragus to tragus, over the head,	365	361	340	356	330
26. Circumf. of chest just above mammæ, .	780	830	830	820	850
27. Distance between nipples, . . .	199	189	182	170	175
28. Breadth of shoulders, across the back, .	425	430	400	375	415
29. Circumference of waist at navel, . .	740	740	710	650	645
30. Breadth of haunches, ...	241	281	273	243	250
31. Length of arm from shoulder to tip of middle finger (arm outstretched), .	600	768	750	692	715
32. Length of upper arm from shoulder to condylus externus ossis humeri, . .	290	335	320	300	296
33. Length of lower arm from olecranon to end of ulna, ...	280	310	285	275	277
34. Length of hand from wrist-joint to tip of middle finger, ...	180	190	210	190	180
35. Length of leg from trochanter major to the ground, ...	910	942½	900	850	863
36. Length of thigh from trochanter major to condylus externus ossis femoris, .	465	430	415	410	393
37. Length of leg from articulation of knee to malleolus externus, lower edge, .	380	445	440	375	411
38. Length of foot (os calcis to tip of great toe),	228	263	244	245	246
39. Arc from notch at root of nose to inion over the head, ...	320	340	316	344	340

Graduated measure used for Nos. 1, 11–13.
Jointed measure used for Nos. 2, 3, 9, 14.
Calipers used for Nos. 4–8, 10, 15–17, 19–23, 27, 30.
Measuring-tape used for Nos. 18, 24, 25, 26, 28, 29, 31–38.

built, and have good features, and the women in their youth are good-looking, with small delicately formed hands and feet. It is of this tribe that my paper treats. I shall not touch upon the Wanyambo who live in Uddu and Karagwe, or the Wasoga who live to the east of the Nile, but it will be necessary to mention a small tribe, the Wahuma, who inhabit scattered villages throughout the whole of Uganda. They number between 40,000 and 50,000. They are probably descended from the original inhabitants of Abyssinia, and there is no doubt that the ancestors of the reigning family of Uganda were Wahuma.

In order to give an idea of the form and size of the Waganda, I give the measurements of five men. The numbers correspond to Virchow's Table (p. 701).

Table of Principal Indices.

Number.	Cephalic Index.	Nasal Index.	Facial Indices.		
			A.	B.	C.
1.	702	717	1150	1398	1140
2.	730	689	1272	1310	1110
3.	728	894	1125	1258	836
4.	742	730	1070	1114	907
5.	727	811	1099	1220	910

Averages.

Number.		Height.	Cephalic Index.	Nasal Index.	Facial Indices.		
					A.	B.	C.
1–5	Waganda 5.	mm. 1649·6	72·6	76·8	114·3	126·0	98·1

Notes on People Measured.—1. Kanjambo, a Mganda. Age, about 26; birthplace, Mukuno; skin, dark brown with reddish-yellow ground; iris, deep dark brown; conjunctivæ, light yellow, with orange-coloured spots; hair short, curly, black, dull; very scanty beard; body very well nourished.

2. Mukuango, a Mganda. Age 48–50; skin rather lighter than 1; badly nourished; no fat; little muscle.

3. Kikonja, a Mganda. Age, about 25; skin, bistre brown; iris, deep brown; conjunctivæ nearly white, having a slight yellow

tinge; head shaved; a few black hairs on upper lip; pretty well nourished; pock-marked; second toe on foot a little longer than first; birthplace, Buriaki.

4. Kitasmibo, a Mganda. Age, about 23; skin dirty senna brown; hair short, curly, black, dull; few hairs on upper lip; pock-marked; birthplace, Dunuga.

5. Kibata, a Mganda. Age, 44; skin nearly sepia-brown; lips a little darker; iris, deep dark brown; conjunctivæ, dirty yellow; hair black, short, curly, dull; a few hairs on upper lip, black, curly, bright; ears small, with small lobes, lying well back; nails light; body fairly well nourished, not very muscular.

The palms of hands and soles of feet of all the Waganda are a lighter shade than the skin; their teeth are all good, none extracted.

Anatomy and Physiology.—The temperature taken in the axilla for five minutes, the subjects being at rest in the shade, at about 9 A.M., averaged 97·6 F. (150 observations taken). Respirations under like conditions averaged 16, pulse 68.

The Waganda do not bear cold very well. They usually keep up a fire in their huts during the cold nights, and in the early mornings they are always to be seen sitting near a good fire. The sun seems to have no untoward effect upon them, and they do not use any protection for their heads. They are hardy, and bear privation well. Their muscles are decidedly red in colour, and the fat has a slight yellow tinge. The mucous membrane of the mouth is highly stained with pigment. The skin is velvety to the touch, this feeling being due to natural secretion and not to the application of grease. They do not perspire much. I noticed no peculiarity in their teeth. The voice is melodious and rather deep.

Pathology.—My residence in Uganda was not sufficiently long to enable me to give any exhaustive account of this subject. I must not, however, pass it over without some few remarks.

Phthisis is not very prevalent in Uganda, but I saw some eighteen or twenty well-marked cases. It is recognised by the natives as an incurable disease. It is treated by the actual cautery applied to the chest walls, by cupping, and also by decoctions of various roots to relieve the cough. Cows' horns are used in place of cupping glasses.

Small-pox occurs in epidemics, and is very fatal. It is rare to find persons pitted, for very few survive an attack. The disease travels from east to west, and according to native tradition it first made its appearance after the arrival of a caravan from Unyanyembe. Persons attacked by it are to a certain extent isolated; they are placed in a small hut in which a large fire is burning; no meat is given them, and the pustules are opened by a thorn, the body being often smeared by butter or oil. This disease has caused so much ravage in the country, that at last the people have connected it with a deity supposed to reside at the top of Mount Gambaragara, and in times of epidemic offerings are made in the hope of staying the scourge.

Toothache does not occur, at least I never heard of a case; but sciatica and lumbago are fairly common. Treatment for these disorders is the application of a red-hot iron, which is usually attended by good results. Cholera has visited Uganda on several occasions, but diarrhœa and dysentery are not very common. A good number of the people suffer from bronchitis, and rheumatism very frequently attacks them.

With regard to malarial fever, those natives who are fairly stationary in one district suffer comparatively little, and from but slight attacks of ague, but after removing to a new district much severer attacks are experienced. It is frequently observed that after war, a number of men are struck down by severe malarial fever. The Waganda have several medicines for treating this disease; all cause profuse perspiration. It was impossible for me to ascertain the nature of these drugs, as the medicine-men regarded me with jealous eyes, and absolutely refused to satisfy my curiosity. On several occasions, when the king told them to show me the various drugs they used, they tried to mislead me by producing valueless specimens.

Ophthalmia is not very common, although cases do at times occur. Blindness is very rare; I only heard of one blind man.

Neither are skin diseases very common; I saw a few cases of eczema, and no doubt leprosy at times occurs; the people much dread it, and recognise its hereditary character. It is very common to see people covered by boils. Local applications of chewed roots are made for them.

Epilepsy is fairly common, especially occurring in girls. No medicine is used in its treatment, and if the girls suffering from it marry, their father rarely receives any dowry for them. Temporary insanity occurs; the fits last three or four days, and those affected usually retire to the jungle, returning when the fit has passed away; they are rarely violent.

Venereal diseases are very frequent, especially among the men. All varieties are seen, but it seems to have a tendency to cure. I saw thirty or forty cases in which the tertiary symptoms were well marked. The natives blame the Arabs for its introduction into the country. I found that, whenever the Waganda came to me saying that they were suffering from a snake in their insides, their complaint was gonorrhœa.

I may mention that all the diseases appear to be very acute, and there is an undoubted tendency to inflammation; but the people do not succumb readily, and appear to possess remarkable vitality. They bear pain exceedingly well, and I am convinced that they do not suffer as acutely as Europeans after an accident, although they do not evince quite so much *sang froid* as Arabs do under the knife.

Wounds heal with remarkable rapidity, and I was much surprised to see how quickly the Waganda recovered after extensive burns or ghastly gashes.

There is a class of medicine-men in Uganda, and although a good deal of superstition is mixed up with and many charms are used in the treatment of disease, they unquestionably have a remarkable knowledge of simples. Their knowledge, too, of the treatment of fractures is very fair. They also evince considerable ingenuity in the application of neatly constructed splints.

Development and Decay.—It was impossible to gain any accurate information as to the average or extreme length of life, but it may be generally stated that few very old persons of either sex are met with. Puberty is arrived at early, and women cease child-bearing at a comparatively early age. Although I examined the teeth of several hundred Waganda, I never saw a case of caries. Their teeth are remarkably well-preserved, and even in old people they are little worn. If children's teeth do not appear at the right time it is considered unlucky, but they are not put to death as among some tribes.

Hair.—The Waganda have short woolly hair, which appears to grow uniformly scattered over the skull. It is coarse and dull, and is not cultivated, but shaven periodically. It is customary at the Court for every one to have their heads shaved whenever the king has received a visit from his barber. Some of the Waganda have a little hair on their faces, and those who possess a slight moustache or beard are very proud of them. The hair from the rest of the body is almost invariably removed, sometimes by means of a razor, otherwise by depilation. The women are the usual barbers; they use a small sickle-shaped razor, which is sharp on its convex side, and they employ their own milk for lubrication. I saw very few grey headed people, certainly not more than a dozen.

Colour.—I have before mentioned the colour of this tribe, and individuals vary very little. The children are decidedly lighter at birth, but at about three years of age they correspond to their parents. The ruling families are undoubtedly of a lighter shade, but this is accounted for by their origin. Here, as in other Central African tribes, one meets with individuals having small white patches due to the absence of pigment. The natives attribute these patches to syphilis (kabalongo), and say that the amount of whiteness shows the extent of the disease. Europeans, they say, must be in a shocking state.

Odour.—The Waganda possess a national and constitutional odour. It is distinctive, but not so objectionable to Europeans as that exhaled by various other tribes. It is certainly not due to dirty habits or to cosmetiques. With one exception, the Waganda do not use any cosmetic application (*see* Customs).

Motions.—The Waganda walk with a long easy swinging stride. The body is well balanced, the head slightly thrown back and the arms are permitted to swing easily. The foot is firmly planted when walking, and the length of stride is about 28 inches. The toes are slightly turned out in walking. When standing at ease they place one foot in advance of the other, the knees being slightly bent. All their attitudes are graceful and unconstrained. Their arms hang with the palm to the side. They are very fleet runners, and spring and jump in a light easy manner, their joints being very pliable, especially fingers and toes. They occupy the squatting position when following the calls of nature as a rule, but on the march they micturate standing. Each finger can be extended separately. In pointing at any object, the whole hand, the ring, and sometimes the middle finger are employed (*see* Labour).

Physiognomy.—The faces of the Waganda are most expressive; joy, sorrow, anger, or disgust betraying themselves on the features immediately. They also possess the power of mimicry, and when delivering a message or relating an occurrence will imitate the tones, gestures, and expressions of the sender of the message or the subject of narration. Affirmation is expressed by nodding the head vertically, negation by a lateral motion. In order to add emphasis both hands are used in the same way.

Physical Powers.—The Waganda are probably one of the strongest of Central African tribes. The men will carry loads of 100 or 120 lbs. weight for 20 miles a day for eight or ten days without inconvenience. A party of Waganda sent from Rubaga to Mrooli, 92 miles as the crow flies, went and returned in five days, including a rest of half a day at Mruli.

Senses.—Sight, hearing, and smell are very acute. The army test-dots were counted accurately at 24 yards by fifteen Waganda. The sense of touch is better developed than in some other African tribes I know. The average least distances at which two blunted points of a pair of compasses could be separately distinguished by fifteen Waganda were as follows:—Tip of tongue, $\frac{1}{12}$th of an inch; tip of nose, $\frac{1}{3}$d of an inch; upper lip, $\frac{1}{4}$th of an inch; palm of the hand, $\frac{7}{12}$ths of an inch; tip of forefinger, $\frac{1}{6}$th of an inch; back of hand, $1\frac{1}{2}$ inch; dorsum of foot, 2 inches.

Abnormalities.—Albinos are occasionally met with; they are looked upon as curiosities, and several of them are retained by the king and the great chiefs as buffoons. As a rule their hair is straw-coloured, and their skin rough and coarse and of a pinkish-white colour; their eyes are very weak, and they often suffer from ophthalmia; they have very little power of smell. They have a bad repute, as they are irascible and treacherous. I could not obtain any opinion from the natives as to their origin, but they stoutly deny their being the offspring of brothers and sisters. One albino whom I personally knew was the third child of a family of four, the first two and the fourth being perfectly normal; this albino was married, and had two normal children by two different wives.

A few dwarfs may be seen about the Court; they are privileged nuisances; their behaviour is very indecent, but they are greatly petted and indulged, and often become possessed of much wealth. It is very rare to find any other abnormalities. The pure Waganda women have a custom which is so much disliked by the men of the surrounding tribes that it effectually prevents intermarriage with them. The practice is that of forming the "Hottentot apron." The labia minora are artificially elongated; of that there can be no reasonable doubt, for I have failed to find any congenital deformity in any of the children that I examined. They are early taught the necessary manipulation, and, as soon as the size of the labia will permit, a weighted appliance is fixed to the parts to help to increase the hypertrophe. The longest labia I noticed extended to within an inch or so of the knee. The origin of this practice I failed to ascertain.

Crosses.—The only intermarriages which take place in Uganda are those of Waganda chiefs with Wahuma girls, and between Waganda and women who have been taken during slave raids.

The first class of marriages produce decidedly superior offspring; the first-born children of the second class, who are generally girls, are inferior, subsequent children showing an improvement (*see* Causes that Limit Population).

Tattooing, &c.—Tattooing, which is so common in all surrounding tribes, is not practised by the Waganda; indeed, it is strictly prohibited, and the laws on the subject are very severe. To this is to some extent due the slight progress which Mohammedanism has made in the country, as circumcision is also forbidden. Any Mganda upon whom this operation has been performed is liable to be burnt to death; indeed, a few years ago some sixty or seventy boys and young men upon whom some Arabs had performed the rite were all burnt by order of the king. Teeth are never extracted, and mutilations of the body, such as boring the nose or lips, are not allowed.

Dress.—With the exception of the Wanyoro, who also clothe themselves from head to foot, the Waganda are the only people in Central Africa that are clothed in a respectable manner. Strict laws are in vogue with regard to dress, and in the streets and public places every one over about five years of age is compelled to be attired completely. Death is the penalty attached to the neglect of this law. In the harems, however, the younger women usually dispense with clothing altogether, or at most wear a simple string of beads around the waist. The national dress is mbugu, a dark cloth made from a species of fig (*see* Manufactures). The men wear a strip of this material as a loin cloth, and a large flowing robe of the same stuff draped like a Roman toga. It passes under the left arm and is tied in a large knot over the right shoulder; the arms are free, and a girdle usually of string fastens the garment round the waist. The women wear loin cloths too, but they fasten their mbugu dress just under the armpits. Instead of or added to this costume the chiefs wear skin clothing, which is made either of a whole bullock skin or of two or three goat skins sewn together, or of from twenty to forty skins of the Ntalaganya, a diminutive antelope about the size of a hare, which has a beautifully glossy coat of a rich dark brown colour. Buffalo hide sandals, in shape like a boat, are invariably worn by the chiefs, and the lower classes usually wear ox skin sandals.

When going to war the men divest themselves of all their clothing save the loin cloth, which on such occasions is usually made of hide, and many of them wear feather head-dresses.

Foreign dress is gradually being introduced, and the chiefs are by degrees discarding the mbugu in favour of Arab and Turkish costume. Ten years ago members of the Court alone were permitted to dress in foreign garb; but of late years greater freedom has been permitted on this point.

The chiefs, pages, and others at Court wear fantastic head-dresses of white or coloured pocket handkerchiefs. Some of the king's bodyguard wear the fez. Away from the capital, if head-dresses are worn at all, they are small caps made of plaited grass. Turbans are very rarely seen.

Ornaments.—The men do not as a rule overload themselves with ornaments, but they content themselves with one or two wire bracelets and a few charms hung round the neck by a small cord made out of the tail of a giraffe. The women, however, are far more gaily decorated; necklaces, bracelets, waistbands, and anklets of beads being extensively worn. All these articles are very well made; the colours are tastefully arranged, and the shapes are varied and unique. Some of the bracelets and necklaces are made of neatly carved wooden beads of home manufacture, and many of the women wear suspended over one shoulder or round the waist a cylindrical pocket, highly ornamented with beads, in which they carry their tobacco, coffee berries, and odds and ends. I must not forget to mention that some few of the chiefs wear very well made finger rings of silver obtained from Maria Theresa dollars.

Habits and Customs.—At court and in the capital the Waganda stand much upon ceremony, and this is not alone confined to the higher classes, but extends, though in a rather less extent, throughout the whole nation. If two men of equal rank meet in the street, they slightly incline their bodies and say *Kulúngi*, or the one may say *Otía*, to which the other replies *Otiáno*. Sometimes also they grasp hands, or place the right hand on the left shoulder of their friend, but this is only if they intend to remain for a short conversation. If an inferior meets a superior, he either bends forward, placing his hands on his knees; or if he has a stick, leans well forward supporting himself upon it; or if of very low rank, he kneels down, and bending forward grasps his legs with his hands, in all cases saying either *Kulúngi sébbo* or *Otía sébbo*, which is replied to by *É*. (*Kulúngi* expresses "good day," *Otía*, "how are you?" and *sébbo*, "master" or "sir.")

A woman meeting a man bends very low before him as salutation, or may even kneel, this being always the case should the man saluted be of high rank. If two men meet after a long absence, or even men and women who are relations, they take hold of each others' hands, and spreading them out throw the head over first one shoulder and then the other, at the same time making use of the following dialogue:—*Otía, otía; otiáno, otiáno; erádi, erádi; nyógi, nyógi; mam, mam;* which is succeeded by an indefinite series of *ugh's*. Members of the same family meeting in the morning do not usually make any remark. Should a superior visit an inferior at his hut, all rise and then kneel down; but should inferiors visit a superior, on entering his presence they first kneel, and subsequently at a wave from his hand seat themselves. When strangers arrive at a hut, it is usual for the occupants to offer them coffee-berries, water, and beer, and the children run for lights for their pipes. Should the visit be made at a meal time the stranger is always invited to partake. Chiefs visiting the king stoop or kneel before him; he stretches out his hand, which they touch between both theirs, after which they place their hands on their lips. If any one receives a favour of the king he thanks him in a peculiar manner. He kneels down, and placing both hands together he sways his body backwards and forwards, his hands rising and falling on either side of his face, while he says *Nyanzig* (I thank), repeating the word and action some twenty or thirty times. He then suddenly falls flat on his face, and commences to beat the ground with his hands and cheeks, the head being rotated at each prostration, first one cheek and then the other touching the ground, the legs being vigorously kicked at the same time. At court it is customary if the king laughs, for every one to laugh, at the same time placing the hand before the mouth. If the king sneezes, everybody sneezes; should the king have a cold, every one simulates one; and as I have before mentioned, if the king visits his barber, every one does the same. Should a favour be requested by a high chief and granted by the king, the chief snatches up a stick, charges towards the king, executes a dance, and expresses his gratitude with exuberant compliments.

On all occasions rules of precedence are strictly enforced. Strangers rank next the host at social gatherings.

Flattery is very commonly practised, but this is less so in the country district than at the capital, where an artificial polish exists.

No remarkable ceremonial customs obtain in Uganda, nor are there any ancient feasts or harvest festivals.

Should a man meet any of the king's wives in the street, he turns aside and averts his head. When at court, too, men are very careful not to look at the king's women, as they might be charged with flirtation. On one occasion, one of my servants nearly lost his head by not knowing this rule. I had taken him up to court to vaccinate him in the king's presence, and whilst I was preparing to do so, he commenced a mild flirtation with one of Mtesa's wives. The chiefs were intensely indignant, and demanded his execution, but the king for once listened to my protestations, and a good laugh at last ended an awkward scene.

Speaking of women, it is the custom for strangers to be provided with temporary wives in Uganda. Unfortunate Europeans who refuse the proffered favour are despised by the men and scorned by the women. Mtesa used to be very sarcastic on this subject, and referred with great delight to Solomon's wives. On one occasion I gave great offence by refusing the munificent gift of eighteen dusky beauties. I suffered for it, however, by having my supplies of food cut short. This may perhaps be as well explained, as it will illustrate another custom. The king's women are allowed to pillage right and left, and Mtesa, who had got tired of supplying my voracious appetite, thought he saw a way out of the difficulty by providing me with a foraging party. The ladies were highly indignant at my supposed depreciation of their charms.

The only occasion for a set speech in Uganda is when a chief or a person of high rank receives a present. If it is small, he takes it in his right hand; if too heavy, he lays his hands upon it and makes a speech of thanks to the giver, extolling the value of the present in exaggerated terms.

For other customs, see under various headings, such as Meals, Treatment of Women, &c.

Habitations.—The first look at a Waganda village informs the traveller that he is in a region inhabited by a tribe very different from any he has hitherto seen. If the place is of a considerable size, broad, clean streets are found between the various compounds. The groups of huts are surrounded by gardens enclosed in well-built wickerwork walls, made from the tall tiger-grass or sugar-cane, supported at intervals by a species of fig tree, which throws out a large crown of branches affording pleasant shade. Above these hedges may be seen the conical thatched roofs of I suppose the largest huts in Africa. Even in small villages the streets though narrower are well kept, and it is rare indeed to find a hut without a courtyard in front of it. It is remarkable also that the streets are straight, and that the fences are straight also instead of the usual circular structures seen almost everywhere else. The compounds inhabited by the principal chiefs are very large; there is only one door, just inside of which a small hut is erected for the porter. The whole of the enclosure is divided by fences into gardens and courtyards, and in each yard are one or more huts. In about the centre of the compound stands the largest hut, which is occupied by the chief. The women belonging to his harem inhabit others beyond it, and separated from it by a strong hedge containing a door. The huts between the chief's dwelling and the main entrance are allotted to the slaves or are used as store-houses.

The huts are dome-shaped in form, and being thatched down to the ground look like huge bee-hives. The materials employed in erecting them are the stout stems of the tall tiger-grass, poles made from the fig trees, and grass. They are constructed as follows:—A fine ring of grass, closely enveloped with the fibrous outer part of the banana stem, is laid upon the ground, and a number of tiger-grass stems are implanted in it and securely tied to it with strips of papyrus. Then a second and third ring are added at intervals of about 15 inches. At length when the curvature of the rings becomes sufficiently slight to allow of the tiger-grass stems being bent without breaking, the rings are formed of them instead of the fine grass employed at first, the whole umbrella-shaped frame being gradually raised as the work proceeds. This forms the framework for the top of the roof, and when finished it is turned over and raised by means of poles to its requisite position. The ground to be occupied by the hut is then covered with poles in parallel lines but decreasing in length from the centre outwards. These support the roof and also form a scaffolding to enable the builders to complete the rafters of the roof and subsequently to thatch it. Long bundles of grass are now tied to the ribs to form the thatch, beginning from the bottom, and finally a peak, formed of a large sheaf of grass very tightly bound together, is added. The free edge of each layer of thatch is carefully trimmed to give it a regular appearance; inside the hut wickerwork walls are constructed, the pattern in many cases being extremely neat.

A large door 8 or 10 feet high is cut out of the side of the hut, over which a neatly curved porch is erected. When this is done many of the poles supporting the roof are removed, and the interior of the hut is divided by numerous partitions of tiger-grass into various compartments, in the innermost of which the owner's bed is constructed. The floor of the hut is level and beaten firmly by clubs; the door is of wickerwork, made to slide backwards and forwards, and fastened behind by a bar and pins; handles are placed in the middle of it, both inside and out, to move it with. No aperture is left for the smoke to escape.

Outside the hut a bank of earth is placed all round, consolidated by wetting and stamping it, in order to prevent the water soaking into the house during the heavy rains. The floors of the huts are carefully covered with soft fine grass; first a small bundle of even lengths is placed on the ground, another at right angles to it and partially overlapping it, and then a third at right angles to it, and so on. Some of the huts, which one might term summer-houses, are lightly built of wickerwork walls and a light thatched conical roof. The wickerwork is often composed of various coloured grasses, and the patterns woven are varied and chaste. The chiefs pride themselves very much upon their houses, and should they find the slightest mistake after they are finished they have them pulled down and rebuilt; the builders in such a case getting no compensation.

A hut here and there may be seen with gable roofs and vertical walls, but they have probably been copied from foreigners and do not need description, save that the walls are composed of three layers, the inner and outer ones being of wickerwork, and the middle one of grass some 2 feet thick.

Furniture.—In the larger establishments huts are provided for different purposes. There is first a reception hall, where the owner receives his guests; next his private hut, where he sleeps, has his meals, and in which he keeps his greatest treasures. Then there are storehouses; one for dried plantains, another for semsem seed, which is kept in large earthenware pots or wickerwork baskets; another serves the purpose of a cellar, and in it may be seen innumerable large bottle gourds filled with the native drink, plantain wine, neatly corked with banana leaves. Another hut serves as a kitchen, and in it are several fireplaces constructed of three stones. People who only possess one hut use its various partitions for the different purposes just described. From the poles which support the roof baskets of various descriptions are hung, suspended by ropes, tied to the poles by a complicated clove hitch. The beds are made of wickerwork, and raised a foot or two from the ground; they are covered by hides and Mbugu cloth. In many of the houses the walls are hung with Mbugu cloth, which is often dyed in various patterns. The huts are remarkably clean, and on account of their large size one is not so much oppressed by the smoke from the fire as is so usually the case in African dwellings. The only drawback to comfort is the grass carpet, which harbours an army of fleas. All stores of tobacco, coffee, &c., are neatly packed in banana leaves and tied with string. Remarkable order obtains in the huts, a place for everything and everything in its place being the universal practice.

Fire.—Fire is obtained, whenever required, by friction, one piece of wood being rotated by the hands in a small hole cut in a piece of hard wood. Wood is the only fuel used. Fire is carried from one place to another by means of a slow match made of Mbugu cloth. A glowing ember is carried from the fire to light pipes, by either two sticks or neatly made iron tongs. At night torches, composed of strips of wood from a resinous tree, are used when going for any distance; this is partly to scare away wild animals.

Food.—The Waganda subsist chiefly upon a vegetable diet, and the banana, of which there are several varieties, is the staple food. The varieties have all different names; that named minvu is eaten raw; nakalalulu, kibuzi, gonya, and mizunzu are the kinds used only for cooking. The bananas grow everywhere, and require little or no cultivation save pruning, which is performed by old women. The sweet potato is next in importance as an article of diet, and is the chief vegetable cultivated. The coffee tree is extensively grown—the berries are very small, and they are eaten whole; nearly every one carries about with him a small wicker box containing dried coffee berries, and should he meet a friend he offers him a few berries as one might offer a pinch of snuff. Small quantities of the following plants are grown:—Sugar-cane, a kind of red spinage, casava, maize, sesamum, millet, tullabone, *Helmia bulbifera*, *Colocasia antiquorum*, several species of beans, a species of solanum, and two or three kinds of pumpkins. The principal edible fruits are—mpafu, a fruit like a damson with a very hard stone and a sweet nut-like kernel, and matungru, a species of amomum.

Arab traders residing in Uganda, have introduced the cultivation of wheat, rice, guavas, papaws, pomegranates, tomatos, and onions, and their cultivation is gradually spreading among the natives. Radishes and *Hibiscus esculentus* have been introduced from Egypt.

Although there are a good number of fowls they are seldom eaten, and eggs are also rarely partaken of.

Beef, mutton, and goat's flesh are all eaten, but they are great luxuries, and can only be afforded by the well-to-do. The best meat by far is the goat's flesh; when young it is tender and well flavoured. The beef is tough and insipid and very lean, and sheep are very scarce. Porcupines are also eaten.

Near the Nyanza and in the islands of Sesse fish is largely consumed. There is a great variety, from the diminutive mukeni, about the size of whitebait, to the large kambari, which often weighs 100 lbs. Milk is used to a considerable extent; as a rule sour milk is preferred. Butter is made as follows:—The evening and the morning milk are mixed, set aside for an hour or two, and then shaken in gourds until the butter is formed; it is then placed in small baskets lined with banana leaves. Cheese is made by the curds being strained through a grass sieve; they are then wrapped in a grass mat and placed under a heavy weight. In some parts of the country the people will not drink milk, as it would entail their having to do with cattle (*see* later). Locusts and ants are much relished; they are generally fried. Salt is extremely scarce, and is considered a great luxury; it is imported from the Albert Nyanza. Antelopes, buffaloes, and elephants are all eaten as opportunity serves. Earth is occasionally eaten (*see* later).

Cooking.—With the exception of milk and one species of banana all articles of food are cooked. Women usually perform all culinary operations save when the men are hunting or at war. There are no ceremonies or superstitions connected with cooking, and the food for both sexes is prepared together, but it is eaten separately (*see* Meals). In large establishments one or more huts are set apart as kitchens, but even those families who only possess one hut cook indoors, probably on account of the rainy climate and the sudden storms. There are comparatively few cooking utensils used in the preparation of food. The pots employed for most purposes are large globular earthen vessels holding about two gallons, and having very wide mouths. The bananas are cooked as follows:—A small quantity of water being placed in the pot, sticks are arranged above it, upon which banana leaves are laid. The unripe fruit is then peeled and placed upon the leaves so that it may be steamed. If meat or fish is to be cooked at the same time, young banana leaves are taken and the greater part of the midrib removed. They are then held over the fire to make them supple, and the meat is wrapped tightly in them and placed on the top of the bananas. This mode of cooking renders the meat very tender. All the gravy is retained in the meat and is served up with it. Sometimes meat is baked in pots; if so, two or three sticks are placed across the bottom to prevent it being burnt. Sometimes the meat is cut into small strips, skewered on sticks, and roasted over red-hot ashes. Some kinds of bananas and the ears of maize are roasted in the ashes. If a sheep or a goat is to be roasted whole, a stake is driven through it, and supported on forked sticks over a bright fire. The stick is turned now and then, and sometimes the meat is basted with oil or rubbed with fat, but no precautions are taken to collect the dripping. No ovens are used, nor are hot stones employed in boiling. The natives prefer the meat well cooked and fresh, high meat being very rarely eaten. The cooking utensils are carefully cleansed after use. Bread or cakes are unknown, save a kind of cake made from banana flour. The dried bananas are pounded in a wooden mortar with a wooden pestle, and the flour is then either mixed with water and boiled as porridge or else baked in an open pot over the fire so forming a cake. Fish and meat are prepared for future consumption by smoking or drying in the sun, but they are afterwards further cooked either by steaming or frying before use. Bananas are also preserved by being split and then dried in the sun (*see* War). Kitchen middens are formed in one corner of the compound not far from the kitchen, but they are periodically removed to the plantain groves or forest. The cooks wash their hands before commencing operations and also before serving the food.

Manufacture of Drinks.—Brewing is extensively carried on in Uganda, as the Waganda have an inveterate objection to drinking water, and many of them boast that from early childhood water has never passed their lips. Almost everyone knows how to manufacture some kind of drink, and men and women, boys and girls, alike engage in this occupation. Two kinds of wine and two kinds of beer are manufactured :—Mubisi, fresh plantain wine, which is a perfectly teetotal drink; mwengi, an intoxicating plantain wine;

mlamba, a non-intoxicating beer made of banana juice with a small quantity of boiled millet seed; and malwa, which has a greater quantity of millet seed added, and is very inebriating.

The Arabs have introduced the manufacture of spirits from mwengi, and distil a liquor from it which contains a very high percentage of alcohol.

The mubisi is made as follows:—A large hole is dug in the ground; it is lined with banana leaves, filled with green bananas, and covered over until the fruit is quite ripe. The bananas are then peeled and mashed with fine dried grass in a large wooden trough, boat-shaped, with a funnel end. A little water is added, the whole is mixed up either by the hand or with short wooden sticks; the trough is then covered with banana leaves, and the mixture allowed to stand for an hour or two. It is then taken out, and the liquor strained through sieves made of grass into large bottle gourds, being then ready for use, and forming a sweet, non-intoxicating pleasant drink.

To make mwengi the above decoction is set aside for three days, when it ferments and becomes a slightly acid and refreshing drink, but it is very inebriating. Malwa and mlamba are made by simply adding a definite quantity of boiled millet seed to the mubisi, setting it aside in large earthenware jars, and stirring it from time to time for two or three days. No substances are added to any of these drinks to change their flavour.

These drinks are never stored; they are made as required, and consumed by the evening of the fourth day. If the mwengi be bottled and kept in a cool place for a couple of months, it tastes very much like champagne.

Meals.—The Waganda usually partake of three meals a day—breakfast at about 7 A.M., dinner at noon, and supper soon after sunset. Each household provides its own food, and eats separately. There is a slight difference among different classes in the arrangement of meals. As a rule in the upper classes the master and a few of his wives eat together, the head slaves eating in a separate group; the remaining wives, children, and slaves eat in their own huts. In smaller establishments the men and women eat in separate groups; while among the lowest class of peasants, where of course the numbers are not so great, men, women, and children eat together.

Among all classes the meals are served in identically the same way. Before eating the hands are washed, either with water or with circular napkins cut out of the succulent stem of the banana, which contain so much sap that no water is required. The meals are served either in the hut or in the courtyard; this depends upon the weather. Part of the floor or ground is covered with a layer of banana leaves, on which the food is placed in wooden bowls or wickerwork baskets. It is the custom at the palace and in the large establishments of the head chiefs for all the food for the mid-day meal to be carried before the king or chief, previous to its being placed before their retainers. The food is covered on its way from the kitchen to the table by either banana leaves or neatly plaited grass mats or wickerwork covers. Mtesa, the late king of Uganda, used to insist on examining various dishes as they passed him, and if they did not satisfy him the cooks were severely punished. The Waganda all eat with their fingers; they never drink during a meal. After the meal is over they wash their hands, then drink. Coffee berries are then handed round and are chewed, but never made into a beverage. They are gathered before they are ripe, boiled, and then dried in the sun. When chewed they have a pleasant aromatic taste and tinge the saliva green. After a few berries have been eaten, pipes are produced, and large quantities of banana wine are consumed. There is no sequence in the order of dishes; all the food is placed at one time on the ground, and after the head of the household has commenced to eat all fall to. The meat is cut by one of the slaves, either with a knife or a tiger-grass splinter. The only person who dines alone is the king.

The following account of a dinner, at which I was present, will afford a glimpse of the mode of procedure at a chief's house:—One day I was visiting the katikiro (prime minister), and he asked me to remain to dinner. Several boys entered the hut to lay the cloth; this consisted in covering two portions of the floor with fresh banana leaves; around these improvised tables the guests seated themselves on mats placed on the floor—the katikiro, about ten other chiefs, and myself at the one, some twenty of our host's wives at the other. I may mention that as each woman entered the hut she threw off all her clothes; the first one rather hesitated when observing me, but after a laughing remark from her husband she made herself at home. As soon as we were seated, large basket trays, piled up with steaming bananas and steamed and roast meats, were brought in and placed upon the table, and each guest was provided with a banana napkin with which to wash his hands before eating. Then, at a sign from the katikiro every one began to eat, helping themselves with their fingers. When the host wished to honour a guest he handed him a tit-bit of meat or a pinch of salt, salt being very rare in Uganda. He also called once or twice to one of his wives, who came across from her table, and kneeling down beside him he placed a pinch of salt in her mouth. During the meal, three or four musicians played pleasing melodies at the door of the hut. As soon as dinner was over, napkins were again handed round and hands were washed; the fragments with the cloths were removed, and banana wine was handed round. We then all removed into a private yard, where native beds were placed in a semicircle under the trees. The katikiro lay down on the centre one, reclining on one of his wives, while the wife of the day (*see* later) reposed beside him; the rest of the party, that is, the chiefs and myself, reclined on other beds, whilst the women grouped themselves behind us. Pipes were then lit, and beer again handed round by slave boys to all save the host himself, who had an immense bowl of beer placed on a stool near him, from which his wife kept him constantly supplied. For about half an hour general conversation took place, then a minstrel, ornamented with a fantastic head-dress, and having a long goat's beard attached to his chin, appeared with a harp. He played and sang for some time; the melody was sweet, and the time which he kept with his goat's beard was good. We were then entertained by wrestling matches, followed by a kicking match between some boys, and lastly by dancing, both solo and in groups; in this the women took part. Some of the dances were very graceful and good, but of others the less said the better, as they were indecent in the extreme. By this time it was dark and torches were lit, which made the dancing appear all the more grotesque, but as the party was getting too lively I said good-bye, and was escorted home by four torchbearers, it being always the custom in Uganda for guests to be lighted and escorted home.

There are no ceremonies used at the commencement of meals.

Cannibalism is unknown in Uganda, but an idea prevails that there are people who roam about the forest at night, and kill and eat wanderers who are not provided with a light. They are supposed to possess the power of making themselves invisible at will and of being invulnerable. This propensity is considered hereditary, and is often attributed to people as witchcraft might be. They are avoided by their neighbours, who will not employ them in any way, and no one will marry a woman who comes of such a stock.

Narcotics.—Both men and women in Uganda are inveterate smokers, and commence the practice at an early age (10 or 12). The king (Mtesa) was the only person I knew who never smoked, and who objected to the smell of tobacco. Before going into his presence it was the custom to chew coffee berries to take away the smell of the smoke. Tobacco is the only substance smoked; it is never used as snuff, nor do they chew it; it is of a very pure quality, and never mixed with other substances. It is indigenous, and varies very much in strength, some being comparatively mild, but most of it very strong. A good deal of care is exercised in the cultivation of tobacco; the plants are not allowed to seed, the flower buds being picked off before they open (*see* Agriculture). The leaves are dried in the sun, made into neat packets of 10 to 20 lbs. weight, tied up in banana leaves, and suspended in the huts till required for use. Neat tobacco pouches are in use; some are made of skin, others of plaited grass, others again in the shape of grass boxes. The patterns made are—bands, chevrons, chequer, concentric rings, spiral, and guilloche. Cigars are unknown, pipes, the bowls of which are made of clay, and vary in size, being used. The bowls are very thin, and beautifully finished and smooth, but as no flux or glaze is applied they are very brittle. Two shapes of pipes are used—one with a round bowl and very small, the other conical, and holding half an ounce or more. The stems are composed of wood, and are 4 or 5 feet in length, and no mouthpieces are employed. Water-pipes are not used, and the pipes are rarely passed from one individual to another. With the exception of coffee and sugar-cane, no substances are chewed. The old women when at work in the field sometimes smoke a pipe with a short stem, which they hold between their teeth; otherwise they smoke the ordinary long-stemmed pipes. Tobacco smoking does not appear to injuriously affect the people.

I was unable to find out any tradition of the importation of tobacco.

Occupations.—Although the Waganda cannot be said to lead hard-working lives, all find more or less continuous employment, save those of the higher ranks. House building and fighting may be said to be the chief occupation of the men, and the cultivation of the ground, with household duties, that of the women; but, as the sequel will show, a good number of the people of both sexes are engaged in various arts and manufactures. One thing only they will never do, and that is to tend or breed cattle (*see* later).

The following is a sketch of the Wagandas' daily life when at home:—

A little before sunrise they get up, and wrap themselves in their mbugus and build up large fires for warmth. Pipes are then lit, and men and women smoke until breakfast is ready, it having been prepared by one or two members of the household. By the time breakfast is finished the sun is well up, and they then go about their several occupations until dinner time. After dinner they smoke again, and it is only the poorer classes and slaves who do any work in the afternoon. No work is done by anyone after supper, when the whole of the inhabitants sit round the fires, smoking and drinking beer, till 8 or 9 o'clock, when they retire for the night.

Morals.—Judged by the standard of surrounding tribes, the Waganda cannot be said to have very high morals. There seems to be an underlying current of feeling that a man's present life will affect his future state, but practically they do not seem to be influenced by this feeling. A standard of right and wrong no doubt exists, and in many things strong public opinion condemns the guilty and rewards the virtuous. Popular legends to some extent keep alive this idea; deeds of bravery or of cowardice are celebrated in tale and song, and children are early influenced by the recitation of such traditions, which doubtless help to shape their lives.

The Waganda are liars, and consider it a virtue to be proficient in the art. It is thought wrong to steal, but it seems to be a much worse offence to be found out. On the other hand, the people are kindly and courteous, given to hospitality, and not avaricious.

They are to a certain extent indolent, but then the necessities of life are easily obtained. They are cleanly, but drunken, and many are gluttonous; drinking is not condemned—gluttony is. They are very indecent.

Human life is little respected, the people being valiant and not afraid to die. Unless strongly moved by passion, they cannot be said to be cruel, and although passionate they are not revengeful, that is amongst themselves; against their enemies they cherish very strong feelings of hatred, and woe betide the district into which they make a raid.

Children are well looked after, and the aged men are respected and kindly treated. With the women it is otherwise, as on account of polygamy, they hold a low place in the social scale. Before marriage they are fairly chaste, afterwards, notwithstanding the severe laws on the subject, they are very lax.

Crimes.—It is rather difficult to give definitely the state of the criminal code, for this reason, that although the Waganda have definite laws with regard to the punishment of crime, yet they think very lightly of it should they escape detection. Crimes against the person may be summed up as follows:—Homicide is considered criminal, except in cases where there has been great provocation, or in some rare cases where a son kills his old father, in order to inherit his honours. Suicide is very rarely practised, and is greatly condemned. Maiming, abduction, and assault may not as a rule be revenged by the party injured, but the ordinary legal procedure must be set in motion. With regard to adultery, persons taken in the act, if the adultery is committed with women belonging to the king or great chiefs, may be summarily executed; otherwise the case must be tried by a judge. Unnatural offences, which have been introduced by the Arabs, are intensely abhorred; they are happily of rare occurrence; the stake is the punishment. Arson and theft are the principal crimes against property. Arson is considered to be an offence against the community, whereas theft is only an injury against an individual. Crimes against the State are very rare; when they occur it is usually on the instigation of one of the sons of the reigning monarch.

Until quite recently, offences against religion have been unknown, but, since the Arabs and European missionaries have entered the country, this has changed. Those who undergo the rite of circumcision are put to death at the stake, and many converts to Christianity have suffered the same fate. (This last since Mtesa's death.)

There is no distinct criminal class.

Agriculture.—There being two periods of maximum rainfall in the year, there are two harvests. The cultivation of the ground is almost entirely carried on by women. The gardens of the Waganda are, as a rule, wonderfully well kept, the various plants being cultivated on separate beds, which are carefully weeded and divided from each other by broad straight walks. The hoe is universally used both for turning up the earth and for removing weeds. In making fresh beds for any plant the soil is generally turned up to a depth of about 9 inches. I have already enumerated the articles grown in these gardens, with the exception of tobacco and the bottle gourd (*see* Food). The tobacco is usually sown pretty thickly in small beds, but when the plants are a few inches high they are carefully transplanted and placed in straight rows. The bottle gourds are also widely cultivated, the plants being trained over trelliswork frames or over the huts, the object of this being to allow the fruit to grow suspended in the air, that it may preserve its shape. These gardens are separated from one another and from the road by high fences of tiger grass or by hedges of euphorbia and other bushes. The bananas are banished from the gardens because their thick foliage would interfere with the growth of other plants. They are grown in plantations; but here, too, great care is taken to keep the ground clear by gathering up the fallen leaves, which, together with the weeds from the gardens and the produce of the kitchen middens, are heaped up round the banana stems, this being the only attempt made by the Waganda to manure the ground. The only tradition connected with the introduction of plants into Uganda is the legend which refers to the banana (*see* Mythology). Each household cultivates its own land as a rule, but persons who possess more produce than they require sell it to others. It can hardly be said that there are crops, as so little grain is grown. The banana is of great importance, as it forms the staple food for the people; its leaves are used for cooking purposes, as paper for packing up parcels, as dinner napkins, plates, and cups. The pulp of the tree is employed for washing the hands instead of soap, and string is also made from the fibres of the plant.

Cattle.—The Waganda do not tend cattle; they have a great objection to having anything to do with them, and the herds are kept exclusively by Wahuma or Wanyambo herdsmen. The king and those chiefs who possess cows always have herdsmen in their employ. The prevailing colour of the cows is brown or iron grey; they are large bony animals. Charms are hung round the cows' necks to make them prolific, and sometimes also bells to prevent them straying. They are bad milkers, giving only from half a pint to a pint and a half at a time, and they give no milk unless the calf is suckling; should it die, milk fails. Women are never allowed to milk the cattle. When their horns begin to form they are often destroyed by the application of a red-hot iron; this is only done to a special breed which have very long horns. There are other breeds with no horns or with very short ones. Castration is not practised. The number of cattle in Uganda is remarkably small, when contrasted with the vast herds which constitute the bulk of the possessions of surrounding tribes. Besides being the herdsmen, the Wahuma are the chief owners of cattle, and they live mostly upon a meat and milk diet.

A great many goats are found in Uganda; they fatten quickly, are very prolific, but are mischievous and damage the gardens. They are generally herded by children, and in large establishments huts are erected into which they are driven at night. The poorer people, who only possess a small number of goats, permit them to sleep in their own huts.

The sheep belong to the Somali breed; they are few in number, and by no means well favoured.

Fowls are to be found in most Uganda villages, but they are very lean and are never fed. A few wretched cats may be seen here and there; they are domesticated, but are of no use as rat or mouse catchers.

Twenty years ago nearly every Mganda had a dog, and this custom still obtains in districts away from the capital. There, however, owing to the influence of the Arabs, who believe that dogs are unclean, the practice has to a certain extent died out. Some of the dogs resemble a smooth English terrier, and are generally tan coloured. They are tied to a leash of very strong cord, which the owner holds in his hand or hangs round the wrist with a running knot. In hunting antelopes, however, the dogs are set free. They are attached to their masters and are well treated. Hydrophobia is unknown.

Manufactures.—The Waganda are very ingenious and clever workmen. All the articles they construct are made with great taste, neatness, and exactitude. They also very readily copy, or adapt to uses of their own articles of foreign manufacture introduced into the country. I shall now describe their different trades in order, and commence with

Pottery.—Pottery is a distinct trade, and a good number of men and women are engaged in it. Boys and girls are at an early age initiated into the art. Two kinds of pottery, a coarse and a fine variety, are manufactured. Vessels for carrying water and for cooking are made of the coarse kind ; they are of all shapes and sizes, and are well proportioned and elegant in outline. The water jugs are round in form, made to contain one or two gallons, and have a narrow long-lipped neck, while those used for cooking purposes are hemispherical, having no necks but a neatly curved lip. Already the Waganda are beginning to imitate European pottery, and plates, basins, and mugs may at times be seen. Drinking cups and tobacco pipes are made of the finer clay. They are very thin aud beautifully worked, but all the pottery is easily broken, as no flux or glaze is used. The fine clay contains a good deal of mica; it is procured from the beds of streams, and is probably formed from the detritus of igneous rocks. No potter's wheel is used. The clay is first freed from stones, is mixed with water, and beaten with wooden clubs on a wooden block into a proper consistency. A lump of this dough is then taken and formed into shape by the hands; a wooden spatula is held in the right hand, the left being used to rotate the clay. No moulds are used in the manufacture of pottery. The pots are ornamented both by scoring with a sharp-pointed stick and impressing with a wickerwork pattern. The most usual patterns employed are circular dots, elliptical punch marks, bands, parallel incised lines, chequer concentric rings, guilloche, spiral pattern, and basketwork. The pottery is burnt after being dried in the sun in large permanent holes dug in the ground. When first burnt it is grey, but after being hung over a smoky fire and polished it acquires a permanent black colour. The pots are first polished with a pad of mbugu, and finally by the palm of the hand. Drinking bowls and both kinds of pipes are sometimes coloured with red oxide of iron or with white clay.

Basketwork.—The wickerwork made by the Waganda is very good indeed; the materials they use are grass and the young leaves of the wild date palm. Baskets of all forms and sizes, trays, covered boxes, fish traps, shields, drinking tubes, and various kinds of mats are made. Some of the work is extremely fine and elegant, and the patterns are very graceful. Both stiff and flexible basketwork is made, and coloured grass is often employed. Blue, black, and red dyes are also used for dyeing the grass. Wickerwork coverings are constructed to protect jars and pots. The large, shallow, circular baskets used as dishes are made as follows:—A continuous ring of fine grass, bound closely round with plantain fibre, is coiled on itself in a wide spiral, the individual rings being sewn strongly together with the same fibre, and so carefully and tightly are these baskets made that they are perfectly water tight. (Fish Traps and Shields, *see* Fishing and War.) Mats for all kinds of purposes are made of grass or of strips of the young leaflets of the wild date palm. These leaflets are dried and bleached in the sun, and then cut carefully into strips and plaited into large mats, which are very pliable, and will roll up without cracking or splitting. The large sized mats are used to carpet the floors; smaller sizes to cover the native beds, and others again are carried by slaves for their masters to rest on when away from home. The tubes which are used for drinking purposes are made as follows:—A hollow curved stick is taken and covered with close fitting basketwork of date palm leaves dyed various colours, while at the bottom is a strainer terminated by a "crown" knot. Small square covers are also constructed for jars and drinking cups. Different styles of plaiting and patterns are employed for almost every purpose for which basketwork is used.

Metal Work.—The work of the smiths is far superior to any seen among the neighbouring tribes. The iron found in Uganda is of excellent quality, and is very abundant; it is obtained by smelting from the ore. The smelting ovens are conical in form, about $3\frac{1}{2}$ feet high, layers of charcoal and iron ore being alternately placed in them. Six, eight, or ten pairs of bellows are employed for the blast; they are worked by men and boys in time to a chant. The tools used by the blacksmiths are of a very primitive nature. Oblong stones of various sizes are used as hammers, large flat ones as anvils, and the tongs are usually merely pieces of green wood with a cleft in them. A few iron hammers, files, and tongs have been imported from Zanzibar, and the Waganda smiths soon learn to imitate European work. For instance, they convert flintlock guns into percussion guns, and they make brass cartridge cases, which, though only cast, are wonderfully true and smooth. The bellows which supply the blast for the clear charcoal fires used by the smiths consist of two earthen pots firmly bedded in the ground; over the mouths of these a pliable skin is fastened, while to the centre of this hollow sticks are tied. A boy holds one stick in each hand and works them up and down rapidly and alternately, closing the end of the hollow stick with his thumb as he presses it down, thus creating a constant blast. There is a hole near the bottom of each pot, on the side facing the fire, and through this the blast passes through a clay tube which conducts it to the hearth.

The spears, knives, and arrow-heads are wonderfully well made, and they also construct chains, bells, and rings for fingers, arms, and legs. The nkumbi or hoe is heart-shaped, with a long flange from the broad end, which is firmly tied to a hook-shaped wooden handle about 3 feet long. The knives are always curved, the blade being about 9 inches long and very thin; they take a keen edge. They are sometimes painted with red oxide of iron procured from an ore resembling hæmatite.

Two kinds of axes are made, the one a rude shaped piece of iron, which is inserted into a heavy wooden handle and used for felling trees, splitting up firewood, &c. The other axe is much more elegant; a broad thin blade, almost crescentic in shape, is fastened like a knife in the end of a long well-balanced handle of wood. The flat part of the blades of knives and axes is covered with a thin film of black oxide of iron, except along the cutting edge; this prevents rust.

Mtesa sent a few of his smiths to the English mission to be taught blacksmithing, and it was surprising to see what progress they made, and how proficient they soon became in the use of English tools. They seemed almost instinctively to understand what the implements were made for, and expressed surprise that they had not made such themselves.

Manufacture of Bark Cloths.—A species of fig (*Ficus ludia*), which grows abundantly throughout Uganda, is the tree from which mbugu or bark cloth is procured. The bark is taken from young trees; two incisions are made round the trunk, a third, which is vertical, joining the other two. The bark is then stripped off and the outer surface carefully removed, and it is then laid on a smooth square block of wood and rapidly beaten in time to a low chant with heavy wooden mallets. These mallets have circular grooved heads, which give to the bark a ribbed appearance like corduroy, and under their blows it quickly thins out like gold under the goldbeater's hammer. When the bark has been beaten out to the requisite thinness it is hung up to dry, and afterwards any holes which may have been produced in the beating are neatly patched with the trimmings from the edges. The thread used for this purpose is made from the bark, or from the fibres of the plantain, and a long thorn is used for a needle; the sewing is remarkably neat. The mbugu when new is of a yellow-brown tint, resembling freshly tanned leather; some of the finer sorts, however, are of a dull brick-red colour. They vary much in quality, some of the better kinds being beautifully soft, and these are procured chiefly from the Sesse group of islands. The principal fault of this cloth is that it soon decays if it gets wet. Sometimes the mbugu is dyed, generally black, or various patterns in black, red, and blue are printed on it. The tree from which the bark is removed is not killed by the operation; the wound is covered with banana leaves, which are bound closely round it, and in process of time new bark grows. A considerable number of people are employed in this manufacture; the women strip the bark from the trees and do any repairing to the cloth that is necessary, but men beat out the bark and make the cloth.

Wood Work.—A large number of joiners are employed, and although they work slowly, whatever they make is well done and neatly carried out. Milk bowls, pear-shaped, containing about a quart, are cut out of a solid block of wood; they are often highly ornamented. Drums, drumsticks, axe handles, and paddles are made in large numbers; and walking sticks, made out of a hard white wood, are beautifully rounded and polished. Small axes and knives are used by the carpenters. Fire is not employed, save for the purpose of hollowing out pipe-stems. Small carved wooden animals are also made; the carving is neatly done, but the forms are not very accurate.

Leather Work.—The Waganda are very good tanners, and manage to get their skins as soft as the best kid leather; they pride themselves very much on this art, and laugh at the unsuccessful attempts of others to compete with them. Lion skins, ox hides, buffalo hides, and the skins of leopards and all the varieties of antelopes are used for leather. In some cases the hair is removed, but generally it is left on. They first dry the skins in the sun, then stretch them out on a frame, and the inner surface is carefully scraped with a sharp knife. They are then rubbed for a long time with flat heavy stones until quite smooth; this produces a fine grain. Butter or oil is then applied in considerable quantities, and the skin once more placed in the sun; this latter process is repeated several times. Both men and women are employed in tanning. Some skins from which the hair has been removed are dyed; others have patterns printed on them, and the thick buffalo hide from which sandals are made is ornamented by either a knife or a red-hot nail. Leather ropes are sometimes used in house-building, if so it is before they are tanned, but the leather used for straps, traps, or nets is first tanned.

Dyeing.—Five colours are used by the Waganda—black, green, orange-yellow, red, and blue. The black dye is the soot of a sweet-scented wood mixed with oil; the yellow dye is obtained from a tree called the mulilila, resembling our lauristinus; it is a gum, and exudes from the bark in small drops. Unfortunately I do not know how the green, blue, and red dyes are prepared. The dyes are used in two ways; either the article to be dyed is immersed in the fluid, or else wooden stamps are used on which the dye is smeared; the most common pattern for these dyes is lozenge-shaped. Earthenware jars, pipes, &c., are coloured by sticks, the ends of which have been chewed until they very much resemble a paint brush.

Beadwork.—A good number of women are employed in the manufacture of bead ornaments; necklaces, bracelets, anklets, stomachers, and rings for the waists are made. Red, blue, white, black, and green beads are all in vogue. The patterns show a great amount of good taste, and none of the gaudy contrasts so usual amongst African tribes are to be seen. The hair from the giraffe's tail is used for stringing the beads. The beadwork is often arranged over pads made of grass tightly covered with banana fibre. Some of the little grass caps before referred to are ornamented with beadwork patterns, the beads being sewn on to them with hairs, and thorns being employed as needles.

String.—String and rope of various sizes and of various materials are manufactured. They are both spun and plaited. String is made from banana fibre, the fibre of a species of aloe, the sinews of animals, their intestines, and more rarely from wool. The long fibres are usually twisted on the thigh with the hand, which is generally wetted. In plaiting, 3, 6, and 9-ply are employed. The ropes are generally plaited, and they are made either of string or of hide. Weaving is unknown in Uganda.

Boat-Building and Navigation.—The Waganda are extremely good boat-builders, and various sizes of boats are made, from small fishing canoes capable of holding two or three men up to the large war canoes containing sixty men. The canoes are made in the following manner:—The straight trunk of a tree of the required length is taken, and the bottom of the vessel is constructed from it by cutting away the superfluous wood with an axe. It is carefully hollowed out down the middle, tapered off at both ends, and at the bow a horn is formed, which projects some 3 or 4 feet above the cutwater when the canoe is finished. Along both edges of this bottom log small holes are bored with a red-hot iron at a distance of 2 or 3 inches apart. Two long planks, hewn with an axe out of the solid trunk of a tree, are then taken, and a number of holes having been bored, to correspond with those in the bottom log, they are tied together with the root of fibres of various plants, curved boards being added at either end where the canoe narrows. These boards are curved by being placed with the ends resting on two logs of wood, heavy weights being placed between them. The planks are sloped outwards at an angle of about 60 degrees, giving additional breadth to the canoe.

The sides of the boat are then completed by other planks tied at right angles to the last mentioned, therefore vertically. Large holes are made along the lower edge of the second row of planks to receive the thwarts, which are securely tied in position by root-fibres or sometimes by thongs.

The outside of the vessel is then painted a light red, with oxide of iron, obtained by burning an ore resembling hæmatite, and then the seams are corked with plantain fibre, which has been steeped in water. The boat is finished by adding the nsanda or curved prow, the top of which is ornamented with a pair of antelope's horns, and from this to the bow a fringe of grass or feathers is fastened to give an additional ornament. The paddles are well made of a hard wood, and both hands are used in paddling. The canoes are steered by the two paddlers in the stern, and propelled with great rapidity. The Waganda are, however, afraid of going out on the lake more than a mile or so, on account of the sudden storms which arise very quickly. When compelled to go from the mainland to an island they invariably paddle along the coast to the nearest point, and then, having rested, make all speed across the intervening channel (for further information, *see* Fleet).

Fishing.—The Waganda who live on the borders of the lake and the Sesse islanders are mostly accomplished fishermen. They not only catch the fish for their own consumption, but after it is dried and sometimes smoked they use it as an article of barter with friends living inland. Various methods are employed to catch the fish. First in importance is—

The Rod and Line.—A light reed or cane, about 10 feet long, forms the rod; the lines are very fine and strong, and manufactured from the fibre of a species of aloe. The hooks are made of native iron, are usually small, and are not barbed. Freshwater shrimps and earthworms form the bait. Night lines are also employed, and are set from canoes at $\frac{3}{4}$ of a mile or a mile from the shore. Some of them are as long as 400 feet in length. They are sunk by means of heavy stones, floats of ambatch wood being used to indicate their position and aid in their recovery. Hooks of a larger size than those used in rod fishing are attached to lines made fast to the main rope at intervals of about 10 feet. The hooks are fastened to the line in two ways—either the shank of the hook is rough and the line is whipped to it, or else the head of the shank has a rough knob below, while a kind of clove hitch secures the line to the hook.

Spearing fish is not widely practised, but sometimes it forms an amusement for the boys, who use light spears for the purpose. Two kinds of wickerwork traps are employed for catching fish. One is like our lobster traps, and used in the same manner; the other consists of a large conical wicker basket, about 4 feet high, open at the large end, around which a ring of twigs is fastened, radiating inwards so as to allow the fish to enter, but preventing their escape. Eight or ten of these baskets, tied side by side, are taken out by canoes, and sunk by means of stones so placed that the baskets lie on their sides with their mouths facing the shore; they are hauled in by long ropes which are made fast to them. Women rarely fish, but boys are early instructed in the art. Women are, however, employed in cleaning and curing fish. The lake is abundantly stocked with them, but I had no opportunity of determining the species.

Hunting.—The Waganda are great hunters, and game is very plentiful. Elephants, buffaloes, zebras, rhinoceros, wild boar, 12 species of antelopes, lions, leopards, jackals, foxes, hyenas, hares, chimpanzees, and several species of monkeys inhabit the forests. Snakes are numerous, many of them being very venomous, and there is a harmless species of bright green which gives its name to that colour (a noandagala). Boa constrictors are also frequently found. Hippopotami, crocodiles, and otters abound in the lake and in the Nile, and there are a great many water-rats whose skins are highly prized. The principal birds are parrots, guinea-fowl, owls, vultures, adjutants, goat-suckers, kites, eagles, ducks, geese, storks, cranes, herons, gulls, scarlet flamingos, darters, the sacred and glossy ibis, and brilliantly coloured honey birds. Among the insects I may mention mosquitos, locusts, white and driver ants, bees, and innumerable butterflies.

There are hunters by profession in Uganda. These men are very courageous and expert. They use spears of different sizes, and generally hunt in parties of three or four. Thus they attack elephants, lions, &c., but notwithstanding their agility and bravery, many fall victims to their would-be prey. These hunters also employ variously constructed traps. For large game the most usual form is the pit-fall. The pits are about 7 feet deep and taper towards the bottom, in which spiked stakes are often inserted. They are very neatly covered over by reeds, over which are spread banana leaves, and these again are strewed with earth. Buffaloes and large antelopes are caught by wreaths composed of the branches of the thorny bush, so contrived that the thorns all point inwards. These wreaths are somewhat conical in shape, and are placed in holes scooped out of the ground. They are secured by a strong rope to a heavy log of wood or to the trunk of a tree. When the animal steps on the wreath its foot goes through it, and the thorns prevent its being shaken off. Other traps are made by suspending heavily weighted spears above the paths by which the animals go to water; they are arranged to fall as the animal passes underneath. Heavy beams of wood are also arranged with a very slight support, which, when touched, allows the beam to fall. Baits are placed beneath these traps.

A great variety of noose snares are employed. Hippopotami are hunted from boats with two-pronged harpoons. The natives are very expert in avoiding the wounded animals.

The inhabitants of several villages often join together for the purpose of driving game into nets. A large enclosure of strong rope nets is made, each village supplying its own proportion of men and nets. The animals are driven within the circle and then speared. By this means hundreds of animals are sometimes slaughtered in a day. In hunting, the man who gives the fatal wound is supposed to appropriate the horns and to get the largest proportion of meat, but a great deal of discussion and quarrelling take place in the hunting expeditions. This is more especially the case when one of the party happens to be of higher rank than the others, as he generally annexes the best of the booty, and permits his retainers to fight for the remainder. There are no laws for the preservation of game in Uganda, but certain skins (I think leopard) and a proportion of the ivory must be handed over to the king.

Meat is preserved by drying it in the sun or smoking it over the fire. The animals are skinned and cut up where they fall.

I only know of three superstitions connected with hunting. The first is, that all good luck for the day would be at an end if a man turned back after once starting out; the second, that the game should always be skinned before bringing it under cover; and the third, that when returning from the hunt a different path must always be followed from the one taken on the way out. If much game has been captured a great feast is often held at night, and fearful scenes of gluttony are sometimes witnessed. I have seen men eat until they have fallen down in a perfectly helpless condition, and have had to be carried home by their friends. Whistles are used for giving signals when hunting. The Waganda track game fairly well. Dogs are used, especially in antelope hunting. Bows and arrows are very rarely used indeed, save by the Wahuma; nor are the Waganda successful with fowling pieces, of which there are a few in the country. The spears used in hunting are the same as those used in war, with the exception of the elephant spears, which are very heavy and large, and only used for thrusting with both hands.

No poison is used by the Waganda in hunting. The only animal they are chary of attacking is the buffalo, which are very fierce. Only large parties of men attack them, and even then many casualties take place.

War.—The Waganda are very warlike; in fact, one may say that they are constantly at war, making continual raids on the surrounding countries for cattle and slaves. All the adult males are compelled to serve in the army when required, and a military organisation, having its headquarters at the capital, ramifies throughout the whole land. The number of men capable of bearing arms in Uganda is probably about 600,000, but certainly not more than half this number would be available at one time or place. The king must be considered as the head of the war office, for he keeps in his charge the war-board, which gives him a general idea as to the number of troops available. This board is covered with numerous holes, in which pegs are placed of three different colours and sizes, representing tens, hundreds, and thousands. The pegs are white for ten men, black for a hundred men, and red for a thousand men. The rows are manipulated from right to left, that is, the black and red pegs are placed to the left of the board. When an expedition is sent out the king takes as many pegs from the board as there are soldiers required, and after the return of the army from war the number of killed are deducted by the chiefs, and they return the pegs which represent the living to the king. The council of war consists of the king and a certain number of chiefs; in fact, it is composed as is the national council (*see* Government). The whole country is divided into districts, and the head chief of the district is the commander of the soldiers living in it, and is responsible to the king and council for providing the requisite number of men. Under his command are sub-chiefs, who are responsible for the soldiers inhabiting different villages. War is declared by the king sitting in council, the big war drum being immediately beaten. As soon as its sound is heard all the chiefs who are present seize their walking sticks, and brandishing them on high execute a war dance before the king, swearing fealty to him, boasting of their own prowess, and of the terrible fate to which they will deliver their enemies. The king then distributes the war pegs to the chiefs, who immediately rush forth to collect their men. The soldiers residing near the capital gather next morning outside the palace attired for battle, dressed only in loin cloths, and their faces whitened with ashes to strike terror into the hearts of the enemy. Some are also smeared with red and black paint. The king stands outside the palace gate holding a shield and two copper spears, which may be only carried by the king and the principal chiefs. He is attended by his court. A war dance is then executed, the troops passing before the king, brandishing their spears, shouting and vowing vengeance on their foes. After this parade the chiefs in command of the army are assembled and receive their orders. Messengers are then sent to the troops at a distance telling them where the trysting place is to be. Several flags and war drums are entrusted to the keeping of the army, which then sets out on the march.

The king is kept informed of the progress of the army by messengers, who wear a leopard skin cape as a sign of their office. I had several opportunities of seeing the Waganda both on the war-path and in actual fight, and was much surprised at the regularity and precision with which all their movements are carried out. On the march they send out skirmishers; their front and flank are always well protected, and they use all the natural facilities of the land both for cover and for reconnoitring their foes. When camping at night the fires are made in hollows, and screened to prevent the enemy seeing them, and sentries are placed round the camp. Commands are given both by word of mouth, drums, and whistles, and disobedience to orders is severely punished. Each chief commands his own men, but a commander-in-chief, aided by a council, directs all the operations. When the army approaches the enemy they do not commence to fight at once, but perform a war dance and curse their enemies in no very polite language, for some considerable time. They then begin to throw their spears, but soon, warming to the fray, yelling and shouting, they rush to a hand-to-hand conflict to the beat of their noisy war drums. The drum takes very much the place of a regimental flag; round it the detachments assemble, and its loss in battle is considered a fearful disgrace. In going from Rubaga to Mruli, I passed a battlefield in which the Waganda had been beaten, and grouped around the war drum I saw the bodies of more than 300 Waganda, so fiercely had they defended their standard. They are extremely brave, and have no fear of death. Their fights are often very sanguinary, and they frequently lose 30 to 40 per cent. of their men. The feats of noted warriors are celebrated in their war-songs and traditions, and warlike achievements are rewarded by an extra share of the spoil or by a rise in rank. After a battle in the open their wounded opponents are not butchered in cold blood, but are left to take care of themselves as best they may; but should a village be sacked, it is the usual custom to put all the adult males to death. The dead are not buried unless they hold high rank. A certain number of medicine-men accompany the army in the field to give aid to the wounded. Should a chief be killed in battle his followers usually run away. In returning from war nightly carousals take place, at which the female prisoners are compelled to be present and the utmost license prevails. At these festivities war songs are sung and tales are told of the heroic deeds of the honoured dead.

In every village stores of dry bananas are maintained by the head man for the use of the soldiers when they are called to war. At the same time especial contributions are levied on the villages through which the army passes on its march. When camping huts are usually constructed for the whole army, and it is wonderful to see the rapidity with which these grass shelters spring up. Four men will erect a commodious hut in three-quarters of an hour.

Women do not accompany the men to war, but the head chiefs take one or two wives and a few female slaves with them to within a safe distance. When camping, the huts for these women and for the chiefs must be first erected. Commanders who are unsuccessful may be reduced in rank or fined. In attacking an enemy's village, they sometimes use red-hot arrow heads wrapped in mbugu cloth to set fire to the dwellings.

Weapons.—The spear is the Waganda's weapon, and it is made remarkably well. The shaft is about 7 feet long, smooth, and very neatly finished. It is made of very hard but comparatively light wood; the head is 15 inches long, the blade 10 inches and $3\frac{1}{2}$ to 4 inches broad. They are very sharp, and are protected by neatly made leathern cases ornamented at the tip by plumes. The cases are joined together by a thong of leather, so that they can be suspended round the shoulders or arm when the spears are in use. The Waganda shields are made of wood, covered with wickerwork of an open zig-zag pattern. They are large enough to cover the whole body when in a stooping position. They are provided with a wooden boss in the centre, which is conical in form and hollowed out inside to reduce the weight and to permit the soldier's hand free play. Across the inside of this boss there is a wicker handle, or sometimes a wooden one, carved in the shape of a lizard or some other animal. The Wahuma possess bows and arrows in addition to spears. The bows are about 6 feet long, and unusually stiff. The arrows, which are feathered, have notched heads and extremely barbed points; they are sometimes poisoned by being dipped in the juice of a species of euphorbia. I doubt, however, whether this is a very strong poison, but the wounds caused by the poisoned arrows have a great tendency to slough. The Wahuma shoot well up to 40 yards. There are probably not more than 2000 guns in Uganda; they are not much used, on account of the difficulty which the people have in procuring powder. Some of the Waganda are fairly good shots with the rifle, but most of them fire from the hip.

Fleet.—The Waganda possess a large fleet of war canoes. Unfortunately, I never had the pleasure of seeing it; therefore all I can say about the canoes is that they are said to contain 40 or 60 men, the fighting men being in proportion to the paddlers of two to one. The latter are protected by shields hung to the thwarts of the boat. The canoes are apportioned out to the various chiefs under whose command they fight, the whole fleet being under the chief admiral, who distributes them mostly amongst the islands in the lake.

Government.—The head of the government of Uganda is nominally the king (Kabakka). Succession to the throne is hereditary, but the new king is selected from a minor, the three hereditary chiefs and the young king's mother carrying on the government until he is of age. (I believe this takes place when his first son is born.) This arrangement prevents the king becoming too powerful, and also avoids intrigues during his lifetime. Directly a king dies all strangers who may happen to be in the country are compelled to live in certain places under a strong guard. They are quite safe there, but should they leave the enclosure they would certainly be killed. A meeting of the three hereditary chiefs is held to elect the new king; should they not agree in their choice they fight, and the victor places his nominee on the throne. With the exception of two or three of the young king's brothers, the whole of the late king's sons are burned; the former are kept in strict confinement, but their preservation is necessary in case of the king dying childless.* The king's power is distinctly limited, that is to say, in vital matters he would never dare to go against the will of the hereditary chiefs. It is true that he is on the throne, and that everything is referred to him; but he is placed and maintained there by his chiefs, who are wise enough to know that there must be a king or there would be everlasting fighting for the supremacy. The king is not permitted to have much property of his own, but he can requisition women, cattle, food, in fact almost anything, to any extent, except land. The reigning family in Uganda is descended from the Wahuma tribe. Mtesa professed to trace back his descent to Kintu (or Ham), the founder of the dynasty. The names of the kings are as follows, but I have grave doubts as to the list being correct. Kintu (or Ham), Chwa, Kalemala, Kimela, Rumaansi, Tembo, Kigala Wampamba, Kaima, Nachibinge,

* Europeans have exercised so much influence on the people that when Mtesa, the late king of Uganda, died, his son Mwanga was placed on the throne without any bloodshed.

Mrondo, Sekamanya, Jemba, Suna I., Chimbugwe, Katarēga, Mtébe, Juko, Kaemba, Tibandeka, Ndaula, Kagura, Chikurwe, Mawaánda, Msánje, Namgába, Chabagu, Jungu, Wasaja, Kamanya, Suna II., Mtesa, Mwanga.

I must now give a short sketch of Mtesa, the late king of Uganda. When I knew him he was about 45 years of age, a splendid man, some 6 feet high, well-formed and strongly built. He had an oval face, and his features were well cut. He had large mild eyes, but if roused by anger or mirth they were lit up by a dangerous fire. He had lost the pure Mhuma features through admixture of negro blood, but still retained enough characteristics of that tribe to prevent all doubt as to his origin. All his movements were very graceful; his hands were slender, well-formed, and supple; he was generally dressed in a simple white Arab kuftan. It is somewhat difficult to describe his character; he was intensely proud, very egotistical, and until towards the end of his life he thought himself to be the greatest king on earth. In his youth, and in fact until 1878, there is no doubt that he was very cruel, but an illness from which he suffered certainly softened him. His chiefs often said to me—"Ah, if Mtesa were well, there would be plenty of executions." It has been said that he was extremely changeable and fickle, and to superficial observers he was so; that is to say, as far as his intercourse with Europeans went. If, however, one looks a little deeper into his character one finds that his apparent vacillation was overruled by a fixed idea, which was to benefit his people, increase his own importance, and to get as much as possible out of the strangers who visited his court. This explains his being one day a friend to the Arabs, on another to the Protestants, and on a third to the Catholics. A new comer, especially if he had a large caravan, was always the favourite of the hour. It is easy enough for anyone to get into Uganda, but to get away again is no easy task unless one is going for a fresh supply of goods. Mtesa liked Europeans and Arabs to be present at his court; it gave him prestige, and he also wished his people to learn as much as they could from the white man, for he well knew and appreciated their superior knowledge. In manner he was courteous and gentlemanly, and he could order anyone off to execution with a smile on his countenance. His mental capacity was of a very high order. He was shrewd and intelligent; he could read and write Arabic, and could speak several native languages. He had a splendid memory, and enjoyed a good argument very keenly. If he could only get Protestants, Catholics, and Arabs to join in a discussion before him he was in his element; and though apparently siding with one or other, who might happen to be at the time in his especial favour, he took good care to maintain his own ground, and I do not believe that he ever really gave up the least bit of his belief in his old Pagan ideas. While too shrewd and intelligent to believe in the grosser superstitions which find credit among his people, he was yet so superstitious that if he dreamt of any of the gods of his country he believed it to be an ill omen, and offered human sacrifices to appease the anger of the offended deity. Shortly after I left Uganda, he dreamt of his father, and in consequence had 500 people put to death. He also believed if he dreamt of any living person it was a sign that they meditated treachery, and he condemned them forthwith to death. This supposed power of divination is said to be hereditary in the royal race. In concluding my remarks about Mtesa, I may say that he denied his Wahuma origin; not only, however, did his features betray him, but many of the traditions he held regarding his ancestors, especially his descent from Ham, point conclusively to an origin in the old Christianity of Abyssinia.

When I was in Uganda Mtesa had two or three hundred women always residing at his court. He did not know exactly how many wives he had, but said that they certainly numbered 7000. He had 70 sons and 88 daughters.

The queen-regent exercises practically the same rights as a king until her son ascends the throne, and for some little time after a good deal of jealousy exists between mother and son, as the mother does not like being deprived of her power. The king's head wife and the "king's sister" are almost invariably present at the council (*see* later), and certainly exercise a considerable influence over the king. This "king's sister" is appointed by the chiefs, and is credited with an immense stock of wisdom. She sits near the king to his left, and is often appealed to by him when he is called upon to decide difficult matters. She also exercises a certain amount of authority in the king's household, and she is not allowed to marry.

The population of Uganda may be divided into four classes, the lowest class being the slave population, consisting of prisoners taken in war and their descendants. They are very well treated, but are liable to be sold to Arab slave dealers. The second are the Bachopi; they form the mass of the population, and from them the army is recruited, which has made the army of Uganda feared far and near.

The third class, that of the Batongoli, are recruited from the Bachopi, but their honours are not hereditary. They govern the provinces, and are obliged to collect a certain number of soldiers in time of war. They receive their rank for distinguished bravery in the field or for other services rendered to the state. Although bearing the same name they are not all of equal rank, as some are governors of towns, others only of small villages. The fourth class consists of Bakungu, nearly all of whom belong to the Luchiko, or council, and are governors of large districts of land. The three great hereditary chiefs belong to this class. They govern the three districts into which Uganda is divided, and naturally take precedence over all other members of their class. The prime minister of Uganda is appointed by the king. He is called the katikiro; he sits next to the king, being also next in authority to him, although he may previously not have been a chief. The privy council is composed of the katikiro, the three hereditary chiefs, and one or two other favourites of the king, and the king's sister. The general council consists of all the Bakungu and Batongoli who are in residence at the capital,—for the rule is that all must reside there in rotation for three months in the year. The other nine months they can live where they like, unless required on account of war. The chief brewer and the head cook to the king are also members of the great council, and possess a considerable amount of influence. Whatever the privy council decides must be carried out, for no king dare oppose their decisions. This general council is in attendance daily at the palace from about nine to twelve, but it does not follow that it meets the king every day, as it is summoned and dismissed at his good pleasure, although in exceptional cases the hereditary chiefs can insist on the council being held. Should the king wish for the advice of the privy council during the sitting of the general council, he summons them close to him, and they confer in a low tone, their voices being rendered inaudible to those around by the strains of a harp and the song of a musician in attendance.

There is no real taxation in Uganda, but the people are compelled to render feudal service to all their superiors. Requisitions may be made on them for all kinds of produce. All the chiefs are judges, and although they have no written laws they manage to administer them in a satisfactory manner. There is a right of appeal from the Batongoli to that of the mkungu of the district; from him to the katikiro, and finally to the king sitting in council. The katikiro sits in the judgment seat almost every day from seven to nine. If a man is charged with any offence, he and his accuser must appear before the judge; they can both call witnesses and argue their cause in person, but the judge alone has the right to cross-examine witnesses.

Laws—(A) *Land.*—The land does not all belong to the chiefs although they possess large tracts in their several districts. Anyone may acquire land, either by annexing a piece of unoccupied property or by purchase. Even head slaves are not debarred from this privilege. At a man's death the land descends to his sons, the eldest son, however, coming in for rather the largest share. Daughters do not inherit land; there is no law, however, to prevent a woman from acquiring it, and some of the witches do in fact possess land of their own. By law an infant may inherit land, but if very young he stands little chance of possessing it, unless he belongs to the family of one of the big chiefs. Disputes as to the possession of land are settled by the judges, the final decision resting with the king in council.

(B) *Game.*—Game is not preserved. (For the only customs regarding it *see* Hunting.)

(C) *Administration of Justice.*—The courts held are conducted in a very orderly manner. There is no difference between civil and criminal procedure. The accuser and accused must always be present in person. Torture is not practised on uncondemned persons.

(D) *Punishments.*—Punishments are inflicted by order of the judge, and are executed by regular executioners, or the judge may appoint any of the bystanders to carry out his orders. At the capital the king has a regular army of executioners. They are known by their insignia of office, which is a fringe mask and a coil of rope worn as a turban.

People are put to death in various ways, strangling and beheading being the most common. Sometimes, however, the criminals are slowly bled to death; they are gashed with tiger-grass splinters, care being taken to avoid the main arteries, or they are tied to a pole, gradually mutilated, cut to pieces, and literally thrown piecemeal to the vultures. Occasionally persons are burned to death. If a person is strangled or beheaded, the body lies where it falls to serve as a warning to evil-doers; no one is permitted to remove it on pain of death. Adultery and murder are, as a rule, punished by death, but generally the payment of a heavy fine is considered sufficient for the latter crime. The hand, nose, or ears may be cut off for theft, the hand being disarticulated at the wrist-joint. One meets a considerable number of people minus nose or ears, the loss of which is considered a great disgrace, not so much for the fault which has been committed, but for having been found out. Small offences are punished by the stocks or by flagellation. Prisoners may be said to be unknown. On the whole, justice is administered fairly, but the punishments tend towards severity. This is especially the case after an appeal to the higher courts.

Causes that Limit Population—1. *Conditions of Marriage.*—Youths of about 16 and girls of 14 marry, but there are no restrictions to marriage at any age after arriving at puberty, if the husband has enough property to pay the dowry. Owing to the frequency of polygamy, however, a large number of the poorer men are unable to marry, and this notwithstanding the larger excess of females over males, being about $3\frac{1}{2}$ to 1. This preponderance of females over males is due to three causes—(1) more females are born than males; (2) a great number of males are killed in war; and (3) there is a constant influx of women into the country as prisoners of war. I have made some observations with regard to the excess of female births which may be of interest, namely, that the very great proportion of children born of newly-caught female slaves are girls. This point is all the more noticeable, because I found that it is only in the first births that girls predominate so largely over boys. To make this clear, I may give the following figures:—Of 300 Waganda women observed 9, or 3 per cent., appeared to be sterile; 291 had children. The male first births were 144, the female first births were 147. Of 500 women who had been captured, 12 only, or 3·6 per cent., appeared to be sterile; and the number of male first births was 79, of female 403. In the subsequent births, however, male and female children born were nearly equal in number, the females being only slightly in excess.

Of the whole 800 women observed 69 had 4 children, 3 had 5, 3 had 6, 3 had 7.

2. *Separation of Husband and Wife.*—Although in the poorer families the women are prolific, it being common enough to meet with mothers of six or seven children, yet on account of polygamy most of the women have only one or two. It is the custom, except in the lowest class of society, for a woman to separate from her husband from the time of her pregnancy until she has weaned her child, and this is not done until it is two years old. Even in the lowest class a few months separation is usual.

Chiefs who have very large harems have establishments in the country to which their women are banished during this period, and in them they are strictly watched. In sexual matters they are very cleanly, regular ablutions being rigorously prescribed.

3. *Loss of Infant Life.*—Still births are very rare, and infant mortality is very slight. Infanticide is never practised, but miscarriages, said by the natives to be due to syphilis, are not infrequent.

Treatment of Widows.—As the custom obtains for the eldest son to marry all his father's widows, with the exception of his own mother, they do not suffer much by the loss of their husbands. At the present time no women are sacrificed at their husband's graves, but there is a tradition that at one time some of the widows of kings and hereditary chiefs were tied up in the enclosures round their husband's graves and starved to death.

The women age at a comparatively early period, and are then compelled to do more field work, &c., than women in the prime of life.

Education of Children.—The children in Uganda are very well behaved. Their education commences at an early age, and they are taught to follow the occupations of their parents. Fighting, dancing, and music are taught to children of six or seven. Strict obedience and respect to their elders are rigorously inculcated, but the children are happy merry little things notwithstanding. I was much struck by the way in which they amused themselves. Instead of making senseless mud pies, I used to see them making miniature villages, copies of mountains, rough models of men and animals of clay, and I was surprised to see how neatly they constructed the miniature huts, which were almost exact copies of the dwellings around them. They would be thus employed for hours together, day after day, and would persevere until their models were complete. When strangers visit their parents they sit at a little distance listening to the conversation, but ever ready to run on any errand that may be required.

The children inhabit the same huts with their parents, but in many of the huts a sleeping room is partitioned off for them.

Slavery.—Slavery has existed in Uganda from time immemorial. The slaves are captives made in war and their descendants. The number of slaves held varies necessarily with the position and wealth of the owner. They are well treated, and their lot is by no means a degraded one; they have definite rights, and although a master may kill a slave, public opinion is against such practice. The head slaves are allowed to marry and to hold slaves themselves, whom they may sell or exchange, but their own descendants belong to their master. About 1000 slaves are exported annually from Uganda; they consist of boys and young men and a small proportion of young girls. Female slaves are as a rule incorporated into the harems of the Waganda. The price of slaves is steadily increasing, and is about four times as high now as it was ten years ago. The slave population is diminishing, and the Waganda are beginning to feel that the exportation of slaves must cease, for if not, they will be compelled to do manual work themselves, which work they strongly object to.

Games and Amusements.—Men and women, boys and girls, amuse themselves by singing and dancing, and there are frequent entertainments in the villages at night. The two sexes dance separately, not in couples. The dances are accompanied by music, and some of the figure dancing is very graceful. A shuffle dance is also performed singly or in groups. The performers advance or recede with knees slightly bent, the arms stiffly held by the sides, with the hands stretched out, and the palms downwards. Every muscle in the body is brought into action, and it is so exhausting that it can only be kept up for two or three minutes. This dance seems to afford considerable pleasure to the people, and a good dancer, that is one who can keep up for a long time, is much in request, some of the chiefs even maintaining professional dancing boys.

Boys also are incited to kicking matches, at which they exhibit considerable agility. They endeavour to strike with the sole of their foot, no sandals being permitted. Wrestling matches are also very common. The right hand may at first be only used until a good grip is obtained, the left being held behind the back. As well as affording amusement, wrestling is practised to settle disputes; in such cases an umpire is often appointed by the two disputants.

The Waganda are exceedingly good story tellers, and wile away many an hour by relating anecdotes in turn. The stories treat of all kinds of incidents, grave and gay, decent and the reverse. The following stories will serve to illustrate their style, as well as to afford some information on other matters :—

1. A hunter had been very unsuccessful for a long time. He was sitting in his hut one day with his wives and children, because a terrible storm raged through the forest; presently a bird flew in for shelter, and the children seeing this tried to catch it. The hunter, however, took its part, and forbade the children to touch it. When the storm had passed away, the bird said to the hunter, "I will help you now; you are a kind man. I will fly before you, and lead you to the prey;" and it did so, and the hunter rejoiced.

2. A chief once had a favourite wife, to whom he committed the care of all he had. Even his other wives, and they were very numerous, were under her control. He returned home from hunting one day, and called his wife, but she had disappeared mysteriously, and was nowhere to be found. This loss was a great grief to him; his household was disordered, and his other wives quarrelled. He was in despair, when one day, as he was walking in the forest and thinking of his lost wife, he cried aloud, "Oh! my treasure, could I but find you." A honey bird flew to him, and said, "Your wife is in the sky." For a moment he was overjoyed, but then became more sorrowful than ever, for, although he might seek throughout the forest, he could not climb the clouds. A rat then came to his aid, telling him of a tree that grew very quickly, and offering to show it to him. He followed the rat through the forest,

until he came to a tree which was visibly growing, and the top of which had almost passed out of sight. At the rat's bidding he climbed the tree, and the honey bird kept him company and encouraged him. As he climbed higher so the tree grew, till at length far above the clouds he landed in the spirit world. The spirits asked him what he required, and he begged for his wife, who was given him as a reward for his perseverance, and they descended the tree together. Then he rewarded the rat and the honey bird. Some time afterwards the chief went to look for the tree, but it had vanished.

3. One night a man was returning to his home from a feast, at which he had eaten largely and drunk much mwengi. He was very tired and sat down to rest; he fell asleep, and when he awoke he found that his torch had gone out, and it being very dark he could not find his way. As he wandered hither and thither in the forest a jackal met him, and asked him where he was going. "I am trying to find my way home," said he. The jackal offered to run on before and show him the right path; he accepted the offer, and they went a considerable distance together. The man then asked the jackal if he were near home. "Yes," was the reply; "you will soon be home; you have feasted, and now we will feast." Having said this he called out "Lion! lion!" and with a loud roar a lion sprang on the man and killed him; so the lion and the jackal got a good meal.

4. Two men once had a dispute as to which was the most successful liar. The one proposed that they should each tell lies, and that the one who told the best should be acknowledged by the other as the most clever. His friend agreed, and asked him to begin. So he told a number of outrageous lies, and then said to his friend, "Now how do you propose to beat me?" "Easily," said he; "everything that you have said is true; now that is the biggest lie." Then they both burst out laughing.

5. Some driver ants once invaded a man's hut. He was so angry that he killed a great number by setting some grass on fire. The ants went away, but held a council of war, and their leader addressed them, and said, "A man, because of his great size, injures us, for he thinks that we are small; he is cruel, so we must punish him." Messengers were then sent by the ants far and wide, and at

the appointed time, the next new moon, they assembled in great numbers, so great that they could not be counted. Several leaders were then appointed and they attacked their enemy's hut, which was soon all "eaten up." The man, his wives, and his children, were also not spared. Know then that the big should not ill-treat the little.

The children are sometimes amused by having tales told them on their fingers. The following string of words for instance, is told off on the five fingers. Mkazi, nyumba, mulongo, toki, mwengi. This is probably intended to illustrate the five wants of a Mganda, for it means a woman, a hut, twins, bananas, and wine.

The only real Waganda game is called mweso. It is played on a board containing thirty-two holes, and stones, coffee-berries, or beads are used. The people will play this game for hours on end, but I am sorry to say that I cannot explain it; it was too difficult for me to comprehend. All I know is that two players move the stones from one hole to another under certain conditions, and under other conditions the one player confiscates the stones of another. That the game is an exciting one may be drawn from the fact that the players are often as furious as crusty old whist players, and that a crowd collects to see the play. They are not, however, allowed to comment on the game until it is finished.

Music.—The Waganda possess a decided genius for music, and are very clever in picking up new tunes. Their voices are soft, clear, and melodious, and of considerable range. They have a great variety of tunes, orchestral, dance, and vocal music having distinct characteristics. They prefer their songs to be accompanied, but are quite capable of keeping in tune without this aid. They have solos and choruses, and many of their musicians improvise readily. Their bands are led by conductors, and some of them number 40 or 50 performers. The king and chiefs have professional singers in their employment and private orchestras of stringed instruments, but they are mostly composed of the Wasoga, who are the best harpists in Central Africa.

The Waganda have songs suited to various occasions—love songs, war songs, dirges, and songs to illustrate many of their traditions. The following two songs were translated by the Rev. C. T. Wilson, the first being in praise of Mtesa, and the second a lamentation over some dead chiefs.

I.

Thy feet are hammers,
Son of the forest.*
Great is the fear of thee;
Great is thy wrath;
Great is thy peace;
Great is thy power.

II.

Oh, separator! †
O, Sematimba!
They tied goats;
They tied goats for him in vain.
Son of a king,
He has no pride.
He freely gives plantain wine.

Lubinga! Lubinga!
Him of whom I speak,
He has no pride.
For he freely gives plantain wine.
Mkwenda! Mkwenda!
Whose home is Chikongi. ‡
Him of whom I speak,
He has no pride.
For he freely gives plantain wine.

Musical Instruments—(1) *Harmonicon* (Madinda).—This consists of twelve to twenty pieces of hard resonant wood which are scooped out in the middle and rested on two parallel logs. This instrument has the greatest compass of any in Uganda. It is played by two performers, who squat on each side of it and strike the logs with drum sticks. A chord of four notes can be played at once.

(2) *Rattles.*—These are simply gourds filled with small stones or beads, and they are shaken in time to the music. Small bells are also used suspended to the wrists and ankles.

(3) *Drums.*—The people are very proud of their drums, of which they have various sizes, from small cylindrical instruments, open at one end and closed at the other by python skin, which are held under the arm and struck with the fingers or hand, to huge drums, formed like kettle drums, which require half a dozen men to carry them, and are beaten with drum sticks. The wooden logs of which

* A synonym for the lion, which is the emblem of royalty.

† A synonym for death.

‡ Chikongi is the place where he is buried.

the drums are made are shaped and hollowed out with the axe. The king's great war drum is said to be very old, and is guarded night and day. Covers made of tanned hide, are used to protect the drums from the influence of the weather. Many of the drums are provided with cords to tighten them up when needed.

(4) *Horns.*—Various sizes are used, made out of elephants' tusks (rare), or the horns of antelopes. The tips are cut off, and they are blown from the side, but two notes can be produced by closing the hole at the tip with the finger. These horns are also used to convey orders on the march and in battle.

(5) *Whistles.*—Although all the Waganda can whistle with their fingers, they have small wooden whistles, with two or three notes. These are blown from the end, and they carry them suspended round the neck by a string.

(6) *Flutes*, which are blown from the end, have two to four notes; they are either made of reeds or hard wood, and are highly polished.

(7) *Harps* are constructed as follows:—A basin-shaped piece of hard wood is taken and covered with python skin or the skin of a water lizard, so as to form a sounding box. To this box is fastened a long curved arm, in the upper portion of which six to eight pegs are inserted, to which the strings are attached so that they can be tuned just like a violin. The other ends of the strings are fastened to a strip of wood which spans the centre of the sounding box. The twisted strips of intestines of either the goat or sheep are used to make the strings. The instrument is played by the fingers of both hands.

All these instruments have only whole tones, but that the Waganda can appreciate semi-tones is proved by the ready way in which they distinguish them when they hear European music. The instruments are always ornamented with plumes, beads, bangles, &c., and the performers array themselves in very striking attire, with monkey or goat skins round their shoulders, and goats' beards attached to their chins.

It is impossible for me to describe the effect produced by sixty or seventy of the above varied instruments,—one of the king's bands, for instance,—but it is melodious, although fantastical and weird. Roving minstrels are always to be found present on occasions of festivity. They both extemporise songs in honour of the event, generally managing to bring in a few verses flattering to the host, which are always much applauded by the guests, and also sing songs which have been handed down by tradition, and are well known by all the people and often called for. Comic songs are also much in request, and are greeted by roars of laughter from the audience, but many of them are very lewd. These bards, as well as being supplied with as much food and drink as they can consume, are rewarded for their services by a present of cowries, mbugu, or even a goat. The songs which pleased me most were those in which solo and chorus followed each other in rapid succession; the pleasing effect was heightened by the surroundings, for generally these gatherings take place under spreading trees, lit up by the silvery light of the moon or the ruddy glare of enormous bonfires.

Mtesa's envoys who accompanied me to England had their harps with them, and I was often surprised to hear them, after they had retired for the night, persevering until they had reproduced some catching melody they had heard during the day. One of them was very fond of sitting down to the piano, and managed to learn in a few days to play two or three simple tunes.

Trade.—There is not very much home trade in Uganda, and it is limited to the barter of native manufactures. Several times a year caravans arrive from Zanzibar, bringing calico of various qualities, guns of cheap Belgian manufacture, powder mostly made in Germany and of a very bad quality, files, knives, needles, coloured pocket handkerchiefs, suits of Arabic clothes and cowries, &c. These articles they exchange for ivory and slaves. This foreign trade has increased immensely during the last ten years, and the people are already beginning to feel the necessity of finding some other commodity with which to procure foreign produce. Ivory is becoming scarce, the price of slaves is rising enormously, and little by little the people are beginning to understand that either they will have to work themselves or else stop the exportation of slaves, of whom about 1000 are exported annually. When an Arab caravan first arrives in Uganda, it is etiquette for the leader to first pay a visit to the king, make him a present, and at the same time give him a list professedly of the whole contents of his caravan. He also gives presents to the katikiro and the three hereditary chiefs. The king and his council then decide what guns and amunition they will buy for the State, and a week or two is generally occupied in coming to terms with the trader and in paying the stipulated price. The Arabs generally ask about five times the amount that they intend finally to accept. They are usually paid for the Government goods in ivory. As soon as this State business is concluded, the king and the principal chiefs make their private purchases, and it is only when they are satisfied that the trader is allowed to dispose of his remaining stock to all comers. About two months are required by the Arabs to dispose of all their goods, and the Government always provides them with canoes to transport the ivory and slaves they have obtained, from Ntebbi, the port near the capital Rubaga, to Kagei, at the south end of the lake. The large traders in Unyanyembe have agents constantly residing in Uganda, who generally collect ivory and slaves to be ready for the arrival of the caravans, and otherwise look after their interests. It was these agents who had a good deal of influence with Mtesa, and who try to make the sojourn of Europeans in Uganda as unpleasant as possible, for they fear that their business will be spoilt, especially that in slaves, by the introduction of European commerce. Formerly a small trade was carried on with the Soudan; coffee, tobacco, mbugu, and cattle were exchanged for fezes, calico, and red slippers, but the withdrawal of the Egyptians from Mrooli put a stop to this traffic.

Strangers residing in the country were, until quite recently, prohibited from buying produce (*see* Treatment of Strangers).

No fairs are held, but at the capital a very primitive sort of market is held daily.

Money.—Exchangeable Values.—The king and a few of the richest chiefs possess Maria Theresa dollars, but they are seldom used as money. The standard value of an article may be said to be reckoned by a string of 100 cowries or an arm's length of calico. Beads, hoes, salt, and fish are also employed as mediums of exchange.

A fat cow costs about 2500 cowries, or three arms' lengths of cloth, or two needles, or a small box of percussion caps, or 20 charges of powder. A young slave boy is worth 100 percussion caps, 4 needles, or about 4000 cowries, whereas a young slave girl is worth about a third more, and a full grown female slave costs about double. A man's load of bananas costs about 50 cowries, a fowl 5 or 10 cowries, a sheep or goat from 500 to 800 cowries. A wedding dowry is usually made up of equal quantities of produce, *e.g.*, 50 slaves, 50 cows, 50 goats, 50 mbugus, 50 loads of bananas, 50 jars of beer, &c., &c., and fines are paid in the same way. It is also a common custom, if a chief is found fault with by the king, for him to give equal proportions of everything which Uganda produces as a peace-offering.

Weights and Measures.—The only measures used in Uganda are the span of the hand, the cubit, and an arm's length, and, with the exception of one balance at the capital used for weighing ivory, no weights are in existence. Capacity is measured by handfuls, and also by baskets and jars of various sizes, the largest containing about two gallons. Tallies and counters are used (*see* Arithmetic).

Communications.—Uganda is the only country that I know of in Central Africa where an attempt is made to facilitate communications between one part of the land and another by real roads. Another remarkable fact is, that nearly all the roads are straight, and lead in direct lines through forests and over hills. Some of the principal roads are 80 feet broad, and the narrowest are not less than 25. I believe that King Suna II. introduced roadmaking into Uganda, and since then they have been regularly maintained. The heads of villages are all responsible for certain portions of the roads, and the king sends out inspectors from time to time to see that the work is properly done.

Should a swamp have to be crossed, causeways are constructed, with bridges at intervals formed by the trunks of trees, to give free passage to the streams which filter through them; and sometimes corduroy roads are even met with.

No metal is placed on the road. With the exception of the small bridges just mentioned, the only bridge known in Uganda is the usual primitive tree bridge. At most of the creeks ferry boats may be found, but these are in nearly all cases private undertakings, passengers being expected to pay a small fee. Heavy weights are carried slung to poles which men carry on their shoulders, sometimes four or six men together. Persons are carried either sitting straddle-legs over the shoulders, or else on a rough stretcher carried on the shoulders of two men. The king's daughters, and the head wives of some of the principal chiefs, are usually carried in the former manner. No animals are used as beasts of burden. There are no inns, and travellers are obliged to obtain accommodation as best they may. Heavy weights, such as the trunks of trees, are hauled along the ground by ropes attached to them. The men pull by word of command. The use of levers is also understood to a limited extent.

Treatment of Foreigners.—Until the novelty of their presence has passed off, foreigners are well treated in Uganda. They are considered the guests of the king, and huts are provided for their use at the capital. There was, however, a difficulty in obtaining food when I was there, as no one was permitted to sell anything to the king's guests. I believe that to some extent this prohibition has been relaxed. The late King Mtesa liked having strangers present at his court; not so however the chiefs, who greatly feared their influence.*

Strangers travelling through the country, accompanied by an escort from the king, are always sure of obtaining good accommodation, as the escort goes to the best hut in the village, turns the inhabitants out, and takes possession of it for the time being. The people are, however, hospitable, and endeavour to make one as comfortable as circumstances will permit. Foreigners are not permitted to enter Uganda without permission of the king; they are compelled to halt at the first village until it is granted. One or two of the king's pages, bearing a drum and flag as marks of authority, are usually sent with a requisite number of porters to transport the stranger and his goods to the capital; but it is not etiquette for this to be done rapidly, and circuitous routes are always chosen, and the halts made are frequent and tantalising. The traveller is also constantly annoyed by the frequent disputes between his escort and the villagers, which sometimes end in blows, and it requires great tact on his part to keep the peace. The king's pages are overbearing, and treat the villagers abominably, requiring them to perform impossibilities, and beating them if they refuse. On one occasion, when travelling with a very small escort, I nearly lost my life through their plundering propensities. The drummer, who marches at the head of the caravan, gets the head of any cow that may be killed for food on the march as a perquisite.

* The objection of the chiefs to foreigners has lately culminated in the murder of Bishop Hannington on the borders of Uganda.

The Waganda are admirable porters, taking great care of any goods committed to their charge. When they halt for the night huts are built for the goods to protect them from the rain, and although you may not see your goods for several days together, yet they will be invariably delivered up to you at the end of the journey in good condition.

Foreign Influence.—The Suaheli language has been extensively introduced into the country by the Arab traders from Zanzibar. The use of chairs and stools is appreciated by many of the chiefs, and a good many articles of European manufacture are gradually finding their way into the country. The number of firearms is yearly increasing.

Marriages.—Polygamy is universal, and even the poorest peasant does his best to obtain more than one wife. The marriages are contracted rather early, and, strictly speaking, marriage is a bargain between the bridegroom and the father of the bride. The usual price for a wife amongst the lower orders is three or four oxen or six needles, or the equivalent in cowries. The price rises according to the rank. The only restriction on marriage is the inability to pay the dowry. The chiefs have very large harems. The marriage ceremonies are of a very primitive character, if they can be called ceremonies at all. In many cases the young husband simply erects his hut, and having paid the dowry, takes his wife home with him. More rarely, however, the preliminaries having been settled, the friends of both parties meet in the bride's hut, where a dinner is provided by her father. The afternoon and evening are spent in dancing, singing, and drinking, after which the bride and bridegroom are conducted by their friends to their hut, the door of which is then closed, while the friends remain outside and carouse throughout most of the night. The next morning they congratulate the newly married pair, who then proceed to give a feast. The songs on these occasions celebrate the joys of marriage, and detail the duties of husbands and wives. Marriages between relations are not forbidden, and brothers sometimes marry their sisters.

In large establishments separate huts are appropriated to the women, but in no case does a single wife have a hut to herself. The wives are very jealous of one another, and only the head wives have definite privileges. In large establishments the favourite for the day wears some distinguishing ornament; in some cases it is a small bell hung round the neck.

Divorce is unknown, for if a wife misbehave herself she is executed. Notwithstanding this stringent law, an immense amount of immorality prevails. There is no class of courtesans, such as exists in the neighbouring country of Unyoro, where an elaborate system is in vogue.

The condition of women in Uganda is a very pitiable and degraded one, as, with the exception of one or two favourite wives, they are mostly devoted to a monotonous and hardworking existence.

Births.—In ordinary circumstances, women are delivered in their usual huts, being assisted by a few female friends, men and children being excluded. The woman is delivered on her back, her legs being placed against the wall of the hut. In difficult cases medicine-men are called in, but I was unable to ascertain whether their aid was successful except in the cases in which they perform abdominal section.*

For a few days before a woman expects her labour, she eats very little food and abstains from exercise. During and after labour frequent ablutions are performed, and the child is washed and oiled soon after birth, and then at once put to the breast. Should the mother's milk be small in quantity, an application of some chewed root is applied to the breasts, which is said to be a very valuable galactagogue. *In primapara*, the nipples are always drawn out by the woman's friends some days before they will be required. In the large establishments of the chiefs an old woman has charge of the women, and acts as head midwife. After labour the women are not expected to work for about fourteen days.

The navel cord is preserved, and in the case of the king and chiefs it is covered with beadwork ornaments. The king's navel cord is committed to a chief of high rank, and he brings it to court on special occasions. The placenta is buried outside of the hut, that of males on the one side, of females on the other.

Births are celebrated by great rejoicings amongst the relations, but should twins be born the whole of the villagers assemble on the fifth or sixth day at the hut in which the woman and children live.

* For a successful case of which, see *Obstet. Trans. Edin.*, vol. ix. p. 28.

It is considered a very lucky event for the whole village, and the general congratulations are hearty and prolonged. The women and girls deck themselves with flowers, tie banana leaves round their waists, and dance round drums, singing meanwhile a song adapted to the occasion. The rest of the company sit in groups, watching the dancers, drinking beer, and smoking. The father makes the round of the groups to receive the congratulations of his friends, the mother sitting in the meantime with her child at the door of the hut, where, one by one, the guests congratulate her. During a pause in the dancing the people assemble in a semicircle round the happy mother, and the eldest grandfather takes the child, and holding it up, cries out, "Its name is so-and-so," *e.g.*, Mwenda or Kataruba. This is greeted with the shouts of "Mwenda, may he live happy, may he be brave, may he have many wives, may he become great," and such-like good wishes for the child's future. A Waganda child receives only one name, but the variety of names among them is very great. The names of gods, animals, and insects are often given. The king, however, and the chiefs, although at first possessing only one name, gradually acquire more, as after each feat of arms or special event in their lives a significant name is given to them, and for this reason I doubt whether the list of kings I have given is correct; I suspect that more than one name has been given to one king in the list. I never heard two lists agree exactly.

Deaths.—When a man dies, a messenger is sent round to his friends to summon them to the funeral, which always takes place within twelve hours after his decease. The body is not embalmed, but simply wrapped in mbugu cloth, during which process his friends sing funeral dirges, and a minstrel is often engaged to sing an extempore eulogy of the man's life. The body is then carried into a jungle, where it is buried in a deep grave. Nothing is buried with the body. The friends then generally return to the dead man's hut, where a cow is killed, and a funeral feast takes place. If a chief dies, his body is placed in a coffin, and the mourning and funeral festivities last three or four days. The kings and their mothers are the only persons to whose memory monuments are erected. Their graves are prepared as follows:—A large square hole is dug, at the bottom of which are laid layer after layer of mbugu, skins, and calico; in order to get enough of the latter commodity, all the chiefs are compelled to contribute largely, and all merchants or strangers who may happen to be in the country are expected to give presents. On the top of these cloths the coffin is placed, and is surrounded and covered by other layers of the same materials. Earth is then piled over them, and a hut is erected over the spot, and enclosed in a strong fence made of tiger grass. When all is completed, a sacrifice of many hundred slaves is offered. From time to time these huts are renewed, and a fresh sacrifice is then made, the victims being always beheaded. When a slave dies he is simply thrown out into the jungle. Most women are buried without any ceremony whatever.

Superstitions.—The Waganda are excessively superstitious, and a thorough examination of their superstitions would, I am convinced, reveal much that is curious and interesting. I am not able to do full justice to this theme, as a long residence in a country is necessary to enable one to collect any save the most superficial information. The Waganda lay great weight on dreams; they imagine that in them future events are depicted, that impending evil may be avoided by attention to nocturnal warnings, and that the names or faces of those who would do them harm are revealed with unerring accuracy in the night watches. Consequently their daily life is influenced by these dreams, but, notwithstanding this, they are not, save under exceptional circumstances, very superstitious of their neighbours. They appear to think that harm is more likely to accrue to them from the numerous sprites which inhabit the trees or bask on the banks of the streams, or from the denizens of the sun, the moon, and the stars. The demons, who are supposed to dwell on the opposite side of the lake, are believed to have the power of spiriting away Waganda; and should any one be lost in an unexplained manner, they say that the demons have carried him off. Some animals too are supposed to have an evil character, others to possess virtues for guarding and directing men. There are numerous stories in which animals play a leading part, by either aiding or punishing men. Thunder and lightning may be said to be worshipped, and most diseases are referred to some deity or demon. If going on a journey or even for a walk, it is considered unlucky to turn back for any article; the Waganda also return by a different path from the one taken in going. Should they stumble when walking, it is a sign of bad luck; and the leader of a party who notices any impediment in the path strikes it as a warning to those following him, and each man as he passes repeats the signal. Some people are supposed to possess the power of the evil eye, and are dreaded in consequence. They are so much dreaded, in fact, that the people are afraid to harm them for fear of their revenge. Rain is believed to be given and withheld by some inhabitant of the spirit world, and the failure of increase in their herds or crops is attributed to the same cause. The fertility of women, cattle, and the fields may be ensured, they think, by proper offerings to the respective deities who overrule their destinies. It is not to be wondered at, if people given to so much superstition, resort to magic in their troubles. Medicine-men are to be found in great numbers in Uganda, and a few witches of high repute dwell scattered throughout the land. These persons are all powerful, though naturally some are more celebrated than others. They profess to interpret dreams, to make rain and withhold it, to cure disease and to induce it, to discover stolen articles and to indicate the thief. They also intimate to their clients that they are able to influence the deities for good or ill—of course, all for a consideration. They often amass great wealth, and form a mighty power in the land. It is from these magicians that the Waganda obtain the numerous charms, which they believe to possess the power of protecting their persons and belongings from injury. Charms are used to keep their dwellings from fire, and their possessions from thieves; others to ward off sickness, or to cure disease. Some are celebrated for their power over the bites of venomous snakes; others are supposed to direct the flight of spear or arrow, while still others make their wives faithful and their cattle prolific. Some charms secure to a suppliant the grant of a favour, and some are used by women in the form of an ointment, with which they smear their bodies, in order to gain their husband's special favour. Most of the charms are simple in construction, but they are manufactured with due mysterious secrecy, in some remote forest glade at dead of night on the appearance of the new moon. The magicians are most careful that no prying eye shall watch their manipulations; in their retreats they construct small huts surrounded by strong tall fences, and in this solitude they perform their mystic rites.

The charms are made of the claws, the teeth, or the horns of animals, often blended into fantastic ornaments highly decorated by beadwork. Others consist of cunningly-devised powders containing numerous ingredients, such as burnt roots and bark and leaves, the nails of dead men, tufts of hair, and sometimes teeth. These powders are either placed in horns, usually closed by python skin, or else they are packed in small neatly made boxes covered by skin. Charms are hung round the waist or the neck, suspended to the rafters of the huts or over the doorway, or else may be they are hung to the branch of some mighty forest tree, supposed to be inhabited by a sprite; others again are cast into the streams or lake to propitiate some offended river deity.

Besides the charms which these magicians retail to their dupes, they profess to possess special ones which never go out of their possession. These they use only on rare and important occasions; for instance, should a great chief be sick, they bring the charms to his hut that they may cure him.

A great many national charms also exist in Uganda, which are regarded as most sacred; huts are provided for their accommodation near the royal palace, and special custodians are appointed to guard them night and day. Some drums and horns are also supposed to possess the special power of striking dread into the hearts of national enemies. Should any great war be undertaken, these charms are brought before the king, and should untoward news arrive from an army in the field, it is not unusual for some of them to be sent to aid by their subtle spell the wavering troops. The Waganda take good care to let their opponents know of their presence, hoping by this means to gain a victory all the sooner.

As I before mentioned (*see* Pathology), some of the magicians practise as doctors, and far be it from me to depreciate their skill, for I am sure, after repeated observation, that many of the drugs they use are active remedies, and that they are administered with considerable insight and skill.

Religion.—It is very difficult to know what the Waganda really think about death and departed friends, and one would be inclined to say that they think nothing of a life after death, were it not that indirect evidence seems to prove that they do not think that death means annihilation, but have an idea that a man's life influences a future state, and that the departed can exert an influence on men and events. At least many of their traditions go to prove the prevalence of this belief, and several of their ancient kings are said to be more or less powerful spirits, who are engaged in watching with interest the actions of their descendants, and are able to overrule the fate of those who honour their memory and make periodical offerings at their graves.

The Waganda have no images or outward symbols of their gods, but they hold that the world was created by the great Spirit Katonda, who is said to have been well pleased with his work, but to be far too mighty to take any personal interest in the world he has made. They therefore do not worship him, but offer their gifts to the lesser gods or demons to whom he relinquished the rule of the world. At least one of these is supposed to be able to depute his power to mortals, namely, Mugasa, the god of the lake. He is a kind of Neptune, and lives in and rules over the Victoria Nyanza. Occasionally he is believed to take up his abode either in a man or woman, who is greatly feared and respected by both king, chiefs, and common people, and is from time to time consulted by them. This oracle can order or prevent war; a word from it is supposed to cure sickness or prevent it, and it has the power of withholding rain or causing famine. Large presents must be given to the person who is supposed to be the incorporation of this spirit whenever advice is asked. Before the Waganda venture to undertake a voyage on the lake they place some food on a paddle, and say a short prayer, asking for protection on the way and a safe return; they then throw the fruit into the lake, and start on their journey. The god to whom is ascribed the power over smallpox, Ndaula,* is another much-feared spirit, who is said to live on the snow-clad summit of Mount Gambaragara. There is also a thunder spirit, to whom are erected arches or else little huts over every place that has been struck by lightning (which is very much dreaded), and strangers are forbidden to approach near them. When, however, the huts fall to pieces they are not rebuilt. In several places river deities are supposed to live, and should the king or one of the three hereditary

* This god is supposed to be identical with the former king of Uganda.

chiefs dream of them, it is customary to offer human sacrifices to them. On such occasions the executioners will be commanded to catch a hundred or so individuals; they rush madly through the streets, seize any one they may happen to find, and when a sufficient number are collected together they lead them to the supposed residence of the spirit, and decapitate them over a large hole dug by the side of the river to receive their blood.

The Waganda have two gods of war, Chiwuka and Nenda, who are said to reside in certain trees in different parts of Uganda. These trees are tended by men who are supposed to possess priestly functions, and to them offerings of black cattle (sheep and goats) are made by the warriors, who pray under the trees before going to war. The animals are not killed when the prayers are offered, but are given into the charge of the priests, who consume them at their leisure. One may say that all the offerings to the deities in Uganda are of a propitiatory character.

Mythology.—When sitting at a camp fire in Uganda the traveller often gains much information concerning the legends of the people. Could he always note down at the time the information thus derived, an immense number of legends might be preserved, but during my travels in the country both note-book and pencil had to be kept as much as possible out of sight. The prying eyes of the king's pages noted every action, and rendered caution in this respect of vital importance.

The Waganda legends and traditions deal with the origin of the tribe, with the colonisation of the country, with the prowess of former monarchs, and the brave deeds of chiefs. They depict the wars in which the country has been engaged, and many indicate changes which have taken place in the manners and customs of the people.

Apart from what I may call these national traditions, legends are told of gods and demons, giants and dwarfs. Fanciful tales of plants and animals are strangely mixed up with allegories exemplifying some virtue or vice.

Some of the legends undoubtedly point to foreign origin, although when they were brought into the country it is impossible to say. The Waganda are very fond of reciting, and in this way legends have been handed down from generation to generation, and one notices that the same story told by an old man and a young one, although having one and the same main idea, yet varies considerably in detail and style. This is less the case when the stories are told by professional story-tellers or sung by the bards. In such cases almost identical sequence is followed, the same sentences and modes of expression being preserved as accurately as the incidents themselves.

The founder of Uganda is said to have been Kintu, and the account the people give of his arrival in the country is shortly as follows:—Many years ago Kintu with his wife, one cow, one goat, one sheep, one banana root, and one sweet potato, crossed the Nile at Foweira, and arrived on the borders of Victoria Nyanza. He settled there, planting his banana and sweet potato, which grew with extraordinary rapidity—in fact, the sweet potato grew so fast that the people say the tendrils could be seen creeping along the ground. His wife bore him four children at a birth each year, and so precocious were they that at two years of age the female children bore sons and daughters. The cattle likewise multiplied as rapidly. The country in this way soon became populated, till at last Kintu was obliged to send many of the families away; he gave each family a piece of the original banana root and potato plant, and they populated the surrounding districts. Kintu appears to have been a kind of priest; he was very humane, and could not bear the sight of blood; even cattle killed for necessary food were slaughtered at some distance from his dwelling. As time went on and age began to tell upon the monarch, his children caused him considerable trouble. They became drunken and quarrelsome, and even murdered one another, and at length being unable to witness their wickedness longer, Kintu departed at night-time with his wife, and their original cow, goat, sheep, banana root, and sweet potato.

His sons sought him three days without success, and then his eldest son took up the reins of power. Tradition says that each succeeding king lived in the hope of one day finding Kintu, and many an expedition, instigated by various kings, searched the whole country through and through without success. It was not until the reign of Maanda that news of Kintu arrived. It happened thus. A peasant one day, some distance from home and fatigued by hard work, passed the night alone in the forest. He dreamed a dream which was repeated three times, in which he thought he heard a voice directing him to go to a spot in the forest where valuable information would be given him. On waking, after some misgivings, he followed the directions of his dream, and on arrival at the place which had been indicated, he came upon a party of men with pale faces, in the midst of whom was seated an aged man with a long white beard. They were all clad in white robes. The old man told the peasant to go to the king, and tell him to come with his wife and his mother to see Kintu. This message he was to give secretly, and to strictly charge Maanda to come in secrecy. The peasant went upon his errand, but in order to gain admittance to the royal presence he was compelled to tell the katikiro or prime minister that he had urgent business with the king. Having gained admittance to his majesty, whom he found with his mother, he told his tale, much to the surprise of the king who had dreamed that night a strange dream in which he had seen the features of this peasant. The king and his mother at once decided to go with him, and they secretly left the royal palace. It soon became noised abroad that the king had gone into the forest accompanied by his mother and a strange man, and the katikiro who was devoted to his master cautiously followed them, dreading some treachery. In course of time, the little party arrived before Kintu, who asked the king why he had not followed his instructions and come alone. Maanda replied that he had taken all precautions, and had repeatedly looked back to see that they were not followed; but Kintu insisted that a spy was present, and stated that he saw him behind a tree. The katikiro, hearing that he was discovered, hereupon stepped forward, and Maanda in fierce anger killed him with his spear. At this Kintu and his company vanished, and the king, his mother, and the peasant wept and cried out for Kintu. No answer was vouchsafed them, save the echo of their own cries. Since then Kintu has never reappeared.

The next story illustrates Kintu's kindness to animals. Kintu was a hunter, and animals would often, after having been caught in his traps, ask for their freedom, saying to him, "You be kind to us in the sunshine, and we will be kind to you in the rain;" that is to say, "You be kind to us now that you are well off, and we will be kind to you when you are in trouble," and he often granted their request. One day, on returning from a hunting expedition, he found that his cattle had been carried away. He searched for them in vain, till at last he met a man who told him that the gods came down from heaven and carried them away. Thereupon Kintu went up to heaven and demanded his cattle, which the gods expressed their willingness to restore after he had performed certain feats. Enough food to satisfy fifty or sixty men was placed before him, and he was ordered to consume it all. While debating with himself how he should accomplish this impossible task, a number of rats, whose lives he had spared on earth, appeared, and soon consumed the food. Overjoyed, he took the empty basket to the gods, who then showed him a deep well, and told him to fill a jug from it, but no rope was supplied him. A number of swallows then appeared, and taking the pitcher from him flew with it down the well, and soon returned with it filled with water. When he took it to the gods, they led him to a vast plain, and showed him immense herds of cattle grazing. His own were amongst them they said, and also added that if he could distinguish them without mistake, they would restore them, but if he made one slip he should forfeit them. A bee now aided him; it flew to him, and said, "I know which are your cattle, and I will go before and hover over each one." This it did, thus enabling Kintu to succeed in this task likewise, and he was then permitted to return to earth, taking his cattle with him.

An ancient warrior named Kibaga is said to have possessed the power of flying. This power was made use of by his king during his wars with the Wanyoro. Kibaga soaring through the skies detected their ambuscades; he also destroyed great numbers of the enemy by dropping rocks upon them. One day Kibaga saw among the captive Wanyoro women a maiden passing fair. Smitten by her charms, he begged her from the king as a reward for his services. His request was acceded to, but the king warned him not to reveal the secret of his powers to his wife. For a considerable time he managed to keep his own council, but his wife, being surprised at his sudden disappearances and as sudden return, at length kept strict watch upon him, and solved the mystery. She was not long in communicating her discovery to her tribe, who at once placed archers on the summit of their highest hills, and soon Kibaga was shot, and was found lifeless, entangled in the branches of a tall tree.

In the reign of Chabugu war was declared against the Wasoga for the first time. On the Waganda assembling to cross the Nile, the Wasoga mocked and defied them, whereupon a mighty chief, Wakinguru by name, requested permission to cross the river and attack the enemy single-handed. He was an immense man, and his shield was so heavy that it required two ordinary men to lift it. Taking this with him and a large bundle of spears, he challenged the Wasoga one and all to combat. They rushed forward to the attack, but so great was his strength that one man after another fell pierced by his spears before they could get near enough to injure him. He fought all day, slaying 600 men, and at night he recrossed the Nile, repeating this exploit on two succeeding days, when the Wasoga acknowledged their defeat and tendered their submission.

As before stated, the graves of the former kings are kept in good order, this being considered a religious duty, as after death the Waganda monarchs are looked upon as semi-gods.

Astronomy.—The length of the Waganda year is six months, this year and the lunar month being the only divisions of time. The first month in the year is the time at which they sow their seed, and is therefore called "the month for sowing food." The others are called the "months for eating food." When the new moon is first seen there are great rejoicings, feastings, and dancing, but this is more noticed at the capital than elsewhere, and I cannot help thinking that the custom has been introduced by the Arabs, it may be many years ago, notwithstanding the fact that the people profess to be able to manufacture charms more successfully at this period than at any other. With this exception there are no set festivals. The day is divided by the height of the sun in the heavens. The stars, of which many have names, are said to be inhabited by superhuman beings, who are thought to be very tall and powerful.

Arithmetic.—Native names are given to numbers up to thousands, and the Waganda are very found of counting. The root of all multiples of 10 is kumi (10), *e.g.*, kikumi is 100, lukumi, 1000. They are expert in mental arithmetic, which is required in mweso, a game of which they are very fond (*see* Games). Notwithstanding this aptitude, they seem to need aids to the memory of figures, for when sent for a definite number of men, cattle, &c., they use either twigs, stones, or a knotted rope as tallies. No written signs for numbers are employed, but wood is at times notched to represent them. Short notches stand for units, longer ones for tens and still longer for hundreds. In driving a bargain it is not possible to cheat them, and this the Arab traders know full well. I have often tested their knowledge in reckoning, and rarely detected them in a mistake. When trying to make me understand numbers they used their fingers, sticks, or lines drawn on the ground to make it clear what they meant. So fond of counting are they that they always count each string of cowries used as money, also the number of beads used in making necklaces, &c., and should a book be given them the first thing they do with it is to count its pages.

Language.—The language spoken in Uganda is very pure, having but a small admixture of Suaheli and Arabic terms, which are chiefly names of articles of trade. The language, which is called Luganda is one of the great Bantu family, and is very rich in words. It has ten classes of nouns, the noun being the most important part of speech. Grammatical inflexions are formed by prefixes. For instance, "lungi," is good; "muntu mulungi," a good man; "Waganda walungi," good Waganda; "miti mulungi," good trees; "nyumba nungi," a good house; "toki dungi," a good banana; "matoki malungi," good bananas. Prefixes added to the verbs, also indicate their person and tense. The inflections of the pronouns, adjectives, and verbs vary according to the class of the governing noun. Adjectives agree with the substantive in number and case, and always follow the noun. As regards numerals, there are words to express all numbers up to thousands. There are personal, possessive, relative, demonstrative and interrogative pronouns. There are several forms of verbs.

The following short vocabulary will give an idea of the character of the language:—

Antelope	Mtengo.	Boy	Mlenzi.
Arm	Mkono.	Brother	Mganda.
Arrow	Kasali.	Brook	Kaga.
Axe	Mbadzi.	Buffalo.	Mbogo.
Banana	Toki.	Cat	Kapa.
Bedstead	Kitanda.	Canoe	Lyato.
Beer	Mlamba.	Camel	Ngamira.
Beads	Nkwanzi.	Calf of leg	Lutumbwe
Beard	Kilevu.	Child	Mwana.
Bow	Mtegu.	Chin	Kilevu.

Cloth . . .	Lugoi.
Clouds . . .	Kili.
Cow . . .	Antu nkazi.
Chief . . .	Mkungu.
Coffee . . .	Mwanyi.
Copper . . .	Chikomo.
Crocodile . .	Gonya
Dog . . .	Mbwa.
Drum . . .	Ngoma.
Ear . . .	Kutu.
Earth . . .	Insi.
Elephant . .	Njovu.
Eye . . .	Liso.
Father . . .	Baba.
Face . . .	Maso.
Fire . . .	Mulilo.
Fence . . .	Kisakati.
Fish . . .	Chenyanja.
Fishhook . .	Roba
Finger . . .	Ngallu.
,, fore . .	Ya vimumbu.
,, middle .	Ya kati.
,, little . .	Ya nasu.
Flute . . .	Ngombe.
Foot . . .	Kigerrie
Forest . . .	Kibila.
Forehead . .	Chenyi.
Fowls . . .	Nkoko
Gazelle . . .	Mpeo.
Giraffe . . .	Ntuga.
Girl . . .	Mwala.
Goat . . .	Mbuzi.
Grass . . .	Subi.
Groundnuts . .	Chinwewa.
Gun . . .	Mundu.
Gunpowder . .	Buganga.
Hand . . .	Mkono.
,, palm of .	Kubutu.
Head . . .	Mtwe.
Heaven . . .	Gulu.
Harp . . .	Nanga.
Hippopotamus .	Mvubo.
Hair of head . .	Mvwili.
Horse . . .	Mbrasi.
Hoe . . .	Nkumbi.
House . . .	Nyumba.
Iron . . .	Chuma.
Ivory . . .	Sanga.
King . . .	Kabakka.
Knife . . .	Nkambi.
Lake . . .	Kidiwa.
Leg . . .	Mugulu.
Leopard . . .	Ngo.
Lion . . .	Mporogoma.
Man . . .	Muntu.
Millet . . .	Mwembe.
Moon . . .	Mwezi.
Mother . . .	Nyabu.
Mouth . . .	Mumwa.
Monkey . .	Nkima.
Mouse . . .	Messe.
Mountain . .	Lusozi.
Morning . .	Incha.
Night . . .	Chiro.
Nail, finger . .	Dwala.
Nose . . .	Nyindo.
Neck . . .	Nsingo.
Ox . . .	Nti.
Paddle . . .	Nkasi.
Pipe . . .	Mindi.
Rat . . .	Messe.
Rain . . .	Nkuba.
Rice . . .	Mpunga.
River . . .	Mugga.
Rope . . .	Mugwa.
Sandal . . .	Ngato.
Serpent . . .	Njoka.
Sister . . .	Mwanyanya.
Shield . . .	Ngubbi.
Sun . . .	Njuba.
Star . . .	Munyenye.
Sheep . . .	Ndiga.
Slave (M.) . .	Muddu.
Spear . . .	Fumo.
Sword . . .	Upanga.
Tobacco . .	Taba.
Tooth . . .	Linyo.
Tent . . .	Gulu.
Thigh . . .	Chiinja.
Tree . . .	Mti.
Wood (timber) .	Lubau.
,, (fire) . .	Luku.
Water . . .	Madzi.
Well . . .	Ludzi.
Wheat . . .	Ng'ano.
Woman . . .	Mkazi.
Zebra . . .	Ntrege.
Bad . . .	-bi.
Big . . .	-anvu.
Black . . .	Dagavu.
Blue . . .	Sama.
Clean . . .	-ungi.

Dear	-kalubo.	16.	Kumi na mkago.
Fat	-ene.	17.	,, na msamvu.
Good	-ungi.	18.	,, na mnana.
Heavy	Zitoa.	19.	,, na mwenda.
Little	-tono.	20.	Abili.
No	Nedda.	21.	Abili mwemu.
Red	Myufu.	22.	,, mubili.
Short	-impi.	23.	,, musatu.
Shallow	Madzi matono.	24.	,, munya.
White	Matukufu.	25.	,, mutano.
Yellow	Cheuvu.	30.	Asatu.
Yes	Wampa.	40.	Anya.
One		50.	Atano.
1.	Mo.	60.	Nkaga.
2.	Bili.	70.	Nsamvu.
3.	Satu.	80.	Kinana.
4.	Nya.	90.	Chenda.
5.	Tano.	100.	Kikumi.
6.	Mkaga.	200.	Bikumi bibili.
7.	Msamvu.	300.	Bikumi bisatu.
8.	Mnana.	400.	Bikumi bina.
9.	Mwenda.	500.	Bikumi bitano.
10.	Kumi.	600.	Lukaga.
11.	Kumi nemu.	700.	Lusambu.
12.	,, na bili.	800.	Lunana.
13.	,, na sutu.	900.	Lwenda.
14.	,, na nya.	1000.	Lukumi.
15.	,, na tano.	2000.	Nkumi bili.

The Lord's Prayer in Luganda.

Katafwe ulio mu gulu, Linya lyo libe takatifu, Manyi go gaje, Kilooza cho chikoliwa mu insi nga chikoliwa mu gulu. Utuwe lelo chakulya chafwe cha buli jo. Utusenyua zambi zafwe nga fwe tubasenyua baotuonona. Totutuka mu kugeza naye utulokola kwa bibi. Nga manyi na tendo ni lyo milembi. Amina.

Note.—For further information about the language, see *An Outline Grammar of the Luganda Language*, by the Rev. C. T. Wilson, M.A., &c.

2. On the Drainage Areas of Continents, and their relation to Oceanic Deposits. By John Murray, Esq.

PRIVATE BUSINESS.

Dr Charles Frederick Pollock, Professor Greenfield, Dr Byrom Bramwell, Mr C. A. Stevenson, and Mr William Milne were balloted for, and declared duly elected Fellows of the Society.

Monday, 17th May 1886.

The Hon. LORD MACLAREN, Vice-President, in the Chair.

The Chairman announced that the Council had awarded—

1. The Keith Prize for 1883–85, to John Aitken, Esq., Darroch, for his paper "On the Formation of Small Clear Spaces in Dusty Air," and for previous papers on Atmospheric Phenomena.

2. The Macdougall-Brisbane Prize for 1882–84, to Edward Sang, Esq., LL.D., for his communication "On the Need for Decimal Subdivisions in Astronomy and Navigation, and on Tables requisite therefor;" and, generally, for his Recalculation of Logarithms both of Numbers and of Trigonometrical Ratios.

3. The Neill Prize for 1883–86, to B. N. Peach, Esq., for his contributions to the Geology and Palæontology of Scotland.

The following Communications were read:—

1. On the Vitality of the Spores of Parasitic Fungi, and the Antiseptic Properties of Ferrous Sulphate. By Dr A. P. Griffiths.

2. The Action of Benzoylecgonin. By Ralph Stockman, M.D., Assistant to the Professor of Materia Medica, University of Edinburgh.

(*From the Pharmacological Laboratory of the University.*)

The recent extensive therapeutic use of cocain has naturally aroused great interest with regard to its chemical constitution. As is well known, when heated with dilute mineral acids, it takes up two molecules of water, and becomes decomposed into benzoic acid, methyl alcohol, and another alkaloid ecgonin. When cocain, however, is simply heated in watery solution for some hours, a less complete decomposition ensues, the solution depositing on evaporation a crystalline substance, which is benzoylecgonin. This substance has been studied chemically by Dr Paul (*Pharm. Jour.*, Oct. 17, 1885, and March 27, 1886), by Merck and by Skraup (*Sitzungsberichte der Wiener Akad.*, 1885). The following short description is taken mainly from Paul's papers on the subject. Benzoylecgonin represents cocain, from which a methyl group (CH_3) has been removed and replaced by hydrogen (H), thus—

$$\left. \begin{matrix} C_{16}H_{18}NO_4 \\ CH_3 \end{matrix} \right\} = \text{Cocain.}$$

$$\left. \begin{matrix} C_{16}H_{18}NO_4 \\ H \end{matrix} \right\} = \text{Benzoylecgonin.}$$

On heating cocain in a closed tube with about twenty parts of water and then evaporating the liquid, benzoylecgonin crystallises out in needles, closely resembling those of ammonium oxalate. It is soluble in water, has a neutral reaction, a bitter taste, and forms a crystallisable salt with hydrochloric acid. Paul points out that it may easily be produced in the process for the extraction of cocain from the coca leaves. It was with benzoylecgonin obtained in this way that my experiments were carried out, and I am much indebted to Mr E. M. Holmes who procured it for me.

Action on Frogs.

Winter frogs of both species—*Rana temporaria* and *R. esculenta*—were used.

When benzoylecgonin dissolved in water is injected under the skin of the back, the effects produced depend largely on the size of the frog and of the dose. Doses under $\frac{1}{20}$ grain had no apparent effect. If $\frac{1}{20}$ to $\frac{1}{15}$ grain be administered to a medium-sized frog, there occur symptoms of slight muscular stiffness, and on the third or even fourth day afterwards a very decided increase in the skin reflexes. With large frogs the effect of such a dose is hardly apparent. If $\frac{1}{10}$ to $\frac{1}{3}$ grain (0·006 to 0·02 grm.) be given, the animal is much more decidedly affected, but the degree varies in individual frogs, the smaller dose having in some cases an equal or even greater effect than the larger. After administration the frog remains for half an hour or more apparently unaffected, and moves about as usual. It then becomes quieter, and shows great disinclination to move spontaneously, but if irritated jumps readily enough. At this period or later the character of its jump becomes altered; there is a very decided stiffness in its movements, and when it jumps it lands rather heavily on its belly, the hind legs being somewhat straggling. The unwillingness to move increases, and the frog, when irritated, walks rather than jumps. In walking the gait is peculiar, the limbs being stiff and almost fully extended. The pupil is always dilated either at this stage or later. In about eighteen to twenty-four hours after administration the muscles are still in the same condition, but the reflex excitability has in the interval become very much increased. The extent of the increase varies, the animal being in some cases thrown into a state of violent tonic spasm, exactly resembling that induced by strychnia, and in other cases simply showing greatly exaggerated reflexes. When the reflexes are only slightly affected respiration and circulation go on as usual.

This condition lasts one or two days, the state of greatly increased reflex excitability gradually passing off, but the skin reflexes remain exaggerated for one or two days longer, at the end of which time the muscular stiffness has also disappeared, and the frog returns to its normal condition. The time required for complete recovery varies in different frogs.

Doses of $\frac{1}{2}$ to 1 grain (0·032 to 0·064 grm.) always proved fatal. Shortly after the injection the animal became very dull and unwilling to move. It could still jump, and did so as previously described, but in a more pronounced manner. In about eighteen hours tetanus supervened, lasting until death from general exhaustion occurred, usually about the third day. Respiration goes on intermittently, and the heart continues to beat until the exhaustion is very marked.

Post-mortem Appearances.—Heart in diastole and not excitable by electric stimuli. Ventricle is acid in reaction, and usually has a peculiar shrunken look.

The veins are filled with venous blood, and the viscera generally are very congested.

The skeletal muscles at the point of injection did not contract to electric stimuli. The other muscles generally contracted at 60 to 70 mm. (Du Bois Reymond induction apparatus and one Daniel's cell), and had a strongly acid reaction.

The sciatic nerves apparently retained their normal excitability or nearly so.

With very large doses, such as 2 to 3 grains, the injection had to be made at several points, owing to the amount of fluid. The poison takes effect in a few minutes, the frog gradually becoming more and more paralysed. Respiration ceases, and it lies in whatever position it may be placed. The heart is also arrested, and death occurs generally without any symptom of increased reflex excitability.

When benzoylecgonin is given by the mouth, both species of frog recover after one grain. It is more slowly absorbed, and the effects last longer than when given hypodermically. When it is injected into the anterior abdominal vein, the symptoms are also similar.

Division of the spinal cord at the medulla has no effect on the convulsions.

Ligature of one iliac artery before administration does not exclude the corresponding leg from the tetanus, while division of one sciatic nerve causes a cessation of the spasms in the same limb.

If the brain be destroyed, the tetanic stage comes on earlier and with smaller doses than in the uninjured animal.

The administration of curara prevents or stops the convulsions. Chloroform abolishes them also, but they gradually return as the effects of the anæsthetic wear off.

From the foregoing general description it is evident that the action of benzoylecgonin is very similar to that of caffein on frogs. The muscular and central nervous systems are primarily affected, the heart suffering less markedly while the peripheral nerves remain apparently untouched.

Action on the Individual Systems.

Heart and Circulation.—If the excised heart be placed in a 1 per cent. solution made with $\frac{3}{4}$ per cent. salt solution, there occurs at once an increase in the number of beats and a more marked systole. The increased rate is maintained for 10 to 15 minutes, after which it slowly falls; the heart finally stopping in diastole. Saturated solutions rapidly killed the heart.

To observe the action on the heart *in situ*, the frog was fastened on its back in the ordinary way, the rate determined, and the alkaloid then injected into the posterior lymph sac. Curara was sometimes used.

Doses of $\frac{1}{4}$ to $\frac{1}{3}$ grain caused very quickly a slight increase in rate (2 to 4 beats per minute), which lasted for about an hour, the heart then returning to its original condition. During the increase the systole was very marked, while the pause in diastole was appreciably shorter than in the normal frog.

Larger doses ($\frac{1}{2}$ to 1 grain) have a much more decided effect both on the rate and rhythm of the heart. The rate increases almost at once 4 to 6 beats per minute, the systolic contraction becomes very decided, while the pause in diastole is hardly perceptible.

The increase in rate passes off in a varying time and is succeeded by a slight fall, the systole, however, still remaining marked. After an hour or thereabouts, the heart in some cases was observed to make long pauses in diastole, often stopping for some seconds, and then going on regularly for a few minutes, when another pause takes place. There is some resemblance to a digitalis heart in the intensity of the systolic contraction and the marked manner in which bundles of the muscular fibres stand out during it. In one case also the base contracted before the apex, giving the latter the appearance of pouching.

The heart stops in diastole. With very large doses the heart is rapidly enfeebled.

Blood-Vessels.—Under the microscope no change could be observed in the calibre of the blood-vessels of the web.

Nervous System—Brain.—It is difficult to decide whether the brain is stimulated or not. After medium doses restlessness generally lasted for a longer time than the pain of injection could account for.

Spinal Cord.—The late stage at which spinal symptoms supervene can only be accounted for on the hypothesis that the alkaloid is at once absorbed by the muscles. The results of the direct application of solutions of benzoylecgonin to the exposed spinal cord go far to prove this. In the experiments made on this point both species of frog were used.

The posterior portions of one or two vertebræ were removed with almost no bleeding, and the animal allowed to rest quietly until it had recovered from the effects of the operation. Some drops of a cold saturated solution of benzoylecgonin were then applied to the exposed cord. In a few minutes the reflexes became more sensitive, and within half an hour a slight touch brought on a tetanic spasm. Spontaneous spasm also occurred, the tetanus ultimately becoming continuous, and lasting for two or three days, when death from exhaustion took place.

If a supersaturated solution were used, there were immediate symptoms of great irritation followed by a few tetanic spasms. The cord became quite paralysed, and the animal lay flaccid and motionless.

Investigation by Türck's method showed no change in the reflex period during the first day. On the second day spasm was invariably present.

Motor Nerves.—The motor nerves are practically unaffected. This was ascertained by tying one iliac artery, the sciatic nerves were then divided high up, and their excitability tested with the Du Bois Reymond coil. The benzoylecgonin was then administered, and the nerves tested from time to time.

Immersion of the sciatic nerve in a weak solution made with normal saline does not appear to injure its conductility.

Sensory Nerves.—These are also unaffected. Neither painting the skin with a saturated solution nor subcutaneous injection produced any local anæsthetic effect.

Striped Muscle.—The action on striped muscle is not nearly so violent as that of caffein is described to be. In all my experiments curarised frogs were used, so as to exclude the motor nerves. If $\frac{1}{4}$ grain or more dissolved in a little water be injected under the skin, the muscles in the immediate neighbourhood retain their contractility very little impaired during the whole day, but next morning they are quite inexcitable. The muscles at a distance are unaffected unless the dose be very large. If the forearm be the seat of injection, generally all the muscles there are found dead after about twenty-four hours; but if a more muscular part, such as the thigh, be selected, all the muscles may retain their contractility although more or less impaired. In the case of caffein, this condition has been ascribed to rigor mortis being induced.

Another method of investigation was also adopted. In a deeply curarised frog the coccygeal region was exposed by reflecting the skin. The muscles on one side of the coccyx were kept moist with saturated solution of benzoylecgonin in normal saline, while those on the other side were kept moist with normal salt solution. The former lost their excitability to electric stimuli very much more rapidly than the latter.

Dr Ashdown examined for me the effect on the histological structure of muscle. When the sartorius is teased in a saturated solution of benzoylecgonin made with aqueous humour, the fibres swell up. There is a tendency to early development of longitudinal striation, and the nuclei appear somewhat early. Transverse cleavage very readily occurs. After this the fibres become somewhat rapidly disintegrated. There is no detachment of the sarcolemma.

Action on Mammalia.

Mammals are by no means susceptible to the action of benzoylecgonin, and want of material necessarily made my experiments few in number.

A rabbit which got 24 grs. subcutaneously showed no symptoms except a very depressed appearance and a great disinclination to move. Next day it had diarrhœa.

On cats a very decided effect was produced, provided the dose were large enough. Two experimente were made—

Experiment I.—Cat, 3 lb. 12 oz., received at 11.5, 15 grs. hypodermically.

11.45.—Reflexes very much exaggerated. Irritation causes a spasmodic start. Animal is very timorous; cowers in a corner of the cage, and seems very much disinclined to move.

12.50.—Reflexes same. Gait is rather stiff.

2.20.—Reflexes less marked. Pupils are very dilated.

The reflex excitability gradually diminished, but the pupil remained dilated all afternoon. At 6 P.M. it was apparently normal, but during the night had very severe diarrhœa.

Experiment II.—Same cat received six days later 25 grs. subcutaneously at 12.5 P.M. Shortly after it vomited several times, and was severely purged and salivated. The reflexes were greatly increased, and the animal trembled continuously.

1.32.—Was seized with a violent tetanic spasm lasting one minute. After this it lay on its side breathing slowly and in a laboured manner. The slightest irritation brought on a spasm.

During the next hour the animal had a succession of tonic and clonic spasms, which brought on a condition of complete exhaustion, in which it was insensitive to external stimuli. The pupil was fully dilated from an early period. Respiration became very irregular and slow; the heart's action was only slightly affected.

Death from general exhaustion, with failure of respiration, occurred at 6.15 P.M. The rigor mortis came on very early, and was very marked. Blood was venous, and the large veins congested. Ventricles were both empty. The viscera, generally speaking, were deeply congested.

The small intestine presented a remarkable appearance. It was firmly contracted, and had a moniliform appearance, owing to the contraction being more intense at some places than at others. It was very anæmic, the lumen was occluded, and all the parasites had been expelled. The bladder was also firmly contracted and empty.

The muscles and sciatic nerves did not respond to the interrupted current.

The unwillingness to move, and the contracted state of the small intestine and bladder, show that both the voluntary and involuntary muscles are profoundly affected, while the spinal symptoms are also of the most marked character. The violent diarrhœa and vomiting are no doubt due to the increased intestinal peristalsis.

A much more extended investigation than I have yet been able to make would be necessary to determine the exact relationship between the dose and the degree in which different systems are affected.

In conclusion, it may be interesting to point out shortly the chief differences between the action of cocain and benzoylecgonin. In frogs cocain in very small doses ($\frac{1}{2}$ mgrm.) produces a short stage of excitement followed by general paralysis, while with larger doses paralysis supervenes almost at once, accompanied by failure of the heart and respiration. No tetanus is induced, and the striped muscles are unaffected. One of the most prominent actions of cocain—viz., paralysis of sensory nerves—is quite absent with benzoylecgonin, as is also paralysis of motor nerves.

In the case of mammalia the general action is strikingly different. The convulsions produced by cocain are dyspnœic from paralysis of the respiratory centre, and come on almost immediately with a comparatively small dose (0·04) in cats; with benzoylecgonin the convulsions are spinal in origin, and come on later. Local application of benzoylecgonin to the eye has no effect on the pupil, while cocain dilates it markedly.

I have to express my thanks to Professor T. R. Fraser for much valuable criticism and advice while carrying on the investigation.

3. Laws of Solution. By William Durham.

In my paper on "Chemical Affinity and Solution," read before the Royal Society of Edinburgh on 16th February last, I gave some general proofs of the correctness of my theory of solution, taken from Thomsen's researches on thermo-chemistry, as given in Muir and Wilson's book on that subject. In the present paper I propose to extend these proofs, and to show the laws of solution, so far at least as chlorides, bromides, and iodides are concerned. I have verified these laws in the case of many sulphates, and have no doubt they govern all cases of solution. My theory is simply this, "Solution is due to the chemical affinities of the constituent atoms or elements of the body dissolved for the constituent atoms of the solvent." For instance, the solubility of $BaCl_2$ in water is due mainly to the affinity of the Ba of the salt for the O of the water, and of the Cl of the salt for the H of the water, and the degree of solubility depends on the relation between these affinities. Now it can be shown, from Thomson's researches, that the *heats of solution in water of chlorides, bromides, and iodides vary directly*—

1st, As the affinity (as measured by heat of combination) of the positive element for O varies;

2nd, As the affinity (as measured by heat of combination) of the negative element for H varies;

and inversely—

As the affinity (as measured by heat of combination) between the positive and negative elements of the salt varies.

That is, the *greater* affinity the positive element has for O, and the *greater* affinity the negative element has for H, the *greater* is the heat of solution, and the *greater* the affinity between the positive and negative elements the less is the heat of solution. Whether the quantity of salt dissolved varies exactly at same rate, or only proportionately, I am not yet in a position to state, but it is generally true that the greater the heat of solution the greater is the amount of salt dissolved in similar compounds. The following examples illustrate the laws just stated—

Compound.	Heats of Formation.	Difference.	Heat of Solution of Chlorides.	Difference.
[Mg,Cl_2]	151010	...	35920	
[Mg,O,Aq]	148960			
		2050		
[Ca,Cl_2]	169820	...	17410	
[Ca,O,Aq]	149260			
		20560		
		−18510	...	18510
[Ca,Cl_2]	169820	...	17410	
[Ca,O,Aq]	149260			
		20560		
[Sr,Cl_2]	184550	...	11140	
[Sr,O,Aq]	157780			
		26770		
		−6210	...	6270
[Sr,Cl_2]	184560	...	11140	
[Sr,O,Aq]	157780			
		26770		
[Ba,Cl_2]	194740	...	2070	
[Ba,O,Aq]	158760			
		35980		
		−9210	...	9070

Exactly similar results are obtained with the bromides and iodides, and also with the chlorides, bromides, and iodides of the alkali metals. There is, however, a variation in the case of metals which form insoluble oxides or hydrates. In the latter case the heats of solution of chlorides, &c., are not so great as they should be if compared with above compounds. Among themselves, however, they follow the above law pretty closely, and seem arranged in groups. Thus, $ZnCl_2$ and $CdCl_2$, and $FeCl_2$ $CoCl_2$ and $NiCl_2$ form two such groups.

In the foregoing illustrations I have shown the effects of the affinity of the positive element of the salt for O on the heat of solution. The following illustrations will show the effects of the affinity of the negative element for H :—

Compound.	Heat of Combination.	Difference.	Heat of Solution of Chlorides, &c.	Difference.
[K,Cl]	105610	...	−4440	
[H,Cl,Aq]	39315			
		66295		
[K,Br]	95310	...	−5080	
[H,Br,Aq]	28380			
		66930		
		−635	...	+640
[K,Br]	95310	...	−5080	
[H,Br,Aq]	28380			
		66930		
[K,I]	80130	...	−5110	
[H,I,Aq]	13170			
		66960		
		−30	...	+30

Exactly similar results are obtained with all the soluble chlorides, bromides, and iodides for which data are available, with the exception of $AuCl_3$ and $AuBr_3$; the difference of heats of solution of these salts being too great in comparison with above. It is apparently proportional, however.

It is pointed out in Muir and Wilson's book that between the heats of formation of soluble chlorides, bromides, and iodides in water, there is a constant difference, no matter what the positive element is. Thus we have—

Salt.	Heat of Formation.	Salt.	Heat of Formation.
[H,Cl,Aq]	39315	[H,Cl,Aq]	39315
[H,Br,Aq]	28380	[H,I,Aq]	13170
Difference,	10935	Difference,	26145
[K,Cl,Aq]	101170	[K,Cl,Aq]	101170
[K,Br,Aq]	90230	[K,I,Aq]	75040
	10940		26130

Now, the reason of this is perfectly obvious. It is due to the laws of solution. Any variation from the above differences on the heats of formation of the anhydrous salt is at once counterbalanced by the heat of solution, which varies inversely. The following example will make this evident:—

Salt.	Heat of Formation.	Heat of Solution.	Total.
[H,Cl]	22000	17315	39315
[H,Br]	8440	19940	28380
Difference,	13560	−2625	10935
[Na,Cl]	97690	−1180	96510
[Na,Br]	85770	− 190	85580
	11920	990	10930

and so on in other cases.

In my last paper I pointed out that the differences in the heats of formation of HCl, HBr, and HI are exactly proportioned inversely to the differences of the atomic weights of Cl, Br, and I. On further consideration, I am convinced the law obtains in all compounds of these elements, and the different proportion found in solutions is due to the modifying action of the affinity of these elements for the O of the water, and in the case of solid compounds to another cause. This, however, with many other points, I leave for further consideration.

Note to Paper on Laws of Solution.

There is another way of putting the matter, which not only confirms the foregoing laws, but also shows the conditions which determine the heats of solution whether positive or negative. The heats of solution are simply balances of transactions between the elements of the body dissolved and the elements of the solvent. The following examples will illustrate this:—

Compound.	Heat of Formation.	Compound.	Heat of Formation.		Difference = Heat of Solution.
Zn,O,Aq	82680	Zn,SO_4	230070		
H_2,SO,Aq	210770	H_2,O	68360		
Neutr.	23416				
	316860	–	298430	=	18430
Ba,O,Aq	158760	Ba,SO_4	338070		
H_2,SO_4,Aq	210770	H_2O	48360		
Neutr.	36800				
	406430	–	406430	=	0
K_2,O,Aq	164560	K_2,SO_4	344640		
H_2,SO_4	210770	H_2,O	48360		
Neutr.	31288				
	406618	–	413000	=	– 6382]

We thus see that on solution the salt and water are virtually though not actually decomposed, and built up again into another system in which all the affinities of the constituent elements take part. When there is no balance of affinities on either side there is no heat of solution, and the salt is insoluble. When the sum of the heats of formation of the salt and of the water is greater than the sum of the heats of formation of the oxide, the acid and of neutralisation, then the heat of solution of the salt is minus—that is, there is absorption of heat, and the temperature is lowered. The above conditions hold good whether the oxide is insoluble or not, and indeed when both oxide and salt are insoluble.

4. On the Fructification of some Ferns from the Carboniferous Formation. By R. Kidston, F.G.S. Communicated by Dr Traquair.

PRIVATE BUSINESS.

The Lord Rayleigh was balloted for, and declared duly elected a British Honorary Fellow of the Society.

Messrs Alphonse Milne Edwards, of the Institute of France; H. A. Newton, Yale College, U.S.; l'Abbé Renard, Louvain; and Tobias Robert Thalèn, Upsala, were balloted for, and declared duly elected Foreign Honorary Fellows of the Society.

Monday, 7th June 1886.

The Hon. LORD MACLAREN, Vice-President, in the Chair.

The Keith Prize for 1883–85 was presented to John Aitken, Esq., Darroch, for his paper "On the Formation of Small Clear Spaces in Dusty Air," and for previous papers on Atmospheric Phenomena, after the following statement by Mr Buchan :—

One of the earliest of Mr Aitken's communications to the Society, and certainly one of the most valuable, is that on "Dust, Fogs, and Clouds," in vol. xxx. of our *Transactions.* The discovery that a solid nucleus is necessary for the condensation of water-vapour is one of the most important contributions, alike to pure and to applied science, which has been made in recent years. Mr Aitken made the discovery independently; but he had been to a certain extent anticipated by Coulier, who, however, by a strange want of judgment, withdrew his statements not long after they had been published. The paper referred to, in intimating the award of the prize, "On the Formation of Small Clear Spaces in Dusty Air," is in continuation of the same subject.

The more important of his other contributions to Meteorology are his papers "On Thermometer Screens," read in June 1884. Owing to the extreme difficulty of making observations of the true temperature of the air at any given instant, meteorologists have contented themselves with uniformity in the methods of observing. In this paper Mr Aitken has, by the novel appliances for observation introduced by him, made a distinct advance towards making observations of atmospheric temperature more approximately correct than those hitherto made; and, it may be added, that the ultimate solution of the problem is likely to be reached on the lines he has thus indicated.

The Makdougall-Brisbane Prize for 1882–84 was presented to Edward Sang, Esq., LL.D., for his communication "On the Need for Decimal Subdivisions in Astronomy and Navigation, and on

Tables requisite therefor;" and, generally, for his recalculation of Logarithms both of Numbers and of Trigonometrical Ratios, after the following statement by the Hon. Lord Maclaren:—

The Society is aware that, by the terms of its foundation, the Makdougall-Brisbane Prize may be awarded either for contributions to the Society's publications, or for services rendered to science outside the work of the Royal Society.

In awarding this prize to Dr Edward Sang, both requisites are fulfilled; because we make this award in recognition of the valuable, original, and responsible work on which Dr Sang has been engaged for many years, and which has been from time to time communicated to the Society, I mean the recalculation of the logarithms of numbers and of trigonometrical ratios. The latest of Dr Sang's contributions on this subject is the paper read in 1884, entitled "On the Need for Decimal Subdivisions in Astronomy and Navigation, and on Tables requisite therefor."

More than fifty years have elapsed since Dr Sang began to take a part in the work of mathematical and physical investigation; and from the year 1857 to the present time he has been a constant contributor to the *Transactions* and *Proceedings* of the Royal Society of Edinburgh. His papers cover a wide range of inquiry, embracing various branches of pure mathematics, mechanics, and optics, as well as the application of these sciences to practical astronomy, chronometry, and naval architecture. I must, however, in this brief notice of the work of Dr Sang, confine myself to the subject immediately in hand.

I begin with one fact, which I state on the authority of the *Encyclopædia Britannica*, and which I think demonstrates the utility and value of the investigations for which this prize is awarded. It is this, that until Dr Sang undertook the labour of independent computation of the logarithmic tables, all the published tables, English and foreign, were derived from one and the same source, viz., from the tables which were compiled more than two centuries ago, partly by Briggs, and partly by the Dutch mathematician Vlacq. If Dr Sang had done nothing more than verify their results by independent computation, he would have rendered a valuable service to mathematical science. But Vlacq's tables of the logarithms of numbers were computed only for numbers below 100,000, and to fourteen places of decimals. Dr Sang, in the tables first communicated to this Society in 1872, extended the tables as far as the number 200,000, and his logarithms were computed to *fifteen* places of decimals. In his later work, communicated to the Society in 1884, the tables are brought down to the number 370,000, and, by adding to each of the logarithms already computed the log. of 2 or 3, the tables can be completed to 1,110,000.

In order that his results should be entirely independent of the work of previous computers, Dr Sang began by computing the logarithms of all the prime numbers from zero to 2000 (and eventually from zero to 10,000) to twenty-eight places of decimals, by a method not known in Vlacq's time, founded on the series for the expression log. $\frac{1+x}{1-x}$.

From the logarithms thus obtained, and their multiples and products, the intermediate quantities were derived (as he explains in his paper in the 26th volume of the *Transactions*, 1872), by means of a system of interpolation, which was ascertained to give accurate results to the fifteenth figure.

The recalculation of the tables of logarithms of the trigonometrical functions was performed with equal care, and by strictly accurate methods. These were also communicated to this Society by papers read in the years 1877 and 1878, and printed in the *Proceedings*. Further tables, adapted to the decimal division of the circle, were communicated in 1884.

Dr Sang's logarithms of numbers, as is well known, are published in the form of seven-place tables. It is to be regretted that the fifteen-place tables have not been printed and published. It is certainly desirable that such a work should be accessible in a printed form in our public libraries. Pending the realisation of this project, it may be hoped that the MS. volumes (which the Fellows had an opportunity of seeing two years ago) may in some way be made available to science.

Even more valuable in its immediate results would be the publication of the million table carried to seven or eight places of decimals. This could be accomplished in two volumes of the ordinary size, and ought to be undertaken at the public expense. I believe there is but one opinion as to the very great accuracy and trustworthiness of Dr Sang's tables. The methods which he used ensured the detection of errors, whether of computation or of transcription, with almost absolute certainty. Such results, I need hardly say, could not be attained without the expenditure of labour, perseverance, and unremitting attention, in a degree exceeding that required by almost any other human undertaking. No considerations, save zeal for the advancement of science and a benevolent desire to lighten the labour of future computers, could have induced Dr Sang to undertake such a gigantic task, or have sustained him through the wearisome mass of mechanical detail which overlaid the more interesting parts of his occupation.

I may conclude with a remark on the subject of Dr Sang's last communication to the Society on this subject,—the paper on decimal subdivisions of the circle. Although the author has in a manner pledged himself to the system of decimal division of the quadrant in the elaborate table of sines which he has constructed on that basis, he is willing to allow that there may be some good in other methods, and, indeed, indicates that he does not view with disfavour the rival proposition of the decimal subdivision of the degree.

So far as the business of astronomical computation is concerned, it really makes no difference whether the circle is to be divided into 1000 equal parts, into 360 degrees, or into 24 hours. But the sexagesimal division of the hour and the degree into minutes and seconds is a real disadvantage, increasing at once the labour of reduction, and the risk of making mistakes in readings. If the degree be selected as the unit of angular measure, and no doubt it is a very convenient unit, undoubtedly the fractional parts of this unit ought to be expressed as decimals of a degree. Apparently the only reason for the non-adoption of this most desirable reform is the want of convenient logarithmic tables adapted to the decimal subdivision of the degree. The quantities corresponding to tenths and hundredths of a degree (being 6′ and 36″ respectively) can be taken directly from existing tables, but the intermediate numbers to thousandths of a degree, or 3″·6, must be got by interpolation. It is to be hoped that Dr Sang's suggestions on this subject will not be lost sight of, because the publication of decimal trigonometrial tables, based on the degree as unit of angular measure, would be a real service to science.

The Neill Prize for 1883–86 was presented to B. N. Peach, Esq., for his contributions to the Geology and Palæontology of Scotland, after the following statement by Professor Geikie :—

The Council has awarded the Neill Prize for 1883–86 to Mr B. N. Peach, for his contributions to the Geology and Palæontology of Scotland. Mr Peach has long been known as one of the most accomplished officers of the Geological Survey of Scotland.

After many years of successful exploration in the Lowlands and Southern Uplands of Scotland, he was deputed to map out the geology of the north-west Highlands, a region showing the most involved and puzzling structure, and one which had been variously interpreted by almost every geologist who has traversed it. In due time, however, Mr Peach, in concert with his colleague Mr J. Horne, succeeded in bringing order out of chaos; and now that bone of contention, over which geologists have worried for more than a generation, has been removed. Only those who know the physical labour entailed in walking and climbing daily for months over such a country, and the enormous difficulty involved in working out the structure of a mountainous region, composed of highly contorted, inverted, fractured, and metamorphosed rocks, which seldom or never show any trace of organic remains, can possibly appreciate the endurance and the skill which Mr Peach and his colleague brought to bear upon their work. But Mr Peach is not only a highly-trained and skilled geologist, he is also an accomplished palæontologist. He inherits his father's inevitable eye. If fossils occur in any given series of rocks, you may be sure they will not escape our friend. And he has thus enriched Scottish geology with many remarkable "finds." And, allow me to remark, there is more skill required to discover fossils than some may be apt to suppose. It is not mere haphazard work. The skilled discoverer knows exactly what rocks to search and how to search them, just as a good angler knows where to throw his bait with successful results. Many geologists can find fossils, but only a very few can describe them, and amongst the latter Mr Peach holds an honourable and prominent position. I need only refer to his papers contributed within the last few years to the *Transactions* of this Society. Thus in his paper, "On some new Crustaceans from the Lower Carboniferous Rocks of Eskdale and Liddesdale," he has described several phyllopods and decapods which are new to science; while, in later papers, he has added to the number of these crustaceans, and has introduced us to several new species of fossil scorpions from the Carboniferous rocks, and some fossil myriapods from the Old Red Sandstone of Forfarshire. All these papers are illustrated by beautiful drawings, for Mr Peach, like Dr Traquair and Mr Kidston, of whose labours Scottish geologists are so justly proud, is an admirable draughtsman. I may add that, while most of Mr Peach's work has been done in connection with the Geological Survey, he has yet accomplished a great deal outside of his official labours. Numerous papers read before the Geological Society of London and the Royal Physical Society, several of them written in conjunction with his colleague Mr J. Horne, testify to his abundant zeal and enthusiasm, and have greatly increased his scientific reputation. One of the latest of these joint-papers, "The Old Red Volcanic Rocks of Shetland," which appears in the current volume of the *Transactions* of this Society, is a masterly exposition of the igneous geology and petrology of Ultima Thule. In Mr Peach we recognise one who has not only maintained but increased the reputation of the Scottish school of geology, and the present award of the Neill Prize can hardly be more gratifying to him than it is to all his fellow-workers in Scotland.

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1. Obituary Notices of

General A. C. Robertson,
A. G. D. Cameron, Esq., and
D. M'Nair, Esq.,

by the President, were read by the Chairman.

The following Communications were read:—

2. On the Tidal Variation of Salinity and Temperature in the Estuary of the Forth. By Hugh Robert Mill, D.Sc., and J. T. Morrison, M.A., of the Scottish Marine Station. (Plate XXVIII.)

The observations which were described in papers read by one of us to this Society in January and April 1885,* and others since made, though as yet unpublished, serve to establish the condition of the Firth of Forth in its seaward reaches as to salinity and temperature. Between Queensferry and the Isle of May the increase in salinity, and the increase or decrease of temperature, are slight and gradual; there is little difference between bottom and surface, and tidal effects are insignificant. Between Queensferry and Alloa, on the other hand, the change in salinity per mile is much greater, and the tidal range is very considerable. The isolated observations which had been made in this region, and especially about Kincardine, seemed to indicate that the same *régime* held there as in the estuary of the Spey,† only the effects were on a reduced scale and somewhat modified.

It was necessary to test the applicability of this theory, and we lately spent a week at Kincardine for this purpose, working from the sailing-boat "Paracelsus" between Kincardine and Cambus.

The words river, estuary, firth, are used with considerable latitude, and it is advisable in considering salinity to employ them with precisely definite meanings. This cannot be very easily done if the terms be used in reference to the geographical position of a river-system; but, if we may suppose that the river proper may be shortened by the intrusion of the estuary and lengthened by its withdrawal, a sufficiently precise meaning can be given. A *river*, then, is a stream of fresh water, which by gradual increase of salinity may merge into an estuary, or by an abrupt accession of salt water may run directly into a firth or sea. An *estuary* is the region where the tidal current effects a mixture of river water with

* Mill, "On the Salinity of the Firth of Forth," *Proc. Roy. Soc. Edin.*, vol. xiii. pp. 29–64 ; "On the Temperature of the Firth of Forth," *Ibid.*, pp. 157–167. See Chart of Firths at page 28.

† Mill and Ritchie, "Physical Conditions of Rivers entering a Tidal Sea," *Proc. Roy. Soc. Edin.*, vol. xiii. p. 460–485.

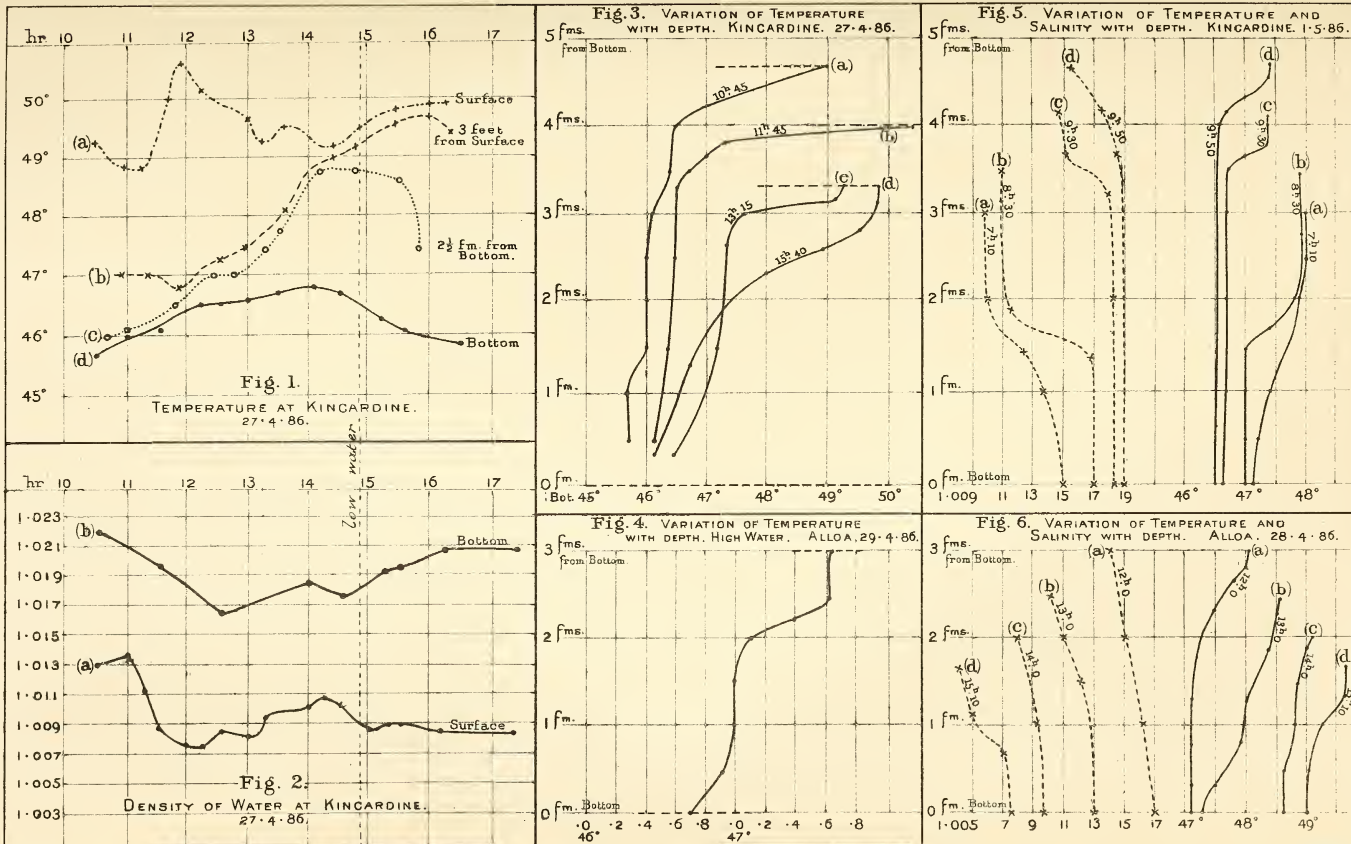


Fig. 1. Temperature at Kincardine. 27·4·86.

Fig. 2. Density of Water at Kincardine. 27·4·86.

Fig. 3. Variation of Temperature with depth. Kincardine. 27·4·86.

Fig. 4. Variation of Temperature with depth. High Water. Alloa, 29·4·86.

Fig. 5. Variation of Temperature and Salinity with depth. Kincardine. 1·5·86.

Fig. 6. Variation of Temperature and Salinity with depth. Alloa. 28·4·86.

McFarlane & Erskine, Lithrs. Edinr.

that of the sea or firth; its length and position in any system depend on many conditions, and may vary slightly with rainfall, tidal range, wind, and other variable factors. In an estuary, salinity increases rapidly from river to firth or sea. A *firth* is an inlet of the sea connected with a river through an estuary;* in it the water gradually increases in salinity from estuary to sea, and tidal effects are not strongly marked. The term *river-system* has been used here in a restricted sense to describe the connected system made up of four parts—river, estuary, firth, and adjacent sea; but this does not affect its more general geographical meaning, which includes tributaries and feeding lakes.

Applying these definitions to the Forth system, the river terminates in ordinary weather between Stirling and Cambus, the estuary stretches from the end of the river to about a mile east or west of Queensferry, and the firth then begins, extending to beyond the Isle of May.

Examination of the estuary was conducted in the manner adopted for the Spey, only the temperature was observed more frequently. The boat was anchored in the channel where the depth varied from 3 to 5 fathoms, according to the tidal phase; samples of water were collected by means of a bottle, the stopper of which was pulled out by a string when it was sunk to the proper depth; temperature was observed with the Scottish-frame Negretti and Zambra's thermometer. Every hour, or half hour if the change was rapid, a series of temperature observations at distances of every 2 or 3 feet from the bottom upwards was made, and if a considerable difference appeared between two positions, one or more intermediate observations served to define it exactly. Observations of density were made in like manner with a small hydrometer graduated directly to read "specific gravity at 60° F." from 1·000 to 1·030; and samples were frequently kept to have their density carefully determined with the delicate hydrometer on shore. Observations were continued for from two to seven hours at a time, and were arranged so as to include the most interesting phases of the tide at positions between Kincardine and Cambus.

* The inlet must be a narrow one relatively to its length, otherwise it is a bay or bight. The Moray Firth, for instance, is not a firth in our meaning of the word.

The weather was throughout clear and dry, and with the exception of one day, April 27, which was extremely warm, the air temperature was low, and an easterly wind prevailed.

Observations of Salinity.

It is unnecessary to give in detail a description of all the sets of observations which were made. The following statement shows the range of density in the water at the places where we worked :—

Table I.—*Density at* 15°·5 C. *of Estuary Water.*

	Tide within half an hour of							
	High Water.		Half-ebb.		Low Water.		Half-flood.	
	Surf.	Bott.	Surf.	Bott.	Surf.	Bott.	Surf.	Bott.
Kincardine. 27.4.86	1·01366	1·02022	1·00950	1·01668	1·00933	1·01953	...	...
28.4.86	1·01666	1·02097	...	...	...	...	...	...
28.4.86	1·01265	1·01776	...	...	...	...	...	...
30.4.86	...	...	...	...	1·01013	1·01443	1·01726	1·01928
1.5.86	...	...	...	...	...	...	1·01511	1·01719
Mean.	1·01432	1·01965	...	...	1·00973	1·01698	1·01618	1·01823
Mean of occasional observations from 1884 to 1886	1·01578	1·01891	...	...	1·00553	1·00916	...	...
Alloa. 28.4.86	1·01338	1·01548	1·00383	1·00582	...	...	...	...
29.4.86	1·01010	1·01530	1·00464	1·00818	...	...	...	...
Mean.	1·01174	1·01539	1·00423	1·00700	...	...	...	...
Mean of occasional observations from 1884 to 1886	1·00160	...	...	...	...	...	...	...
Cambus. 1.5.86	1·00367	1·00498	...	...	...	...	...	...

This table shows that a difference of density at the surface corresponding to 0·00459, and at the bottom to 0·00267, may be expected between high and low water at Kincardine ; the difference between the density of bottom and surface water being 0·00533 at high water, and 0·00725 at low water.

The decrease of density on the surface and at the bottom as the tide falls may vary in rate with varying conditions. The readings of the small hydrometer (uncorrected for temperature, which was practically constant throughout each series of observations) for several occasions are given below, and the figures in the case of

April 27, at Kincardine, are represented in the form of a curve in Plate XXVIII. fig. 2.

Table II. gives particulars of a complete ebb and part of a flood at Kincardine, and of an ebb and the end of flood and beginning of ebb at Alloa:—

TABLE II.—*Tidal Variation of Salinity.*

Kincardine, 27.4.86			Kincardine, 1.5.86			Alloa, 28.4.86			Alloa, 29.4.86		
Hour.	Density.		Hour.	Density.		Hour.	Density.		Hour.	Density.	
	Surf.	Bott.		Surf.	Bott.		Surf.	Bott.		Surf.	Bott.
10.30*	1·013	1·022	...	...	...	...	...	...	...	...	...
11	1·0135	...	7	1·010	1·0145	11.45†	1·016	1·020	11	1·014	1·0175
11.15	1·0115	...	7.30‡	1·010	...	12	1·0165	1·019	11.15	1·014	1·017
11.30	1·009	1·020	8	1·010	...	12.30	1·014	1·018	11.30	1·013	1·017
12	1·008	...	8.30	1·011	1·017	12.45	1·013	...	12	1·014	1·0175
12.15	1·008	...	9	1·012	...	13	1·0125	1·0155	12.30§	1·013	1·018
12.30	1·009	1·017	9.30	1·015	1·018	14	1·010	1·0115	13	1·012	...
13	1·0085	...	10	1·0155	1·019	14.30	1·009	1·010	13.30	...	1·017
13.15	1·010	...	11.30	1·018	1·019	14.45	1·007	1·010	14	1·012	...
14	1·0105	1·0185	...	...	...	15.	1·0065	1·0095	14.15	1·010	1·015
14.15	1·011	...	...	...	...	15.30	1·005	1·0065	14.30	1·009	...
14.30	1·010	1·018	...	...	...	16	1·005	1·006	14.45	1·009	1·013
15	1·009	..	...	...	...	...	...	...	15	1·008	1·012
15.15	1·0095	1·020	...	...	...	...	...	...	...	...	...
15.30	1·0095	1·020	...	...	...	...	...	...	...	...	...
16.15‖	1·009	1·021	...	...	...	...	...	...	...	...	...
17.15	1·009	1·021	...	...	...	...	...	...	...	...	...

* High water at 10. † High water, 11h. 15m. ‡ Low water, 7h. 25m.
§ High water, 12h. 20m. ‖ Low water at 16h. 20m.

At a given time the vertical distribution of salinity in the water was found to be determined by the depth, position, and state of tide. At Alloa, for instance, the difference between bottom and surface water was so slight, and the depth so small, that the hydrometer employed was of little use in tracing the form of the density curve.

As the tide fell the water got fresher uniformly and gradually, the rate of freshening at surface and bottom being practically the same until about half-ebb, when the surface showed signs of more rapid dilution; but before low water the slight and uniform change was re-established. If the ebb continued long enough at Alloa to let the level of the water fall from 2 to 3 feet below the ordinary low-water mark, our observations indicated that it would be entirely fresh in ordinary weather. In times of flood, of course, fresh water is found even farther down the estuary. The curves of salinity obtained at Alloa on April 28 are shown on Plate XXVIII. fig. 6.

At Kincardine there was always a more marked change in salinity with depth, and while at high water there was a minimum difference between surface and bottom, and a nearly uniform vertical distribution, in the early part of ebb the greater part of the increase of density was in the first fathom, and in the early part of flood in the fathom nearest the bottom. The travelling downward of the point of inflection in the curve corresponding to the increasing freshness of the upper strata of water as the tide falls is shown clearly in diagram 5, Plate XXVIII.

Observations of Temperature.

The relation of the temperature of the water to its salinity was such at the time of our observations that surface water which was fresher was also warmer than that at the bottom, and water from the upper part of the estuary was warmer than that in the lower part. It thus happened that an increase of salinity was always accompanied by a decrease of temperature, and a decrease of salinity by an increase of temperature. It will be seen, by reference to Plate XXVIII. figs. 5 and 6, that the curves illustrating the vertical distribution of temperature in the water at any time were almost mirror images of those representing density. The position and amount of inflection in the corresponding curves are, in fact, the same, though the directions are opposite. It thus appears that at this season of the year the thermometer alone is sufficient to trace out the interaction of the frithial and fluvial water in such an estuary as that of the Forth. The following notes, although taken from individual cases, illustrate what we found to be the conditions characteristic of the various phases of tide during the period of our observations. The range of temperature for the whole time was rather less than 5° F., varying from 50° to 45°·5, and the difference between surface and bottom rarely amounted to so much as 3°.

Ebb Tide.—Kincardine : depth of water, 3 to 5 fathoms. From one to three and a half hours of ebb the vertical distribution of temperature remains practically the same, being nearly uniform from the bottom to about 4 feet from the surface, where there is a sudden increase in the rate of rise. The temperature of the whole mass of water increases uniformly with time, so that the curves of vertical distribution for successive half-hourly periods are parallel to each other. This indicates a movement of water *en masse* from the upper to the lower parts of the estuary.

From three and a half to five hours ebb the temperature of the bottom water does not increase much, but between $1\frac{1}{2}$ and 3 fathoms from the bottom there is a continuous rise of temperature, which becomes less marked near the surface. The curves show a shearing displacement during this period, and appear to indicate that the current at the bottom is slackened, and that the upper and middle layers of water flow on over it.

During the last hour of ebb the bottom water gradually but distinctly cools, and the fall of temperature is shared in by the lower fathom and a half; the next fathom shows a gradual rise in temperature, while the surface layers remain nearly unaltered. The water on the bottom appears to be flowing, while that on the surface is still ebbing. Ships anchored in the channel begin to swing, and turn completely round, from half an hour to twenty minutes before boats anchored in a similar position are moved, a fact which proves conclusively that flood tide sets in first at the bottom.

Ebb tide at Kincardine is illustrated by the curves in Plate XXVIII. fig. 3.

Ebb Tide.—Alloa: depth from $3\frac{1}{2}$ to 1 fathom. The difference of temperature (and of salinity also) between surface and bottom is here so slight that it is difficult to determine the exact vertical distribution. Speaking generally, the curves move along the scale nearly parallel to themselves, showing a movement of translation in the water from the upper part of the estuary firthwards; there are indications, but too slight to be held as altogether satisfactory, that a certain amount of shearing motion takes place as at Kincardine just before the turn of the tide (see Plate XXVIII. fig. 6).

Flood Tide.—Kincardine: depth from 3 to 5 fathoms. During the two first hours of flood the whole body of water from surface to bottom falls in temperature uniformly, the curve of vertical distribution showing an inflection in the second fathom from the bottom. This indicates a flowing up-stream of the whole water. An upward travelling of the inflection along the curve shows that the actual increase of depth is due not to the damming back of water above, but to rapid influx from the lower parts of the estuary. During the next two and a half hours the temperature is nearly uniform from the bottom to within one fathom of the surface, where there is a sharp rise. After five hours flood, while the lower strata are still falling in temperature, the surface fathom is rising rapidly; showing that ebb has begun above while flood continues below, the result being, of course, a shearing motion.

The greater part of both flood and ebb tide is characterised by a strong current as nearly as possible of equal velocity at surface and bottom, but at the turning points of flood and ebb, and for about an hour before and after these crises, there is a shearing motion, the sliding of one layer over another. By this means the same condition of things is established at high and at low water, viz., a colder bottom layer, a warmer surface layer, and a short intermediate region of comparatively rapid change of temperature (see Plate XXVIII. fig. 4.)

In the foregoing discussion for "rise of temperature" may be substituted "decrease of salinity," and for "fall of temperature" "increase of salinity."

The "Leaky Tides."—The fishermen at Kincardine speak of a tidal phenomenon which occurs both during flood and ebb. It consists of a temporary stoppage or reversal of the current; when this takes place during ebb it is called the "leaky flood," and when during flood the "leaky ebb." We were not able to get any very precise information regarding it, and during our stay we were only once fortunate enough to see the effect. From such descriptions as we could procure, and from our observation of one leaky flood, the explanation seems to be as follows:—About an hour before calculated low water at Kincardine the tidal current has become imperceptible in the lower part of the estuary, and shortly afterwards it turns and runs up. The stream of salt water going up the estuary meets the down-running current of fresher water as a wall, and serves to dam it back for some time, slackening the rate of ebb throughout the whole estuary, or even reversing it for a short time. Very soon, however, the difference in density of the two streams asserts its influence, the salter water penetrates the lower layers of the fresher, and flows up under it as a very diffuse and ill-defined wedge, while the surface layers, being released from the pressure, flow outwards again until ebb tide is completed, and the force of the flood tide is strong enough to ensure reversal of direction all along the estuary.

The subject of leaky tides deserves more careful observation for a longer period than we were able to devote to it.

Explanation of Plate XXVIII.—By way of a summary of the principal results, the meaning of the various curves in the Plate may be briefly pointed out.

Figs. 1 and 2 show the variation of temperature and density during an entire tide at Kincardine on 27th April 1886.

Fig. 1. Kincardine, 27th April 1886, from 10.30 o'clock to 16.30 o'clock, *i.e.*, from 2 hours ebb to 2 hours flood. Depth varied from 4 fathoms 4 feet to 3 fathoms 2 feet.

Curves showing the variation with time or phase of tide of the *temperature* of the water:—

(*a*) at the surface,
(*b*) at 3 feet below surface,
(*c*) at $2\frac{1}{2}$ fathoms above bottom,
(*d*) at bottom.

Abscissæ mark time, ordinates temperature.

Surface curve is made irregular by sun-heating. The others show that while the bottom layer attains its maximum temperature an hour before low water, the intermediate maximum is later, and the water near the surface is warmest after low water. The shearing motion that occurs near high water is made very evident by these curves.

If corresponding curves for 12 hours could have been obtained, they would probably have shown—

(1) at the bottom, a minimum temperature *after* high water, and a maximum *before* low water, and therefore a steep rise.

(2) near the surface, a minimum temperature *before* high water, and a maximum *after* low water, and therefore a steep fall.

Fig. 2. Kincardine, 27th April 1886, from 10.30 o'clock to 17.30 o'clock, *i.e.*, from 2 hours ebb to 3 hours flood.

Curves show variation of density with phase of tide

(*a*) at surface,
(*b*) at bottom.

So far as interpretable, these curves accord with those of temperature in fig. 1.

Fig. 3. Kincardine, 27th April 1886, between hours of 10.45 and 15.40.

Curves showing variation of temperature with depth at the following instants :—

(*a*) 10.45 o'clock, or $2\frac{1}{4}$ hours ebb.
(*b*) 11.45 o'clock, or $3\frac{1}{4}$ hours ebb.
(*c*) 13.15 o'clock, or $4\frac{3}{4}$ hours ebb.
(*d*) 15.40 o'clock, or 1 hour flood.

(*a*), (*b*), (*c*) are similar in form, and probably indicate translation of water *en masse*.

In (*d*) the shearing motion above referred is clearly suggested by the back-throw of the bottom of the curve.

Fig. 4. Alloa, 29th April 1886. Variation of temperature with depth at high water. Form of curve is supposed to be typical of both high and low water.

Fig. 5. Kincardine, 1st May 1886, between 7.10 and 9.50 o'clock. Dotted curves show variation of salinity with depth; plain curves show variation of temperature with depth at

(*a*) low water.
(*b*) 1h. 20m. flood.
(*c*) 2h. 20m. flood.
(*d*) 2h. 40m. flood.

Note the great similarity between the two sets.

Fig. 6. Alloa, 28th April 1886, between 12 and 15.10 o'clock.

Dotted curves show variation of salinity with depth, plain curves of temperature with depth at

(*a*) 1 hour ebb.
(*b*) 2 hours ebb.
(*c*) 3 hours ebb.
(*d*) 4 hours ebb.

As in fig. 5, the two sets of curves are strikingly similar.

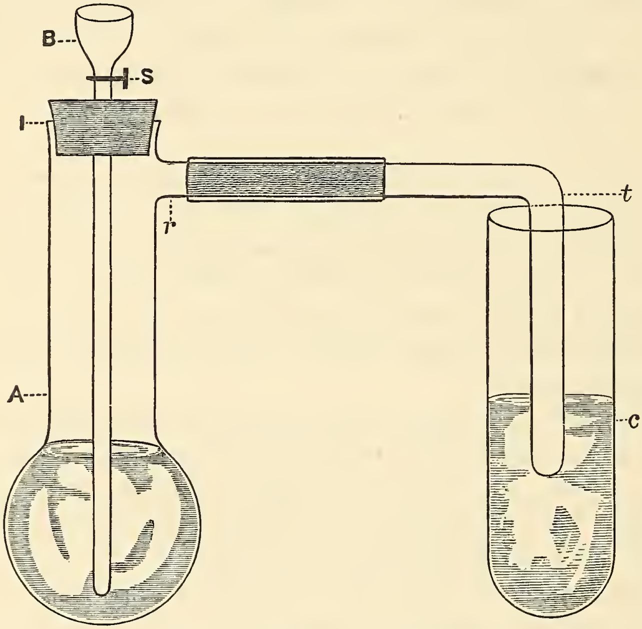
3. On a New Method and Reagent for detecting Chlorides, Bromides, and Iodides, in the presence of each other, and also in presence of Nitrates and Chlorates. By John Jas. Barlow, Manchester Technical School.

A short time ago I published a method in the *Chem. News*, vol. liii. p. 41, "On the use of Hydrogen Peroxide as an oxidising agent for detecting and estimating Manganese;" showing the advantages it had over other sources of oxygen for oxidation purposes, simply on account of the fact, that when using hydroxyl you do not introduce any objectionable foreign substance, such as manganese, chromium, potassium, lead, &c.

Since then I have used it with advantage in many other chemical operations where oxidation was necessary, amongst others, the substance of the present paper—the detection of chlorine, bromine, and iodine. The detection of these substances, in the presence of each other, has been accepted as (to say the least) troublesome; and numerous papers have been published within the last four years on the subject by A. Cavazzi; P. S. Brito, M.B.; E. Hart; and F. Jones, F.R.S.E., though none of the methods given by these chemists can be called satisfactory; the last two may be considered the best, though they both introduce foreign substances, and in the last, F. Jones' method, where MnO_2 is used for oxidising, I could not detect the substance, if in small quantity, and its introduction always prevents the various changes which occur in the solution from being observed.

The following method, which has given entire satisfaction both to myself and also to Dr Griffiths, F.R.S.E., Technical School, Manchester, and some of his students, consists in principle of eliminating, step by step, as it were, the iodine, bromine, and chlorine in succession by means of dilute H_2SO_4 and a solution of hydrogen peroxide. To insure success, close attention should be given to various little details mentioned.

The sketch shows the apparatus used, and consists of a glass tube A, about 4 inches long and $\frac{3}{4}$ inch diameter, with a small bulb blown on the bottom capable of holding 10 c.c. It is fitted with a tight cork I, through the centre of which passes a small funnel tube B. This must reach to within $\frac{1}{4}$ inch of the bottom of the bulb, and



should be fitted with a stopcock S, just below the funnel. On one side of the tube A, just underneath the stopper I, is the arm *r*, about 1 inch long and $\frac{1}{4}$ inch diameter, on the end of which is joined, by a piece of rubber tubing, a glass tube *t*, bent at right angles, the long arm being about 5 inches; this conveys the vapours which distil over into the receiving tube C (*i.e.*, an ordinary test-tube), which contains the solution of starch, ether, &c.

In making an experiment, place the substance under examination (it is best not to use more than 0·25 grm. at once) in the tube A, nearly fill the bulb with water, then run down B, after warming slightly, two drops of dilute sulphuric acid (1 in 5). If nitrates or chlorates are present, the fluid will change colour, yellow or red, due to the liberation of iodine; if so, boil until the colour disappears. If chlorates and nitrates are absent, no change of colour takes place in the bulb, until on adding two drops of hydrogen peroxide, whence if iodine be present, the liquid in the bulb immediately assumes a yellow, then a rosy red colour, and on boiling a violet vapour makes its appearance in the upper part of the tube, even when only minute quantities of iodine are present; dispel the iodine gradually by carefully adding hydroxyl, two drops at a time. The iodine being expelled, add two drops of dilute H_2SO_4 and three or four drops of hydroxyl; the bromine will now make its appearance, and hydroxyl solution must be added, two drops at a time, until it has all disappeared, which will be known by the clearness of the liquid in the distilling bulb, and will be also almost colourless. Very often a little chlorine can be detected coming over with the bromine, but this only occurs when the quantity is large, or when too much H_2SO_4 has been added, and so making the solution strongly acid. In fact, this must be done if the experiment is to be successful in all cases, and great care must be exercised in adding the H_2SO_4, as well as the hydroxyl (H_2O_2). If now, after the bromine has disappeared, a few drops of a solution of $AgNO_3$ be added to the solution remaining in the bulb, a white precipitate of AgCl will appear, showing the presence of a chloride. It is always better to divide the solution into two parts, or take only a portion for the detection of a chloride.

In every experiment I detected the iodine when present, either by the flash of red colour in the distilling bulb, the vapour (violet) in the upper part of the tube, or the blue colour with starch, even if the iodine present only amounted to the one-thousandth part of the substance present.

In only one case, out of a great many experiments, was I unable to detect bromine, and that when the amount of bromine, compared with the iodine and chlorine, was very small. The detection of the chlorine was always sure, in some cases by the smell, but always by means of silver nitrate ($AgNO_3$).

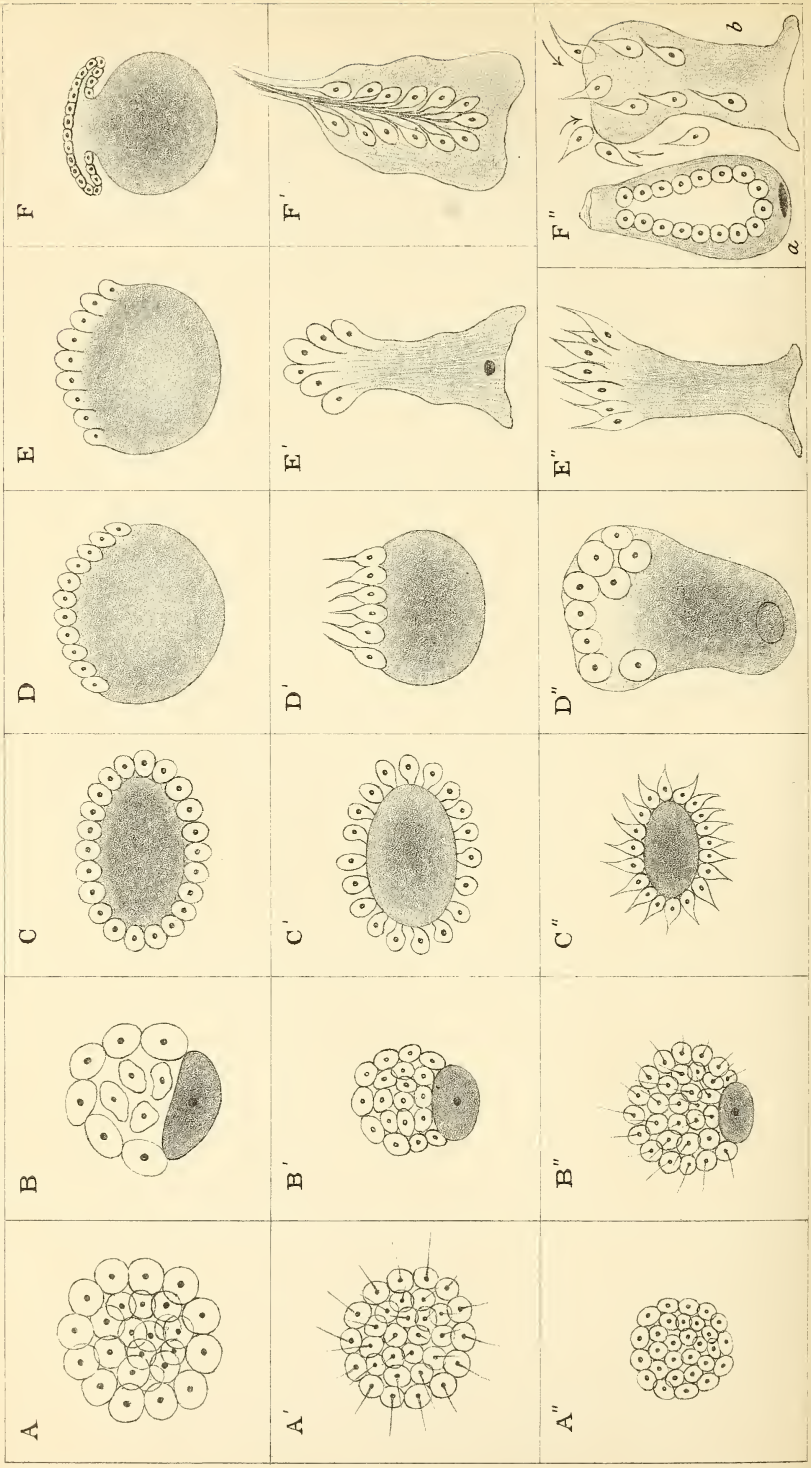
The following acids do not interfere with the test:—hydrosulphuric, sulphurous, hyposulphurous, carbonic, phosphorous, and hydrofluoric acids.

When the chlorine, bromine, and iodine are in combination with the heavy metals, the experiment in some cases is not so successful, so that it is always better to boil with Na_2CO_3 or K_2CO_3, so as to expel the heavy metals, and get the acid radicles in combination with sodium or potassium.

The following results of carefully worked experiments, out of many more, I give in detail, to show the trustworthiness of the method :—

	Ingredients in the Mixture.	Weight of each Salt in the Mixture.	Observations.	Remarks.
1	I	0·001 grm.	Red colour in bulb, violet vapour, starch coloured blue.	
	Br	1·000 "	Strong and thick Br vapours, starch coloured yellow, ether red.	
	Cl	0·100 "	Smell of chlorine, and white pp. of AgCl.	
2	I	0·001 "	Red colour in bulb, violet vapour, starch coloured blue.	
	Br	0·010 "	Smell of Br strong, ether coloured red.	
	Cl	1·000 "	Strong smell of chlorine,* and white pp. of AgCl.	* The Cl came off latterly with the bromine.
3	I	0·100 "	All the iodine reactions.	
	Br	0·001 "	Smell of Br (slight). Ether coloured yellowish-red.	
	Cl	0·500 "	Strong smell of chlorine, and white pp. of AgCl.	
4	I	1·000 "	Iodine in abundance.	
	Br	0·001 "	Could not obtain with certainty the bromine.	This is the only case, which I attribute to the large quantity of iodine.
	Cl	0·100 "	Smell of Cl and white pp. of AgCl.	
5	I	0·001 "	Red colour in bulb,* no violet vapour, starch, slight blue.	* The presence of the NO_3 interfered.
	Br	0·010 "	Bromine smell and ether coloured red.	
	Cl	0·100 "	Chlorine smell, and white pp. of AgCl.	
	NO_3	1·000 "	Nitrous fumes mixed with the bromine.	
6	I	0·010 "	Red colour in bulb, no violet vapour, starch blue.	
	Br	0·010 "	Starch coloured deep* yellow, ether red.	* Cl colours starch, but the colour is a very light yellow.
	NO_3	1·500 "	Nitrous fumes in abundance.	
	ClO_3	0·500 "	Strong smell of chlorine, and white pp. of AgCl.	
7	I	0·001 "	Red colour in bulb, violet vapour, starch coloured blue.	
	Br	0·001 "	Starch coloured yellow, ether coloured red.	
	Cl	0·001 "	White pp. of AgCl.	* If there is a strong effervescence, on addition of first two drops of acid, add more until effervescence ceases.
	SO_3	0·100 "	Smell of burning sulphur, discoloured iodine solution.*	
	S	0·010 "	Smell of H_2S, black spots on lead paper.*	
	CO_3	1·000 "	CO_2 reaction, strong effervescence.*	

Comparison between segmentation of ovum and division of mother-sperm-cell.



4. On the Anatomy of *Suberites domuncula*. By J. Arthur Thomson, M.A. Communicated by Patrick Geddes, Esq.

5. History and Theory of Spermatogenesis. By Patrick Geddes and J. Arthur Thomson. (Plate XXIX.)

The development of spermatozoa has been for the last twenty years the subject of prolonged research and controversy, which cannot yet be said to have resulted in satisfactory solution of the involved problems. In view of the intrinsic difficulties of the subject, and the discrepant results and nomenclature of different authorities, it is the object of the present paper to recapitulate the history of investigation, to collate the results and the nomenclature, and to propose a theory which will explain and rationalise the maze of apparently conflicting observations.

§ 1. *History.*—The modern period of investigation, despite a few researches by Wagner, Von Siebold, and others, practically opens with Kölliker's fundamental observation* (1841), that the head of each spermatozoon arose from the nucleus of a seminal cell (Samenbildungzelle).

In 1844 Meckel described, in Helix, how the cell destined to become spermatozoa arose superficially from a mother-cell, in the epithelium of the germ follicle. According to Kölliker, however, the central body round which the immature sperms were grouped was no cell, but only the residue of the mother-cell within which the sperm cells had arisen endogenously. The research of Ankermann* (1854) also deserves mention, for his derivation of each spermatozoon from a distinct cell.

The account of spermatogenesis became somewhat more complex when Kölliker described, in 1856, two kinds of cells lining the tubules—(*a*) outer cells with large nuclei and nucleoli, and undergoing rapid multiplication; (*b*) inner cells, becoming differentiated into seminal cells, which formed in some cases cysts, and from whose nuclei the spermatozoa were formed. Henle also distinguished two kinds of round cells (*a*) with granular, and (*b*) with

* For papers referred to see Bibliography, in which the authors' names are arranged alphabetically.

clear refracting nuclei, from both of which sperms were developed: he emphasised the cellular homology of the spermatozoon, deriving the head from the nucleus, and the tail from part of the protoplasm, while Kölliker was more inclined to regard the whole as a modified nucleus.

That the simple developmental history described by Kölliker and Henle did not express all the facts of the case was proved by the researches of Sertoli, who (1865) described in the seminal tubules certain "ramified cells" which projected between the round cells, and were often branched internally, while the peripheral end of each, with the nucleus, was in direct contact with the wall of the canal. He regarded their function, however, as only secretory, and contrasted them as epithelial and fixed, with the round, mobile cells which had the direct role of producing sperms. This discovery was abundantly confirmed, but especially by Merkel, who described (1871) large cells lying close to the *tunica propria*, which he called *Stützzellen*, and regarded as forming a supporting framework for the adjacent round cells from which the spermatozoa developed.

These round cells had been hitherto regarded as alone directly essential to spermatogenesis, but a contrary opinion was maintained in the classic research of Von Ebner (1871). Within the endothelial tunic of the seminal canals of the rat, he described a layer of two kinds of cells—(*a*) round granular cells, and (*b*) larger, elliptical cells, the latter confluent at the base, and forming a protoplasmic layer or *Keimnetz*. The inner end of each of these large cells enlarges and divides, forming irregular digitate prolongations which project into the lumen of the duct. At the base of the whole cell, which with its prolongations he termed a *Spermatoblast*, the primitive nucleus remains undivided, while at the base of each lobe a nucleus is observed, which he ascribed to endogenous origin. The nucleus of each digitation elongates to form the main portion of the head of a spermatozoon, and a thin film of protoplasm elongates into the tail. The heads of the resulting spermatozoa at first press downwards within the spermatoblast, reaching almost to the *Keimnetz;* their tails protrude into the lumen. When finally liberated the sperms curl themselves up to roll down the seminal tubule, and the more or less branched stump of the spermatoblast is left bare. The round cells take no part in the process (though he also described multinuclear cysts); they originate from blood corpuscles, and perform nutritive or mechanical functions.

Over this a vigorous controversy at once arose. Merkel (1874) identified Von Ebner's spermatoblasts with his *Stützzellen*, but while maintaining the origin of the sperms from the round cells, allowed that they were *secondarily* received into side pocket-like cavities of the Stützzellen. According to Merkel, this secondary stage had thus been mistaken by Von Ebner for the primary.

The next important contribution was that of Sertoli, who described the fixed, ramified, epithelial cells as before, and identifying them with Merkel's *Stützzellen* and the lower part of Von Ebner's spermatoblasts, still maintained that they took no part in the actual spermatogenesis. This he ascribed wholly to the mobile round cells which arise between the fixed cells, and which he distinguished in their youngest state as "germinative," and later as the larger "seminal" cells from the division of which the small numerous nematoblasts or undifferentiated spermatozoa result.

Merkel was supported by Von Brunn, and by Bloch who followed the development of the "round cells." Neumann, on the other hand, denied the existence of Merkel's framework altogether, and described free nucleus formation within the spindle-shaped, first blunt, then fringed, spermatoblasts, which, differing from Von Ebner, he regarded as modified from the ordinary epithelium of the tubule. He also described the origin of spermatozoids from *free* cells, which he explained as separated lappets of spermatoblasts. Krause (1876) also essentially supported Von Ebner, but described the spermatoblasts as ciliated cells with ramified and even anastomosing processes, so doing away with a connective system altogether. Von Ebner was further corroborated by Mihalkowics, Rivolta, and others, and his account of the processes has been perhaps most generally adopted (*cf.* Landois, Frey, &c.). Blumberg (1873) attempted to reconcile the disputants by ascribing spermatogenetic functions to both spermatoblasts and round cells.

Semper's well-known researches on the urinogenital system of Elasmobranchs included an important contribution on spermatogenesis. He described an invagination of the germinal epithelium or of the primitive ova into the subjacent stroma, where they form a primitive follicle, which again comes into relation with the incipient tubule. All primitive ampullæ exhibit (*a*) large, granular cells with round nuclei, and (*b*) smaller cells with more oval nuclei, in regard to which the possibility is suggested that the narrowed nuclei form the round. At a later stage two distinct layers are observed; the narrow nucleated cells form for a while an outer epithelium, but afterwards disappear; this is succeeded by a stage where the lumen is apparently lined by large conical cells with two nuclei, of which the inner are long and granular, while the outer are round and homogeneous. The inner oval nuclei bud off externally a large number of round spermatoblast nuclei, first regularly and then irregularly grouped. These are enclosed within the conical mother-cell, and are separated from the ampulla wall by the large oval nucleus of the "Deckzelle," in regard to whose origin, from a modification of an outer layer of spermatoblast nuclei, or from the outer narrow-nucleated cells of the primitive ampulla, Semper remained undecided. The sixty or so spermatoblast nuclei, elongate to form the heads of the spermatozoa, which lie originally near the "cover-cell"; the whole mass forms a bundle filling the greater part of the mother-cell, from which they are expelled by the swelling up of the "cover-cell."

The important series of researches by Von la Valette St George was meanwhile leading up to a quite different view of spermatogenesis. In his fifth communication, in 1875, he distinguishes within the seminal tubule, two kinds of cells—(*a*) epithelial cells, homologous with primitive ovules, and dividing to form *spermatogonia* which lie close to the *tunica propria;* and (*b*) small round cells lying between the spermatogonia, and having no other function than that of enveloping the spermatogonia and their successors. Each spermatogonium forms by division a multinuclear cyst or *spermatogemma*, consisting of a mass of daughter-cells or *spermatocytes.* These spermatocytes may either (*a*) all develop into spermatozoa (Mammals), or (*b*) a single spermatocyte may become modified as a basilar cell (Plagiostome Fishes), or (*c*) a number may form an envelope round the others (Amphibians and Fishes). In comparing these divergent results with those of Merkel and Sertoli on the one hand, and those of Von Ebner on the other, he regards his primitive spermatogonia, lying round the *tunica propria*, as equivalent to Von Ebner's "Keimnetz" and the base of Merkel's

"Stützzellen," the central part being simply the follicular cells altered by reagents. The spermatoblasts were explained away as misinterpretations of the temporary union of a number of spermatocytes originating from the same parent spermatogonium.

Helmann (1879) similarly described the division of each primitive cell into a mass of daughter-cells which are differentiated into spermatozoa; while Krause referred the origin of the sperms to the indirect division of the (germinative) follicular cells, which form spermatogemmæ (or Knäuelzellensäule) of "spermatoblasts," while the nucleated basal portion forms the "spermatogonium." With this Meyer (1880) also agreed, regarding the follicular cells of Von la Valette St George as the earliest stages of the spermatogonia and spermatogemmæ. Nussbaum's well-known memoir on the differentiation of the sex-elements contained an account of spermatogenesis, which substantially agreed with that of La Valette. From the primitive male ovule, spermatogonium and follicular cells both arise, as in some cases of oogenesis; by indirect division within the spermatogonium, cells are formed which become spermatocytes, though a few peripherally situated probably form a second enveloping membrane —the "Cystenhaut."

It is most convenient, at this stage, to refer to the spermatogenesis of Invertebrates, which has also been the subject of numerous important researches, together comprehending almost every group. It is only necessary to allude to a few of these. In 1877 F. E. Schulze described the spermatogenesis of the sponge *Halisarca*, in which germinal mesoderm cells, analogous to those which give rise to ova, divide repeatedly to form morula-like masses, composed of about thirty cells, each of which develops into a spermatozoon. Round the larger clumps, a mesoderm capsule of flat polygonal endothelial cells is formed, as round the ova. An interesting observation on the spermatogenesis of *Sycandra raphanus* is due to Polejaeff (1882), who described the nuclear division of the primitive amœboid cell,—the smaller half forming a cover cell (*Deckzelle*), which embraces the sperm-cells resulting from the repeated division of the larger half (the *Ursamen-zelle*).

In 1844 Meckel had described the spermatozoa of the snail, as arising superficially from a mother-cell, and this view had been confirmed by various authors. According to Duval, the mother-cell exhibits an endogenous formation of nuclei, which, travelling outwards, form the spermatocyte-cells, apparently budded out on the surface. The mother-cell degenerates, the nucleus alone remaining to serve as a basis of attachment for the spermatocytes, but finally also undergoing atrophy. With this, Keferstein's account in general agreed. M. v. Brunn, however, denied the endogenous formation of nuclei, and maintained the persistence of the basal-cell to form new generations of spermatocytes. Blomfield also described in Helix the division of the spermatogonia to form morula-masses ("spermatospheres") of "spermatoblasts," one of which (the "blastophoral cell," situated next the ampulla-wall) is, at an early stage, marked off from the others, remaining inactive while the other "spermatoblasts" of the "polyplast" are more or less supported by it, in their continued multiplication. What Duval had described in the snail, Hallez corroborated by the observation of an essentially similar process in some Planarians; while Graff found in other species that no cytophoral remnant survived, but that the whole of the spermatogonium became converted into a "spermato-morula" of spermatocytes. The spermatogenesis of some Trematodes was described by Lorenz (1878) as consisting in the enlargement of an epithelial cell, the endogenous appearance of nuclei, and segmentation into a morula-like mass of somewhat indistinctly separate cells, round a small central remnant. In 1880 Blomfield investigated the process in the earth-worm, and described how a "spermatospore" cell divides into a number of "spermatoblasts," with a central mass of inactive protoplasm, the "blastophore,"—the whole result forming a "spermatosphere," of which each of the "spermatoblasts" is differentiated to form a spermatozoon. His results are, on the whole, more analogous to those of Von Ebner than to those of La Valette. Besides his subsequent research on the spermatogenesis of the snail to which we have already alluded, he described that of the frog. In this case a hollow spermatogemma arises, each of its cells elongates to form a spermatozoon; these, while immature, arrange themselves in bundles round one of the more superficial cells, which "become blastophoral corpuscles,"—a view which recalls Merkel's explanation of Von Ebner's spermatoblasts, mentioned above, viz., that the spermatozoa, after completing their development, are only temporarily lodged in the recesses of the former.

Herrmann has described the spermatogenesis of certain Crustacea as consisting in the division of the nucleus of a male ovule to form a group of spermatoblasts, each of which becomes differentiated into a spermatozoon. A more thorough investigation, however, is due to Grobben. The germinal layer of the Crustacean testes is described as consisting of (*a*) large cells with round nuclei (the spermatoblasts of Von Ebner, &c.), and (*b*) of a nucleated protoplasmic mass between the bases of the former. The reserve nucleated masses (*Ersatzkeime*) represent, according to Grobben, the earliest stage; the larger nuclei are changed into spermatoblast-nuclei, while the former probably multiply and grow for the future replacement of used-up spermatoblasts. Each of these reserve germs (Ersatzkeime) is potentially a spermatoblast; the difference between them is secondary. The comparative spermatogenesis of Arthropoda has lately been the subject of elaborate study by Gilson, who distinguishes primordial "metrocytes," multiplying into direct metrocytes or "mother-sperm cells," which divide up into "spermatic cells"—each the immediate predecessor of a spermatozoon.

Sabatier (1882) has also described the spermatogenesis of several Invertebrates. Within mother-cells or "spermatospores" nuclear multiplication and superficial budding occur, resulting in a number of stalked claviform cells or "protospermoblasts." These are detached, increase in size, exhibit nuclear multiplication and superficial budding, resulting in the production of a second generation of spermoblasts—the "deuto-spermoblasts," which form the spermatozoids. In regard to numerous groups, Nemerteans, Echinoderms, Molluscs, and Ascidians, he maintains the occurrence of two generations of cells of which the first become the blastophores of the second, the "spermatospores" of the "protospermoblasts," and the latter in turn of the "deuto-spermoblasts."

Most nearly related perhaps to Sabatier's account is the divergent description given by Bolles-Lee of the spermatogenesis of Appendicularia. In the large mother-cells of the testis scattered nuclei appear, originating, however, not from the mother-cell nucleus, but, peripherally, from the protoplasm. There is, further, no "polyplast" stage, but the developed nuclei, *i.e.*, the "spermatoblasts," form a "germinative epithelium," and are differentiated on the surface into spermatozoa.

The researches of Jensen on the spermatogenesis of numerous invertebrate forms, were mainly corroborative of the views of La Valette St George. A spermatogonium divides into a mass of spermatocytes, or a spermatogemma, which includes a distinct, sometimes nucleated cytophore (sperm blastophore). This is regarded, however, not as a separated off portion of the mother-cell, but as the result of the internal destruction of the central spermatocytes, or of those nearest the ampulla wall.

In the recent account of the spermatogenesis of *Ascaris megalocephala* given by Van Beneden and Julin, primitive male ovules or "spermatomeres," form, by direct division, spermatogonia; each of the latter divides indirectly into four spermatocytes, which together form a spermatogemma. Each spermatocyte forms a cytophoral portion towards the centre of the spermatogemma, and these four portions compose the so-called cytophore, from which the spermatozoids are liberated. This recent research is of further interest, though this does not specially concern us here, for the description of a process, observed in the formation of the spermatogonia, which exactly corresponds with the account of polar cell formation given by Van Beneden.

One of the clearest accounts of invertebrate spermatogenesis is given by Voigt in regard to *Branchiobdella*, in which the following five stages are distinguished—(1) sexual cells, (2) spermatogonia (or Stammsamenzellen), (3) spermatocytes (or Samenvermehrungszellen), (4) spermatides (or Samenausbildungszellen), and (5) spermatozoa (or Spermatosomen). The first are the embryonic cells, the second are the homologues of the ova and the origin of a sperm-bundle, the third form collectively a spermatogemma, the fourth are not yet perfectly differentiated sperms, nor freed from the separated-off portion of the spermatocyte. The same nomenclature is followed by Platner in his recent account of Pulmonate spermatogenesis. The spermatogonia are at an early stage the only cells in the hermaphrodite gland besides the ova. They divide indirectly to form spermatocytes, but a large proportion of them persist, arranged in pillars between the spermatocyte groups, and subsequently form not only a new generation of spermatocytes, but also new "basal cells," after the others have disappeared. These basal cells appear at an early stage adjacent to the alveolar wall, and resemble spermatogonia, though they never divide, but merely serve as centres, round which the spermatocytes are associated. The spermatocytes divide indirectly to form spermatides or undifferentiated spermatozoa.

After this notice of some of the more important accounts of invertebrate spermatogenesis, it is necessary to return to the much more complicated and debated spermatogenesis of vertebrates.

Renson (1882) described small round granular cells at the periphery of the canal adjacent to the tunica propria, which he regarded as the germinative cells of Sertoli and Krause, the granular cells of Von Ebner's Keimnetz, and the follicular cells of La Valette. These segment into multinuclear cysts—the "spermatoblasts" of Krause, or the spermatogemmæ of La Valette,—and from the resulting cells the young sperms or nematoblasts result. The immature nematoblasts, however, group themselves round the extremity of certain large projecting epithelial cells (cellules de soutien),—obviously the spermatoblasts of Von Ebner,—and actually sink into their protoplasm to complete their development. When fully developed, the heads of the young spermatozoa have attained the base of the supporting cell, but this now elongates and bears them anew in the lumen of the duct into which they are expelled.

The researches of Herrmann (1882) on the spermatogenesis of Elasmobranchs are essentially confirmatory of those of Semper. The "male ovules" within the "male tubes of Pflüger," multiply by the transformation of small flattened cells round about them, and within each ovule 50 to 60 "spermatoblasts" are produced by endogenous formation, preceded, however, by a segmentation.

According to Sabatier, spermatogenesis always occurs in two generations of cells. From the nuclear division and germination of mother-cells or spermatospores, claviform stalked cells (protospermoblasts) arise. These are detached, increase in size, divide, and produce on their surface deutospermoblasts, or the spermatocytes of Von la Valette. The protospermoblasts thus form the blastophore of the deutospermoblasts, from which the spermatozoa directly originate. In Plagiostome fishes Sabatier describes how the epithelial cells form *culs-de-sac*, in which some of the cells increase in size, and form spermatospores or male ovules. In the peripheral protoplasm of these spermatospores, endogenously formed nuclei appear—the protospermoblasts. The nucleus of each of these divides to form numerous deutospermoblasts, which are for the most part differentiated into spermatozoids, though a few degenerate into a problematic body.

The researches of Jensen, to which we have already referred, extended also to Vertebrates. Within the ampullæ of Plagiostome fishes two forms of cells occur (*a*) with large round nuclei—the future spermatogonia, (*b*) with narrow smaller nuclei—the follicular cells. It is important to note, however, that he maintains that the latter also develop into the former. From the division of each spermatogonium a cellular pillar results—a spermatogemma of spermatocytes; while a single narrow follicular nucleus lies at the base of each pillar, forming the Deckzelle of Semper, the Cystenkern of Von la Valette, the Noyau basilaire of Herrmann. The spermatogemmæ become eventually, however, hollowed out, and that by the destruction of some of the internal spermatocytes, so that the final result is that of a number of spermatocytes surrounding a central cavity, while the cytophoral portion at the base, towards which the sperms dive down, has a distinctly follicular origin.

The researches of Swaen and Masquelin (1883) on Elasmobranchs, Amphibians, and Mammals are of importance, as tending towards reconciliation. In the testes of Selachians, when the primitive ampullæ are once formed, "male ovules" (spermatogonia) and follicular cells, are quite distinct, and the latter do not transform into the former. The male ovules divide indirectly to form spermatogemmæ, while the follicular cells, after having formed incomplete envelopes to the male ovules, and to the spermatogemmæ, disappear save one, which travels down and insinuates itself between the ampulla and the spermatogemma, there constituting the basilar cell. The fully-developed spermatogemma of about sixty spermatocytes exhibits a central cavity or "loge caudale," in which the incipient spermatozoa or nematoblasts are embraced, their tails projecting into the lumen of the duct. The basilar cell, which has also been enlarging, has likewise an influence on their arrangement; its protoplasm fuses with the intercellular substance of the spermatogemma, surrounds the heads and bodies of the nematoblasts, which thus sink down towards the basilar nucleus, only to be again expelled by the elongation of the latter. A similar process occurs in the spermatogenesis of the salamander, where, however, the follicular cells form a complete envelope round the male ovules during their whole segmentation and subsequent evolution. In Mammals the true male ovules are small parietal cells, regarded by La Valette as follicular. Each divides into a temporarily inert portion (follicular cells of La Valette, germinative cells of Sertoli) and "an active male ovule," which multiplies by division to form a spermatogemma of spermatocytes. When the spermatocytes have developed into nematoblasts, neighbouring "supporting cells" (cellules de soutien) behave like the basilar cells of Selachians, and fuse with the intercellular substance connecting the former, thus producing the spermatoblasts of Von Ebner. The follicular or supporting cells also surround inferiorly the temporarily inert male ovules.

The research of Biondi, which has just been published, claims to have effected a reconciliation of preceding discordant observations by attributing the discrepancies to the different stages at which the development has been observed. In his observations, which apply mainly to mammals, he recognises only one kind of round cell, alike in mature and in immature tubules. The epithelial cells of Sertoli, the Stützzellen of Merkel and Henle, the spermatoblasts of Von Ebner, are secondary modifications arising from the protoplasmic débris of the round sperm-producing cells. From each primitive-cell (Stammzelle) a generation of cells arise, arranged in column fashion, in which one can distinguish three zones—the single primitive-cell at the base, two to three mother-cells in a second row, and four to six daughter-cells in an innermost third row. When the pillar is complete, sperm-formation begins from the centre outwards, each nucleus becomes a sperm, the pillar becomes a sperm-bundle, and the spermatozoa are squeezed out by the pressure of adjacent pillars, while from the primitive-cell of one of these a new primitive-cell arises by tangential division, to begin anew the formation of a fresh pillar in place of that which has been modified. The spermatozoa lying embedded in the débris of unused protoplasm and of nuclear remnants, are compacted by pressure of adjacent pillars to form a so-called spermatoblast. He refers Sertoli's Keimzelle to the canal wall, and identifies his seminal cells and nematoblasts with his own mother and daughter cells respectively. La Valette's spermatogonium, spermatocytes, and cells of the spermatogemmæ, are equivalent to Biondi's three stages—stammzellen, mother-cells, daughter-cells. In a similarly bold way he brings the results of other observers into harmony with his own, though the deviations from the three-zoned pillar process, which he has himself observed, certainly seem to throw doubt on the possibility of any general reconciliation of the discrepant results of authoritative observers being effected in this way.

In an almost contemporary research by Von Wiedersperg, the spermatozoa of rat, &c., are traced to the "round cells" which result from the repeated division of the peripheral cells of the tubules.

An account of mammalian spermatogenesis has recently been given by H. H. Brown (1885). Certain cells in the most external layer of the tubule, next the basement membrane, seem to form the essentially spermatogenetic cells. These "spore-cells" are supposed to be the direct descendants of the primitive male ova. Each spore-cell, apparently by a process of nuclear budding, forms two cells, one of which divides by karyokinesis to form the more internal "growing and multiplying cells," which are the direct predecessors of the sperms. There are, however, other inactive cells in the tubule—"the supporting cells," and with these the young sperms become associated very shortly after their liberation. Brown agrees with Swaen and Masquelin in deriving the sperms in the Elasmobranch testis from primitive male ova, and the supporting cells from follicular cells, corresponding to the cells of the Graafian follicle in the ovary, and suggests a similar origin for the supporting cells in mammals. With Brown's account a later investigation by Benda essentially agrees, while a research by Grünhagen seems, on the whole, to corroborate Biondi.

§ 2. Having thus summarised* the principal observations on spermatogenesis, we must, as a necessary step towards clearness, collate the all too-abundant nomenclature, the confusion of which affords a suggestive index to the want of lucidity on the subject. Not only do we find a maze of frequently tautologous terms, such as spermatogonium, spermatoblast, spermatocyst, spermatogemma, spermatocyte, spermatomere, spermosphere, spermoblast, and a dozen more; but the frequent use of the same term, *e.g.*, spermatoblast, with different connotation by different investigators. The subjoined tabular comparison, necessary for our present purpose, may not be without a wider use.

* See also § *Spermatogenesis* in "Reproduction," *Ency. Brit.*, vol. xviii., 1886.

Starting from one of the most defensible set of terms—that used by Voigt after Semper—with the four or five stages of (1) sex-cells, (2) spermatogonia, (3) spermatocytes, (4) spermatides or immature (5) spermatozoa, it will be convenient in the citation and comparison of observations by different authorities to distinguish the different stages by the following simple notation :—(1) The spermatozoon, denoted by S ; (2) the immature sperm or the spermatide, by S^0 ; (3) the spermatocyte, by S^0_0 ; (4) the cell which gives rise to the spermatocytes, or the spermatogonium, by S^1 ; (5) its antecedent, by S^2 ; and so on. These symbols can be readily bracketed after the terms cited, and all confusion thus obviated without new or dogmatic nomenclature.

§ 3. Since equally competent observers give most divergent accounts of the nature of spermatogenesis, it seems all but impossible that any one mode of development prevails. A forcible reconciliation may indeed be attempted by a detailed criticism of the observations, by pointing out, as Biondi has lately attempted, how the different phenomena described may occur as the various phases of one developmental cycle. The discrepancies are, however, too great for any such general mode of reconciliation. Unless we attach considerably greater weight to the observations of at least a majority of all the above workers than they sometimes incline to grant to those of each other, the literature and iconography of histology become of little worth. Accepting the results of competent authorities, it is our object in this paper to propose a possible rationale of the existence of several different modes of development, and a consistent method for their classification and comparison.

In 1847 Reichert pointed out the homology between the ovum and the mother sperm cell, and this has been for long recognised with more or less definiteness in the various attempts which have been made to draw parallels between the processes in the development of the two elements. Thus Von la Valette St George compared spermatogonium (S^1) with ovum, and the follicular skin of the former with the follicular cells of the latter. Nussbaum, following La Valette, has in his well-known memoir on the differentiation of sex, drawn a similar more extended parallel, and has maintained that in *Amphibia* and *Teleostei* the spermatogonium and its follicular

TABLE OF COMPARISON.

	S^2	S^1	S^0_0	S^0	S
Voigt (and Semper), Gasteropoda	sex-cell	spermatogonium or Stammsamenzelle	spermatocytes, Samenvermehrungszellen	spermatides, Samenausbildungszellen	spermatosomata, Samenkörper
Gilson (Crustacea)	primordial metrocyte	metrocyte or mother-cell	spermatic cells	spermatozoids	
Biondi (Mammals)	stamm-zelle	mother-sperm cell	daughter-cells	spermatozoids	
Brown (Mammals)	spore-cells	growing sperm cells	young spermatozoa + supporting cell		sperms
Swaen and Masquelin (Fishes, Amphibians, Mammals)	primitive male ovule + follicular cells	active male ovule dividing into inert male ovules forming spermatogemma of spermatocytes + basilar or supporting cell		nematoblasts	spermatozoa
Renson (Mammals)	... ...	germinative cell—seminiferous cell dividing into multinuclear cyst of	nematoblasts	spermatozoids	
Jensen (Invertebrates and Fishes)	... ...	spermatogonium, dividing into spermatogemma of	spermatocytes + cytophore portion	spermatozoa	
Julin and Van Beneden (Ascaris)	primitive ovule — or spermatomere	spermatogonium, dividing into spermatogemma of	spermatocytes	spermatozoa	

			(Two generations)	
Sabatier (Invertebrates, Fishes, &c.)	primitive reproductive cell—male ovule	spermatospore, dividing into protospermoblasts, which bud off	deutospermoblasts	spermatozoids
Balfour	germinal cell	spermospore, dividing into sperm morula or spermosphere of	spermoblasts	spermatozoa
Blomfield (Earthworm, Helix, Frog, &c.)	... ...	spermatospore, dividing into spermatosphere of	spermatoblasts	spermatozoa
		or (sperm polyplasts +	blastophoral portion)	
Krause	... ...	germinative follicular cells divide into spermatogemmæ of	spermatoblasts + basal portion (= spermatogonium)	spermatozoa
Von la Valette St George (general)	primitive ovule	spermatogonium, dividing into spermatogemma or spermatocyst of + follicular cells	spermatocytes + basilar cell	spermatosomata
Semper (Elasmobranchs)	primitive cell	mother sperm cell dividing into	spermatoblasts + cover cell	immature and mature sperms
Von Ebner (Mammals)	germinal cells round cells	spermatoblast	lobes of spermatoblast	spermatozoa
Merkel (Mammals)	round cells supporting cells form	divide into framework		spermatozoa
Sertoli (Mammals)	germinative cells becoming	seminiferous, which divide into	nematoblasts or undifferentiated sperms	
	epithelial cells form	branched, supporting framework		

TABLE OF COMPARISON.

	S^2	S^1	S^0_0	S^0	S
Voigt (and Semper), Gasteropoda	sex-cell	spermatogonium or Stammsamenzelle	spermatocytes, Samenvermehrungszellen	spermatides, Samenausbildungszellen	spermatosomata, Samenkörper
Gilson (Crustacea)	primordial metrocyte	metrocyte or mother-cell	spermatic cells	spermatozoids	
Biondi (Mammals)	stamm-zelle	mother-sperm cell	daughter-cells	spermatozoids	
Brown (Mammals)	spore-cells	growing sperm cells	young spermatozoa + supporting cell		sperms
Swaen and Masquelin (Fishes, Amphibians, Mammals)	primitive male ovule + follicular cells	active male ovule dividing into inert male ovules forming spermatogemma of spermatocytes + basilar or supporting cell		nematoblasts	spermatozoa
Renson (Mammals)	... ...	germinative cell—seminiferous cell dividing into multinuclear cyst of	nematoblasts	spermatozoids	
Jensen (Invertebrates and Fishes)	... ...	spermatogonium, dividing into spermatogemma of	spermatocytes + cytophore portion	spermatozoa	
Julin and Van Beneden (Ascaris)	primitive ovule — or spermatomere	spermatogonium, dividing into spermatogemma of	spermatocytes	spermatozoa	
Sabatier (Invertebrates, Fishes, &c.)	primitive reproductive cell—male ovule	(Two generations) spermatospore, dividing into protospermoblasts, which bud off	deutospermoblasts	spermatozoids	
Balfour	germinal cell	spermospore, dividing into sperm morula or spermosphere of	spermoblasts	spermatozoa	
Blomfield (Earthworm, Helix, Frog, &c.)	... ...	spermatospore, dividing into spermatosphere of	spermatoblasts or (sperm polyplasts + blastophoral portion)	spermatozoa	
Krause	... ...	germinative follicular cells divide into spermatogemmæ of	spermatoblasts + basal portion (= spermatogonium)	spermatozoa	
Von la Valette St George (general)	primitive ovule	spermatogonium, dividing into spermatogemma or spermatocyst of + follicular cells	spermatocytes + basilar cell	spermatosomata	
Semper (Elasmobranchs)	primitive cell	mother sperm cell dividing into	spermatoblasts + cover cell	immature and mature sperms	
Von Ebner (Mammals)	germinal cells round cells	spermatoblast	lobes of spermatoblast	spermatozoa	
Merkel (Mammals)	round cells supporting cells form	framework	divide into	spermatozoa	
Sertoli (Mammals)	germinative cells becoming epithelial cells form	seminiferous, which divide into branched, supporting framework	nematoblasts or undifferentiated sperms		

cells probably result from a primitive cell with morula-like division of its nucleus, as has been repeatedly observed in oogenesis. A more intimate parallelism is suggested by the comparison repeatedly proposed, with a measure both of morphological and physiological probability, between the polar cells of the ovum and similar bodies occurring at various stages in spermatogenesis.* In the use of terms like sperm-morula, sperm-blastula, &c., Balfour and others have dimly suggested the further comparison between the division of the sperm-mother-cell (S^1) and the segmentation of the ovum. This comparison it is one of the objects of this paper definitely to formulate, collating various modes of spermatogenesis with apparently homologous modes of segmentation.

The unification is sought by comparing the manifoldness of spermatogenesis to the manifoldness of segmentation, for as the segmentation of the ovum is varied, the same is not *à priori* impossible in the segmentation of the male ovule. These two sets of phenomena, in regard to which our knowledge has progressed separately through empirical evolution, seem to have in short the same morphological and physiological rationale. This comparison hinted at in the nomenclature of Balfour and others, has also been proposed by Herrmann (1881):—"The division of the male ovule into a series of generations of daughter cells forming spermatoblasts, is a phenomenon comparable to that exhibited by the ovum in the formation of the blastoderm. The cellular individualisation occurs by segmentation (in most ova, and for instance in the male ovules of Selachians), or by superficial germination (in the ova of Arthropods and in most male ovules), or by other mechanism, always, however, fundamentally of the same nature. It seems then more important to determine exactly the mechanism of division than to give a particular name to each stage of segmentation."

Such suggestions have, it seems to us, great value; the comparison must, however, be developed in detail. (*a*) In such a simple case of spermatogenesis as that illustrated by sponges, where a cell differentiated from the mesoderm divides up into a regular sphere of uniform cells, each an incipient spermatozoon, or where this occurs with the interesting specialisation of one of the two first halves to

* *Cf.* J. Arthur Thomson "On Recent Researches on Polar-Cells," &c., in *Quart. Jour. Micr. Sci.* (1886).

form a cover cell for the whole, there seems no difficulty in regarding the term sperm-morula applied to such a case as in the truest way descriptive, and in regarding the process as distinctly homologous with that which occurs in the regular and total segmentation of the ovum (fig. A′, A″).

(*b*) The division of the mother-sperm cell is not, however, always equal, but forms occur, *e.g.*, in Plagiostome fishes, where one cell predominates in size over the other (B′, B″), a phenomenon which admits of ready comparison with such a phase of unequal ovum-segmentation as is represented in fig. B, where the morula consists of a large number of small cells, and of one somewhat predominant yolk-filled cell.

(*c*) The not unfrequent form of spermatogenetic segmentation which Blomfield has described in the earthworm, where the incipient sperm-cells enclose a more or less large undivided mass, at once suggests a comparison with the centrolecithal segmentation as exhibited, for instance, by a Peneus ovum, where the formative cells surround the central yolk-mass. And just as in cases of the latter, the individual cells are sometimes seen not very well defined off from the central nutritive mass, so is it also in various forms of spermatogenesis (fig. C′, C″).

(*d*) Just as it was seen that, in those forms of sperm-segmentation which are directly comparable to morulæ, one cell might predominate in size over the others (fig. B′ B″); so forms occur (see Gilson, &c.) where the sperm-cells are borne on the surface of a large undivided mass (fig. D′, D″), forming as it were a blastodermic plate, as seen in forms of partial ovum segmentation where the formative cells appear round one pole of the large undivided yolk-mass (fig. D).

(*e*) Between the last-mentioned case and that described by Von Ebner there is but a step (fig. E′, E″). The nucleated lappets, which he has described as crowning the large nutritive blastophore, differ but little from the formative cells just referred to, except in the indefiniteness of their separation from the nutritive mass, a phenomenon which also finds its parallel in stages of partial ovum-segmentation (fig. E).

(*f*) In another form of spermatogenesis, observed for example by Semper in the Rays, the spermatocytes were found to be sunk within the hollow of the nutritive blastophore (fig. F′). This cannot, indeed, be directly collated with any actual form of ovum segmentation, but rather with the inversion of such a form of gastrula as is seen (*e.g.*) in Teleostean ova, where the yolk protrudes in hernioid fashion from the endoderm cells of the epibolic gastrula (fig. F). Starting from the uninvaginated form, we should thus have in these two types of sperm and ovum segmentation what might be regarded as the result of invagination from different sides,—in the former the nutritive, normally internal portion becoming the layer enveloping the formative cells,—just the reverse of what occurs in the latter. Of this inverted gastrulation, possibly represented in Elasmobranchs, traces may be detected in such a case as that described by Renson in mammals, where the sperms produced alongside of the large nutritive cells yet find their way into them, and sinking in are again borne up and finally set free (fig. F″, "obgastrula" type).

In regard to such a comparison, which appears to us a possible method of reconciling, without discrediting, the discrepant observations of competent authorities, and of rationalising the various methods of spermatogenesis, by comparing them with parallel processes in ovum-segmentation, the writers do not overlook that such a theory must wait for *absolute* verification till more data are available as to the behaviour of the nuclei in both cases, especially in spermatogenesis, for without this a real similarity of process can only be inferred from the likeness of the result. It must be noted also that the theory in no way falls with the failure of any particular instance. Further, if it be true that the multitudinous details of spermatogenesis can be morphologically rationalised by collating them with the details of ovum-segmentation, the physiological problem remains of interpreting both in terms of that difference in protoplasmic metabolism on which sex must finally depend. In a subsequent paper* by one of us, these sex differences are traced to a preponderance of anabolism in the female and katabolism in the male, and if this conception be applied to the preceding, the physiological rationale of the morphological process may become no longer wholly unintelligible.

* Geddes, "Theory of Growth, Reproduction, Sex, and Heredity," *Proc. Roy. Soc. Edin.*, 1886.

EXPLANATION OF DIAGRAM.

The first line, A–F, exhibits types of ovum segmentation :—A, regular morula; B, unequal segmentation, *e.g.*, in some Molluscs; C, centrolecithal type, *e.g.*, in Peneus; D, partial segmentation; E, the same, with the cells less markedly defined off from the yolk; F, inverted gastrula or "obgastrula" form, *e.g.*, in Teleosteans.

In the next two lines various types of spermatogenesis are collated with the above to illustrate the parallelism :—A′ and A″, morula type, as in Sponge, Turbellarian, Spider, &c. ; B′ and B″, where the division is unequal, and one large nutritive cell is seen (Plagiostome fishes, Von la Valette St George); C′ and C″, after Blomfield, Jensen, &c., showing central cytophoral or blastophoral nutritive portion; D′ and D″, sperm-blastoderm, with a few formative cells on large nutritive blastophore, after Gilson, &c. ; E′ and E″, the same, with the sperm cells less definitely separated off, after Von Ebner and his followers; F′ and F″, "obgastrula type," in which the nutritive portion has come to surround the formative cells, after Swaen and Masquelin, Renson, &c. (See Text.)

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6. On Tungsten. By John Waddell, D.Sc. Communicated by Dr Crum Brown.

7. On Certain Theorems mainly connected with Alternants. By A. H. Anglin, M.A., LL.B., F.R.S. (Edin.), &c.

1. It is well known that if h_n denote the sum of the homogeneous products of $a, b, c, \ldots l$ of n dimensions, while h'_n refers similarly to $b, c, d, \ldots l$, then

$$h'_n = h_n - ah_{n-1}.$$

The proof, which is very simple, may be stated thus:—

We have

$$\begin{aligned} h_n &= a^n + a^{n-1}h'_1 + a^{n-2}h'_2 + \ldots + a^2h'_{n-2} + ah'_{n-1} + h'_n \\ &= a(a^{n-1} + a^{n-2}h'_1 + a^{n-3}h'_2 + \ldots + ah'_{n-2} + h'_{n-1}) + h'_n \\ &= ah_{n-1} + h'_n; \end{aligned}$$

that is,

$$h'_n = h_n - ah_{n-1}.$$

2. This theorem admits of a wide generalisation, the direction of which may be suggested by writing the right-hand member as a determinant, so that the simplest case takes the form

$$h_n' = \begin{vmatrix} 1 & a \\ h_{n-1} & h_n \end{vmatrix},$$

or, say, rather

$$h'_{p+1} = \begin{vmatrix} 1 & a \\ h_p & h_{p+1} \end{vmatrix},$$

which again, merely for shortness' sake and in order to give greater prominence to the suffixes, may be written

$$(p+1)' = \begin{vmatrix} 1 & a \\ (p) & (p+1) \end{vmatrix}.$$

To take the next case in order of complexity, we have

$$\begin{vmatrix} (p+1)' & (p+2)' \\ (q+1)' & (q+2)' \end{vmatrix} = \begin{vmatrix} (p+1)-a(p), & (p+2)-a(p+1) \\ (q+1)-a(q), & (q+2)-a(q+1) \end{vmatrix}$$

$$= \begin{vmatrix} (p+1) & (p+2) \\ (q+1) & (q+2) \end{vmatrix} - a \begin{vmatrix} (p) & (p+2) \\ (q) & (q+2) \end{vmatrix} + a^2 \begin{vmatrix} (p) & (p+1) \\ (q) & (q+1) \end{vmatrix}$$

$$= \begin{vmatrix} 1 & a & a^2 \\ (p) & (p+1) & (p+2) \\ (q) & (q+1) & (q+2) \end{vmatrix}.$$

In like manner we have

$$\begin{vmatrix} (p+1)' & (p+2)' & (p+3)' \\ (q+1)' & (q+2)' & (q+3)' \\ (r+1)' & (r+2)' & (r+3)' \end{vmatrix}$$

$$= \begin{vmatrix} (p+1)-a(p), & (p+2)-a(p+1), & (p+3)-a(p+2) \\ (q+1)-a(q), & (q+2)-a(q+1), & (q+3)-a(q+2) \\ (r+1)-a(r), & (r+2)-a(r+1), & (r+3)-a(r+2) \end{vmatrix}$$

$$= \begin{vmatrix} (p+1) & (p+2) & (p+3) \\ (q+1) & (q+2) & (q+3) \\ (r+1) & (r+2) & (r+3) \end{vmatrix} - a \begin{vmatrix} (p) & (p+2) & (p+3) \\ (q) & (q+2) & (q+3) \\ (r) & (r+2) & (r+3) \end{vmatrix}$$

$$+ a^2 \begin{vmatrix} (p) & (p+1) & (p+3) \\ (q) & (q+1) & (q+3) \\ (r) & (r+1) & (r+3) \end{vmatrix} - a^3 \begin{vmatrix} (p) & (p+1) & (p+2) \\ (q) & (q+1) & (q+2) \\ (r) & (r+1) & (r+2) \end{vmatrix}$$

$$= \begin{vmatrix} 1 & a & a^2 & a^3 \\ (p) & (p+1) & (p+2) & (p+3) \\ (q) & (q+1) & (q+2) & (q+3) \\ (r) & (r+1) & (r+2) & (r+3) \end{vmatrix}.$$

The method of procedure is evidently quite independent of the order of the determinant, so that we have the general theorem

$$\begin{vmatrix} (p+1)' & (p+2)' & (p+3)' \ldots (p+m-2)' \\ (q+1)' & (q+2)' & (q+3)' \ldots (q+m-2)' \\ (r+1)' & (r+2)' & (r+3)' \ldots (r+m-2)' \\ \cdot & \cdot & \cdot \quad\quad\quad \cdot \\ \cdot & \cdot & \cdot \quad\quad\quad \cdot \\ \cdot & \cdot & \cdot \quad\quad\quad \cdot \\ (z+1)' & (z+2)' & (z+3)' \ldots (z+m-2)' \end{vmatrix}$$

$$= \begin{vmatrix} 1 & a & a^2 & a^3 & a^{m-2} \\ (p) & (p+1) & (p+2) & (p+3) \ldots & (p+m-2) \\ (q) & (q+1) & (q+2) & (q+3) \ldots & (q+m-2) \\ (r) & (r+1) & (r+2) & (r+3) \ldots & (r+m-2) \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ (z) & (z+1) & (z+2) & (z+3) \ldots & (z+m-2) \end{vmatrix}$$

the number of letters, p, q, r, . . . z being $m-2$.

It should be observed that, as the demonstration does not take into account any properties of h_n or h'_n, but merely the equation of relationship, this result is true of *any* functions which happen to be related as this equation indicates.

3. The connection which the theorem $h'_n = h_n - ah_{n-1}$, and its generalisation have with the theory of alternants, arises from the fact that every h is representable as the quotient of two alternants, viz., the quotient of an alternant of the second simplest form, *e.g.*,

$$\begin{vmatrix} 1 & a & a^2 & a^3 & a^x \\ 1 & b & b^2 & b^3 & b^x \\ 1 & c & c^2 & c^3 & c^x \\ 1 & d & d^2 & d^3 & d^x \\ 1 & e & e^2 & e^3 & e^x \end{vmatrix} \quad \text{or} \quad | a^0b^1c^2d^3e^x | , \quad (x<4)$$

by an alternant of the simplest form, *e.g.*,

$$| a^0b^1c^2d^3e^4 | ;$$

which latter being the difference-product of a, b, c, d, e we denote also by $\zeta^{\frac{1}{2}}(abcde)$. In the particular case here instanced the suffix of h would $x-4$.

4. We come now to show that, if the complementary minors of all the elements of the last column of an alternant be taken, their product is divisible by some power of $\zeta^{\frac{1}{2}}(abc\ldots)$. This result, it will be seen, rests formally on the fact that the said minors are themselves alternants.

First, let us consider the case where the indices of the minors are consecutive, so that each minor is the difference-product of the letters which it involves.

Denoting throughout the phrase, "Product of complementary minors of elements of last column" (in any alternant) by P_m, we see that (in the case of three letters, a, b, c), in the case of

$$| a^0 b^1 c^n |$$

the value of P_m is obviously

$$| a^0 b^1 c^2 | \quad \text{or} \quad \zeta^{\frac{1}{2}}(abc).$$

Again, in the case of

$$| a^0 b^1 c^2 d^n |$$

the factor $(a-b)$ obviously occurs only in the cofactors of the elements c^n and d^n, and similarly with regard to the other factors in the difference-product of a, b, c, d.

Thus we have

$$P_m = | a^0 b^1 c^2 d^n |^2 \quad \text{or} \quad \zeta(abcd).$$

So, in the case of

$$| a^0 b^1 c^2 d^3 e^n |,$$

since the factor $(a-b)$ obviously occurs only in the cofactors of the elements c^n, d^n, and e^n, and similarly with regard to the other factors in the difference-product of a, b, c, d, e, we have

$$P_m = | a^0 b^1 c^2 d^3 e^4 |^3 \quad \text{or} \quad \zeta^{\frac{3}{2}}(abcde).$$

While, generally (the number of letters $a, b, c, \ldots k, l$ being m), in the case of

$$| a^0 b^1 c^2 d^3 \ldots k^{m-2} l^n |$$

since the factor $(a-b)$ occurs in the cofactors of the elements

$c^n, d^n, e^n, \ldots l^n$, that is, $m-2$ times, and similarly for the other factors in the difference-product of $a, b, c, \ldots l$, it follows that

$$P_m = | a^0 b^1 c^2 d^3 \ldots k^{m-2} l^{m-1} |^{m-2}$$

$$\text{or} \qquad \zeta^{\frac{m-2}{2}}(a, l, c, \ldots l) .$$

Secondly, when the indices of the minors are not consecutive.

Before proceeding to the nth order, we shall, for greater clearness, first consider a particular case—say, the fifth order.

In the determinant

$$| a^0 b^1 c^2 d^r e^n | ,$$

since from a known result in the theory of alternants the minor

$$| b^0 c^1 d^2 e^r | = \zeta^{\frac{1}{2}}(bcde) h'_{r-3} ,$$

we have by § 1

$$| b^0 c^1 d^2 e^r | = \zeta^{\frac{1}{2}}(bcde) \begin{vmatrix} 1 & a \\ (r-4) & (r-3) \end{vmatrix} ,$$

with like results for the other four minors of the determinant. Hence the value of P_m in

$$| a^0 b^1 c^2 d^r e^n |$$

is equal to P_m in

$$| a^0 b^1 c^2 d^3 e^n |$$

multiplied by the product of

$$\begin{vmatrix} 1 & a \\ (r-4) & (r-3) \end{vmatrix}$$

and four like expressions with b, c, d, e respectively in the first row instead of a; a result which may be represented thus:

$$P_m = \zeta^{\frac{3}{2}}(abcde) . \Pi \begin{vmatrix} 1 & a \\ (r-4) & (r-3) \end{vmatrix} .$$

Again, in

$$| a^0 b^1 c^q d^r e^n | ,$$

since it has been previously established that the minor,

$$| b^0 c^1 d^q e^r | = \zeta^{\frac{1}{2}}(bcde) \begin{vmatrix} (r-3)' & (r-2)' \\ (q-3)' & (q-2)' \end{vmatrix} ,$$

which by § 1

$$= \zeta^{\frac{1}{2}}(bcde) \begin{vmatrix} 1 & a & a^2 \\ (r-4) & (r-3) & (r-2) \\ (q-4) & (q-3) & (q-2) \end{vmatrix} ,$$

with like results for the other four minors, we have

$$\text{P}_m \text{ in } | a^0 b^1 c^q d^r e^n |$$

$= \text{P}_m$ in $| a^0 b^1 c^2 d^3 e^n |$ multiplied by the product of the cofactor of $\zeta^{\frac{1}{2}}(bcde)$ last written and four like expressions with b, c, d, e respectively in the first row instead of a; and thus we have

$$\text{P}_m = \zeta^{\frac{3}{2}}(abcde) . \Pi \begin{vmatrix} 1 & a & a^2 \\ (r-4) & (r-3) & (r-2) \\ (q-4) & (q-3) & (q-2) \end{vmatrix} .$$

Lastly, in

$$| a^0 b^p c^q d^r e^n |,$$

since the minor

$$| b^0 c^p d^q e^r | = \zeta^{\frac{1}{2}}(bcde) \begin{vmatrix} (r-3)' & (r-2)' & (r-1)' \\ (q-3)' & (q-2)' & (q-1)' \\ (p-3)' & (p-2)' & (p-1)' \end{vmatrix}$$

$$= \zeta^{\frac{1}{2}}(bcde) \begin{vmatrix} 1 & a & a^2 & a^3 \\ (r-4) & (r-3) & (r-2) & (r-1) \\ (q-4) & (q-3) & (q-2) & (q-1) \\ (p-4) & (p-3) & (p-2) & (p-1) \end{vmatrix} \text{ by § 1,}$$

with like results for the other four minors, we have

$$\text{P}_m \text{ in } | a^0 b^p c^q d^r e^n |$$

$= \text{P}_m$ in $| a^0 b^1 c^2 d^3 e^n |$ multiplied by the product of the cofactor of $\zeta^{\frac{1}{2}}(bcde)$ last written and four like expressions with b, c, d, e respectively in the first row instead of a; and thus

$$\text{P}_m = \zeta^{\frac{3}{2}}(abcde) . \Pi \begin{vmatrix} 1 & a & a^2 & a^3 \\ (r-4) & (r-3) & (r-2) & (r-1) \\ (q-4) & (q-3) & (q-2) & (q-1) \\ (p-4) & (p-3) & (p-2) & (p-1) \end{vmatrix} .$$

Generally, in the case of m letters $a, b, c, \ldots h, k, l$, since in

$$| a^0 b^1 c^2 \ldots h^{m-3} k^z l^n |,$$

the minor

$$| b^0 c^1 d^2 \ldots k^{m-3} l^z | = \zeta^{\frac{1}{2}}(bcd \ldots l) h'_{z-m+2},$$

which by § 1

$$= \zeta^{\frac{1}{2}}(bcd \ldots l \begin{vmatrix} 1 & a \\ (z-m+1) & (z-m+2) \end{vmatrix},$$

with $m-1$ like results for the other minors, we have

$$\mathrm{P}_m \text{ in } | a^0 b^1 c^2 \ldots h^{m-3} k^z l^n |$$

$= \mathrm{P}_m$ in $| a^0 b^1 c^2 \ldots k^{m-2} l^n |$ multiplied by the product of the cofactor of $\zeta^{\frac{1}{2}}(bcd \ldots l)$ last written and $m-1$ like expressions with $b, c, d, \ldots l$ respectively in the first row instead of a; and thus we have

$$\mathrm{P}_m = \zeta^{\frac{m-2}{2}}(abc \ldots l) \,.\, \Pi \begin{vmatrix} 1 & a \\ (z-m+1) & (z-m+2) \end{vmatrix},$$

where Π consists of m factors from a to l inclusive.

Again, in

$$| a^0 b^1 c^2 \ldots g^{m-4} h^y k^z l^n |,$$

since the minor

$$| b^0 c^1 d^2 \ldots h^{m-4} k^y l^z | = \zeta^{\frac{1}{2}}(bcd \ldots l) \begin{vmatrix} (z-m+2)' & (z-m+3)' \\ (y-m+2)' & (y-m+3)' \end{vmatrix}$$

which by § 1

$$= \zeta^{\frac{1}{2}}(bcd \ldots l) \begin{vmatrix} 1 & a & a^2 \\ (z-m+1), & (z-m+2), & (z-m+3) \\ (y-m+1), & (y-m+2), & (y-m+3) \end{vmatrix}$$

with $m-1$ like results for the other minors, we have

$$\mathrm{P}_m \text{ in } | a^0 b^1 c^2 \ldots g^{m-4} h^y k^z l^n |$$

$= \mathrm{P}_m$ in $| a^0 b^1 c^2 \ldots k^{m-2} l^n |$ multiplied by the product of the cofactor of $\zeta^{\frac{1}{2}}(bcd \ldots l)$ last written and $m-1$ like expressions with $b, c, d, \ldots l$ respectively in the first row instead of a; and thus we have

$$\mathrm{P}_m = \zeta^{\;2\;2}(abc \ldots l) \,.\, \Pi \begin{vmatrix} 1 & a & a^2 \\ (z-m+1), & (z-m+2), & (z-m+3) \\ (y-m+1), & (y-m+2), & (y-m+3) \end{vmatrix}$$

And in like manner it may be shown that in

$$| a^0 b^1 c^2 \ldots f^{m-5} g^x h^y k^z l^n |$$

$$\mathrm{P}_m = \zeta^{\frac{m-2}{2}}(abc \ldots l) \,.\, \Pi \begin{vmatrix} 1 & a & a^2 & a^3 \\ (z-m+1), & (z-m+2), & (z-m+3), & (z-m+4) \\ (y-m+1), & (y-m+2), & (y-m+3), & (y-m+4) \\ (x-m+1), & (x-m+2), & (x-m+3), & (x-m+4) \end{vmatrix}$$

Lastly, when the minors involve $m-2$ general indices $p, q, r, \ldots x, y, z$, since in

$$| a^o b^p c^q \ldots g^x h^y k^z l^n |$$

the minor

$$| b^o c^p d^q \ldots h^x k^y l^z |$$

$$= \zeta^{\frac{1}{2}}(bcd \ldots l) \begin{vmatrix} (z-m+2)', & (z-m+3)' & \ldots & (z-1)' \\ (y-m+2)', & (y-m+3)' & \ldots & (y-1)' \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ (q-m+2)', & (q-m+3)' & \ldots & (q-1)' \\ (p-m+2)', & (p-m+3)' & \ldots & (p-1)' \end{vmatrix}$$

with $m-1$ like results for the other minors, it will follow as before by the application of § 1 that

$$P_m \text{ in } | a^o b^p c^q \ldots h^y k^z l^n |$$

$$= \zeta^{\frac{m-2}{2}}(abc \ldots l) . \Pi \begin{vmatrix} 1 & a & a^2 & & a^{m-2} \\ (z-m+1), & (z-m+2), & (z-m+3) & \ldots & (z-1) \\ (y-m+1), & (y-m+2), & (y-m+3) & \ldots & (y-1) \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ (q-m+1), & (q-m+2), & (q-m+3) & \ldots & (q-1) \\ (p-m+1), & (p-m+2), & (p-m+3) & \ldots & (p-1) \end{vmatrix}$$

5. If it be not already known, there is no difficulty in showing that the product of all the determinants of the second order, which can be formed from any two rows of elements, can be expressed as an alternant. Thus, taking two rows of three elements each,

$$\begin{matrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \end{matrix}$$

we have

$$\begin{vmatrix} a_2 & a_3 \\ b_2 & b_3 \end{vmatrix} \begin{vmatrix} a_1 & a_3 \\ b_1 & b_3 \end{vmatrix} \begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix}$$

$$= a_1(a_2b_3 - a_3b_2)a_2(a_1b_3 - a_3b_1)a_3(a_1b_2 - a_2b_1) \div a_1a_2a_3$$

$$= (a_1a_2b_3 - a_1a_3b_2)(a_1a_2b_3 - a_2a_3b_1)(a_1a_3b_2 - a_2a_3b_1) \div a_1a_2a_3$$

$$\left.\begin{matrix} = \zeta^{\frac{1}{2}}(a_2a_3b_1,\ a_1a_3b_2,\ a_1a_2b_3) \div a_1a_2a_3 \\ \text{or } -\zeta^{\frac{1}{2}}(a_1b_2b_3,\ a_2b_1b_3,\ a_3b_1b_2) \div b_1b_2b_3 \end{matrix}\right\} \quad . \quad . \quad . \quad (A)$$

There is also another alternant expression for the product $|a_2b_3||a_1b_3||a_1b_2|$, which may be obtained either from (A), or quite independently as follows :—

We have

$$|a_2b_3||a_1b_3||a_1b_2|$$

$$=\left(\frac{b_3}{a_3}-\frac{b_2}{a_2}\right)\left(\frac{b_3}{a_3}-\frac{b_1}{a_1}\right)\left(\frac{b_2}{a_2}-\frac{b_1}{a_1}\right)\times(a_1a_2a_3)^2$$

$$=\begin{vmatrix} 1 & \frac{b_1}{a_1} & \left(\frac{b_1}{a_1}\right)^2 \\ 1 & \frac{b_2}{a_2} & \left(\frac{b_2}{a_2}\right)^2 \\ 1 & \frac{b_3}{a_3} & \left(\frac{b_3}{a_3}\right)^2 \end{vmatrix}\times(a_1a_2a_3)^2$$

$$=\begin{vmatrix} a_1^2 & a_1b_1 & b_1^2 \\ a_2^2 & a_2b_2 & b_2^2 \\ a_3^2 & a_3b_3 & b_3^2 \end{vmatrix} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad \text{(B)}$$

6. Further, the right-hand member of either (A) or (B) is readily seen to be

$$\begin{vmatrix} a_1^2b_2b_3 & a_1 & b_1 \\ a_2^2b_1b_3 & a_2 & b_2 \\ a_3^2b_1b_2 & a_3 & b_3 \end{vmatrix},$$

so that by developing this in terms of the elements of the first column and their complementary minors, we have the identity

$$a_2b_3||a_1b_3||a_1b_2|=a_1^2b_2b_3|a_2b_3|-a_2^2b_1b_3|a_1b_3|+a_3^2b_1b_2|a_1b_2| \quad . \quad \text{(C)}$$

If now we consider the determinants in this identity as minors of the determinant $|a_1b_2c_3|$, and apply the Law of Complementaries,* we have the conjugate theorem

$$b_1b_2b_3|a_1b_2c_3|^2=b_1|a_1b_3||a_1b_2||b_2c_3|^2-b_2|a_1b_2||a_2b_3||b_1c_3|^2$$
$$+b_3|a_2b_3||a_1b_3||b_1c_2$$

or, after division, by $b_1b_2b_3|a_2b_3||a_1b_3||a_1b_2|$,

$$\frac{|a_1b_2c_3|^2}{|a_2b_3||a_1b_3||a_1b_2|}=\frac{|b_2c_3|^2}{b_2b_3|a_2b_3|}-\frac{|b_1c_3|^2}{b_1b_3|a_1b_3|}+\frac{|b_1c_2|^2}{b_1b_2|a_1b_2|} \quad . \ . \quad \text{(D)}$$

Further, if we write a's for b's in this result, and *vice versa*, the

* Thomas Muir, M.A., *Trans. Roy. Soc. Edin.*, vol. xxx. p. 1.

right-hand side changes form and sign, while the left-hand side changes sign only; so that we have a second expression for

$$\frac{|a_1b_2c_3|^2}{|a_2b_3||a_1b_3||a_1b_2|}:$$

which two results may be combined in one enunciation as follows:—

If (12) denote either

$$\frac{|b_1c_2|^2}{b_1b_2|a_1b_2|} \text{ or } \frac{|a_1c_2|^2}{a_1a_2|a_1b_2|},$$

then

$$(23)-(13)+(12)=\frac{|a_1b_2c_3|^2}{|a_2b_3||a_1b_3||a_1b_2|} \quad . \quad . \quad . \quad \text{(I)}$$

7. In an exactly analogous way, starting with the two rows of elements,

$$\begin{matrix} a_1 & a_2 & a_3 & a_4 \\ b_1 & b_2 & b_3 & b_4, \end{matrix}$$

we can show that

$$|a_1b_2||a_1b_3||a_1b_4||a_2b_3||a_2b_4||a_3b_4|$$

$$\left.\begin{aligned} &=\zeta^{\frac{1}{2}}(a_2a_3a_4b_1,\ a_1a_3a_4b_2,\ a_1a_2a_4b_3,\ a_1a_2a_3b_4)\div(a_1a_2a_3a_4)^3 \\ &\text{or } \zeta^{\frac{1}{2}}(a_1b_2b_3b_4,\ a_2b_1b_3b_4,\ a_3b_1b_2b_4,\ a_4b_1b_2b_3)\div(b_1b_2b_3b_4)^3 \end{aligned}\right\} \quad . \quad . \quad (\text{A}_1);$$

and also

$$=\begin{vmatrix} a_1^3 & a_1^2b_1 & a_1b_1^2 & b_1^3 \\ a_2^3 & a_2^2b_2 & a_2b_2^2 & b_2^3 \\ a_3^3 & a_3^2b_3 & a_3b_3^2 & b_3^3 \\ a_4^3 & a_4^2b_4 & a_4b_4^2 & b_4^3 \end{vmatrix} \quad . \quad . \quad . \quad (\text{B}_1)$$

and therefore

$$=\begin{vmatrix} a_1^3b_2b_3b_4 & a_1^2 & a_1b_1 & b_1^2 \\ a_2^3b_1b_3b_4 & a_2^2 & a_2b_2 & b_2^2 \\ a_3^3b_1b_2b_4 & a_3^2 & a_3b_3 & b_3^2 \\ a_4^3b_1b_2b_3 & a_4^2 & a_4b_4 & b_4^2 \end{vmatrix};$$

and thence expanding in terms of the elements of the first column and their complementary minors, and using (B), we have the identity

$$|a_1b_2||a_1b_3||a_1b_4||a_2b_3||a_2b_4||a_3b_4|$$

$$=a_1^3b_2b_3b_4|a_3b_4||a_2b_4||a_2b_3|-a_2^3b_1b_3b_4|a_1b_3||a_1b_4||a_3b_4|$$

$$+a_3^3b_1b_2b_4|a_1b_2||a_1b_4||a_2b_4|-a_4^3b_1b_2b_3|a_2b_3||a_1b_3||a_1b_2| \quad . \quad . \quad . \quad (\text{C}_1)$$

With the help of the Law of Complementaries we should then obtain the conjugate theorem

$$| b_1c_2 || b_1c_3 || b_1c_4 || b_2c_3 || b_2c_4 || b_3c_4 || a_1b_2c_3d_4 |^3$$

$$= | b_1c_2 || b_1c_3 || b_1c_4 || a_1b_3c_4 || a_1b_2c_4 || a_1b_2c_3 || b_2c_3d_4 |^3$$

$$- | b_1c_2 | \,.\,.\, | a_1b_2c_3 | \,.\,.\, | b_1c_3d_4 |^3 + | b_1c_3 | \,.\,.\, | a_1b_2c_3 | \,.\,.\, | b_1c_2d_4 |^3$$

$$- | b_1c_4 || b_2c_4 || b_3c_4 || a_1b_2c_4 || a_1b_3c_4 || a_2b_3c_4 || b_1c_2d_3 |^3 ;$$

or, after division by

$$| b_1c_2 || b_1c_3 | \ldots | b_3c_4 || a_2b_3c_4 || a_1b_3c_4 || a_1b_2c_4 || a_1b_2c_3 | ,$$

$$\frac{| a_1b_2c_3d_4 |^3}{| a_2b_3c_4 || a_1b_3c_4 || a_1b_2c_4 || a_1b_2c_3 |}$$

$$= \frac{| b_2c_3d_4 |^3}{| b_2c_3 || b_2c_4 || b_3c_4 || a_2b_3c_4 |} - \frac{| b_1c_3d_4 |^3}{| b_1c_3 || b_1c_4 || b_3c_4 || a_1b_3c_4 |}$$

$$+ \frac{| b_1c_2d_4 |^3}{| b_1c_2 || b_1c_4 || b_2c_4 || a_1b_2c_4 |} - \frac{| b_1c_2d_3 |^3}{| b_1c_2 || b_1c_3 || b_2c_3 || a_1b_2c_3 |} \quad . \; . \; . \quad (D_1)$$

As before, we observe that, if in this result we write a's for b's and *vice versa*, and again if in the result so obtained we write b's for c's and *vice versa*, in each case the right-hand side changes form, while the left hand side remains unaltered, so that we obtain two additional expressions for this side; hence—

If (123) denote

$$\frac{| b_1c_2d_3 |^3}{| a_1b_2c_3 | \mathrm{P}_m} , \qquad \frac{| a_1c_2d_3 |^3}{| a_1b_2c_3 | \mathrm{P}_m} , \quad \text{or} \quad \frac{| a_1b_2d_3 |^3}{| a_1b_2c_3 | \mathrm{P}_m} ,$$

then

$$(234) - (134) + (124) - (123) = \frac{| a_1b_2c_3d_4 |^3}{\mathrm{P}_m} \quad . \; . \; . \; . \quad (\mathrm{II.})$$

where in each expression P_m denotes the product of the complementary minors of the elements of the last column of the determinant in the numerator.

In like manner it can be shown that,

If (1234) denote

$$\frac{|b_1c_2d_3e_4|^4}{|a_1b_2c_3d_4|\,P_m}, \quad \frac{|a_1c_2d_3e_4|^4}{|a_1b_2c_3d_4|\,P_m}, \quad \frac{|a_1b_2d_3e_4|^4}{|a_1b_2c_3d_4|\,P_m},$$

or

$$\frac{|a_1b_2c_3e_4|^4}{|a_1b_2c_3d_4|\,P_m},$$

then will

$$(2345) - (1345) + (1245) - (1235) + (1234)$$

$$= \frac{|a_1b_2c_3d_4e_5|^4}{P_m} \quad \text{. . . . . (III.)}$$

8. It is thus evident that the theorem is a general one, so that starting with the two rows of m elements each,

$$\begin{array}{ccccc} a_1 & a_2 & a_3 & \ldots & a_m \\ b_1 & b_2 & b_3 & \ldots & b_m, \end{array}$$

we can show that the product of all the determinants of the second order which can be formed from them, viz.:—

$$|a_1b_2|\,|a_1b_3|\,|a_1b_4| \ldots |a_{m-1}b_m|,$$

which consists of $\frac{1}{2}m(m-1)$ factors,

$$\left.\begin{array}{l} = \zeta^{\frac{1}{2}}(a_2a_3\ldots a_mb_1,\ a_1a_3\ldots a_mb_2,\ \ldots,\ a_1a_2\ldots a_{m-1}b_m) \div (a_1a_2a_3\ldots a_m)^x \\ \text{or} \\ (-1)^{\frac{1}{2}m(m-1)}\zeta^{\frac{1}{2}}(a_1b_2b_3\ldots b_m,\ a_2b_1b_3\ldots b_m,\ \ldots,\ a_mb_1b_2\ldots b_{m-1}) \div (b_1b_2b_3\ldots b_m)^x \end{array}\right\} \quad \text{. . . . . . } (A_2)$$

where the index $x = \frac{1}{2}(m-1)(m-2)$; and also

$$= \begin{vmatrix} a_1^{m-1} & a_1^{m-2}b_1 & a_1^{m-3}b_1^2 \ldots b_1^{m-1} \\ a_2^{m-1} & a_2^{m-2}b_2 & a_2^{m-3}b_2^2 \ldots b_2^{m-1} \\ \cdot & \cdot & \cdot \quad\quad \cdot \\ \cdot & \cdot & \cdot \quad\quad \cdot \\ \cdot & \cdot & \cdot \quad\quad \cdot \\ a_m^{m-1} & a_m^{m-2}b_m & a_m^{m-3}b_m^2 \ldots b_m^{m-1} \end{vmatrix} \quad \text{. . . . . . } (B_2)$$

and therefore

$$= \begin{vmatrix} a_1^{m-1}b_2b_3\ldots b_m, & a_1^{m-2}, & a_1^{m-3}b_1, \ldots b_1^{m-2} \\ a_2^{m-1}b_1b_3\ldots b_m, & a_2^{m-2}, & a_2^{m-3}b_2, \ldots b_2^{m-2} \\ \cdot & \cdot & \cdot \quad\quad \cdot \\ \cdot & \cdot & \cdot \quad\quad \cdot \\ \cdot & \cdot & \cdot \quad\quad \cdot \\ a_m\ \ b_1b_2\ldots b_{m-1}, & a_m^{m-2}, & a_m^{m-3}b_m, \ldots b_m^{m-2} \end{vmatrix};$$

and thence expanding in terms of the elements of the first column and their complementary minors, and observing the corresponding result to (B_2) for two rows of $m-1$ elements each, viz. :—

$$\begin{vmatrix} a_1^{m-2} & a_1^{m-3}b_1, & \dots & b_1^{m-2} \\ a_2^{m-2} & a_2^{m-3}b_2, & \dots & b_2^{m-2} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ a_{m-1}^{m-2} & a_{m-1}^{m-3}b_{m-1}, & \dots & b_{m-1}^{m-2} \end{vmatrix} = |a_1b_2||a_1b_3|\dots|a_{m-2}b_{m-1}|,$$

we have the identity

$$|a_1b_2||a_1b_3||a_1b_4|\dots\dots|a_{m-1}b_m|$$
$$= a_1^{m-1}b_2b_3\dots b_m|a_2b_3||a_2b_4|\dots|a_{m-1}b_m|$$
$$- a_2^{m-1}b_1b_3\dots b_m|a_1b_3||a_1b_4|\dots|a_{m-1}b_m|$$
$$+ \dots\dots\dots\dots\dots\dots\dots$$
$$+(-1)^{m-1}a_m^{m-1}b_1b_2b_3\dots b_{m-1}|a_1b_2||a_1b_3|\dots|a_{m-2}b_{m-1}| \quad \dots \quad (C_2)$$

Using the Law of Complementaries, we should then obtain the conjugate theorem (involving elements formed from m letters $a, b, c, \dots k, l$).

$$b_3c_4\dots k_m||b_2c_4\dots k_m|\dots|b_1c_2\dots k_{m-2}|.|a_1b_2c_3\dots l_m|^{m-1}$$
$$= A_1B_1|b_2c_3d_4\dots l_m|^{m-1} - A_2B_2|b_1c_3d_4\dots l_m|^{m-1}$$
$$+ A_3B_3|b_1c_2d_4\dots l_m|^{m-1} - \dots\dots\dots$$
$$+(-1)^{m-1}.\ A_mB_m|b_1c_2d_3\dots l_{m-1}|^{m-1},$$

where the coefficient of $|a_1b_2c_3\dots l_m|^{m-1}$ in the left-hand side consists of $\frac{1}{2}m(m-1)$ factors, formed by taking the m suffixes $m-2$ together; and in which coefficient $A_1, A_2, A_3, \dots A_m$ denote the products of those factors in which the suffixes 1, 2, 3 . . . m respectively occur, and so have each $\frac{1}{2}(m-1)(m-2)$ factors; while $B_1, B_2, B_3, \dots B_m$ denote the products of those factors in the expression

$$|a_2b_3c_4\dots k_m||a_1b_3c_4\dots k_m|\dots\dots|a_1b_2c_3\dots k_{m-1}|$$

in which the suffixes 1, 2, 3, . . . m respectively occur, and so have each $m-1$ factors.

Hence dividing off by

$$|b_3c_4 \quad \ldots k_m||b_2c_4 \quad \ldots k_m|\ldots|b_1c_2 \quad \ldots k_{m-2}|$$
$$\times|a_2b_3c_4\ldots k_m||a_1b_3c_4\ldots k_m|\ldots|a_1b_2c_3\ldots k_{m-1}|$$

we get

$$\frac{|a_1b_2c_3\ldots . l_m|^{m-1}}{|a_2b_3c_4\ldots k_m||a_1b_3c_4\ldots k_m|\ldots|a_1b_2c_3\ldots k_{m-1}|}$$
$$=\frac{|b_2c_3d_4\ldots l_m|^{m-1}}{|a_2b_3c_4\ldots k_m|\mathrm{P}_m}-\frac{|b_1c_3d_4\ldots l_m|^{m-1}}{|a_1b_3c_4\ldots k_m|\mathrm{P}_m}$$
$$+\frac{|b_1c_2d_4\ldots l_m|^{m-1}}{|a_1b_2c_4\ldots k_m|\mathrm{P}_m}-\ldots\ldots\ldots$$
$$+(-1)^{m-1}\cdot\frac{|b_1c_2d_3\ldots l_{m-1}|^{m-1}}{|a_1b_2c_3\ldots k_{m-1}|\mathrm{P}_m}, \quad \ldots \quad (\mathrm{D}_2)$$

where in each expression in the right hand side P_m denotes the product of the complementary minors of the elements of the last column of the determinant in the numerator.

As before, by interchanges in certain letters, the right-hand side changes form, while the left remains unaltered, so that we get $m-2$ additional expressions, which will be seen from the following general enunciation :—

If $(123\ldots m-1)$ denote any one of the following $m-1$ expressions,

$$\frac{|b_1c_2d_3\ldots l_{m-1}|^{m-1}}{\mathrm{KP}_m}, \quad \frac{|a_1c_2d_3\ldots l_{m-1}|^{m-1}}{\mathrm{KP}_m}, \quad \frac{|a_1b_2d_3\ldots l_{m-1}|^{m-1}}{\mathrm{KP}_m},$$

$$\ldots\ldots, \quad \frac{|a_1b_2c_3\ldots h_{m-2}l_{m-1}|^{m-1}}{\mathrm{KP}_m}, \text{ where } \mathrm{K}\equiv|a_1b_2c_3\ldots k_{m-1}|,$$

then

$$(234\ldots m)-(134\ldots m)+(124\ldots m)$$
$$-\ldots\ldots+(-1)^{m-1}\cdot(123\ldots m-1)$$
$$=\frac{|a_1b_2c_3\ldots l_m|^{m-1}}{\mathrm{P}_m} \quad \ldots\ldots \quad (\mathrm{IV.})$$

9. The foregoing results admit of the following interesting *geometrical* interpretation.

Let ABC be a triangle the equations to whose sides in ordinary co-ordinates are

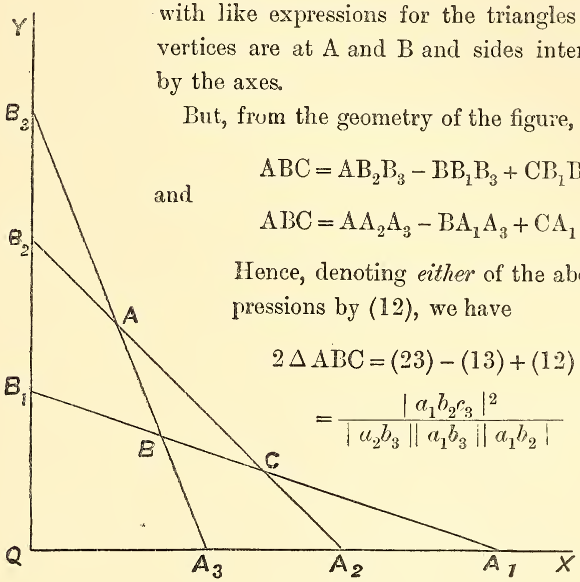
$$a_1x+b_1y+c_1=0, \quad a_2x+b_2y+c_2=0, \quad a_3x+b_3y+c_3=0,$$

and suppose the sides when produced to meet the co-ordinate axes OX and OY in A_1, A_2, A_3 and B_1, B_2, B_3 respectively. Then

$$2\,\Delta\,CB_1B_2 = \frac{(b_1c_2 - b_2c_1)^2}{b_1b_2(a_1b_2 - a_2b_1)},$$

and

$$2\,\Delta\,CA_1A_2 = \frac{(a_1c_2 - a_2c_1)^2}{a_1a_2(a_1b_2 - a_2b_1)},$$



with like expressions for the triangles whose vertices are at A and B and sides intercepted by the axes.

But, from the geometry of the figure,

$$ABC = AB_2B_3 - BB_1B_3 + CB_1B_2$$

and

$$ABC = AA_2A_3 - BA_1A_3 + CA_1A_2\,.$$

Hence, denoting *either* of the above expressions by (12), we have

$$2\,\Delta\,ABC = (23) - (13) + (12)\,,$$

$$= \frac{|\,a_1b_2c_3\,|^2}{|\,a_2b_3\,|\,|\,a_1b_3\,|\,|\,a_1b_2\,|} \quad \text{by (I.)}$$

Again, let PQRS be a tetrahedron, the equations to whose planes are of the form $ax + by + cz + d = 0$, which we may call 1, 2, 3, 4; and suppose the planes 1, 2, 3, meeting in S, when produced to intercept on the co-ordinate plane of YZ the triangle A, B, C,

Then, by the foregoing,

$$2\,\Delta\,A_1B_1C_1 = \frac{|\,b_1c_2d_3\,|^2}{|\,b_2c_3\,|\,b_1c_3\,|\,|\,b_1c_2\,|}.$$

Multiplying this expression by the x of the point S, namely, $|\,b_1c_2d_3\,| \div |\,a_1b_2c_3\,|$, we thus get

$$6 \text{ vol. } SA_1B_1C_1 = \frac{|\,b_1c_2d_3\,|^3}{|\,b_2c_3\,|\,|\,b_1c_3\,|\,|\,b_1c_2\,|\,|\,a_1b_2c_3\,|}.$$

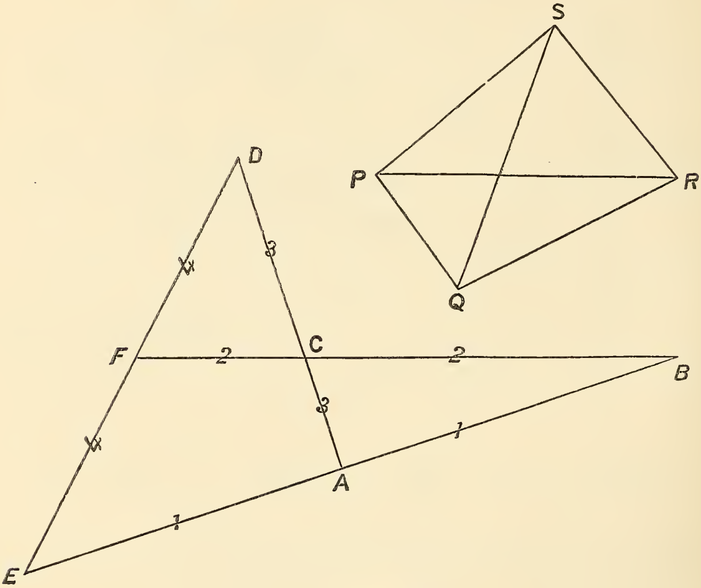
In like manner, if $A_2B_2C_2$ and $A_3B_3C_3$ be the triangles intercepted on the co-ordinate planes of ZX and XY respectively by the planes 1, 2, 3 produced, we shall get

$$6 \text{ vol. } SA_2C_2B_2 = \frac{|a_1c_2d_3|^3}{|a_2c_3||a_1c_3||a_1c_2||a_1b_2c_3|}$$

and

$$6 \text{ vol. } SA_3B_3C_3 = \frac{|a_1b_2d_3|^3}{a_2b_3||a_1b_3||a_1b_2||a_1b_2c_3|}$$

with corresponding expressions for the tetrahedra similarly formed, and having their vertices at P, Q, and R respectively.



But, from the geometry of the figure, we have

$$PQRS = PDFC + REBF - QADE - SABC,$$

where EABCD is the figure formed on *any* co-ordinate plane by the planes 1, 2, 3, 4 produced.

Hence, denoting by (1 2 3) *any one* of the above three expressions obtained for volumes, we have

$$6 \text{ vol. } PQRS = (234) - (134) + (124) - (123)$$

$$= \frac{|a_1b_2c_3d_4|^3}{|a_2b_3c_4||a_1b_3c_4||a_1b_2c_4||a_1b_2c_3|} \text{ by (II).}$$

By proceeding to deduce the next case from that just obtained, in the same way as we deduced the case of a tetrahedron from that of a triangle, we multiply the expression $| b_1c_2d_3e_4 |^3 \div P_m$ by the x of four equations of the form $ax + by + cz + du + e = 0$, and thus obtain

$$\frac{| b_1c_2d_3e_4 |^4}{| a_1b_2c_3d_4 | P_m},$$

which is denoted by (1234). In like manner we obtain the expressions denoted by (12345), &c., and so the general type of expression denoted by $(123 \ldots m-1)$; but as these expressions are of 4, 5, and higher dimensions, the results involving them are of little importance geometrically.

PRIVATE BUSINESS.

James Oliver, M.B., was balloted for, and declared duly elected a Fellow of the Society.

Monday, 21st *June* 1886.

Sheriff FORBES IRVINE, Vice-President, in the Chair.

The following Communications were read:—

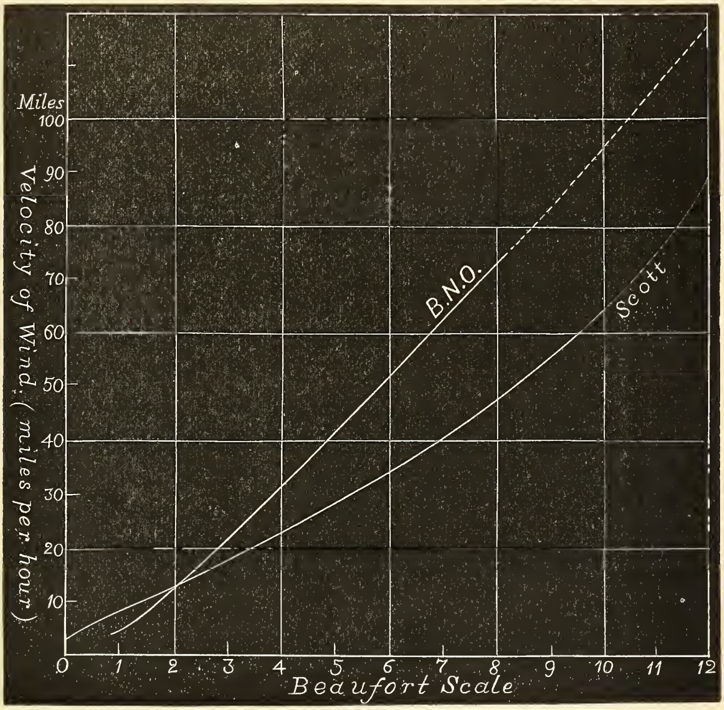
1. The Diurnal Variation in the Direction of the Summer Winds on Ben Nevis. By R. T. Omond, Superintendent, Ben Nevis Observatory.

The most cursory examination of the wind records of the Ben Nevis Observatory shows that there is, even in fine weather, no strongly marked daily variation in their direction; nothing comparable to the land and sea breezes observed on our own coasts in summer. In order to see whether there was not some regular daily change concealed in the extremely variable winds actually observed, I reduced, by means of a traverse table, to north-south and west-east co-ordinates each observation during the summer months (June, July, August) of 1884 and 1885, taking account of the velocity of the wind as well as of its direction, so as to get the actual mean air motion at each hour of the day. As the anemometers at Ben Nevis cannot be trusted to work continuously even in summer, but get frozen fast every now and then, it was necessary to do this from the hourly eye observations. The scale for wind pressure used is supposed to be the ordinary Beaufort Scale, running from 0 to 12, and in reducing the observed winds to miles per hour I used the numbers given by Mr Scott of the Meteorological Office, which are usually regarded as the standard for this purpose. Since then I have found that our variety of the Beaufort Scale differs from the standard in a rather curious manner. In the following table the velocities in miles per hour corresponding to each Beaufort number is given—first, according to Mr Scott, and second, from the averages of the readings of the Robinson Anemometer when working satisfactorily at Ben Nevis Observatory.

B. Scale, .	0	1	2	3	4	5	6	7	8	9	10	11	12
Scott, .	3	8	13	18	23	28	34	40	48	56	65	75	90
B.N.O., .	...	5	12	21	31	39	50	63	73				

The result is shown graphically in the diagram. In this the abscissæ are the numbers of the Beaufort Scale, and the ordinates miles per hour. At the top are put the numbers of the Land Scale used in the reports from Ben Nevis published in the daily papers; each number in it is just one-half of the corresponding Beaufort number. The red line is drawn from Mr Scott's constants showing the velocity corresponding to each number. The black line gives the results got at Ben Nevis Observatory up to force 8. It will be seen that at 1 our velocity is lower than the standard, at 2 about the same, and at all above that higher. And what is more remarkable, while Mr Scott's is a pretty regular curve, ours, making allowance for the shakiness due to the small number of observations, is practically a straight line. There are no observations above force 8, but the velocity corresponding to force 8 on Ben Nevis (force 4 in the newspaper reports) is very nearly equal to what is usually called force 11, namely, 73 miles an hour; and if the line continues straight at the higher values, as indicated by the dotted extension on the diagram, the average velocity of the wind in a first class Ben Nevis gale, such as was experienced in February 1885, must be somewhere about 120 miles an hour.

By using Mr Scott's numbers to reduce the Ben Nevis observations a considerable error is thus introduced, especially at the higher velocities. To reduce this error as far as possible, I have only taken those days in summer in which no wind of over force 3 (21 miles an hour) was recorded. This practically picks out all the fine days, and on these days the daily variation might be supposed to be better marked than during stormy weather. In the summer of 1884 there were 27 such days, and in that of 1885, 47. Along



with each day was included the observation of the previous midnight, so as to have the data for correcting the residual inequality in the means. For 1884 the mean air motion for the whole day was from about S.W. by S., and for 1885 from W.N.W. The mean winds at each hour, however, differed much from these, and in spite of the difference between the days' means in the two years, the hourly means agreed substantially with each other, both in direction and velocity. The two years were therefore added together, the mean wind for the day then coming out as W.S.W., and of very small velocity, only about $1\frac{1}{4}$ miles per hour. By subtracting the co-ordinates of the mean wind for the whole day from those of the mean wind at any hour, we get what may be called the difference wind of that hour; that is to say, the wind which must be added to the mean wind of the day to produce the wind of that hour. The difference winds thus got show a well-marked diurnal variation. From 3 to 8 A.M. there is a northerly wind of about $2\frac{1}{2}$ miles an hour, and from 11 A.M. to 2 P.M. there is a south or S.S.E. wind of about 3 miles an hour. At the other hours the difference winds are small and variable in direction, except about midnight, when there is an indication of a moderate difference wind in the same direction as the mean daily wind. This last may be due to the daily variation in velocity (independent of direction) which is such a well-marked feature on Ben Nevis. When sufficient data are collected, I hope to be able to get a clue as to how far this diurnal variation in velocity is due to a horizontal wind and how far to vertical currents. It may be noted in passing, that the hours at which these difference winds change their direction have no connection with the hours of change of watch at the Observatory, so they cannot be due to any difference in the estimation of the wind by different observers.

The most marked features in the diurnal variation are the northerly winds shortly after sunrise, and the southerly ones about noon. I think the most obvious explanation of their cause is to be found in the shape of Ben Nevis. The ridge of the hill top runs east and west; on the north side is a deep gorge with precipitous sides, into which the sun only penetrates for a few hours after sunrise in summer; the south side consists of a steep slope going down into Glen Nevis at an angle of about 30 degrees. In the early morning the sun's rays slanting down the northern valley would warm the air in it, while the south side of the hill was still cold from the night's radiation, and thus cause a northerly wind across the top. As soon as the sun swings round to the south the northern valley is in shade, while the bare stony slope to southward gets warmed in its turn, and a reverse or southerly wind is set up.

If the above explanation is correct, these winds are purely local, and not connected with any general system of land and sea breezes. To attempt to explain them on the latter hypothesis, I believe it would be necessary to assume that Ben Nevis was in the back-draught of the land and sea breezes; that the southerly winds of noon were the overflow from a low-lying cyclone occupying central Scotland, and that the midnight westerly winds were the return current from the lower night land wind feeding an anticyclone similarly placed; while the northerly winds shortly after sunrise could only be accounted for by supposing the daily cyclone to originate in the upper atmosphere shortly after sunrise, and extend downwards as the heat of the day increased, finally dying out at a low level.

2. The Meteorology of Ben Nevis. By Alex. Buchan, M.A.

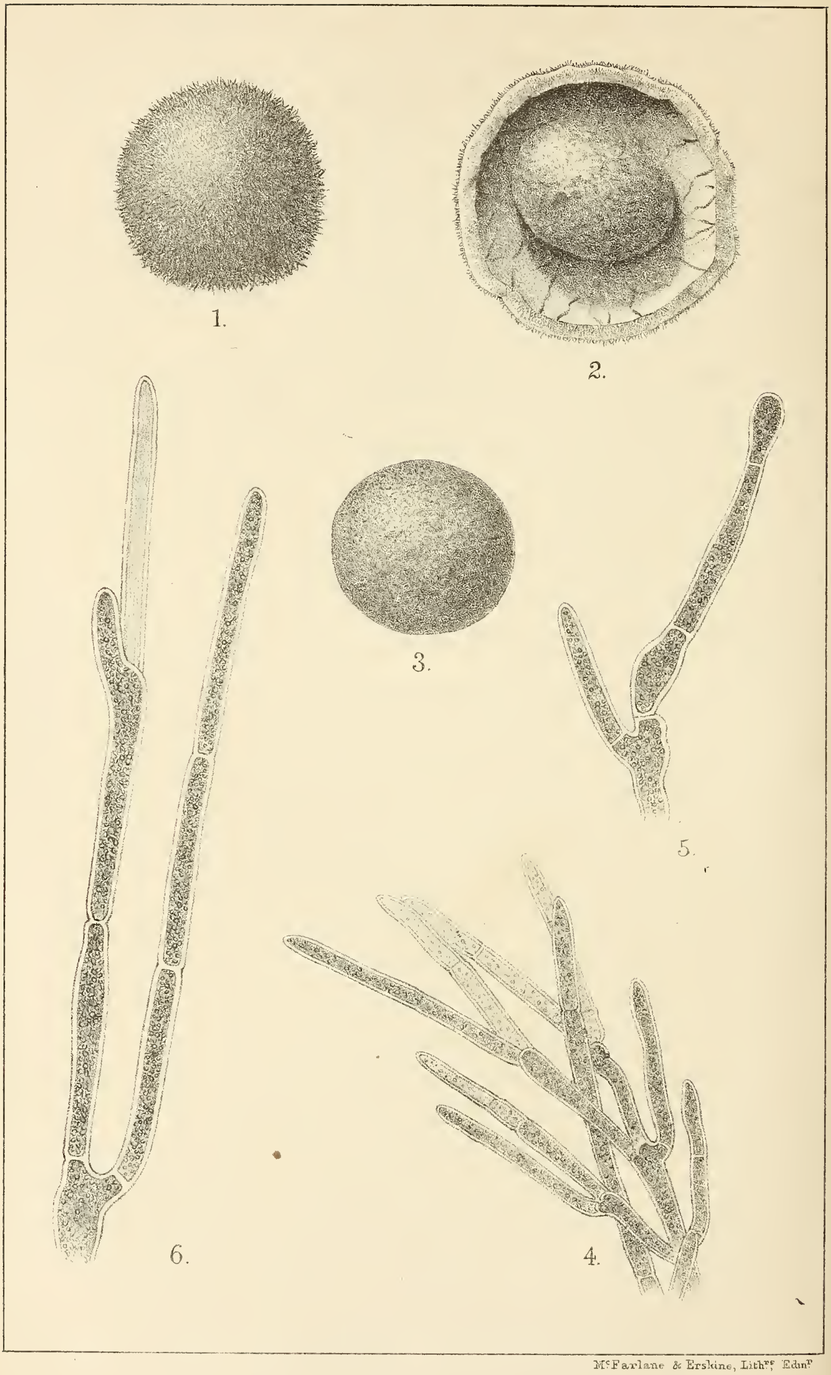
From the commencement of the meteorological researches on Ben Nevis, a double set of observations have been carried on—one set on the top of the Ben, and the other at a station at Fort William near the level of the sea. It is not so much from the observations made on the top considered by themselves, as to their relations to those made at the base, that we may hope to arrive at a better knowledge of the atmosphere, and particularly at a better understanding of the principles of weather forecasting. Accordingly, both stations were from the first fitted up with the best instruments.

The observations on the top are made hourly, and those at Fort William six times a day; and to the latter station, in addition, a barograph and a thermograph have been added, the results of which are particularly valuable as affording a ready means of detecting inadvertent errors of observation or of transcription. Thus the system of observation for Ben Nevis yields as trustworthy records as can possibly be obtained. As regards the observations of temperature at the Observatory, it is absolutely necessary that these be made with the eye, owing chiefly to the heavy snow-drifts and incrustations of ice, with which everything exposed to the free atmosphere gets frequently covered. Owing to the violence of the winds which occasionally blow for hours together at a mean velocity of about 120 miles an hour, maximum and minimum thermometers do not give trustworthy results.

Mr Omond and his staff of assistants went into residence in the end of November 1883. The present paper deals with the two and a half years' observations from that date, to May 31, 1886. From these observations, the hourly variation of atmospheric temperature, pressure, and wind velocity have been calculated, and the results, illustrated by diagrams, were submitted to the meeting. From the double set of observations, it is seen that the rate of decrease of temperature with height is 1° for every 270 feet of ascent. This result has a peculiar value attached to it, seeing that both at the Observatory and at the sea-level station, the arrangements carried out are such as to minimise the effects of solar and terrestrial radiation.

The corrections to sea-level for the barometric observations at the Observatory, 4406 feet high, have been emphatically determined from the double set of observations, for each tenth inch of the pressure at sea-level from 28·500 inches to 30·600 inches, and for every 2°·0 of the outside temperature from 18°·0 to 60°·0. The results are closely accordant with the figures for a sea-level pressure of 30·000 inches published by General Hagan of the U.S. Signal Office, and in use by the American observers. For each 2°·0 from 18°·0 to 60°·0, the sea-level corrections for Ben Nevis are 0·020 inch greater than the figures of the Signal Office.

The sea-level corrections for the Observatory have been worked out from the formula given by Laplace in his *Méchanique Céleste* in the form employed by the Meteorological Council. At an outside temperature of 45°, the correction derived from the formula is the same as the correction calculated directly from the observations. At lower temperatures, the correction from the formula steadily increases, and at a temperature of 20°, and sea-level pressure of 30·000 inches, it is 0·040 inch larger than the empirically determined correction. At temperatures higher than 45°, the empirically determined correction is the larger one. The general result is, while by the formula, the correction for each increase of 2° of the temperature is 0·018 inch less, by the observations directly it is only 0·015 inch less, or the difference in the correction for a difference of 2° of the outside temperature is a sixth part greater than observations shows it to be.



McFarlane & Erskine, Lithrs Edinr

3. On some Algoid Lake-Balls found in South Uist. By G. W. W. Barclay, F.R.S.E. (Plate XXX.)

In August of last year I was in South Uist on an angling expedition, and, while fishing one of the lochs on the island, my attention was drawn to some very remarkable balls that were lying in great numbers at the bottom. I examined a good many of these, and found that they were composed of innumerable algal filaments so intertwined and matted together as to form an outer covering of an almost felt-like consistency, which could, however, be torn open without difficulty. This outer coating varied (speaking very roughly) from about a twentieth to two-twentieths of an inch in thickness, or even more, and the interior of the balls consisted, so far as the naked eye could see, only of mud. The microscope, of course, tells a different story.

I made a number of inquiries at the time with a view to discovering if possible the nature and origin of these balls, but beyond the fact that they were well known to have existed from time immemorial in this loch (and, it was confidently asserted, in no other loch on the island), I could ascertain nothing about them. I brought away some of the balls with me, and, failing to find any mention of them in any books on the Hebrides to which I could gain access, I wrote to the principal inhabitants of the island, and to any one else whom I thought likely to be able to assist me in my efforts to discover what the balls were and how they originated—but without result. I was not at that time aware that lake-balls of this kind are found in several European countries, and, after making that discovery, I should scarcely have thought them sufficiently curious to justify my taking up even a very little of the time of the Society, but that some of my friends who had seen them and who are learned in botanical matters seemed to consider them rarities, and to think that some account of them might be interesting. I venture, therefore, to offer a very brief description of the balls (of which I have placed a number on the table for inspection), and to give an account of the locality in which they were found.

A microscopic examination of the balls shows that they are composed of a filamentous alga, *Cladophora glomerata*, a variety of

Cladophora œgagropila of Rabenhorst, described and pictured in Hassall's *Algœ*, p. 213, in part. I have had two diagrams prepared showing (*a*) the appearance of the alga under the microscope, and (*b*) a highly-magnified view of one of the filaments; and I am able, by the kindness of Professor Dickson, to show under the microscopes in the ante-room portions of the coverings of these balls (see Plate XXX., figs. 4, 5, and 6). I must express my special thanks to Dr J. M. Macfarlane, to whom I am indebted for the microscopical preparations, and for much kind assistance in other ways. Under one of the microscopes will be found a slide showing a portion of the *contents* of one of the balls. The interior is seen to be filled with diatoms and the decomposed remains of the inner ends of the radiating filaments. Some of the filaments exhibit fructification, the cell contents in several of them being differentiated into spores which in time will be set free to propagate the plant.

The loch in which these balls are found—Lower Kildonan by name—is an irregular sheet of water, less than half a mile across in any direction. It lies near the west coast of the island, and is connected with the sea by the so-called "river" Roglass, which is, in reality, little more than a large ditch some 8 feet broad and about three-quarters of a mile in length. The whole of the west side of South Uist is very flat, and the loch itself lies only a few feet above the sea-level. Lower Kildonan is a fresh-water loch, being connected with several other inland lochs, as will be seen from the Ordnance Survey map; and its water, except when and where the tide from the Roglass enters it, is fresh. It is, however, precisely at this part of the loch where the water is occasionally rendered brackish by the tide that these balls occur, and this is interesting in view of the fact that *Cladophora œgagropila* is found both in fresh and salt water. The loch here is quite shallow, and the bottom seems to be a mixture of sand and mud, the former predominating. The balls lie in a depth of 2 to 3 feet, and cover areas of many square yards, showing conspicuously by their dark colour against the light sandy bottom. They lie alongside of one another in great numbers, and vary in size from about a quarter of an inch to 3 or 4 inches in diameter. In some cases a complete small ball is found inside a larger one, and a specimen of this kind is on the table. Mr MacLean of Milton told me he had frequently seen balls containing *more* than one smaller one, but I did not come across any case of this sort. The balls are for the most part spherical or nearly so, but a considerable proportion of them are irregular in shape, as the specimens exhibited show. I heard them described not badly, if in a somewhat unscientific way, by one of the islanders as being like "a lot of potatoes." The smaller the balls the more spherical do they seem to be. I unfortunately made no attempt to secure the *largest* I met with, but I remember an angler saying he had seen one ball "as big as his hat." As this gentleman was a clergyman there could, of course, be no doubt as to the correctness of his statement, and the only question is as to the size of his head, which I stupidly omitted to measure. I can only say that I saw no balls of anything like the size of my own head.

There are three sets of the balls on the table here this evening—(1) some of those which I took out of the loch in August last, and which have been lying untouched ever since; (2) some which Mr Charles MacLean of Milton (whose farm is close to the loch) was good enough to get for me during the winter; (3) some which were sent to me last week by Mr Mearns, the obliging hotel-keeper at Lochboisdale, whose inn—a most comfortable house—is about 7½ miles from Lower Kildonan. Illustrations of two of the balls exhibited are given on the accompanying Plate. Figs. 1 and 2 represent one of the fresh balls not many days out of the water. Fig. 3 shows a dried specimen, taken from the loch nearly a year ago.

I have also placed on the table a very interesting ball of the same description, which has been lent to me by Professor L. Fischer of the Botanical Gardens in Bern, and which comes, he tells me, from Ellesmere, in Shropshire. At a meeting of the Naturforschende Gesellschaft of Bern in 1884, Professor Fischer referred to these algoid lake-balls, of which he says a number of varieties are distinguished according to the structure of the filaments and the size of the balls. He says they are met with in lakes chiefly in Sweden, Norway, Northern Germany, Austria, and Upper Italy; and he adds that they are also found in the sea ("auch marine Fundorte werden angegeben"). I wrote to Professor Fischer, and received from him this English lake-ball. It will be seen that the filaments are longer and more silky, and of a somewhat different shade of green from the other balls exhibited.

I have mentioned that the people in South Uist, to whom I put my first questions regarding the balls, asserted that they were found in no other loch in the island except Lower Kildonan. But they went further than this, and I found in the course of my inquiries a very persistent and ever-recurring legend, that only in one other loch in Scotland were these curiosities to be found, most of my informants adding that that other loch was in Orkney. Mr Angus MacLennan, for example, Lady Gordon Cathcart's factor in South Uist, writes—" I understand the same kind of balls are to be found in some other *one* loch *only* in Scotland."

Mr Ranald MacDonald, her Ladyship's factor at Cluny Castle, says, in reply to a question—" I did hear that similar balls were found in a certain place in Orkney, but I am sorry that my information is of a very general and indefinite character."

Mr MacLean of Milton writes—" I believe they are not to be found in any loch in Scotland. I heard some gentlemen, a good many years ago, make the remark that they were found in one loch in Orkney, but whether that statement was correct or not, I have no proof of it."

And Mr Campbell, the oldest Roman Catholic priest in the island, writes—" I heard only of one other loch in which these balls were found, but the locality in which it is situated I cannot remember now."

I followed up the hint as to Orkney, and communicated with Mr J. W. Cursiter of Kirkwall, who is a Fellow of the Society of Antiquaries, and a well-known authority on Orcadian matters. He asserts positively that no such balls have been found in the Orkney Islands, and I have not been able to ascertain that they are absolutely *known* to occur in any other loch in Scotland.

[Postscript.—Since reading this paper, I have had the pleasure of seeing Mr Cursiter at Kirkwall, and although he is certain that there is no record of these balls having been met with in Orkney, we were interested to find *Cladophora glomerata* included in a published list of the algæ known to occur in the Islands.]

Description of Plate.

Fig. 1. Fresh lake-ball, showing the growing ends of the filaments protruding.
Fig. 2. Fresh lake-ball in section, the cavity being partially filled with a spherical ball composed of the remains of the decayed interior.
Fig. 3. Dried ball of smaller size.
Fig. 4. A few of the filaments, × 100°.
Figs. 5 and 6. Filaments seen under high power, × 400°.

4. The Duration of the Life of Red Blood Corpuscles, as ascertainable by Transfusion. By William Hunter, M.D. (Edin.), late President of the Royal Medical Society, Edinburgh.

(*Abstract.*)

The question as to the normal duration of the life of red blood corpuscles has hitherto been considered more as a matter for speculative inquiry than for experimental proof. Attempts have from time to time been made by various observers to solve it experimentally, by injecting the blood of one animal into the circulation of another, whose blood corpuscles were of different size and shape, and then noting how long the foreign blood corpuscles remained discoverable in the body of their host. As might have been anticipated, the success of such experiments has not been very striking.

Marfels and Moleschott, so early as 1856, arrived in this way at the conclusion that the normal duration of their life must be a very long one, since even after the lapse of months they could still recognise the corpuscles of the sheep in the circulation of the frog.

Brown-Séquard, also (1857), made some similar observations, with, it must be confessed, somewhat anomalous results; for whilst the blood corpuscles of the dog or rabbit were recognisable in the blood of fowls a month after injection into the circulation, on the other hand, the blood corpuscles of fowls were not to be found in the blood of dogs or rabbits even one hour after injection.

These results were not well reconcilable with each other. The latter observation was probably the more correct of the two, since as is now known from the experiments of Panum, Landois, Ponfick, and others, such a method of investigation, implying as it does the use of "dissimilar" blood, *i.e.*, blood derived from an animal of another species, is doomed from the outset to failure, the blood corpuscles of such blood when introduced into the body of their host always breaking down within a few hours of injection, and in larger quantities being directly poisonous to the organism into which they are injected.

It is, therefore, only by transfusion of "similar" blood, *i.e.*, blood derived from an animal of the same species, that any results bearing on the question can be arrived at. That the corpuscles of such blood continue to live, for a certain time at least, in the body of their host, was to be assumed from some of the very earliest experiments on transfusion made by Dr Lower in 1666, in which dogs continued in good health, after all the blood in their bodies had been replaced by that obtained from other dogs.

The first observer, however, to make direct observations on the actual duration of the life of such transplanted or transfused blood corpuscles was Panum in 1863.

His method was crude and inaccurate. He judged of the number of corpuscles present in any quantity of blood by the difference in specific gravity between the blood serum, and the blood defibrinated. In this way, after withdrawing blood from a dog and replacing it with defibrinated blood, he was enabled to show that two days later the number of blood corpuscles remained almost unaltered, and that five days later the majority of them still remained within the circulation.

It was naturally impossible by this rough method to determine more closely the further fate of the transplanted corpuscles. This could only be done by actual enumeration of the corpuscles before and after the injection, a method of investigation at that time unknown; but even since its introduction, the results obtained have not been so definite as *à priori* might have been expected. They serve, however, to throw some light on the subject.

There are two ways in which, by means of transfusion, information as to the duration of the life of red blood corpuscles may be obtained, viz., either by transfusion of blood into an animal without foregoing depletion, or by transfusion of blood after previous withdrawal of some of the animal's own blood.

In the latter case, the difficulty is to determine afterwards what proportion of the blood corpuscles found present belong to the animal, and what proportion is derived from the transfused blood; since by the withdrawal of blood the standard of comparison,—the number of corpuscles originally present,—has been lost. The difficulty is one which from its very nature it is quite impossible for us to overcome.

It might be thought that in the former method, viz., transfusion without any foregoing depletion, we have at hand a ready means of ascertaining the duration of life of the red blood corpuscles, since the normal standard is in no way interfered with, and the duration of the increase in the number of blood corpuscles after the transfusion will, therefore, represent the extent of their duration of life.

This is indeed the case, so far as the tranfused corpuscles are concerned; but the question always arises, how far the duration of life of such transplanted blood corpuscles can be taken as a criterion of that of normal red blood corpuscles. By transfusion of blood into the circulation of a healthy animal, an abnormal condition of the blood—a so-called plethora—is for the time being brought about, which, so far as we know, may very materially influence the duration of life of the injected corpuscles. The excess of blood corpuscles thus introduced can only be got rid of by a process of increased blood destruction on the part of the organism, and thus the transfused blood corpuscles are not placed under exactly the same conditions as those under which they normally run their life course. In spite, however, of these disadvantages, this method enables us to arrive at least at an approximate estimate.

Worm-Müller found after such transfusions in dogs, that two or three days afterwards the number of blood corpuscles present in the blood closely corresponded with the number of the original *plus* the injected corpuscles, but that a few days later the blood corpuscles began to break down, and by the end of a few weeks at most the whole of the injected corpuscles had been removed from the body. The greater the quantity of blood transfused, the longer did this process of removal last; for whilst after the transfusion of 20 to 30 per cent. of blood the whole of the injected corpuscles were removed in the course of a few days, after injection of 60 to 80 per cent. their removal was not complete till about the end of the second or even the third week.

According to these results, therefore, the longest duration of life of transplanted corpuscles in dogs would be about 2 to 3 weeks.

Quincke's more recent observations, also made on dogs, would seem to agree with this estimate, the duration of life according to him being at least 2 or 3 weeks. His method of investigation, however, is open to the objection that the percentage amount of hæmoglobin in the blood, which he always estimated, does not always necessarily correspond with the number of blood corpuscles present. With this reservation, his statement may be accepted as at east corroborative of that of Worm-Müller.

The result of my own experiments, made on rabbits, go in the main to confirm the accuracy of this estimate of Worm-Müller and Quincke.

The method of transfusion adopted by myself differed somewhat from that of previous observers. Instead of being introduced directly into the circulation through a vein, the blood was injected into the peritoneal cavity, the absorption from which, as is well known, is so rapid and continuous, that peritoneal injection has claims to be considered as a slow method of intravenous injection. In some respects, indeed, for experimental purposes it offers advantages over the latter, since, apart from the greater simplicity with which the operation can be carried out, the absorption into the circulation (mainly through the lymphatics of the diaphragm and the thoracic duct) is so continuous and steady, prolonged as it is over a period of some 24 to 48 hours, that time is given during its progress for the removal of the fluid part of the blood, and hence little or no distension of the vascular system is likely to occur after the injection of even the largest quantities.

The method is naturally open to the objection, that the fact of the blood corpuscles having been extravasated before reaching the circulation may possibly affect their vitality, and thus shorten the duration of their life. That a certain number of them, under such circumstances always suffer a local death, is certain; but this number is relatively small, and, as will be seen, the results show that the vitality of those absorbed is not in any way affected by their temporary sojourn in the peritoneal cavity.

The increase in the number of corpuscles in the blood as ascertained by actual enumeration, after reaching a maximum on the second or third day, became gradually less and less, till at the end of a certain time, varying somewhat in the different experiments, the number of blood corpuscles had returned to their normal, this period of time representing, therefore, the duration of life of the injected corpuscles in that particular case.

The experiments were made both with defibrinated and with entire blood. The duration of the increase after the injection of entire blood was:—In two experiments 26 days, in one 21 days, in one 19 days, and in one 14 days; average life duration being thus 21 days. With defibrinated blood the time varied from 14 to 21 days, or an average of $17\frac{1}{2}$ days.

The *longest* duration of life of transfused blood corpuscles in rabbits may, therefore, be taken as from 2 to 4 weeks.

This applies naturally to only a few of the corpuscles injected, doubtless the youngest and, therefore, the most resistant at the time of injection. The great majority become destroyed at a much earlier period, oftentimes with great rapidity.

The quantities of blood injected were very large, varying from about 40 to 90 per cent., but after the injection of smaller quantities the return to the normal was complete in a few days (5–7). It is thus probable that the above period does not represent the *average* life duration of transplanted corpuscles. On the contrary, all the observations go to show that it is more in virtue of the large numbers injected than of any special vitality of the corpuscles, that some of them succeed in remaining so long in the circulation.

Small quantities of blood are, therefore, probably removed from the body in a few days, judging at least from the rapidity with which large numbers of corpuscles, *e.g.*, 40 per cent., are destroyed in from 14 to 21 days, *i.e.*, a destruction of blood at a rate of some 2 to 3 per cent. daily, in addition to the normal amount of blood destruction going on in the body.

This consideration is of importance, in view of the value to be attached to the operation of transfusion in man, in whom the quantities of blood transfusible are relatively so very small.

The question then arises, how far the results obtainable in rabbits are applicable to the case of other animals. Since the metabolism of the body probably varies somewhat in each different species, may it not be that the duration of life of the blood corpuscles likewise varies?

As has been seen, the results obtained in dogs and rabbits agree in a somewhat striking manner, and certainly do not lend much support to the above view. They both alike point to a period of some two to four weeks as being the longest duration of life of transfused blood corpuscles.

On the other hand, from two experiments which I made on dogs, it would almost appear as if in them the process of blood destruction were in reality more rapid than in rabbits, in one case the normal being reached on the sixth, in the other on the eighth day. The quantities of blood injected were, however, relatively very small.

The results of these experiments go to support the view previously expressed, that the duration of life of transfused corpuscles is dependent more on the activity of the blood-destroying organs, than on the vitality of the blood corpuscles themselves. An excess of blood corpuscles is not tolerated by the organism for any length of time. Hence it is more natural to assume that the period required for the destruction of the injected corpuscles is shorter than that of the normal duration of life of the red corpuscles, than to assume the reverse, viz., that transfused corpuscles are capable of living longer in the circulation than the animal's own blood corpuscles.

Such are the results obtainable by transfusion without foregoing depletion. Although, as already indicated, they are more to be relied on than those obtained by transfusion after depletion, some very interesting results are still obtainable by the latter method. Attention has not before been drawn to these in this connection.

Von Ott found in experiments on dogs, that after injection of an equal quantity of $\frac{3}{4}$ per cent. common salt solution in place of the blood previously withdrawn ($\frac{1}{2}$ to $\frac{2}{3}$ of its total quantity), the number of red corpuscles remaining in the blood reached their minimum, not on the day of injection, but two or three days later; and from this time onwards a steady and continuous rise took place, reaching the normal from the 16th to the 24th day after the operation.

If blood serum instead of salt solution were injected, the result was the same, viz., the normal was reached in from 17 to 24 days.

In other words, the blood behaved as if no fluid at all had been injected; for Hunerfäuth had previously shown that under such circumstances, viz., after simple loss of blood, the return to the normal was not complete till the 19th to the 23rd day, and Lyon had similarly found that the time required varied from 19 to 25 days.

The time required, therefore, *for the blood to return to the normal after bleeding*, viz.,

16–24 days (Von Ott),
19–23 days (Hunerfäuth),
19–25 days (Lyon),—

is almost exactly the same as that required *for the removal of excess of blood corpuscles*, viz.,—

14–21 days (Quincke),
14–21 days (Worm-Müller),
14–26 days (myself).

This similarity in the results is probably more than a mere coincidence, and can only be explained by assuming that after loss of blood the return to the normal is effected, partly by an increased formation, but mainly through a diminished destruction of blood corpuscles; and the time taken for complete restoration probably thus represents approximately the average duration of life of the newly-formed red corpuscles.

But Von Ott further found, that if after withdrawing $\frac{1}{2}$ to $\frac{2}{3}$ of the blood he replaced this quantity with an equal quantity of defibrinated or entire blood obtained from another dog, the result was not, as might have been expected, that the restoration in the number of the animal's blood corpuscles was from that time complete; on the contrary, from the day of injection a gradual fall in their number occurred till a minimum was reached on the nineteenth to the twenty-second day, not on the second, as after transfusion of salt solution or serum, and from that time onward a gradual increase in their number took place, reaching the normal two to three weeks later.

If we assume, therefore, that this period of nineteen to twenty-two days represented the time taken for the destruction of the injected corpuscles, and there is no reason to assume otherwise, since after the injection of simple saline solution the minimum was reached on the second or third day, then we must conclude that this period represented the duration of life of the injected corpuscles under conditions, viz., anæmia, the very reverse of that obtaining after the production of an artificial plethora.

These results may be tabulated in the following order:—

A. *After Transfusion.*—Time taken for destruction of blood corpuscles:—

Worm-Müller, ...	14–21 days.
Quincke, ...	14–21 „
Myself, ...	14–26 „

B. *After Loss of Blood.*—Time taken for recovery :—

Hunerfäuth, ...	19–23 days.
Lyon, ...	19–25 „

After subsequent injection of

(*a*) Saline Solution :—

Von Ott, ...	16–24 days.

(*b*) Serum :—

Von Ott, ...	17–24 days.

C. *After Loss of Blood and Subsequent Transfusion of Blood.*—Time taken for destruction of transfused corpuscles :—

Von Ott, ...	19–22 days.

and for subsequent recovery—

Von Ott, ...	2–3 weeks.

The evidence thus obtained in so many different ways all agrees in pointing to a period of some three or four weeks as being the longest duration of life of transfused blood corpuscles.

It has already been seen that the probabilities are all in favour of this life-duration being shorter, rather than longer, than that of the normal red blood corpuscles, so much so at least as to justify the assumption, that this period of time represents approximately the average duration of the life of red blood corpuscles in the rabbit, the dog, and presumably also in man.

Monday, 5th July 1886.

The Hon. LORD MACLAREN, Vice-President, in the Chair.

The following Communications were read :—

1. The Electric Resistance of Nickel at High Temperatures. By Professor C. G. Knott.

2. Effect of External Forces on a System of Colliding Spheres. By Professor Tait.

3. Notes on the Characters and Mode of Formation of the Coral Reefs of the Solomon Islands, being the Results of Observations made in 1882–84, by H. B. Guppy, M.B., F.G.S., during the Surveying Cruise of H.M.S. "Lark."

I will commence my paper with a brief description of the typical characters of a reef in this region, referring particularly to the distribution of the corals. There would appear to be a large number of new specific forms among the reef-corals of these islands, whether hydroid or actinoid. Out of nearly seventy species that I sent to the British Museum, almost a quarter are new or undescribed;* and there is every probability that similar success will fall to the lot of other collectors in these seas. There is yet much to be learned of the fauna of the deeper parts of the reef-coral zone; and patient dredging will doubtless yield fruitful results. Here, not improbably, will be found the corals of deep-sea genera and the *Rhynconella* that I discovered in an upraised barrier-reef in the Shortland Islands.† Having only a small canoe, I was not able to dredge in these depths; but I may remark, as a good omen for others, that, when sounding off a reef on one occasion, I brought up from a depth of 14 fathoms a new and very distinct species of *Distichopora* (*D. ochracea*), which is described and figured by Mr J. J. Quelch in the *Annals and Magazine of Natural History* for July 1885.

In describing a typical reef, I will begin with the reef-flat. This portion of a reef is generally some 500 or 600 yards across. Its surface, which is for the most part strewn with sand, is covered at low tide by a depth of water of from a few inches to a foot, with here and there a projecting block of dead coral and an exposed bank of sand. Living coral is comparatively scarce on the reef-

* Owing to ill-health, Mr Stuart Ridley has not hitherto been able to proceed with the description of the new species. I am, however, greatly indebted to him for a preparatory list of the collection. A probably new genus is represented by one of the specimens. I sent to the Australian Museum at Sydney a collection of large specimens, which probably contains additional new species.

† *Vide* my paper on the Calcareous Formations of this Group, *Trans. Edin. Roy. Soc.*, vol. xxxii. part 3.

flat; but every now and then occurs a bed of *Madrepora* having the living tips of its branches bared by the retreating tide. Small nobs and bosses of *Porites** (*P. tenuis*, V., and *gaimardi*, E. & H.) lie loose on the sand. Tufts of that fragile coral, *Seriatopora pacifica* (Br.), are to be occasionally seen. Numerous molluscs, annelids, and echinoids find a home in the blocks of partially dead massive corals. Holothurians, star-fishes, and sea-urchins lie in numbers on the sand; while those singular algæ, *Halimeda opuntia* and *Caulerpa* sp., grow on different parts of the flat.

I now come to the description of the weather margin of a reef in these islands. Traversing a surface formed of loose fragments of dead corals, aptly compared with a bed of clinkers, one stands within the wash of the breakers, which even in the calmest weather hurl themselves with apparently irresistible fury against the reef. A gradual slope of comparatively bare rock, furrowed by fissures or channels and descending to a depth of 4 or 5 fathoms, receives the wash of the breakers.† With the exception of a tiny clump of a *Pocillopora* or a *Stylophora*, or a large dome-shaped mass of a *Meandrina* or a *Cœloria*, that may be occasionally exposed during the recoil of the waves, this sloping surface is largely bare of living coral. It is only in the fissures which traverse the slope that the corals may be truly said to thrive. Here the *Stylophora* (sp. *mordax*, D.) and the *Pocillopora* ‡ that were just mentioned, attain to some size. Here also flourish small masses of a *Porites*, and a *Cœloria*, an encrusting *Montipora*, compressed tufts of *Madrepora appressa* (D., var.), and a bossy *Madrepora* hitherto undescribed. As I have already indicated, the large massive corals are only occasionally to be seen in the wash of the breakers. They prefer the less accessible part of the reef, beyond the first line of rollers. In truth, it may be generally stated that corals do not thrive in the break of the trade-swell in these regions. They are only to be found in luxuriance on the slopes of the declivity that is usually situated in depths between 5 and 15 fathoms, a declivity which may be truly termed the growing edge of the reef. § Now and then,

* One that I found had enclosed or grown around a piece of pumice.

† *Vide* p. 883, where this gradual slope is described as a constant feature of the outer side of a reef in these seas.

‡ An undescribed species.

§ *Vide* p. 883.

however, as at low-water springs, some large block is torn off by the rollers and cast upon the reef: it is at these unusually low conditions of the tide, especially when they follow upon a succession of gales, that the greatest destruction is effected on the weather slope. There is, for instance, a very stout species of *Pocillopora* that seems to flourish just beyond the ordinary position of the first line of breakers. When, however, at low-water springs the seas are unusually heavy, fragments of its large branches are broken off and thrown up on the flat. The two algæ, *Halimeda opuntia* and a species of *Caulerpa*, are often attached to the rocks in the wash of the surf, and *Nulliporæ* partially encrust the surface; but the last mentioned are of no thickness, and never form those raised margins described by Mr Darwin in the case of Keeling Atoll and of other reefs.

The foregoing remarks refer to such reefs as receive the brunt of the trade-swell. There are other reefs, however, such as the barrier-reef of Choiseul Bay, which are placed in more protected situations, where they are not exposed to such heavy rollers. Here the corals living in the wash of the breakers are more numerous and in greater variety. In addition to the corals above mentioned, there are to be found here a gamboge-coloured *Porites* (*P. parvistella*, Quelch), growing in flattened nobs, together with small masses of that singular-looking coral *Hydnophora microcona* (L.). *Madreporæ*, such as usually prefer the quieter waters of the lagoon, here attempt to flourish; but they are to be frequently observed broken off at their base of attachment. There may be also noticed, growing in the wash of the rollers, the vertical plates of the hydrozoan corals, *Heliopora cœrulea** and *Millepora platyphylla*, Ehr.)†

On the lee sides of small coral islands, where they are protected to a great extent from the swell, the massive and branching corals coexist in great profusion. Here, on account of the absence of the heavy rollers, they do not form a continuous reef-flat, but are

* Mr S. Ridley informs me that there are two apparently distinct species in my collection, one being probably new.

† The Stylasteridæ, which Professor Mosely has placed with the other hydrozoan corals in the sub-order Hydrocorallinæ, did not frequently come under my notice among the reefs of these islands, and then only as small specimens.

gathered together in irregular patches or masses, that sometimes rise with wall-like sides from depths of 12 or 15 feet of water. Such patches are covered with a luxuriant growth of coral, and there is little or nothing of those sandy flats which I have described in the case of reefs that are exposed to the trade-swell. The following description of a particular locality may be taken as fairly typical.

In the shallow depths of a fathom and under at low tide, there flourished both massive and branching species of *Porites* (*P. tenuis*, V., and *P. lævis*, D.), three species of *Millepora* (*M. intricata*, E. & H., and *gonagra*, E. & H., together with an unnamed flat branching species), the singular *Rhodorrhœa** *lagrenœi* (E. & H.), and *Seriatopora pacifica* (Br.) and *hystrix* (D.). Less frequent, though still abundant in this shallow water, were the massive corals, *Cœloria dœdalea* (E. & S.), and another unnamed species of the same genus; *Favia rotulosa* (E. & S.), with another species also unidentified; *Solenastrœa sarcinula* (E. & H.); and undescribed species of *Goniastrœa* and *Rhodorrhœa*. With these were associated *Mussa multilobata* (D.), and other species of the same genus, *Stylophora palmata* (Bl.), and different forms of *Pocillopora* and *Madrepora*. *Rhodorrhœa lagrenœi* occurred in level tufted beds of a dark-brown colour, which were traversed by single vertical plates of the undescribed species of *Millepora*, above referred to. I frequently observed the association of these two corals in this region. In depths of from 2 to 8 fathoms, there existed thickets of the branching *Porites* (*P. lævis*, D.), which also lived, but in less profusion, in the shallower water, being associated in depths of from 2 to 3 fathoms, with extensive beds of *Rhodorrhœa lagrenœi*. The stout columns of *Isopora* (*Madrepora*) *labrosa* (D.) were occasionally to be seen at different depths. Now and then a huge castellated pile of a massive *Porites* rose up from a depth of 12 or 15 feet to within half a fathom of the surface. Beds of Alcyonarians encrusting the dead corals were interspersed amongst the living corals. A species of *Anthelia*† occurred most frequently, its stoloniferous base often investing the dead branches of *Porites lævis*. A pretty *Xenia* was less common, being attached to the same species of *Porites*, and often to the

* Sometimes written Rhodaræa.

† From a depth of 13½ fathoms I brought up a living fragment of this *Anthelia*.

extremity of a branch. In addition there were mat-like growths of other Alcyonarians, resembling, but on a much more extensive scale, our common British *Alcyonium.*

It will have been observed in the foregoing description that thickets of *Porites lœvis* principally usurped the depths between 2 and 8 fathoms. Such, however, was not my usual experience in these localities, these depths on the lee sides of islands being generally occupied by arborescent and other branching *Madreporæ.* In Selwyn Bay, on the lee side of Ugi Islands, these *Madreporæ* throve in the shallower portion of the reef-coral zone in depths less than 10 fathoms; whilst *Seriatoporæ* * seemed to prefer the deeper parts of the zone in depths of 20 fathoms. This accords with Mr Darwin's experience on the leeward side of Mauritius.† It is manifest, however, that we have little or no acquaintance with the causes that favour or prevent the growth of particular species of corals in any one locality; and thus we often meet with unexpected facts. For instance, the stout coral, *Isopora labrosa* (D.) is able to adapt itself to any situation, whether on the weather slopes of reefs in depths beyond 5 fathoms, or on the dark muddy bottom of mangrove-skirted channels, or in the clearer water of lagoons. I might mention several other examples of the same kind amongst certain species of *Porites* and *Millepora.* A species of *Madrepora*,‡ that commonly came up in my soundings from depths of 8 to 12 fathoms on the weather slopes of reefs, appeared in one locality to flourish at similar depths on the lee or protected side of an island.§

I come now to refer to the corals that grow in the interior of lagoons and lagoon-channels. A large extent is occupied by sand and chalky mud; but in the shallower portions, and especially in those situations which are near the breaks in the reef, corals thrive in great profusion. These quiet waters are more particularly the home of the foliaceous and branching corals. Amongst the former may be observed *Turbinaria frondens* (D.), *Merulina ampliata* (E. & S.), *Oxypora contorta* (Quelch), and species of *Pachyseris*,

* Probably a new species, as Mr Ridley informs me.

† *Coral Reefs*, 1842, p. 81.

‡ This coral, according to Mr Quelch, closely resembles *M. cerealis* of the West Indies. Its range of depth appears to be 2 to 13 fathoms.

§ For some further particulars of my coral-soundings, *vide* a short paper in the *Annals and Magazine of Natural History*, June 1884.

Montipora, and *Echinopora*. Amongst the latter occur numerous *Madreporæ*, such as *M. hyacinthus* (D.), *M. effusa* (D.), *M. appressa* (D.), and several other species. *Pocilloporæ*, such as *P. pulchella* (Br.) and *P. acuta* (L.), here thrive; also *Seriatoporæ* (*hystrix*, D., and *pacifica*, Br.); *Milleporæ* (*intricata*, E. & H., and *gonagra*, E. & H.), and *Stylophora palmata* (Bl.). The Fungidæ are well represented by several species of *Fungia* and *Ctenactis*, together with *Halomitra tiara* (V.), and a species of *Podabacia* not yet determined. The massive corals here found are species of *Porites* usually possessing flat dead summits, and often 8 to 10 feet across; species of *Symphyllia*, *Cœloria*, and *Rhodorrhœa;* and *Favia rotulosa* (E. & S.). Amongst other of the common corals found in lagoons and lagoon-channels occur *Heliopora cœrulea*,* and *Isopora labrosa* (D.). The *Heliopora* prefers situations in the vicinity of openings in the reef, and all places where it can be exposed to a plentiful supply of sea-water. This hydroid coral, together with a massive species of *Rhodorrhœa*, with which it is associated, covers a considerable portion of the bottom of a small boat-harbour in Oima Atoll. *Isopora labrosa* often attaches itself to and partly invests *Millepora gonagra* (E. & H.). Alcyonarians also flourish in the quiet waters of the lagoon; amongst them are species of *Alcyonium*, *Xenia*, and *Anthelia*. The *Xenia* may occur in extensive beds encrusting and concealing the unsightly patches of the dead branching corals. A huge empty *Tridacna* shell, which was covered on the outer surfaces of its valves with this pretty Alcyonarian, formed quite a picture in Oima Atoll. Occasional masses of the Alcyonarian coral, *Tubipora* sp., are also to be observed. Amongst the algæ that thrive in lagoons, is an edible species of *Caulerpa*, which is distinct from the non-edible species that grows on the reef-flat and in the wash of the surf (*vide* p. 859).

The observing naturalist will find abundant material for the study of the complex relations that exist between the multitudes of creatures that frequent coral reefs. The protective colouring of the small crabs that live among the branching corals often attracted my attention. I recall in particular the instance of a small crab that finds its home amongst the branches of a *Pocillopora*. The light purple colour of its carapace corresponds with the hue of the

* *Vide* footnote on p. 859.

coral at the base of the branches, where it lives; whilst the light-red colour of the big claws, as they are held up in their usual attitude, similarly imitates the colour of the branches themselves. To make the guise more complete, both carapace and claws possess rude hexagonal markings which correspond exactly both in size and appearance with the polyp-cells of the coral. Another species of crab, that climbs about the blue-tipped branches of a *Madrepora*, has the points of its pincer-claws similarly coloured. It is interesting to note that these two crabs are adapted to live each on its own species of coral. Had I caused them to exchange their homes, their borrowed hues and markings would have at once made them conspicuous objects for their enemies.

The Inter-Tidal Exposure of Living Corals.—A short exposure to the air is generally stated to be fatal to living corals. The statement of Mr Beete Jukes that an exposure of two or three hours to the air, sun, (and rain), will not kill many of the coral polyps as long as they are left in their position of growth and thus retain their moisture, has not often been quoted, but it nevertheless accords with my experience.*

Different kinds of reef-corals, however, bear different degrees of inter-tidal exposure. The minimum amount is to be seen in the case of many of the massive and branching species, which at low tide, and especially at "low water springs," are bared for a few seconds twice or three times in the minute, as the larger waves roll past them. To this group belong species of *Porites*, *Meandrina*, *Seriatopora* (*hystrix*, D., and *pacifica* Br.), and *Millepora*, &c. Then, there are corals which can sustain exposure to the extent of from 5 to 10 inches for an hour with impunity, as long as they are washed over by a wave every three or four minutes. Such corals are *Heliopora cœrulea*, *Millepora platyphylla* (Ehr.), and *intricata* (E. & H.), *Stylophora mordax* (D.), *Pocillopora* sp., and several species of *Madrepora*. Lastly, we come to the corals that can withstand continuous exposure for from one to two hours without injury. I have seen the nobs of *Porites tenuis* (V.), which are so common on the reef-flats, uncovered for nearly three-quarters of an hour. The living margin of a boss of a *Symphyllia* I have seen exposed to the extent of 6 inches for about an hour. Some of the *Madreporœ* are

* *Voyage of H.M.S. Fly*, 1847, vol. i. p. 119.

particularly hardy in this respect. At "low water springs" the extensive beds of a species of *Madrepora*, that thrives on reef-flats, are uncovered to the extent of 5 or 6 inches for an hour and a half; and other species, such as *M. hyacinthus* (D.), will bear exposure equally well. Of all the corals in these islands, however, those belonging to the genus *Cœloria* appear to be best able to withstand prolonged exposure. I have seen living blocks of these massive corals bare to the extent of from 12 to 18 inches at the lowest tides. A lump of *Cœloria dædalea* (E. & S.), that I observed on one reef, had its upper surface exposed for almost two hours; and I have frequently noticed the living margin of another species of the same genus to be uncovered to the extent of several inches for about an hour. On one occasion, five hours after I had taken two lumps of this last species out of the water, I placed them with some other corals in a closed perforated tin that was kept in the sea, a foot or two below the surface, for a couple of days. On opening the tin, I found all the specimens of coral decomposed, with the exception of one of the lumps of *Cœloria*, which was quite fresh and apparently still alive.

The soft beds of Alcyonarians are sometimes completely exposed for 5 or 6 inches at the lowest tides. The *Xeniæ*, however, I rarely, if ever, saw bared. Many other organisms living on the reefs are able to withstand inter-tidal exposure. Thus, in Oima Atoll I saw tufts of Sertularians and the common blue star-fish (*Ophidiaster ?*) uncovered at "low water springs." At the same time two of the large *Tridacnæ* (*T. gigas*), that lay on their hinge-borders upon the sand, were partially exposed. One of them was half out of the water, and must have been uncovered for at least an hour.

Coral Reefs and Shoals.—The earliest condition of the coral reefs in this group is to be found in that of the numerous detached submerged reefs or shoals lying below the limit of the constructive power* of the breakers, which in the sheltered waters between the larger islands rise up to within 4 or 5 fathoms from the surface, and in the more open waters, where they are exposed to the trade-swell, are covered by a depth of from 7 to 10 fathoms.

* By this expression I mean that the reefs had not reached that level at which the breakers would be able to tear off and heap up fragments of the corals.

Lark Shoal, a submerged reef which rises between the islands of Ulaua and the Three Sisters from a depth of 200 fathoms, is covered by a minimum depth of 7 fathoms. It is exposed to the full force of the trade-swell, and its position is often marked by a dangerous tide-rip. As limited by the 20 fathom line, this shoal measures 1 by $1\frac{1}{2}$ miles. The numerous soundings obtained by Lieut. Oldham and the officers of the "Lark" gave no indication of a central hollow on its surface. On the contrary, they showed that the shoal possesses a comparatively level summit covered by from 7 to 10 fathoms of water. From the ship's side the dome-shaped massive corals could be discerned; and the paucity of branching corals was evidenced by the absence of fragments in the armings of the lead. In most of the soundings the armings were clean; but occasionally portions of the joints of the calcareous alga, *Halimeda opuntia*, together with coral sand and gravel, were brought up. Out of twenty casts taken by myself on both sides of the ship in a depth of 9 fathoms, all but three showed clean impressions, and in five of them the nature of the coral could be recognised. Two similar shoals, lying to the south of Eddystone Island, are described on page 876. Other detached coral patches, covered by from 5 to 10 fathoms of water, lie close off the south coast of St Christoval (*vide* page 870).

The numerous submerged reefs of Bougainville Strait occur just within the edge of the submarine platform, or submerged extension of Bougainville Island, which is delineated by the 100 fathom line in the recent Admiralty chart. They are generally covered by from 4 to 8 fathoms of water, and have very level surfaces, over one of which the ship dragged her anchor without a check for about half a mile. On one of them I brought up with a grapnel from a depth of 8 fathoms a portion of a *Pocillopora* with stout expanded branches, which appeared to be the prevailing coral. On another I found *Psammocora planipora* (E. & H.) in considerable quantity in 6 fathoms, this being the only occasion on which I found this coral. From the same depth of 6 fathoms on this shoal, I brought up two masses of coral rock, of which the largest, a little more than a cubic foot in size, was a fragment of *Porites tenuis* (V.), for the most part dead, and covered by *Nulliporæ*, and extensively bored by molluscs and annelids. Small specimens of other living corals were attached to it, such as *Pocillopora pulchella* (Br.), an encrusting *Montipora*, and *Orbicella Laperouseana* (var).* The smaller piece of rock showed no coral structure to the eye, and was much honeycombed: it was incrusted with *Nulliporæ* and *Polyzoa.* Another of the submerged reefs, covered by from 6 to 7 fathoms of water, was marked by streaks and patches of calcareous sand, and possessed apparently but little living coral. I obtained here branches of a *Madrepora*, which commonly occurred on the weather slopes of reefs in depths of from 8 to 12 fathoms (*vide* p. 861).

With reference to the character of the bottom in the deeper parts of Bougainville Strait, I should remark that in depths of from 20 to 40 fathoms calcareous sand and gravel usually occur. These materials are largely composed of the tests of *Orbitolites*, and the joints of the calcareous alga *Halimeda opuntia.*† Small unattached corals of the genus *Heteropsammia* here flourish.‡ Fragments of *Nulliporæ* were frequently brought up from all depths down to 86 fathoms, where Lieut. Leeper obtained a small nob apparently alive. The foraminifer, *Polytrema rubra*, was occasionally found attached to these fragments.

In the sheltered waters of this strait there is no intermediate condition between the submerged reefs covered by 4 to 8 fathoms of water and those which are marked on the surface by a reef-flat with its accompanying islet, or by a sand-key. From the manner in which the channel was studded with submerged or sunken reefs, it was at first thought that the survey would be attended with some risk to the ship; but Lieut. Oldham subsequently found that, on account of her small draught, H.M.S. "Lark" could sail with safety over any of the reefs that were not marked at the surface by reef-flats or sand-keys. When I had examined these submerged reefs, I was led by their characters to conclude that they had reached the limit of their upward growth, and that they have since been extending laterally, so as to form long and narrow platforms, some of which are more than 10 miles in length, and are in fact submerged barrier-

* This was the only occasion on which I obtained this *Orbicella.* Numerous other organisms were found in or upon this mass of rock, such as Ophiuroids, a *Comatula*, *Olivæ*, *Arcæ*, a small eel-like fish, &c.

† This alga grows on reef-flats and in the wash of the surf.

‡ More than one species of *Heteropsammia* live in these depths of from 20 to 40 fathoms, *H. multilobata* being common. The majority, if not all, were characterised by the presence of the *Sipunculus* (*Aspidosiphon*).

reefs (*vide* p. 877. That they have remained at much the same depth from the surface for a considerable number of years, is shown by the circumstance that in 1768 a shoal covered by 5 fathoms was found near the middle of the strait by the "Etoile," one of Bougainville's vessels.* During the 116 years that have elapsed between the visit of the French navigator and the recent survey of this strait by Lieut. Oldham, neither the upward growth of the coral nor any movement of elevation have been sufficient to raise the surface of this shoal within the limit of constructive breaker-action; and in consequence it is still submerged.

It is certainly a remarkable circumstance that in this group we found no detached sunken reefs which would render the navigation of these seas dangerous for a vessel of light draught (9 or 10 feet). All detached reefs that had not reached the surface were below the limit of constructive breaker-action, their depth varying between 4 and 10 fathoms, according to the sheltered or exposed character of their situation. It therefore appeared to me that a movement of elevation was first necessary to bring these submerged reefs within the power of the breakers, since the upward growth of the corals was arrested a little below their limit of constructive action.

We may thus find a partial explanation of the submerged condition of the leeward sides of many atolls, and of the total submergence of a few other reefs belonging to the same class, *in the inability of detached submerged reefs to raise themselves within the constructive power of the breakers without the assistance of a movement of elevation.* It may appear somewhat bold to suggest that atolls owe their appearance at the surface to such a movement; but it is a singular circumstance that I found this to be the case with Oima Atoll (*vide* p. 879); and thisis the very movement which Professor Dana and Mr Couthouy have shown to be in operation amongst the numerous atolls of the Low Archipelago, many of which have experienced elevations varying between 2 or 3 and 250 feet.† In the Fiji and Pelew Groups, upraised reefs having the characters of atolls coexist with reefs of the same class that have been formed at the present sea-level. However this suggestion may apply to

* *Voyage autour du Monde*, 2nd edit., Paris, 1772, tome ii. p. 183.

† Dana's *Corals and Coral Islands*, and Couthouy's *Remarks on Coral Formation*, &c.

atolls, it readily accounts for the existence of the numerous submerged reefs in the Solomon Group, which lie at a constant distance below the surface. Another circumstance favouring the view that detached sunken reefs cannot raise themselves to within the constructive power of the breakers is to be found in the fact that on the weather sides of reefs in this group corals do not thrive in the wash of the breakers; there is here a gradual slope descending to a depth of 4 or 5 fathoms, which is largely bare of living coral (*vide* p. 858).

The formation of the reef-flat is worthy of a passing remark. I have often observed that on the lee sides of islands, especially of those of small size, the corals grew in irregular patches at the sea-border, and did not form a reef-flat such as existed on the weather side which was exposed to the trade-swell. Professor Semper would apparently attribute the absence of the reef-flat on the lee side of an island to the circumstance of the corals not being exposed to strong impinging currents; but in these islands, however, it is evidently due to the corals not being subjected to the action of the breakers.

I have now come to the description of the reefs which have reached the surface. The three principal classes are to be found in this region, but of these the fringing and barrier-reefs are more commonly distributed, whilst the atolls are comparatively few in number and of small size. A line of barrier-reef, probably not much under 60 miles in length, and bearing innumerable islets on its surface, fronts the east coasts of the islands of New Georgia at a distance of from 1 to 3 miles from the shore. Extensive reefs of the same class, having a broad deep-water channel inside them, lie off the north side of the large island of Isabel, and off the south coast of Choiseul. Similar reefs of smaller extent skirt the west end of Guadalcanar; and existing and elevated barrier-reefs occur in Bougainville Strait. Of this class of reef I was only able to examine those of the last locality: they will be subsequently referred to in my general description of the reefs of this strait.

I will now proceed with the description of the reefs of the islands we visited.*

St Christoval.—My observations were for the most part restricted to the north side of this large and mountainous island. The reefs

* For the description of the elevated reefs and their foundations, I must refer the reader to my paper in the *Trans. Edin. Roy. Soc.*, vol. xxxii. part 3.

that skirt at intervals this coast belong to the fringing class. They are marked here and there by wooded islets, and in some parts they have experienced an upheaval of a few feet. They attain their greatest breadth of nearly a mile in the vicinity of Cape Surville and Star Harbour, but usually their breadth does not exceed a quarter of a mile. The 100 fathom line lies generally about 1200 yards from the edge of the reef-flat, and from this fact the angle of the submarine slope may be computed to be about 10 degrees. Where the land rises precipitously from the sea, as on the east side of Cape Keibeck, there are scarcely any reefs. They are absent usually from the shores of the wide bays which receive the waters of the large streams: here the beaches are of dark sand, which is composed partly of volcanic and partly of calcareous materials.

The north coast of the peninsula included between Star Harbour and Cape Surville is low, and fringed with mangroves; and it is often a difficult matter to distinguish where the reef ends and the land-surface begins, since the mangroves push forward their lines on the flat whilst it is yet covered by the sea at high water. By the agency of these trees, unassisted by any elevation, much land is reclaimed from the waves. One may walk for a distance of 100 yards from the margin of the vegetation on a recently formed wooded tract raised but a couple feet and less above the sea-level, which is composed almost entirely of coarse calcareous sand mixed with fragments of corals and shells belonging to familiar reef species of the genera *Cypræa*, *Strombus*, *Turbo*, *Trochus*, *Tellina*, *Tapes*, *Hemicardium*, *Cytherea*, &c. These shells have lost most of their colour and have an ancient appearance. A species of the Auriculidæ, *Pythia scarabæus* (Lin.), lives commonly on these recently formed tracts throughout these islands, and its empty shells occur mingled with those of the marine genera just mentioned. Pumice pebbles may usually be traced amongst the trees for some 15 or 20 paces, and in some places they are very numerous.

The north coast of St Christoval, to the west of Cape Keibeck, is often bordered by a recently elevated flat of coral rock, which, at the sea margin where it has been worn back by the waves into low cliffs, is raised from 4 to 6 feet above the high water level. These flats rise gradually, as one proceeds inland among the trees, to a height of from 12 to 15 feet. They are frequently traversed by deep fissures and narrow gulleys, running at right angles to the coast, which are being constantly widened by the action of the sea, and are often of considerable length. Frequently, when following a coast path, I have come unexpectedly, within the margin of the trees, upon the termination of one of these narrow gulleys, at the bottom of which, 10 or 12 feet below me, the water was rushing to and fro with each advancing and receding wave. The coral rock of these flats is much honeycombed on the surface, and its sharp cutting edges soon destroy a stout pair of boots. It is extensively undermined by the sea, and, as might be expected, blow-holes are of common occurrence. They vary in size from the mere bubbling of air and water through a small hole in the rock to the grand spout which sends its foam 20 feet into the air. On this coast of St Christoval I have had my helmet blown off my head, while standing without knowing it over one of these holes. They are of frequent occurrence on the coral limestone coasts of these islands.

Besides the solvent action of rain on the elevated coral flats of the coast, numerous other agencies assist in the removal of the rock. On the raised coral flats of the north coasts of St Christoval, *Nerita marmorata* (Homb. & Jacq.) thrives in numbers just above the high water level. The calcareous excretions of these molluscs were to be observed in nearly every hole and crevice of the rock in this situation; and it was evident to me that in this manner they increased in size the cavities into which they crept.

On the south side of St Christoval I only became acquainted with the coast to the westward of the entrance of Makira Harbour. Here the sea border is of a different character. Lofty hills rise direct from the sea to a height of from 1000 to 1500 feet, and tall cliffs of ancient volcanic rocks start up perpendicularly from the deep water at their base. Lines of shore-reefs and elevated reef-flats, such as are found on the north side of the island, are not to be found here. In their place there are off-lying isolated coral patches lying from 5 to 10 fathoms below the surface, and rising with wall-like sides from deep water. On p. 867 I have given an explanation of the submerged condition of these and other similar sunken reefs.

The Three Sisters.—Off the north coast of St Christoval lie the three small islands thus named. They may be briefly described as coral islands which commenced their growth as submerged flat-topped reefs resembling in their character the present condition of the neighbouring Lark Shoal. These reefs were subsequently elevated about 70 feet above the sea, and the islands have since assumed an atoll structure. From their arrangement and from the depth of water separating them from the adjacent islands,* it may be inferred that these coral islands are based on three submerged peaks which lie at some unknown distance below the surface. They are included within the same 100 fathom line. On the weather or eastern sides the submarine slope is gradual for the first few fathoms; it then descends to the depth of 100 fathoms at an angle rather in excess of 20°. On the lee sides the submarine slope descends usually at a smaller angle.

Malaupaina, the southernmost of these islands, is about 3½ miles in length and rather over half a mile in breadth. Its lee or western half, which is mostly occupied by mangrove swamps that are overflown by the sea at high water, contains two lagoons opening by narrow entrances on the west coast. A low bank, raised 2 to 3 feet above the high tide level and from 20 to 100 paces in width, intervenes between the sea and the mangrove swamps within, and forms the western margin of the island: it is composed, sometimes of sand, at other times of shells and loose coral fragments, and occasionally of coral rock; whilst its surface supports such trees as the casuarine, pandanus, and cocoa-nut palm. The weather or eastern portion of the island may be described as a broad wooded tract elevated between 10 and 15 feet above the sea. Between the tide marks on this coast, there is an extensive flat of coral rock traversed by deep fissures and narrow gulleys, running at right angles to the trend of the coast, in which rushes to and fro the wash of each roller that breaks on the edge of the reef. Situated towards the interior of the island, and separated by the northern lagoon, are two low hills of coral limestone,† the level summits of which are elevated from 50 to 70 feet above the sea. Of the two lagoons, the southern is the deepest: it has a depth of 9 fathoms, and is shut in

* A cast of 400 fathoms to the west and another of 260 to the north-east failed to reach the bottom.

† Hand specimens from one of these hills were in part chalky. *Vide* my paper on the "Calcareous Formations," *Trans. Edin. Roy. Soc.*, vol. xxxii. part 3, pp. 563, 575.

by a bar over which at low water neaps there is less than a fathom of water; in the northern lagoon there is only a depth of 3 or 4 feet at low tide. Outside the entrance of each lagoon, there is a second lagoon-like basin of more recent origin: the southern of these basins has a depth of from 20 to 26 fathoms, and affords a very sheltered anchorage; while the northern is shallower, and more obstructed. Both the inner lagoons are lined by mangroves, and they communicate with the extensive mangrove swamps in their vicinity. Some of these swamps, when exposed at low water, present extensive tracts of a white chalk-like mud dotted here and there with clumps of mangroves. On the surface lie shells and coral fragments, and large masses of *Meandrina* and *Cœloria* occur as they grew, their summits being at present raised 1 to 2 feet above high water.

In remarking on the history of the formation of this island, I will first refer to its condition at high tide. If a bird's-eye view could then be obtained, the larger portion of its surface would present the appearance of an expanse of water in which, were it not for the mangroves, the eye would be unable to distinguish between the swamps temporarily overflown by the sea and the permanent inner lagoons. The two low hills would stand out from the water nearly surrounding them as imperfect islands; and such a panoramic view would carry us back to the time when they existed as two submerged reefs lying, like Lark Shoal, a few fathoms beneath the surface. Then ensued a period of upheaval, during the latter part of which the permanent land surface was formed on the eastern or weather side, and the island assumed the character of a double atoll. After a pause in this movement, there was a more modern elevation of a few feet, since which the outer lagoons have been formed, and the inner lagoons have been gradually filling up. The interesting point in connection with the formation of this island is one which is of importance in connection with the early history of small atolls;* for it is evident that it commenced as two flat-topped submerged reefs, and that the atoll form has been assumed since these reefs have been upheaved. In the neighbouring Lark Shoal we have the first stage in the production of an atoll; but the characteristic form, as I hold, will not be assumed until it has

* Atolls only a mile or less in width.

reached the surface. Further on in this paper I shall show that large atolls probably assume their characteristic form below the surface, as pointed out by Mr Murray.

I was not able to visit the other two islands. They have, however, the same general appearance and about the same elevation. Lieut. Malan, who coasted round both of them and landed on Malaulalla, tells me that they are counterparts of Malaupaina, the southern island which I have above described at length. In Malaulalla he found a lagoon shut off apparently from the sea, but he did not notice one in the northern island of Alita. On the north-east coast of the island last mentioned, he observed a line of cliff of coral limestone 30 to 40 feet in height.

Santa Anna.—The shore-reefs, which skirt the coast of the upraised atoll of Santa Anna, vary in width from 150 to 600 yards, according to the steepness of the land; and the average submarine slope to the 100 fathom line ranges from 6 degrees to rather over 20 degrees. The reef-flats between the tidal levels are traversed by fissures 2 to 5 feet broad, which extend far beyond the breakers, and may usually be traced from the surface by the white sand that has collected in them. On the west coast the shore-reefs enclose a remarkable circular lagoon, 700 to 800 yards in width, which has a depth of 16 to 17 fathoms, and affords a snug anchorage for ships. It is known as Port Mary.

On the south shore of this lagoon, a dark red compact rock has been exposed at the bottom of some holes, a foot in depth, which have been excavated for water by the natives in the rock of the reef-flat. The same rock occurs as embedded masses in the surface of the reef-flat on the east coast, where it contains enclosures of coral rock and other débris. I also found it lining the sides of a vertical fissure in a coral limestone cliff, where it was from 1 to 2 inches thick. This rock effervesces with an acid; but, as I learn from Mr Murray, it is mainly composed of a red ochreous material, probably deposited from water that has found its way through fissures and cavities in the coral limestone. Its exposure on the surface of the reef-flat (near its inner edge) may probably be due to the solvent action of the sea water which overflows the flat towards high tide. The circumstance of its lining the sides of a fissure in a coral limestone cliff is very suggestive of its origin. Professor

Liversidge* has described a similar rock brought by Commodore Goodenough from the New Hebrides. It contained small fragments of coral and shell, which gave it the appearance of a bone breccia from a cave deposit; but the mode of its occurrence is not stated. I should add that in one locality small patches of a fibrous calcite about an inch in thickness encrusted the surface of the reef-flat near the base of the cliff.

Ugi Island.—This island is fringed by shore-reefs of varying width, which are most extensive on the north-west coast, and are absent or broken up in Selwyn Bay. Broad belts of recently formed land, strewn with coral and shells, edge the reef-flats. On the east coast, the shore-reef encloses a long narrow lagoon, a mile in length, and possessing a depth of 10 fathoms and under. In the shore-reef on the south coast there is a small circular basin or lagoon, about 100 yards across and 6 fathoms in depth, which is approached by a narrow entrance, and would make a good boat-harbour.† It is worthy of remark that this island has a rude crescentic shape, which it has only assumed during the last hundred feet or so of elevation. The small coral island of Biu, which lies about 2 miles to the northward, and is included within the same 100 fathom line, is fringed by shore-reefs. It is about 1½ miles in length, and may be briefly described as a patch of coral reef which has been upheaved about 100 feet above the sea, and is still girt by living reefs. In its central elevated portion I found a chalky coral limestone.

Rua Sura Atoll.—This small atoll, which lies 2½ miles off the north coast of Guadalcanar, has an elongated shape, and is about 3 miles in length. Three wooded islets have been formed on its south side; but the remainder of the circumference of this atoll is either just awash at low tide, or is covered by less than a fathom of water. The actual depth of the lagoon was not ascertained; its depth, however, must be considerable, since casts of as much as 37 fathoms failed to reach the bottom. The soundings taken out-

* *Vide* a paper on the Composition of some Coral Limestones, &c., from the South Sea Islands, read before the Royal Society of N.S.W., October 6, 1880.

† These "holes" in the shore-reefs are not uncommonly found in other islands of this group. They are often termed "boat-harbours," when accessible; and are usually 100 to 150 yards across, with depths of 20 fathoms and under.

side this atoll were not sufficiently numerous to enable me to estimate the angle of the submarine slope.

The largest of the three islets that have been formed on the reef is half a mile across, and rather more than a mile in length. In its interior, which is thickly wooded, the soil is made up in varying proportion of humus and calcareous sand. Numerous shells, belonging to familiar reef species, and large massive corals occur on the surface in the centre of the island and all over its area. Pumice pebbles are commonly found on the surface near the coast; and they may be often seen to largely compose the miniature cliffs of sand which have been worn back into the beach by unusually high tides. This islet is elevated in its interior some 15 or 20 feet above the sea. On its south coast occur low cliffs of coral rock, 4 to 5 feet in height, which betoken a recent elevation of a small amount. The other two islets are evidently of similar character, though of more modern formation. On the south coast of the larger islet occur a number of rounded blocks of volcanic rocks,* pebbles of which are to be found embedded in the rock of the reef-flat. The largest of these blocks must have weighed, according to its measurement, about 2 cwt.; but the majority of them were considerably less than 30 lbs. in weight. Some of them, which were raised 2 to 3 feet above high water mark, had apparently reached their present position before the last upheaval. All of them had evidently been transported by floating trees, which are very commonly met with among these islands: they were probably originally derived from the adjacent portion of Guadalcanar. I have frequently found blocks and pebbles of volcanic rocks in the roots of trees which have been thrown up on the reefs of this group. In some cases they were so firmly embedded that they could only have been set free by the final decay of the tree.

Florida Islands.—Fringing reefs, varying in width from 150 to 600 yards, skirt the coasts with which I am acquainted on the east and south sides of this sub-group. They present nothing of special interest.

Eddystone or Simbo Island.—This volcanic island originally existed as two distinct islands, which have become united by the

* Dolerites and other dense basic rocks, all much altered and sometimes schistose.

elevation of an intervening coral reef. The northern part, in which no traces of volcanic activity came under my observation, is entirely surrounded by fringing-reefs, with the exception of the north point, where the land terminates in a bold precipice. Off the east coast there is a very steep submarine slope to the 100 fathom line of from 30 to 35 degrees. In the midst of the reef on the west side there is a large hole, 18 fathoms in depth and about 150 yards across, which may mark an old crater cavity. In the southern half of the island, where the subterranean fires are not yet extinct and where many fumaroles exist, no reefs occur on the west and south coasts. On the east side, however, there is an elevated barrier-reef, which attains a height of rather under 200 feet, and is known as Simbo Islet. Off the west side of the low connecting neck, which is formed by an elevated coral reef, there is a short barrier-reef that by its protection forms the harbour. Just within its inner margin, this reef encloses a remarkable hole, 14 fathoms deep, which resembles the one on the north-west coast of the island.

Two shoals or submerged coral patches lie 1 and 2 miles to the southward of the island, rising on all sides from deep water where casts of 100 fathoms did not reach the bottom. They have level summits covered by from 5 to 10 fathoms of water; and as delineated by the 10 fathom line, they measure, each of them, about half a mile in length. In their characters they are counterparts of Lark Shoal, which is described on p. 865, and, as I hold, they have probably reached the upward limit of their growth.

Bougainville Strait.—This strait, which previous to the survey by H.M.S. "Lark" was little known, separates the two large islands of Bougainville and Choiseul, and is about 25 miles across. On examining the chart of the strait,* it will be observed that a broad submarine plateau, about 15 miles in width and covered by from 30 to 50 fathoms of water, forms the submerged extension of the east extremity of Bougainville Island. At its outer edge this plateau terminates abruptly in a steep slope of from 15 to 25 degrees, which is sharply delineated on the chart by the 100 fathom line, and descends to considerable depths. Its surface is uniformly level, but a deep hole occurs towards the middle of the strait

* I am greatly indebted to the Hydrographer, Captain W. J. L. Wharton, R.N., for an early copy of the chart of Bougainville Strait.

(outside Masamasa Island), where a depth of 80 fathoms was found; and another, in which 100 fathoms of line did not reach the bottom, lies off Cyprian Bridge Island. This plateau is connected with a similar but very much smaller submerged extension of Choiseul Island by a narrow neck rather over 2 miles in width. The submarine contour of this strait is well shown by the 100 fathom line in the chart. It will be there seen that the two large islands of Bougainville and Choiseul are connected by a submerged ridge, and that an elevation of some 350 feet would join them together.

Broken lines of barrier-reef (sometimes elevated) and elongated coral shoals covered by from 4 to 10 fathoms of water, which may be regarded as incipient barrier-reefs, mark the edge of the Bougainville plateau within a few hundred yards of the 100 fathom line. Thus, commencing to the west of the Shortland Islands, we find a broken line of barrier-reef. Following the edge of the plateau eastward, we come to the south side of the Shortland Islands, where elevated lines of barrier reefs, removed from 20 to 100 feet and more above the sea, form the coasts.* Further eastward, a broken line of barrier-reef follows the contour of the southern coasts of the island of Fauro where they approach the edge of the plateau.† Linear submerged patches of reef, covered by from 4 to 10 fathoms of water, prolong this line of barrier-reef to the eastward for a few miles, and subsequently follow the curve of the edge of the plateau as it sweeps northward to the mouth of the strait. Besides the islands already mentioned, numerous smaller islands and rocky islets of volcanic formation, which preserve in some instances their volcanic profile, rise out of the waters in the interior expanse of the plateau, and other larger islands of a similar character, such as Ovau, Oima, Masamasa, and Piedu, lie around the northern end of Fauro.‡

* In my paper on the recent Calcareous Formations, I have shown that Alu, the main island, has been formed by the upheaval of a succession of barrier-reefs that have grown outwards on a bottom of foraminiferous volcanic muds from a nucleus of volcanic rock.

† I visited several portions of this line of reef. A detailed description is, however, unnecessary.

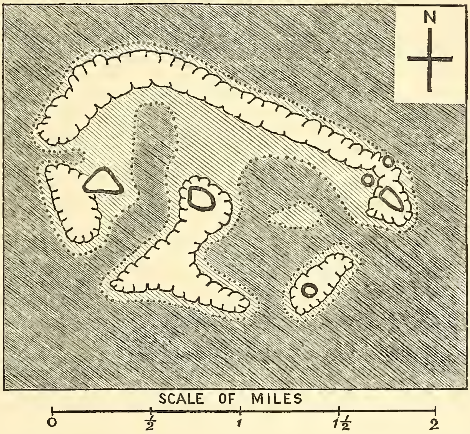
‡ The island of Fauro is of volcanic formation. The rocks composing it are mostly andesites, together with altered dolerites, diorites, quartz-felsites, dacites, &c. Similar rocks are found in the other islands and islets of the straits. No traces of activity came under my notice in any of the volcanic islands that I visited.

Corals only appear to thrive at the margin of this plateau, where they have produced the lines of barrier-reefs and submerged shoals already alluded to. Narrow shore-reefs fringe the coasts of the larger islands, but in the interior waters of the plateau corals do not flourish, and reefs are almost absent altogether from the long stretches of dark sandy beaches that form the adjacent coasts of Bougainville.

On the opposite side of this strait a broken line of barrier-reef skirts the western extremity of Choiseul, enclosing a lagoon-channel known as Choiseul Bay, 13 to 18 fathoms in depth, and from $\frac{1}{2}$ to $\frac{3}{4}$ of a mile in width, where a sheltered anchorage is afforded. On this line of barrier-reef five wooded islets have been formed. They are made, for the most part, of materials thrown up by the waves at the present sea-level; but the presence in some of the larger islets of elevated coral rock in mass affords evidence of the whole line of reef having been recently upheaved some 6 feet or more. An islet of coral limestone, which rises up in the midst of the lagoon-channel between 20 and 25 feet above the high tide level, affords testimony of previous upheaval; and the hills near the coast, composed as they are of foraminiferous and pteropod muds incrusted by coral limestone, have been antecedently upheaved. Here, then, as in the Shortland Islands, a barrier-reef has been formed in a region which has been undergoing elevation during a prolonged period. . . . . I should have added that this barrier-reef of Choiseul Bay meets the coast at the head of the bay where it joins the shore-reef: to the southward it is continued as a submerged line of reef covered by 5 or 6 fathoms of water with a channel, 30 fathoms deep, inside it.

Before concluding my remarks on this strait I will refer to Oima Atoll (*vide* plan), a singular atoll of small size which lies in the northern entrance about $1\frac{1}{2}$ miles within the edge of the submerged plateau. It measures nearly 2 miles in its longest diameter and rises from depths of 40 to 50 fathoms with a submarine slope varying between 12 and 26 degrees. This atoll has been formed around a group of rocky islets which are composed of hornblende—andesite and range in height from 20 to 100 feet above the sea. The variation of the texture of the rock in different islets, and other facts, show that there were four volcanic necks here represented. This atoll encloses two basins, 20 fathoms deep, which are separated by a bank that is only partially exposed at "low water springs." H.M.S. "Lark" found a sheltered anchorage in the western basin. The bottom in the deeper parts is formed of a chalky mud. In the interior of the lagoon, corals thrive most on the banks that face the breaks in the reef and on the sides of the entrances. There are, however, extensive sandy tracts covered by less than a fathom of water at low tide, on which may be observed very large flat-topped masses of *Porites,*

Oima Atoll, adapted from a Sketch of my own, assisted by the Plan in the Admiralty Chart.



The white portion represents the reef above the sea level bearing the six volcanic islets. The inner shaded space is the lagoon, of which the lighter tint represents depths less than a fathom, and the darker tint the deeper part, which has a depth of 20 fathoms.

10 to 16 feet across, completely dead, and only projecting a few inches above the sand. These huge corals had evidently been killed by the accumulation of sand; and it was apparent that through this agency the lagoon was filling up. This atoll does not seem to have experienced any upheaval since the commencement of its growth, although it is situated in an area of elevation. However, the existence of old erosion lines, with their accompanying caverns, on two of the volcanic islets affords evidence of *a prior upheaval to the extent of some four or five feet.** I should observe that numerous full-grown *Tridacnæ* (*T. gigas*), which occur alive in the

* The bearing of this fact is referred to on page 867.

shallower parts of the lagoon, where they are covered by from 6 inches to a foot of water at "low water springs," lie on their hinge-borders upon the sand, and not, as I have usually found them, in cavities in the coral rock.

The Formation of Barrier-Reefs.—During my lengthened stay in these islands, I devoted considerable attention to the subject of the formation of barrier-reefs as well as to the growth of coral reefs in general. In the course of my investigations I took about 300 soundings, ranging between 4 and 50 fathoms, off the weather sides of reefs, and I obtained in several instances the submarine profiles.* As typical of other reefs in this group, I will briefly describe the seaward slopes of the following reefs :—

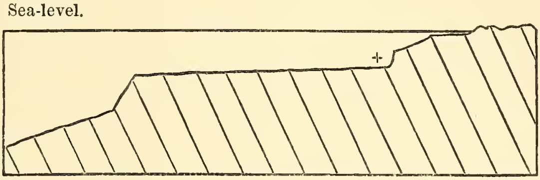
(*a*) *Onua Reef* (*vide* section 2).—This is a fragment of a barrier-reef on the south-east side of the Shortland Islands. For the first 80 or 90 yards from the edge of the reef-flat, there is a gradual slope down to a depth of about 5 fathoms. There is then a rapid fall of about 10 fathoms; at the foot of this declivity there lies a narrow ledge, and beyond there is a moderate slope of 13° to the 100 fathom line. Judging from my soundings, corals thrive down to depths of 15 fathoms, where the sand commences and covers the slopes below. This depth, it will be noted, corresponds with the base of the submarine declivity, a situation where, as indicated by the cross in the section, we should expect the sand to collect.

(*b*) *The Barrier-Reef of Choiseul Bay.*—As shown in section 3 the submarine portion of this reef at first slopes gradually for the first 70 or 80 yards from the edge of the reef-flat to a depth of 4 or 5 fathoms, when it plunges down by a steep declivity another 9 or 10 fathoms, from the foot of which there is a rapid talus-like slope to a depth of about 20 fathoms from the surface. Beyond, there extends a broad ledge, covered by from 23 to 25 fathoms of water, which terminates in a slope of about 10° to a depth of 100 fathoms, which is the limit of the section. An inspection of this section would lead one to expect that an accumulation of sand and gravel, preventing the growth of reef-corals, would be found at the foot of the declivity, viz., in depths of from 15 to 20 fathoms, and that in the level region beyond, from the absence of such accumulations, there

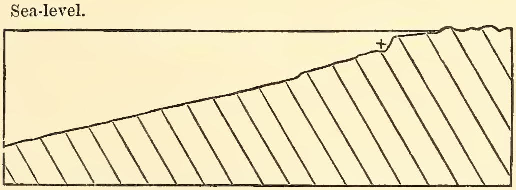
* In a short paper, published in the *Annals and Magazine of Natural History* for June 1884, I have dealt more particularly with the soundings.

would be more favourable conditions for the growth of coral. My soundings afford evidence that such is the disposition of the detritus on the outer slope of this reef. Living corals flourished on the upper part of the submarine slope down to the base of the declivity: here in depths of 15 to 20 fathoms (marked by a + in the section) sand and gravel had accumulated, and there was but little living

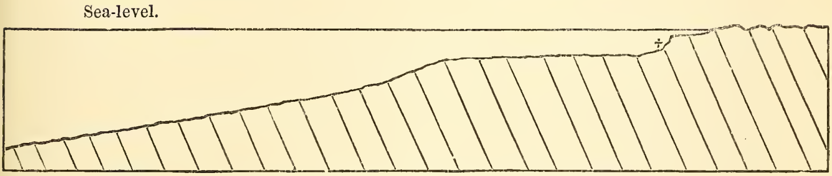
Sections showing the Seaward Slopes of Reefs in the Solomon group. (Drawn on a true scale to the 100–fathom line, $\frac{1}{10}$ inch = 100 *feet.) The crosses mark the bases of the declivities where the sand collects.*



Section 1. Port-Mary Reef, Santa Anna.



Section 2. Reef of Onua Islet, Shortland Islands.



Section 3. Barrier-reef of Choiseul Bay.

coral. On carrying the soundings further seaward on the broad ledge beyond, I found that the sand and gravel began to disappear and that the armings in the greater proportion of the casts made in depths of from 23 to 40 fathoms showed the presence of living coral. This disposition of the detritus is readily to be explained.

Sand and gravel, derived from the constant action of the rollers breaking on the edge of the reef-flat, would naturally tend to collect at the foot of the first declivity in depths of 15 to 20 fathoms; in such a situation living coral would be scarcely expected to thrive; but in the more level region beyond, as the sand and gravel thinned away, conditions more suitable for the growth of coral would be found, and this is the conclusion towards which my soundings pointed. There would thus appear to exist on the outer submarine slope of this barrier-reef, in depths of 15 to 20 fathoms, a belt of detritus dividing into two portions the zone in which the reef-building corals thrive. (I have marked the position of this belt in the section by a cross.) Had my soundings been confined to the upper of these two sub-zones, I should have been justified to a great extent, on reaching the belt of sand and gravel, in concluding that coral did not thrive in depths beyond 15 fathoms; but by subsequently extending such soundings seaward across this band of detritus into the lower or outer sub-zone, I should have exposed the fallacious character of such a conclusion.

(*c*) *Port Mary Reef*, *Santa Anna* (*vide* section 1).—My soundings were taken off the outer edge of the reef enclosing the harbour. The seaward profile of the reef may be thus described. For a short distance from the edge of the reef-flat there is a gradual descent. This is followed by a rapid slope until a depth of about 16 fathoms is reached, when within a distance of a couple of boats' lengths, there is a drop of another 16 fathoms. From the foot of this declivity there is an easy descent for about 450 yards, with a fall of some 9 or 10 fathoms, which terminates in a precipitous slope where there is a drop of about 25 fathoms. The submarine slope beyond descends at an angle of 18° or 19° to considerable depths. Corals thrive down to a depth of 30 fathoms. Beyond this depth sand and gravel more frequently come up in the armings. It will be noticed that the lower limit of the coral zone apparently corresponds with the base of the first declivity (marked with a cross in the section), as in the cases of the two reefs previously described, and that the deeper extension of the zone in this instance is evidently due to the deeper situation of the declivity in question. Sand and gravel cover the more level tract beyond; but there were indications given by my soundings of the thinning away of the detritus towards the further edge of this ledge where some of the armings showed clean impressions.

(*d*) *Oima Atoll.*—On the other slopes of this atoll, for the first 70 or 80 yards from the edge of the reef-flat, there is a gradual descent down to a depth of 4 fathoms. Beyond this the reef slopes rapidly away at an angle varying between 12 and 26 degrees on different sides of the atoll, to depths of from 45 to 50 fathoms, the general level of the surrounding bottom. There appears to be no sudden break or declivity on the seaward slope of the reef, such as came under my notice in the cases of most other reefs. The corals flourish down to depths of 25 fathoms. The slopes beyond are for the most part covered with sand and gravel.

I will now sum up the principal characters of the seaward slopes of reefs in this group, as exemplified by those I have just described, and it should be observed that, although these remarks apply to reefs of any of the three classes, I have more particularly in view at present the reefs belonging to the barrier class. For the first 70 or 80 yards from the edge of the reef-flat there is usually a gradual slope to a depth of from 4 to 5 fathoms. This gentle slope, which is *largely bare of living coral* (*vide* page 858), is traversed by prolongations of the fissures or channels that cross the outer portion of the reef-flat between the tide levels. These fissures may sometimes be traced by means of the white sand that collects in them, to a distance of 100 yards from the edge of the reef-flat. I have observed them on the seaward slopes of some reefs to be placed at regular intervals of from 25 to 30 feet. They vary in width between 2 and 5 feet. In the depths less than 5 fathoms the corals prefer the sides of these fissures, and are not, as I have already stated, in any quantity on the intervening spaces.

Beyond this gentle slope, which terminates as observed above, in depths of from 4 to 5 fathoms, there is generally a rapid descent to a depth varying between 12 and 18 fathoms, which is usually sufficiently steep to be pronounced a declivity. In some reefs, however, as at Port Mary, this declivity may be situated at a somewhat greater depth. It is, however, *on the face of this precipitous slope* that the corals flourish. This is, in fact, the growing edge of the reef.* The sand and gravel, produced by the action of

* I learned from a pearl diver in these islands that he had frequently noticed, when diving on the outer sides of the reefs, that at the base of a

the breakers at the margin of the reef, collect at the foot of this declivity in depths generally of from 15 to 20 fathoms, but sometimes in rather greater depths as at Port Mary. However, since the growth of coral is suppressed by this accumulation of sand and gravel that collects at the foot of the declivity, which I have termed the growing edge of the reef, it follows, as I have already pointed out in the instances of the Onua, Choiseul Bay, and Port Mary reefs, that the apparent lower limit of the zone of corals will be determined in the case of each reef by the depth at which the base of the declivity lies. The "raison d'être" of the declivity is to be found in the circumstances that the corals flourish only on the outer slopes of reefs, in depths beyond the first line of breakers, *i.e.*, below a depth of 4 or 5 fathoms. Here they are exposed to the strength of the tidal currents, and, as clearly shown by Professor Semper, they would tend to form precipitous or wall-like declivities growing outwards, as Mr Murray holds, each on its own talus.

With regard to the disposition of the sand and gravel on the slopes below the growing edge of the reef, my soundings showed that where the descent is at all rapid (*i.e.*, more than 10° or 12°), as is generally the case, this detritus extends down far beyond the depths in which corals thrive, but that where the slope is gradual (*i.e.*, less than 5°), as in the instance of the barrier-reef of Choiseul Bay, the lower limit of the sand and gravel lies within the coral zone which is, in point of fact, divided into two sub-zones by a belt of detritus.

The results of my examination of the seaward slopes of reefs have supplied me with an explanation of the formation of barrier-reefs, which I will briefly review in the light of numerous observations I have made in this group, both on existing and elevated coral reefs.*

precipitous slope in depths of 15 to 20 fathoms, the rock overhung to such an extent that he was able to get underneath the projecting portion. This was evidently due to the outward growth of the corals on the face of the declivity.

* I first described this view of the formation of barrier-reefs in a short paper, entitled "Suggestions as to the Formation of Barrier Reefs," &c., which was read before the Linnean Society, New South Wales, in October 1884 (*Proc.*, vol. ix. part 4). At that time I was in ignorance of the fact that substantially the same explanation had been proposed many years before by Professor Joseph Le Conte in the instance of the Florida barrier-reefs. In 1856 Professor Le Conte

If we imagine an island, originally formed from the materials ejected from some volcanic vent and bare of coral-reefs, to afford, after the extinction of the subterranean fires, the conditions of growth on its coasts for reef-building corals, a fringing reef of varying width according to the degree of inclination of the submarine slope will ultimately invest its shores. In course of time, the detritus of the corals will collect in a band of calcareous sand and gravel on the outer slope of the reef, marking the apparent limit of the depths in which the reef-corals are usually stated to thrive. But the vertical and horizontal extension of such a band of detritus will be mainly determined, as my observations have shown, by the presence and position of submarine declivities and by the degree of inclination of the slope. In such a zone of sand and gravel corals will not thrive; but if the submarine slope has a very gradual inclination, as in the case of the barrier-reef of Choiseul Bay, the lower limit of this zone of detritus may lie within the depths in which reef-building corals flourish, and a line of barrier-reef begin lying parallel with the fringing reef, but separated by a deep channel.*

On the other hand, should the submarine slope have a more rapid descent, the lower limit of the belt of detritus may extend far beyond the depths in which reef-corals can thrive; in such a case no barrier-reef will form, and the original fringing reef will continue to grow outwards on its own talus. On this view the occurrence of barrier-reefs and of fringing-reefs on different parts of the coast of the same island may be readily explained as due to the different degrees of inclination of the submarine slope.

pointed out that the explanation of the circumstance that the Florida peninsula had been formed by a succession of barrier-reefs, instead of by a continuous fringing-reef, was to be found in the fact that, since corals will not grow on muddy shores or in water upon the bottom of which sediment is collected, the favourable conditions can only be obtained some distance from the shore. There, as he remarked, a barrier-reef would be formed, *limited on one side by the muddiness, and on the other by the depth of the water* (*vide American Journal of Science*, 2nd series, vol. xxiii. p. 46, and *Nature*, October 14, 1880). This view seems to have attracted scarcely any attention since it was first proposed; but the circumstance that I arrived independently at the same conclusion with reference to the barrier-reefs of the Solomon Group is one that lends it very powerful support.

* Such a reef covered by 5 fathoms of water lies south of Choiseul Bay.

Keeping in view the foregoing explanation of the formation of a barrier-reef in a district which may for a long period have experienced no change in the relative positions of land and sea, we can perceive how in an area of elevation line after line of barrier-reef will be formed as from time to time fresh portions of the sea-bottom, previously below the reef-coral zone, are brought up within the depths in which reefs commence their growth; line upon line of barrier-reef will be thus advanced, each growing up along the lower limit of the belt of detritus derived from the line of reef inside it. In process of time the elevating movement assisted by the accumulation of sediment, the growth of branching corals, and the reclaiming agency of the mangrove, will bring about the filling up of the passages or lagoon-channels between the lines of reef, until at length a tract of land is produced rising gradually from the sea-border to the interior but with the ancient lines of barrier-reef still indicated by ridges of coral-limestone on its surface. Such in fact is in my mind the history of the formation of the Shortland Islands, and I opine of the western extremity of the Choiseul Island. In the former locality we have the original island of volcanic formation in the north-west corner, from which, as from a nucleus, line after line of barrier-reef has been advanced in a south-easterly direction, forming ultimately, during the continuance of the elevation, the large island of Alu. Should this elevating movement be at present suspended, as would appear to be indicated by the great width of the reef-flats still overflowed by the sea on the weather coasts of the outlying islands, there yet remains a considerable addition to be made to the sea-border of Alu by the filling up of the passages between the lines of islands which represent elevated barrier-reefs on its weather coasts. Such a process is in actual operation at the present time in the passages, the encroachment of the mangrove on either side and the upward growth of coral in the channels being the agencies at present effecting this operation. These remarks may be made more clear by a reference to the sections of the Shortland Islands, which are given in my paper on the recent calcareous formations (*Trans. Edin. Roy. Soc.*, vol. xxxii. part iii.), and in vol. ix. part 4, of the *Proceedings of the Linnean Society, N.S.W.*

It follows from this view of the formation of barrier-reefs that the lagoon channels should never be deeper than the zone in which reef-corals flourish; but, as a matter of fact, the depths inside barrier-reefs as well as atolls not unfrequently exceed those in which reef-corals are believed to thrive. For instance, to take the case of barrier-reefs, with which we are at present concerned, depths of from 40 to 50 fathoms occur inside the line of barrier-reef that skirts the eastern end of Bougainville Island in the Solomon Group. Soundings of between 50 and 60 fathoms have been obtained inside the Vanikoro reef in the Santa Cruz Group. Depths of 40 fathoms are found within the barrier-reef lying west of the Fiji Islands, and inside the great Australian barrier-reef the depth increases to 60 fathoms. It is the depths of from 35 to 60 fathoms which are found occasionally within both barrier-reefs and atolls that lend the greatest support to the theory of subsidence. However I have found a simpler explanation of the difficulty.

In the Solomon Group the depth of the reef-coral zone on the outer slopes of reefs varies greatly in different localities. In most plases its lower limit is 12 to 15 fathoms; in others again it is from 20 to 25 fathoms; whilst off the reef of Choiseul Bay I did not seem to have reached this lower limit in soundings of 40 fathoms.* This variation I found to depend upon the disposition of the sand and detritus on the seaward face of the reef, and this was itself determined by the degree of inclination of the slope and by the presence and position of submarine declivities. In the protected waters of lagoons and lagoon-channels, the main determining condition is to be sought in the degree of clearness of the water. The estimates of observers in other regions have been equally varied. MM. Quoy and Gaimard placed the lower limit of the zone in the Pacific at 5 or 6 fathoms. Ehrenberg formed a similar estimate with reference to the Red Sea corals. In the Florida Seas, Professor A. Agassiz has ascertained it to be less than 10 and usually not more than 6 or 7 fathoms. Professor Dane would place it at 20 fathoms in the Pacific. Mr Darwin's limit is 20 to 30 fathoms for all reef-regions. In the Red Sea, again, large beds of living coral were found in depths of 25 fathoms by Captain

* These depths and other particulars are to be found in my paper in the *Ann. & Mag. Nat. Hist.*, June 1884. More recent data have led me to change some of the views there expressed.

Moresby and Lieutenant Wellstead.* This great variation is, as I hold, and as Mr Darwin also held, to be attributed to the difference in the local conditions in the various localities in which the observations were made. In the case of the Red Sea, Captain Moresby himself attributed the less depth at which Ehrenberg found living corals to the great amount of sediment. In the majority of instances, the observers were led to consider that in passing from the living corals to the sand beyond they had necessarily passed the lower limit of the reef-coral zone; but I have already shown that if the submarine slope is gradual, living coral may be found in the depths beyond the sand. If, however, as is usually the case, the slope is somewhat steep, the sand will extend to depths far beyond the zone of living coral. It was the limited depth at which reef-corals thrive in the Florida seas as compared with depths of the zone in other regions that led Professor A. Agassiz to infer that the vertical distribution of reef-corals is determined by local causes rather than by the general influence of depth. "There seems to be," thus he goes on to remark, "no simpler explanation of the limited bathymetrical range than that of the baneful action of the silt held in suspense near all reefs"† The local causes that confine the reef-building corals to such shallow depths in the Florida seas are to be found, as Professor Agassiz implies, in the unusually large quantities of calcareous sediment contained in the water in the vicinity of the reefs and in the gradual character of the submarine slope of the rapidly advancing Florida Bank, the muddy surface of which is being constantly disturbed by the action of the waves and of the tides.

From the foregoing remarks we may with confidence infer that the lower limit of the reef-coral zone is determined rather by local conditions than by the general influence of depth. If this be granted, there can be but little hesitation in allowing that under favourable circumstances, such as a moderate submarine slope and unusually clear water, reef-corals may commence to build in depths beyond those generally assigned, as for instance, in those of 50 and 60 fathoms. We have here, then, a ready explanation of the exceptional depths

* Dana's *Corals and Coral Islands* (1872), p. 115; Darwin's *Coral Reef* (1842), p. 83.

† Memoirs, *American Academy of Arts and Sciences*, vol. xi. part ii. No. 1, 1885.

of some lagoons and lagoon-channels. I should add that Mr Darwin also arrived at the conclusion that local conditions, such as the degree of clearness of the water and the extent of inclined slope, might partly determine the depth of the coral zone,* but he did not attribute the same importance to such causes that I have done, and thus he came to seek for other explanations of the anomalous depths within some atolls and barrier-reefs.

My observations on the recent calcareous formations of the Solomon Group† enable me to approach this subject by another road. These investigations have shown that coral-reefs are based usually on a partially consolidated *volcanic mud or ooze* often foraminiferous, generally abounding with recent shells, and now and then laden with pteropod-shells in considerable numbers, the thickness of the overlying coral-rock rarely exceeding a hundred feet. That the reef-corals commence to grow on such a bottom, and not on a layer of detritus of sand and gravel, is shown by the fact of my finding at Santa Anna two massive corals of the Astræidæ, the largest 4 feet in diameter, imbedded in the position of growth, at a height of 40 feet above the sea, in the base of a coral-limestone cliff where they almost rested on the subjacent partially consolidated ooze. It is a noteworthy circumstance that in my numerous soundings off the outer edge of reefs in this group, which extended to fifty fathoms, the armings never brought up any other indication of the nature of the bottom, outside the usually accepted coral-zone, than that of calcareous sand and gravel. In truth, my soundings down to depths of 50 fathoms failed to reach the ooze. It would therefore appear that such reefs as those of the Shortland Islands commenced to build in depths greater than fifty fathoms. If elevation had brought the ooze within these depths uncovered by the calcareous detritus, the armings would probably have recorded such an occurrence amongst some of my numerous soundings.

An apparent objection here presents itself. If reefs begin to build their foundations in depths greater than those which are generally assigned to them, the thickness of the elevated reef-formation discovered by me in the Solomon Group should have been much greater than 150 feet, the actual limit of their thickness. It

* *Coral Reefs* (1842), p. 84.

† *Vide Trans. Edin. Roy. Soc.*, vol. xxxii. part iii. p. 545.

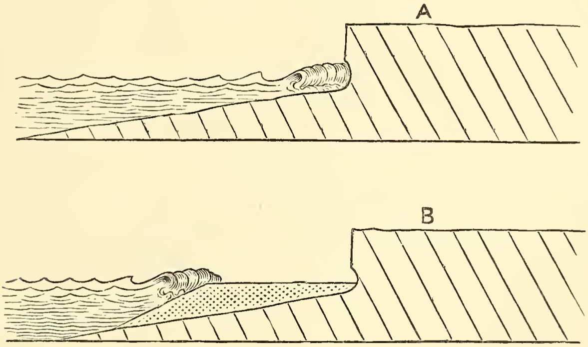
will, however, have been gathered from the previous remarks that local conditions will usually confine reef-corals to depths less than 25 or 30 fathoms, and that it will be only under occasional circumstances that reefs will commence to be formed in deeper water. Fringing-reefs themselves are at first restricted to shallow waters around the coast, and their seaward extension in localities where the submarine slope is at all steep, as is generally the case, must be extremely slow. Again, in a area of elevation, such as that in which the Solomon Islands are included, barrier-reefs, which may have begun to grow in depths not less than 50 fathoms, might owe their approach, towards the surface as much to the elevating movement as to the very slow upward growth of the corals. It should also be borne in mind that the rapid subærial denudation, to which these regions of heavy rainfall are subjected, would be an important agency in the thinning away of the raised coral formations.

The Evidence of the Outward Growth of Barrier-Reefs and Atolls.—* (*a*) Whilst examining Oima Atoll, I was particularly struck with the difference in size between the massive corals in the interior of the lagoon and those which occurred near or at the outer border of the reef. In the lagoon, the large masses of *Porites* ranged from 10 to 16 feet in diameter; whilst the largest masses that I found in the wash of the breakers at the outer edge of the reef, which belonged to species of *Cœloria* and *Meandrina*, measured only 5 feet across. I have also noticed, in the case of barrier-reefs in this strait, that the massive corals are largest near the inner edge of the flat and diminish in size as one approaches the outer edge of the reef. Thus, in case of one of the Shortland reefs, I found masses of *Porites* at the inner edge of the flat which measured from 6 to 10 feet across; whilst the largest massive corals (referable to the genera, *Coeloria* and *Meandrina*), that I found near the outer edge of the reef, measured from 3 to 4 feet. These facts are of importance, since, according to the theory of subsidence, the central portion of the lagoon of an atoll and the inner portion of the lagoon-channel of a barrier-reef are more recently produced than any other portion of the area of such reefs. Here, then, the massive corals ought to be much smaller than those

* This mode of growth is one of the chief points on which Mr Murray dwells. My observations go to support his view.

situated towards the margin of the reef. On the contrary, I found them much larger and belonging to species of *Porites* (*P. tenuis*, *P. gaimardi*, *P. aspera*, &c.) which must be of slow growth as compared with the species of the two genera, above mentioned, that are commonly found at the outer edge of reefs in these seas. Such facts are only to be explained on the hypothesis that the reef has gradually grown outwards as from a centre and quite independently of any movements of subsidence.

(*b*) In the cases of those partially elevated lines of barrier-reefs, which occur on the weather side of the principal island of the Shortland Islands, the present reef-flats are backed by a line of low coral limestone cliffs at the base of which is an old line of erosion. This mark might easily be taken as evidence of an upheaval, since the water coming over the reef-flat at high tide scarcely reaches it; but, as shown in the accompanying diagram, it is only necessary in



A. Here the waves are represented as breaking at the base of the cliff.
B. A shore-reef has now been formed, against the outer edge of which the waves are breaking.

imagination to remove the reef-flat in order to picture to oneself the rollers breaking at the base of the cliff and to perceive that this line of erosion has been formed at the present sea level. By the advancing growth of the outer margin of the reef, the cliffs have been cut off from the action of the waves. Such lines of erosion may be partially concealed by sand. They are commonly to be observed in cliff-girt coral islands, like Santa Anna, which have narrow shore-reefs extending seaward from the foot of the cliffs.

(*c*) The characters of the wooded islets, that have been formed on the barrier-reefs of Bougainville Strait and of other localities in the group by the action of the waves at the present sea level, can only be explained on the assumption of the outward growth of the reefs. They are situated on the leeward side of the reef-flat and border the lagoon-channel. At their weather margins facing the weather edge of the reef, they are but scantily vegetated. Here, on a soil composed almost entirely of calcareous sand, broken shells, coral débris, and pumice pebbles, the *Pandanus* and *Casuarina* with such shrubs as *Scaevola Kœnigii* alone can flourish. It is at their weather margins that these islets are constantly receiving accessions. In one place it will be observed that the mangroves push forward their lines on the reef-flat whilst it is yet covered by the sea at high water. In another place it will be noticed that during the prevalence of strong winds at spring tides the waves have thrown up a bank of sand a little above the ordinary high water mark. Under cover of this bank, various hardy creeping plants and binding weeds, such as *Ipomaea pes caprae* and *Triumphetta procumbens*, push forward from the edge of the vegetation and invading the newly acquired strip prepare the soil for the *Casuarina*, *Pandanus*, and the different shrubs that rapidly follow in their rear.

On crossing the islet to its lee side, where it borders the lagoon-channel, we find the soil contains a larger proportion of humus. Here the vegetation is much denser and of a different character. Such trees as *Barringtonia speciosa*, *Calophyllum inophyllum*, *Thespesia populnea*, &c., form a thick belt, with their branches overspreading the water.

From the foregoing remarks it will be evident that the lee side of an islet is its oldest portion, and that its weather side is the growing margin. Such islets, therefore, extend themselves seaward towards the weather edge of the reef. They would, in the course of time, occupy the whole area of the reef-flat, were it not for one counteracting circumstance, the more rapid outgrowth of the reef. Mr Murray attributes the position of the islets on the inner side of the reef-flat to the gradual removal, by solution and other agencies, of the lagoon-edge of the reef as it grows outward at its seaward edge.*

The Solution of Dead Coral.—From the manner in which the

* *Proc. Roy. Soc. Edin.*, 1879–80, x. 505.

upheaved coral rocks thin away as one ascends the slopes of these islands, an idea may be formed of the rapidity with which dead coral may be removed in solution by the carbonic acid in rain water. The extensive deposits of calcareous tufa, that incrust the sides of the streams and form step-like ledges in their courses, have been derived originally from the solution of these rocks. The surfaces of the elevated reef-flats of St Christoval and other islands are honeycombed in a remarkable manner by the atmospheric agencies; and in places where the rock is exposed to the dripping from overhanging cliffs, it is worn into holes, 12 to 18 inches deep, containing water.

In a similar manner the carbonic acid contained in sea-water acts on dead coral; but of the extent of its action and of its ultimate effect I was unable to obtain the same direct evidence. It is to this agency that Mr Murray mainly attributes the formation of lagoons and lagoon-channels. As bearing on this subject, I append the following remarks:—

In the interior of Oima atoll I noticed some large masses of living coral which presented the characters of miniature atolls. One large circular mass of *Madrepora* (with short branches), which measured 18 feet across and 2 feet in height, possessed a dead centre that was depressed 9 or 10 inches below the level of its living margin. In this basin at "low water springs" there were a few inches of water forming a miniature lagoon; whilst the living margin was exposed for several inches above the surface. In the lagoon sea-urchins, star-fish, sea-anemones, stalked mushroom-corals, and cowries were to be seen in the crevices; tiny fish darted about from one side to the other; while a beautiful blue Botryllian and pink *Nulliporæ* partially concealed the unsightliness of the dead coral. From the manner in which the dead branches of the *Madrepora* in its central basin were blunted and rounded off, it was evident that, as the mass grew outwards, it had died and been subsequently dissolved away in its centre. An adjacent flat-topped mass of *Porites*, measuring 13 feet across, at the same condition of the tide presented an example of another miniature atoll. Its central portion was dead and hollowed out into a basin, which was occupied by a small pool of water; whilst its living border was exposed for a few inches above the surface. In the pool grew tiny lumps of a *Pocillopora* and some Alcyonarians.

The increased temperature during the bright sunlight of the sea-water covering the reef-flats probably assists in the solution of the dead coral. On two occasions, whilst wading at mid-day in water ankle-deep (3 to 4 inches), I found its temperature to be about 15 degrees (Fahr.), above that of the surface of the sea. Where the water was a foot in depth, the increase in temperature was about 8 degrees.

Sea-water,	84°	Sea-water,	83°
Reef-flat—		Reef-flat—	
(*a*) 3 to 4 in.,	100°	(*a*) 3 to 4 in.,	98°
(*b*) 12 in.,	92°	(*b*) 12 in.,	no observation.

Still higher temperatures are to be found in the waters of the shallow pools that have been left on the reef-flats by the retreating tide, and are exposed to the rays of the noon-day sun. In a pool an inch in depth, and frequented by small fish and hermit-crabs, the water was heated up to 106° (Fahr.). In another pool, 4 inches deep, the temperature was 99°. The temperature of the sea at the time of these observations was 83°. After the sky had been clouded over for an hour, the shallower pool had lost 7 or 8 degrees of heat; whilst the temperature of the deeper pool had only fallen about 3 degrees, and still remained about 13 degrees above that of the surface of the sea.

The Organic Degradation of Coral Reefs.—It was a singular misconception respecting the habits of holothurians that led me to the consideration of the degradation of reefs by the numerous organisms living upon them. It was stated by Mr Darwin,* on the authority of Dr Allan, that these animals subsist on living coral. Professor Dana,† however, pointed out that this habit was not warranted by the evidence; and Professor A. Agassiz,‡ in his memoir on the Florida reefs, expressly states that holothurians do not feed on the living coral; Professor Semper § evidently holds the same view. During my lengthened stay in the Solomon Group, I never observed a single instance of this habit, and I arrived somewhat reluctantly at a conclusion which compelled me to give

* *Coral Reefs* (1842), p. 14.

† *Corals and Coral Islands* (1872), p. 229 ; *vide* also his earlier works.

‡ *Mem. Amer. Acad. Arts and Sci.*, vol. xi. part ii. No. i. 1885, p. 127.

§ *Animal Life*, vol. xxxi. Internat. Scient. Ser., p. 413.

up a theory I had formed on the subject.* Mr Saville Kent and other observers † have come to the same opinion. This negative fact may therefore be considered as established.

The sand and gravel that I found in the intestines of these animals were composed of dead coral, fragments of molluscan shells, small entire univalve and bivalve shells, foraminiferous tests, including the large *Orbitolites*, the joints of the calcareous alga, *Halimeda opuntia*, and other materials. Professor Semper, Professor Agassiz, and Mr Saville Kent have pointed out that the nutriment is chiefly obtained from the organic particles, diatoms, and foraminifera, associated with the sand and gravel. Holothurians avoid these materials in enormous quantities. After several observations on one of the commonest species of the reef-flat, I arrived at the conclusion that each individual daily discharged not less than two-fifths of a pound (av.) of sand and gravel, and that in the course of a year fifteen or sixteen of these animals would discharge a ton of these materials, which would tend through this continual process of trituration and attrition to be reduced to the finest mud. Multitudes of other creatures take part in this operation of degradation, the first stage of which is to be seen in the destructive effect of the boring-molluscs, annelids, echinoids, sponges, &c., on the masses of dead corals. In the later stages, not only the holothurians, but all echinoderms (echinoids, asteroids, ophiuroids), together with fish, molluscs, and crustaceans are actively engaged. Thus by the process of organic degradation coral masses are reduced to fragments, and these again to sand and gravel, which in their turn are ground down into mud. Mr Darwin held that by this agency the fine sands and muds of the coral reefs are produced. His misconception respecting the habits of holothurians does not materially affect his conclusion. Of the importance of this agency I feel convinced. Professor A. Agassiz, however, contends that, as in the case of the Florida reefs, it is very slight as compared with the action of the breakers. These reefs, I would point out, are somewhat exceptionally situated. Here the rollers pass over the muddy slopes of a submarine bank before they reach the reefs, and in consequence, after storms, the sea is discoloured with chalky sediment for miles around. Such

* *Nature*, Nov. 2, 1882, and Feb. 21, 1884.

† *Nature*, March 8 and 29, 1883.

a phenomenon is unusual in the Pacific, where, on account of the greater rapidity of the submarine slope, the rollers dash at once against the face of the reef. Professor Dana, who regards this process of organic degradation as inadequate, would attribute the formation of the chalky mud of lagoons and reef-flats to self-trituration of the gentlest kind possible.

Very fine sand may be distributed over the bottom of lagoons and lagoon-channels in the following manner:—I have often observed this material floating in the shallower places on the calm surface of the water, the particles being connected together and coated by some oily film, such as invests the pellets of sand voided by holothurians and other animals that frequent coral reefs. A touch of the finger, by wetting the upper surfaces of the particles, causes them to sink. This material appears to be taken up by the water as it runs gently off the sandy flats that are exposed by the ebbing tide. In this manner, during a calm day, sand may be transported on the surface of the water from the margin to the centre of a lagoon, when some slight disturbance, such as a cat's paw of wind, will send it to the bottom.

I may here refer to the important part which echinoids take in the degradation of coral rock. On every reef it will be noticed that the blocks of dead coral, and especially the flattened dead summits of the massive corals, such as *Porites*, display singular narrow and somewhat tortuous grooves, 8 to 12 inches long, 1 to 2 inches wide, and 3 to 4 inches deep.* The sides of these grooves are worn smooth and are lined by a pink nullipore. Nestled at the bottom of each is to be found a solitary echinoid belonging to a species of *Echinometra*, the size of which exactly corresponds with its furrow, so that it is difficult to dislodge it without injuring the animal. That these grooves are the permanent homes of these echinoids is shown in the character and arrangement of the spines on the two sides of the tests, which are in close apposition with the walls of the furrow. The spines are here small and partially stunted, and no longer radiate from the animal, but are pressed back against the test. These grooves are evidently produced by the occupant, for it is well known that echinoids are able to gouge holes for themselves in the solid rock. According to Professor A. Agassiz, species of

* These grooves are often preserved on flats of coral rock that have been recently elevated a few feet or more above the sea.

Cidaris and *Echinometra* dig holes in the coral rock of the Florida reefs. In the Solomon Island reefs, *Echinometræ* occasionally occupy round deep holes of their own workmanship, but cavities of this shape are generally formed by other species of echinoids.

Submarine Deposits at present forming outside Coral Reefs.—The calcareous sand and gravel that strew the outer slopes below the zone of living corals in depths between 20 and 100 fathoms and beyond, are largely composed of reef-débris, the tests of two species of *Orbitolites* (*Orbitolites complanata* and *heterostegina*), the joints of the calcareous alga, *Halimeda opuntia*, and of *Nulliporæ*. I have found the two species of the Foraminifera just mentioned *living* at all depths between a couple of feet and 75 fathoms; and frequently when I have been using a lead having a broad cup 3½ inches across, ten or twelve of their tests have been brought up together on the arming. Their bleached tests, for when alive or recently dead these Foraminifera are of a sea-green colour, are equally numerous in the chalk-like mud exposed inside the reefs by the retreating tide, and together with the joints of the *Halimeda* they may be said to largely compose many beaches.* I have only found this calcareous alga living on reef-flats and in the wash of the breakers on the outer borders of reefs and among the troubled waters caused by tide-rips on coral shoals, which are covered by less than 10 fathoms of water. In my soundings on the outer slopes of reefs I only brought up the dead joints. It may be truly said that next to coral débris the tests of *Orbitolites*, fragments of *Nulliporæ*, and the joints of *Halimeda opuntia* are the most important rock-forming materials in depths of from 20 to 100 fathoms on the outer slopes of reefs in these seas.†

* The Foraminifer, *Tinoporus baculatus*, is also commonly found in the sand of the Solomon Island beaches.

† Similar deposits of *Orbitolites* are forming off the Australian shore between the inner reefs of the great barrier-reef. Mr Beete Jukes found that the dredge, from depths of 15 or 20 fathoms, was sometimes filled with *Orbitolites:* these organisms seemed in some places to make up the whole sand of a beach of a coral island (*Student's Manual of Geology*, 1862, p. 131). The important part taken by *Halimedæ* and *Nulliporæ* in the composition of deposits of coral reefs attracted the attention of Mr Darwin. We are informed by him that joints of a *Halimeda* and small fragments of *Nulliporæ*, all dead, thickly strew the bottom in depths greater than 90 fathoms, off Keeling Atoll; and also that Capt. Allen, R.N., in his survey of the West Indies, found that in depths between 10 and 200 fathoms the armings very generally came up covered with the dead joints of a *Halimeda* (*Coral Reefs*, 1842, p. 86).

Other macroscopic Foraminifera, such as *Operculina complanata*, *Alveolina boscii*, &c., occur, both alive and dead, amongst the sand and gravel. To fragments of *Nulliporæ* the Foraminifer *Polytrema priniaceum* is sometimes attached. Small unattached corals of the genus *Heteropsammia* came up frequently in the sand and gravel, from depths between 20 and 40 fathoms off reefs.

The composition of this deposit on the outer slopes of reefs and the depths to which it extends are points of importance. Its materials would form a white compact limestone, such as I have described in my paper on the calcareous formations (p. 574)* as the commonest type of the so-called coral limestones in the Solomon Group. A rock of this description might be formed at any depth between 20 and 100 fathoms in places where the submarine slope is steep; but where the slope is moderately rapid, *i.e.*, less than 20°, as it usually is, these deposits will be probably restricted to depths considerably within the 100 fathom line.

I should here observe that these remarks apply only to the deposits forming off coral reefs. On coasts, such as those of St Christoval, and in harbours, such as Treasury Harbour, where numerous streams carry down a quantity of sediment into the sea, this material is mixed in varying proportions with the calcareous sand and mud.

Of the nature of the deposits forming off the coasts of these islands in depths beyond 100 fathoms, I have been able to judge from the character of the soundings made by Lieutenant Oldham in H.M.S. "Lark" between the north coast of St Christoval and the adjacent islands of Ugi and the Three Sisters. There appears to be a maximum depth here of rather over 400 fathoms. In depths of 100 to 200 fathoms the nature of the bottom varies according to the locality. Thus, off the St Christoval coast, where the sediment brought down by the numerous large streams is in great part derived from volcanic rocks, the deposits forming in these depths consists of a dark calcareous mud sometimes foraminiferous and mixed with coarser volcanic detritus; while off the coasts of the small islands of Ugi and the Three Sisters, the bottom between these depths of 100 and 200 fathoms is formed for the most part of calcareous sand mingled with macroscopic foraminifera.† The material

* *Trans. Edin. Roy. Soc.*, vol. xxxii. part 3.

† From a depth of 100 fathoms there came up on one occasion dead coral fragments in addition to the sand.

brought up from depths between 200 and 400 fathoms were usually either a dark calcareous mud or a dark mud containing but little lime. In places the bottom seemed to be rocky with but little sedimentary matter.

I here append a few of the soundings which appear to be of special interest:—

420 fathoms.—Gravel (size $\frac{1}{5}$ of an inch) formed of a somewhat decomposed volcanic rock. A single valve of a delicate shell (*Leda*, sp.) was also brought up.

370 fathoms.—An almost impalpable dark-coloured non-calcareous mud or clay, of which a large portion appeared to be of vegetable orign, a low plant-growth or alga investing the minute siliceous grains.

350 fathoms.—A subangular fragment ($\frac{1}{2}$ an inch across) of some calcareous rock, with a portion of the shell of one of a species of the Balanidæ apparently recently fractured.

230 fathoms.—A single subangular pebble, almost an inch long, of a finely crystalline basic volcanic rock (spec. grav. 2·85). No accompanying mud or sand.

170 fathoms.—Small angular, probably crushed, fragments ($\frac{1}{5}$ of an inch) of a dark compact calcareous rock.

From the several soundings that were made between 100 and 400 fathoms in this locality, I came to the conclusion that the volcanic muds, which form the bulk of such islands as Ugi and many others in the Solomon Group, are at present forming off the coasts of reef-girt islands in depths greater than 100 fathoms. In the case of those portions of the coasts of the large islands, such as St Christoval, which on account of the sediment brought down by the streams are bare of reefs, the soundings of the survey have shown that these volcanic muds are forming at all depths from a few feet beneath the low tide level to a depth of some hundreds of fathoms.

Some of the principal points of this paper I will briefly summarise as follows:—

1. That fringing-reefs, barrier-reefs, and atolls exist in this group. They arrange themselves into two classes (*a*), those formed at the present sea-level, and (*b*) those that have been upheaved to

heights varying from a few feet to several hundred feet above the sea, which I have already treated in a previous paper.

2. That the numerous detached submerged coral shoals in these seas, which represent in fact the early condition of a coral reef, are not able, without the aid of a movement of elevation, to raise themselves to within the constructive power of the breakers. Being arrested in their upward growth at depths varying between 5 and 10 fathoms, according to the exposed or protected character of their situation, they form flat shoals of no great size.

3. That atolls of small size, *i.e.*, a mile or so across, do not assume their characteristic form until they have reached the surface. A small flat-topped shoal is first brought by upheaval to or above the sea-level. Lateral extensions or wings grow out on either side, so as to ultimately form a horse-shoe reef. Such a reef presents its convexity against the prevailing surface-currents, to which in truth it owes its shape. The southern island of the Three Sisters was evidently produced in this manner (*vide* p. 16). In some atolls, as in the instance of Oima Atoll (p. 21), one or more islets of volcanic rock have served as points from which the reef begins to grow, guided in its direction by the prevailing surface-currents. The foregoing remarks do not refer to large atolls. On account of their large extent they would probably have assumed their form beneath the surface, since, according to the principle laid down by Mr Murray, they would then have a relatively smaller periphery for the supply of food and sediment to the interior than would be possessed by the small submerged shoals above described.*

4. That the characters of the seaward slope of a reef are as follows:—For the first 70 or 80 yards from the margin of the reef-flat there is usually a gradual slope, largely bare of living coral, which terminates at a depth of from 4 to 5 fathoms in a rapid descent to a depth varying generally between 12 and 18 fathoms. It is this declivity that constitutes the growing edge of the reef, and the sand and gravel, produced by the constant action of the breakers, collect at its base.

5. That where there is a rapid submarine slope, *i.e.*, more than 10° or 12°, as is usually the case, the sand and gravel, produced in the manner just referred to, will extend far beyond the depths in

* *Proc. Roy. Soc. Edin.*, vol. x. p. 505.

which reef-corals thrive; but that in the case of reefs possessing a gradual seaward slope, *i.e.*, less than 5°, the lower margin of this band of detritus will lie within the zone of reef-building corals, and in consequence a line of barrier-reef will be ultimately formed beyond this band with a deep water channel inside.

6. That where the area is undergoing elevation, a succession of concentric lines of barrier reefs would thus originate, line after line being advanced, as fresh portions of the sea bottom are brought towards the surface, each line growing upward along the lower margin of the band of detritus derived from the line of reef inside it. In such a manner have the Shortland Islands been formed.

7. That the forgoing explanation of the formation of barrier-reefs in these islands is substantially the same as that proposed thirty years ago by Professor Joseph Le Conte in the instance of the Florida reefs. He then pointed out that since corals will not grow on muddy shores or in water upon the bottom of which sediment is collected, the favourable conditions can only be obtained at some distance from the shore, where a barrier-reef would ultimately be formed *limited on one side by the muddiness and on the other by the depth of the water.*

Since I was not acquainted with Professor Le Conte's view, my explanation has all the more value. The independent agreement of the two views is itself a third argument in favour of this mode of formation of barrier-reefs, which may now be briefly stated.

These reefs will only grow on gradual submarine slopes, *i.e.*, on those less than 5°; and since corals cannot thrive in the shallower depths on account of the accumulation of sand and the presence of sediment in the water, a reef can only be formed in the depths at some distance from the shore where these unfavourable conditions do not exist. If such depths are within the reef-coral zone, then a barrier-reef will be produced. The foregoing conditions may be described as the *determining causes* of a barrier-reef. After the reef has been formed, other agencies, such as solution, organic degradation, and the scouring action of tidal currents, will keep the lagoon-channel open.

The circumstance that barrier-reefs often exist at the margin of a submarine plateau, beyond which the slopes descend rapidly to great depths, has hitherto not been satisfactorily explained. I may cite the instances of the great Australian barrier-reef and of the barrier-reef of Bougainville Strait described in this paper (page 20). Such plateaux have a very gradual slope, and, provided that their outer margins are within the limits of the reef-coral zone, they would afford the most favourable conditions for reef-growth.

This explanation of the origin of barrier-reefs in no way affects the views at present held by Mr Murray, Professor A. Agassiz, Professor Semper, and others, concerning the formation of atolls. Atolls of small size may be produced in the manner referred to in paragraph three on page 41. Those of large size would assume their form, whilst still submerged, on account of the condition of the food-supply favouring the growth of coral at the circumference. When such a reef has reached the limits of breaker-action, the sand and detritus accumulating in its centre would repress in a greater degree the growth of the coral; and finally, after the reef has reached the surface, the lagoon would be further deepened by the solvent action of sea-water and by the organic degradation of the dead coral.*

Nor is my view of the origin of barrier-reefs inconsistent with that held by Mr Murray and other naturalists. The chief point of difference is that I do not consider that the agencies of solution, diminished food-supply, organic degradation, and tidal scour, are the determining causes of the formation of the lagoon-channel, but that they are auxiliary causes which come into play after the reef has begun to grow at that distance from the shore where the suitable conditions for reef-growth exist.

On the formation of fringing-reefs, my observations throw no additional light. These reefs, when occurring alone, often characterise steep submarine slopes, but they may accompany barrier-reefs on coasts where the slope is more gradual.

8. The statement that lagoons and lagoon-channels are sometimes deeper than the zone in which reef-corals thrive, is founded

* Mr H. O. Forbes, in his recent account of Keeling Atoll, refers to the welling up of dark sulphureous water in the lagoon, by which the corals, molluscs, fish, and other organisms were killed over a large area of the basin (*A Naturalist's Wanderings in the Eastern Archipelago*, 1885, p. 22). Such an agency can scarcely be exceptional, and probably takes a part in the formation of lagoons.

on a misconception of the conditions that limit the depth of this zone. All observations go to show that the depths at which reef-corals thrive vary greatly in different localities, the variation being due to differences of local conditions, such as the degree of inclination of the submarine slope, the presence of submarine declivities, the amount of sediment held in suspension, the force of the breakers, and other influences. The main determining condition is to be found in the injurious effect of sand and sediment rather than in the general influence of depth, and the distribution of these materials is dependent on the local conditions above referred to. Local conditions will usually restrict the reef-coral zone to depths less than 30 fathoms; but I have shown that where there is a gradual submarine slope, reef-corals are to be found in depths beyond the sand and gravel.* Since most observers, however, have regarded these materials as necessarily limiting the zone, they did not push their inquiries beyond. Under favourable conditions, reef-corals may thrive in depths of 50 or 60 fathoms, and thus we can readily explain the apparently abnormal depths inside some atolls and barrier reefs. The fact that I came upon some upraised massive corals resting in their position of growth on a partially consolidated ooze, which I never found in depths less than 50 fathoms, goes to support this view.

9. That proofs of the outward growth of barrier and other reefs on their own talus, a point to which Mr Murray attaches much importance, are to be found—

(*a*) In the circumstance that massive corals may be commonly observed to increase in size as one approaches the lagoon from the outer margin of the reef-flat.

(*b*) In the presence of old lines of erosion which have evidently been produced at the sea-level, but which have been cut off from the action of the waves by the advancing edge of the reef-flat.

(*c*) In the characters and position of the wooded islets, situated on reefs, which would, in course of time, cover the whole reef-flat, were it not for one counteracting circumstance, the outward growth of the reef.

* I found living reef-corals on one occasion at a depth of 40 fathoms.

10. That the deposits at present forming on the outer slopes of reefs in depths down to 100 fathoms consist largely of coral débris, Foraminiferous tests, especially *Orbitolites*, the joints of the calcareous alga *Halimeda opuntia*, and portions of *Nulliporæ*. Similarly composed deposits have been found in other regions of coral reefs in the same situation. A rock of this composition is one of the commonest types of coral limestone (so called) in the Solomon Group.

4. The Eggs and Early Stages of some Teleosteans. By J. T. Cunningham, Esq.

5. The Reproductive Organs of *Bdellostoma*, and a Teleostean Egg from the West Coast of Africa. By the Same.

6. A Synthetic Outline of the History of Biology. By Patrick Geddes.

To appreciate the present position of biological science, it is necessary to have a clear conception of the history. For this, abundant historical materials are indeed available, and reach their highest level in the standard works of Sachs* and Carus.† Such detailed histories, however, produce, by their very completeness, a measure of embarrassment. Moreover, the existence of numerous distinct lines of research, often equally prominent at the same time and in the same work, is apt to obscure the fact that the science has really had a simple and natural evolution. What the student demands is not so much any detailed chronological survey, but rather a sketch which will show how the whole system of modern biology, with its increasingly exhaustive analysis of detail, lies within a few essential lines of research, as laid down by a definite succession of original thinkers. This has already been done for the morphological aspect of the science in the author's article "Morphology," in the *Encyclopædia Britannica*, and for the physiological side more recently in Dr Michael Foster's article "Phy-

* *Geschichte der Botanik.* † *Geschichte der Zoologie.*

siology." Referring, then, for more extended treatment to these two sketches, it is the object of this paper, after (1) briefly recapitulating the main lines of progress in each case, (2) to make clear the essential parallelism in the evolution of these two aspects of biology, and (3) to make practical application of the synthetic outline thus reached.

§ 1. *Morphology.*—(*a*) We must regard Buffon as neither distinctly a morphologist nor physiologist, but as a general natural historian, whose wide and brilliant survey of all that was known of the forms and habits of organisms gave a semblance of order and method to the chaotic accumulations of the mediæval or "encyclopædist" school, which found in his famous *Histoire Naturelle* at once its monument and grave. Without forgetting the labours of Ray and other early systematists, we may fairly say that the modern period opens with Linnæus. He is to be noted here, not so much for his detailed labours,—for his introduction of binomial nomenclature, definition of the successively higher categories of species and genus, order and class, precision of descriptive terminology, and the like,—but more generally for that isolation of the conception of form from that of function, in which he laid the basis of the future science of pure morphology. The exhaustive catalogue of natural forms which Linnæus began was continued by his pupils and intellectual heirs. It is still in progress, as the recent "Challenger" expedition testifies. Each new species described means a leaf added to the *Systema Naturæ*, and the whole work has thus, as it were, been under continual revision and perfection by a constant succession of sectional sub-editors.

(*b*) The transition from the study of the general form to that of its component organs was made by Jussieu, and thence introduced into zoology by Cuvier. A new school of morphology arose, in which superficial description was supplemented by detailed anatomical research, and this line of advance has been followed up by a series of brilliant Cuvierians. The school is thus an unending one, to which every new descriptive anatomical research belongs as clearly as if it were published as an appendix to the *Règne Animal* itself.

(*c*) The next step is due to Bichât, who penetrated below the study of organs, and analysed the body into a series of simple tissues with definite structural characters. Here, again, a new movement—the histological—found its beginning, and thus, under the *Anatomie*

Générale, may be grouped not only the labours of his immediate school, but researches on embryonic layers and tissue structure, which form so large a proportion of recent literature.

(*d*) Histology had not, however, found in the study of tissues its ultimate basis. Yet a deeper mine of morphological inquiry was opened up when Schwann referred all plant and animal structure to its cellular type and origin. The tissue was analysed to a cell aggregate, and that study of cells in their form and structure, in their development and modifications, which still mainly occupies histologists, was thus fairly initiated.

(*e*) Finally, the researches of Dujardin, von Mohl, Schultze, and others directed attention from the cell as such to its all important component protoplasm. With this began a new epoch, in which a fundamental basis for the study of organic structure is sought in the investigation of protoplasm.

The history of morphology is thus that of a progressive analysis; the study of form, so well expressed in the labours of Linnæus, is succeeded by the study of organs in the comparative anatomy of Cuvier; while the histological movement inaugurated by Bichât's analysis of organs into tissues is developed in the study of cells which Schwann suggested, and finally in the investigation of protoplasm, which affords the latest and deepest problem of morphological research. No deeper analysis is possible, without passing out of morphology altogether into chemistry and physics, and we are thus warranted in regarding our analysis as practically ultimate. Along these five great lines of inquiry our morphological researches are still progressing towards exhaustiveness, and while all, or at least most, of these are combined in any exhaustive monograph, such as those of the Naples Station or of the "Challenger" expedition, it is yet in no way arbitrary to classify the labours of morphologists as being respectively continuations of the *Systema Naturæ*, the *Règne Animale*, the *Anatomie Générale*, the *Cell Theory* of Schwann, and Dujardin's description of protoplasm, or of one or more of these.

§ 3. *Physiology.*—(*a*) The early physiology, which had not shaken itself free from mystical interpretations of the processes of the body, but still clung to the hypotheses of animal and vital spirits and the like, was little more than a superficial study of habit and temperament. Of this non-analytic line of study Haller, though somewhat in advance of contemporary research, may be taken as a convenient representative.* It is still represented, of course, by many physiological naturalists, and such recent explanations as that of the origin of sex in terms of parental temperament, "superiority," &c., may be named as convenient instances.

(*b*) The progress of anatomical research could not, however, fail to show that many vital processes were associated with definite organs, and here begins that study of the functions of each organ taken as a whole, which formed for so long the sole problem of physiology. As a typical representative of this school we may perhaps name Johannes Müller.

(*c*) Bichât was, however, physiologist as well as morphologist, and in the physiological side of his *Anatomie Générale* function was referred below the mechanism of an organ to the fundamental properties of its component tissues. Bichât thus not only deepened both morphology and physiology by a new analysis, but showed them to coincide in the study of tissue. The plane of contact between the two subsciences being demonstrated, we can thus understand how Bichât was the first thinker who clearly formulated the conception of a united biology.

(*d*) With the advent of the cell theory, function, which had been referred from organ to tissue, had now to receive a yet deeper interpretation in terms of cell-structure. Such a cellular physiology was soon suggested by Goodsir, and developed by Virchow and his school.

(*e*) The interpretation of function in terms of organisation, which had thus been attempted at different levels, began even here to break down, and as attention was directed to the nature of protoplasm, physiology began to undergo what Foster well describes as a change of front. The physiologist must begin to read the riddle, alike of function and structure, in terms of the molecular changes (metabolism) within the protoplasm. These are distinguished as (*a*) the constructive, assimilative, synthetic, or "anabolic" changes,

* It must be noted that in the selection of these leaders of physiological inquiry, no dogmatic attempt is made to determine the relative claims of different pioneers. The need of vividness is sufficiently served by selecting names which must at least be allowed to be those of leading and characteristic types.

in which food is built up into more complex and unstable molecules; and (*b*) the destructive, disruptive ("katabolic") changes in which the protoplasm breaks down into waste products. In terms, then, of these physical and chemical processes of anabolism and katabolism, we have to explain the whole series of vital phenomena. The chemical appendix of the physiological manual has, so to speak, to become the book, and the present book the future appendix.

§ 2. In the former portion of this outline morphological research was traced through the study of form, organ, tissue, and cell, still it found its deepest expression in the investigation of protoplasm; and we have just seen how the phenomena of life, successively discussed as habits and temperaments, as functions of organs, as properties of tissues, and as modifications of cells, find their final empirical explanation in terms of protoplasmic processes. The progressive lines of inquiry are thus accurately parallel. The two sides of the science exhibit a precisely similar evolution.

The results of our survey may be conveniently summarised in the accompanying diagrams. The columns to the right and left of

MORPHOLOGY.					General Survey.	PHYSIOLOGY.				
Protoplasm.	Cells.	Tissues.	Organs.	Forms.		Habits and Temperament.	Functions of Organs.	Functions of Tissues.	Functions of Cells.	Functions of Protoplasm.
Dujardin.	Schwann.	Bichât.	Cuvier.	Linné.	Encyclop ↓ Buffon.	Haller.	Müller.	Bichât.	Virchow.	Bernard.

Fig. 1.

the middle line (fig. 1) indicate the various physiological and morphological lines of research. Under the names of the leading types, selected as representative, it is the task of a detailed history to fill in those of their followers.

If we suppose the diagram rolled into a cylinder, the meeting of the two edges will readily illustrate how, in the study of protoplasm, morphology and physiology come into ultimate contact. Again, if the diagram be folded along the middle perpendicular lines, a gradual unfolding from the centre outwards will, as column after column is exposed, illustrate the historic evolution of the science. The same facts are expressed in another way by the second diagram. The five horizontal lines indicate the different levels, along which morphological or physiological research has arisen and must proceed. Or we may conceive the diagram as representing a double series of five shelves, on which the literature of the different planes of research is disposed. The two series of classic works already

MORPHOLOGY (form)⟵ BUFFON ⟶PHYSIOLOGY (function).

L IN NÉ	Organism.	H AL LE R
C U VI ER	Organ.	M Ü LL ER
B IC H ÂT	Tissue.	B IC H ÂT
Sc H W A N N	Cell.	V IR CH O Ẇ
D. UJ AR DI N	Protoplasm.	B ER N AR D

Fig. 2.

referred to, unite to form literally the biological pentateuch of morphology and physiology respectively, to one or more of which each recent research, however "original," must, without exception, be simply regarded as a commentary, or as an appendix. For, since not *qualitatively* distinct, their originality is simply of a *quantitative* order.

Where, however, it may be asked, is the position on such a scheme of Darwin and other evolutionists? To some extent, indeed, on all the lines or levels. Their special labours are distinctly so classifiable, *e.g.*, the "Monograph of Cirripedia," mainly under

Linnæus, partly under Cuvier, and so on. But the conception of evolution cannot, of course, be classified with either of the sub-sciences of form or function, but rather they with it. Evolution considers form and function no longer statically, but in movement. The line of thought which follows out the conception of evolution cannot thus be represented in the above diagram; it lies in a third plane, and must be traced through the pile of accumulated concrete facts at right angles. Evolution bears, in fact, the same relation to morphology and physiology as history to statistics.*

§ 3. *Application.*—The preceding summary, if indeed just and accurate, will (*a*) enable the student to recognise the historic evolution in its naturalness and unity, and (*b*) afford a ready and orderly method of passing beyond the limits of his own immediate specialty towards the unravelment, nay, even the mastery, not indeed of the entire quantity, but of the whole essential literature of biology. But (*c*) a yet more important practical result is forcibly suggested by this bird's-eye view. If, as has been shown, morphology and physiology have alike found not only a deeper, but an ultimate contact, in the study of protoplasm, then we have travelled to the very limits of empirical research, and, qualitatively speaking, can go no further. As Foster suggests, a new departure becomes, however, possible. Without, of course, checking the detailed labours of morphologist and physiologist in developing any of the five inductive lines of inquiry, it is now incumbent on the biologist to interpret the results deductively in terms of their fundamental secret, nay, even to verify them by prediction. It is no longer sufficient to accumulate additional empirical detail, however interesting; what has been already gained must also be appreciated and rationalised. It is necessary, in short, to retrace the progress of the science, to interpret structure and function at all their levels, in terms of protoplasm, and thus furnish the deductive *rationale* of each hitherto merely empirical order of observed fact and connecting theory. If the waves of inductive research have reached their utmost (qualitative) limit, the possibility of returning on the reverse wave is now at least open, great though may be the risks. But a concrete example of this is still required. In the author's recent *Encyclopædia Britannica* articles, the phenomena of Reproduction and Sex

* *Cf.* the writer's "Classification of Statistics," *Proc. Roy. Soc. Edin.*, 1881.

(*q.v.*) have been discussed inductively; while the following paper applies the result gained to the deductive interpretation of organ, tissue, and cell in their connection with the reproductive function. In other words, these two attempts at the treatment of these subjects, traversing as they do the whole field of morphology and physiology, both vegetable and animal, affords a crucial test alike of the justice of the above historical outline, and of the practicability of its deductive application. In the *Britannica* articles, the facts of outward form and habit, the reproductive organs, tissues, and cells, are respectively described in the conventional (*i.e.*, inductive or empirical) order, and the required rationale of the whole series of phenomena (the theory of sex and reproduction) is finally reached (see "Sex," *Ency. Brit.*) in terms of the metabolism of protoplasm. The following paper attempts the reverse, *i.e.*, unconventional and deductive, yet rational method, the applicability of which has just been argued for; it postulates merely the simple and ordinary conception of protoplasmic metabolism, and successively deduces from this the form and essential functions of the reproductive cells, tissues, and organs, and even the external characters and temperament of the sexes.

7. Theory of Growth, Reproduction, Sex, and Heredity. By Patrick Geddes.

From the synthetic outline of the history of biology contained in a previous paper, the practical corollary was deduced, that it was now legitimate, if not indeed urgent, for the biologist to reverse the usual order of investigation, and instead of merely adding inductively to the categories (therein enumerated) of accumulated fact, boldly to set about interpreting these in terms of their fundamental secret,* that of constructive and destructive metabolism—anabolism and katabolism. Selecting a set of problems at once peculiarly comprehensive and peculiarly difficult, which the author has in recent

* As already noted in the previous paper, the physiologist no longer seeks to explain function in terms of organisation, but rather both in terms of protoplasm. It is thus necessary to postulate an acquaintance with the modern conception of protoplasm, for which reference may be made to M. Foster's *Ency. Brit.* article on "Physiology," and the writer's article on "Protoplasm." The general theory may be summarised in the accompanying

essays* discussed inductively, it is the object of the present paper to apply the modern conception of protoplasmic anabolism and katabolism to the phenomena of growth, reproduction, sex, and heredity. At different levels of analysis, attempts have indeed been made to rationalise these phenomena, the theories of sex alone being said to number hundreds, but it has been already pointed out that an interpretation of function in terms of protoplasmic changes is, in its nature at least, ultimate.

§ 1. *Growth.*—The first adequate discussion of growth is due to Spencer,† who pointed out that in the growth of similarly shaped bodies, the mass increases as the cube of the dimensions, the surface only as the square. Thus in the growing cell the nutritive necessities of the increasing mass are ever less adequately supplied by the less rapidly increasing absorbing surface. The early excess of repair over waste secures the growth of the cell, but the neces-

diagram. Protoplasm is regarded as an exceedingly complex and unstable compound, undergoing continual molecular change or metabolism. On the one hand, more or less simple dead matter or food passes into life by a series of assimilative, ascending changes, with each of which it becomes molecularly more complex and unstable. On the other hand, the resulting protoplasm is continually breaking down into more and more simple compounds, and finally into waste products. The ascending, synthetic, constructive series of changes are termed "*anabolic*," and the descending, disruptic series, "*katabolic*." Both processes may be manifold, and the predominance of a particular series of anabolic or katabolic changes implies the specialisation of the cell. The upper figure (A) represents the complex unstable protoplasm as if occupying the summit of a double flight of steps; it is formed up the anabolic steps, it breaks up and descends by the katabolic. The lower figure (B) is a projection of the upper, its convergent and divergent lines serving to represent the various special lines of anabolism and katabolism respectively, and the definite component substances ("anastates" and "katastates") which it is the task of the chemical physiologist to isolate and interpret.

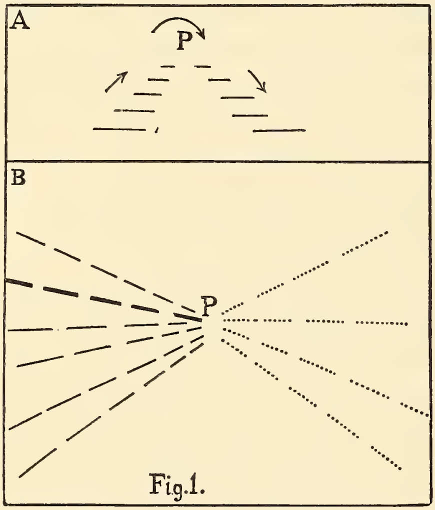


Fig.1.

* "Reproduction" and "Sex," *Ency. Brit.*, vols. xx. and xxi.

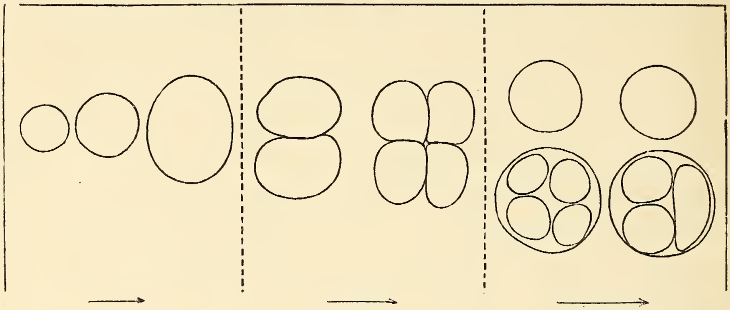
† *Principles of Biology.*

sarily disproportionate increase of surface implies less opportunity for nutrition, respiration, and excretion, and waste thus overtakes, balances, and threatens to exceed repair. Three alternatives are then possible ; (*a*) a temporary equilibrium may be established, and growth ceases, or (*b*) the increase of waste may bring about dissolution and death, or still more frequently (*c*) the balance of mass and surface may be restored by the division of the cell.

Now, these facts may be expressed in lower and more definite terms. The early growth of the cell, the increasing bulk of contained protoplasm, the accumulation of nutritive material, correspond to a predominance of processes which are constructive or *anabolic*. The growing disproportion between mass and surface implies a relative decrease of anabolism, while the simple continuance of life or metabolism entails a gradually increasing preponderance of destructive processes or katabolism. While growth continues, the algebraic sum of the protoplasmic process is of course + on the side of anabolism, and growth may thus be defined as the preponderance of an anabolic tendency, rhythm, or diathesis. The limit of growth, when waste has overtaken and begun to exceed the income or repair, corresponds in the same way to the maximum of katabolic preponderance consistent with life, in other words, to the climax of the katabolic diathesis. It is well known, for instance, that cell division occurs especially at night, when nutrition is at a standstill, and when there is therefore a relative katabolic preponderance.

Nor does this definition of the limit of growth apply only to cells, but also, of course, to cell-aggregates. The phenomena of growth in the history of tissue and organ, of organism and stock alike are expressible in terms of the anabolic and katabolic balance above referred to. The average size of the species, the length of its life, the advent of the reproduction which marks the beginning of death, must submit to be similarly rationalised. The palæontologist, even, may be enabled to understand the rationale of that attainment of great bulk exhibited by so many of the highest types of ancient as well as of modern faunas, and also of the constant tendency of such gigantic forms to extinction.

§ 2. *Reproduction* (*a*) *Asexual.*—It has been noted above that a continued surplus of anabolism involves growth, that this growth is sooner or later checked by the preponderance of katabolism, and that the most frequent alternative is the restoration of the balance by cell-division. To this physiological necessity, then, is referable (with



Continuous Growth. Continuous Cell÷ⁿ. Discontinuous Growth or Reproduction.

Fig. 2.

Spencer) the origin of discontinuous growth or *asexual reproduction.* Budding, simple-division, and spore-formation like continuous cell-division, are simply different forms of the necessary separation which must occur at the limit of growth, if the continuity of life is to be preserved. Like continuous cell-division, asexual reproduction occurs when waste or katabolic processes are in the ascendant. But what holds true in the growth of the individual cell, is valid also in regard to the aggregate. There, too, a limit of growth must eventually be reached, when discontinuous growth in some form becomes inevitable. The essential difference is simply that at first in the unicellular individual the disintegration and reintegration entirely exhaust the organism and conclude its individual existence, while in higher forms the process becomes more and more localised.

(*b*) *Sexual Reproduction: Phylogenetic Evolution.*—Turning now to the connection between asexual and sexual reproduction, it will be convenient, in the first place, to resume the facts of the phylogenetic evolution, and then to interpret these physiologically. The clear morphological account given by Vines (see his discussion of "Reproduction—Vegetable," *Ency. Brit.*) may be taken as a basis. (1) A simple protophytic alga like *Protococcus* usually exhibits a perfectly continuous asexual cycle, in which the cell divides into a number of equal spores which come to rest and develop to the normal size. A hint of incipient differentiation appears in the occasional division of the cell into a larger number of smaller spores, which settle down, however, and develop just like their more richly dowered neighbours. (2) In *Ulothrix*, again, both large and small spores may be formed by division, and both may simply come to rest and germinate. In such a case, however, the macrospores seem to form a weakly plant, unless they have previously united in pairs in conjugation. (3) The reproduction of *Ectocarpus* is also effected by macro- and microspores, and in this case the latter generally though not invariably conjugate. Between the conjugating forms, moreover, a certain physiological difference can be detected; some soon come to rest and settle down, and it is with these that their more energetic neighbours by-and-by conjugate. There is thus the beginning of a distinction between male and female elements. (4) Further, and more markedly, in *Cutleria* the two kinds of spores result from perfectly distinct sporangia, and the larger, less mobile *macrospores*, which soon come to rest, are fertilised by the smaller, more active microspores. Both the dimorphism and the fertilisation characteristic of sexual reproduction have thus become, in a measure, defined.

Let us now review these morphological facts in the light of protoplasmic processes. We see in *Protococcus* how spores of smaller size, that is to say, less predominantly anabolic, are yet able to develop independently; and that this also happens with the microspores of *Ulothrix*, resulting, however, in a weaker plant, while a more successful development may be ensured by a process comparable to mutual nutrition. Individually they are too katabolic for anything but weak independent development; in uniting, however, they are strong. The case of *Ectocarpus* is peculiarly instructive, not only in the association of more marked microspores with the almost constant occurrence of fertilisation, but also in the presence of two distinct conjugating types,—the comparatively sluggish, more nutritive, preponderatingly anabolic (female) cells, which soon settle down, and the more mobile, finally more exhausted and emphatically katabolic (male) spores. In *Cutleria* too the less mobile and more anabolic macrospores are fertilised by the more active and more katabolic microspores, which have now gone too far for the possibility of independent development.

In the Protozoa, also, amid the general occurrence of continuous cycles of asexual reproduction, we find hints of sexual dimorphism and fertilisation. Both among Radiolarians and Infusorians the conjugating elements may differ in size; in the *Volvocineæ* especially macro- and microspores occur, which may conjugate with one another, though the process is usually restricted to the latter.

The almost mechanical flowing together of exhausted cells, as illustrated in plasmodia, is connected through the known surviving cases of multiple conjugation with normal conjugation, and we have just seen how gradually the dimorphism appears which marks the transition from conjugation to fertilisation, and makes the latter indispensable. Enough has been said to indicate this extremely gradual differentiation of asexual into sexual reproduction. The very gentleness of the gradation leads one to regard the two processes as analogous responses to the same physiological necessities. The same disturbance of the balance between anabolism and katabolism which results in the occurrence of asexual reproduction, when continuous growth or continuous cell-division was no longer possible, leads, in more developed forms, to the separation of the dimorphic and mutually dependent elements of sexual reproduction. As asexual reproduction occurs at the limit of growth, so a check to the asexual process involves the appearance of the sexual, which is thus still further associated with katabolic preponderance.

The familiar history of the Aphides may serve as an illustration. During the summer months, with favourable temperature and abundant food, the Aphides produce parthenogenetically, generation after generation of females. The advent of autumn, with its attendant cold and scarcity of food, brings about the birth of males, and the consequent recurrence of strictly sexual reproduction. In artificial environment, equivalent to a perpetual summer, the asexual process may be prolonged for years, while a lowering of the temperature and diminution of the food at once reintroduce sexual reproduction. The occurrence of the latter is, in other words, associated with the setting in of conditions which make for katabolism.

This opposition between nutrition and reproduction, which, after life and death, is the most obvious antithesis in nature, is often taken advantage of for practical purposes. The removal of the reproductive organs, in flowers, for instance, increases the vigour of vegetative growth; while in the well-known expedient of root-pruning, nutrition is checked in order to favour sexual reproduction. Again we note the connection between the latter and katabolic ascendency, and thus the familiar generalisation that nutrition varies inversely as reproduction (perhaps most familiarly illustrated in the contrast between the leafy and spore-bearing portions of many ferns—*Osmunda*, *Botrychium*, &c.) admits of being more precisely restated in the thesis, that as a continued surplus of anabolism involves growth, so a relative preponderance of katabolism necessitates reproduction.

It is again on the present view readily intelligible why in the exceptionally favourable anabolic environment of bacteria and many parasitic fungi sexual reproduction should not occur. Marshall Ward* has pointed out that the more intimate the degree of parasitism or saprophytism, the more degenerate the sexual reproduction. The greater the anabolism, in other words, the more growth, and the less sexuality. That such comparatively complex organisms can continue their asexual reproduction, dispensing altogether with the acknowledged stimulus of fertilisation, may probably be, at least partially, explained by the presence of abundant waste products acting as extrinsic stimuli.

The relation of sexual to asexual reproduction, which has been already referred to in its phylogenetic history (p. 914), is sometimes beautifully illustrated in the life of the individual. There are, for instance, frequent reversions from the sexual to the asexual process, and from the latter to vegetative growth. Among cryptogams the sexual reproduction is sometimes suppressed; thus the fern plant, for instance, may spring from the prothallium asexually. Nor is it uncommon for the asexual reproduction by spores to be replaced by a continuous vegetative growth. In the flower-head of an *Allium*, again, we constantly find that some of the flowers have degenerated into asexual buds. A still more beautiful illustration of the conditions of genesis is afforded by the tiger lily. In this form growth at first tends to remain continuous, and the base of the bulb bears simple vegetative buds. Further up, however, where nutrition reaches its maximum, the axils of the leaves contain buds, which are separable though still asexual. Finally, further up still, where

* "Sexuality of Fungi," *Quart. Jour. Micr. Sci.*, xxiv.

nutrition is relatively lese active and katabolism is maximised, the formation of flowers indicates the appearance of sexual reproduction.

(*c*) *Alternation of Generations.*—The alternation between tapeworm head and proglottides, between fixed hydroid and swimming bell, between leafy fern plant and inconspicuous prothallus, and the like, are familiar facts, which have, however, been studied almost exclusively on their morphological side. Even on superficial inspection, however, of any of those numerous cases, where an asexual form alternates with one or more dimorphic sexual generations, it is evident that we have here to do in two generations with what is often so obvious in one—the familiar antithesis between nutrition and reproduction. A consideration of the physiological distinctions between the asexual and sexual generations, shows that the former is the expression of favourable nutritive conditions resulting in vegetative growth, or at most in asexual multiplication, while the latter is conditioned by less propitious circumstances. Just as a well-nourished plant may continue propagating itself by shoots and runners, and just as an Aphis in artificial summer may for years reproduce parthenogetically, so a hydroid with abundant food and otherwise favourable environment may be retained for a prolonged period vegetative and asexual, while dearth of food and otherwise altered conditions evoke the appearance of the sexual generation. That the tapeworm head, or the encysted scolex before it, should in a plethora of nutriment remain asexual, while the proglottides, further from the sources of supply, &c., exhibit sexual reproduction, conforms to what we have already seen in regard to the relation of the two processes to one another and to the conditions favouring anabolism or katabolism. The contrast between the deeply-rooted, well-expanded fern plant and the weakly-rooted, slightly-exposed prothallus, is obviously that between an organism in conditions favourable to the continuance and preponderance of anabolic processes, and that of an organism in an environment where katabolism is, at an early stage, likely to gain the ascendant, the former therefore is asexual, the latter sexual. A survey, in fact, of the conditions and characteristics of the two sets of forms inevitably leads us to regard the asexual generation as the expression of predominant anabolism, and the sexual as equally emphatically katabolic. Alternation of generations is indeed but a rhythm between a relatively anabolic and katabolic preponderance. The conception must be applied, however, not only to the general facts, but to specially difficult cases. Thus the peculiarity in the life-history of mosses, where the naturally vegetative or asexual generation is not independent, but grows, as it were, parasitically upon the sexual, explains the comparative failure of that line of evolution, and the more successful development of those other cryptogams in which the asexual generation, developing its predominantly anabolic tendency, finds sufficient foothold in the struggle for existence. So phenomena, like apogamy and apospory in ferns, the shortening of the sexual generation in phanerogams, and the like, must be analysed. In short, all the modifications of form, floral and other, in one or in two generations, must be explained—not in terms of "spontaneous variation," *i.e.*, by unaccountable variations in each special case, with natural selection varying also with circumstances for each special case, as has been usually believed and maintained—but in terms of the fundamental protoplasmic processes, by reference to the rhythm of anabolism and katabolism.

§ 3. *Nature of Sex.* A. *Inductive.*—In what has been already noted in regard to incipient sex, it was the object to indicate how sexual reproduction was related to the asexual process, and how both were associated with a preponderance of katabolism. There remains, however, the further problem of the real nature of sex, or the rationale of sexual dimorphism. In attempting to define the distinctive characteristics of male and female, it is necessary to begin with the sexual elements themselves. The difference between male and female is there exhibited in its fundamental and most concentrated expression. It is in the sexual elements, indeed, that the continuity of organic life is secured, the vegetative organisms being but appendages to the direct immortal chain of sex-cells. In comparing ovum and spermatozoon it is necessary, in the first place, to refer briefly to the possible phases of cellular life.

Starting from an undifferentiated and amœboid cell, it is a simple fact of observation that the continuance of life in varying environment opens up the possibility of great variation in the protoplasmic metabolism, so that the algebraic sum of anabolism and katabolism must vary within the widest limits. Suppose, then, a continued surplus of anabolism over katabolism,—the result is necessarily a growth in size, a reduction of kinetic energy and movement, an increase in potential energy and reserve food-material. Irregularities thus tend to disappear; surface-tension, too, may aid, and the cell acquires a spheroidal form. The result—a large and quiescent ovum—is thus intelligible enough. Again, starting from the amœboid cell, if katabolism be in growing preponderance, the increasing liberation of kinetic energy thus implied must find its outward expression in increased activity of movement and in diminished size; the more active cell becomes modified in form by passage through its fluid environment, and the natural result is the flagellate sperm-cell. The morphological characters of the sexual elements are thus expressible as the results of preponderant anabolism

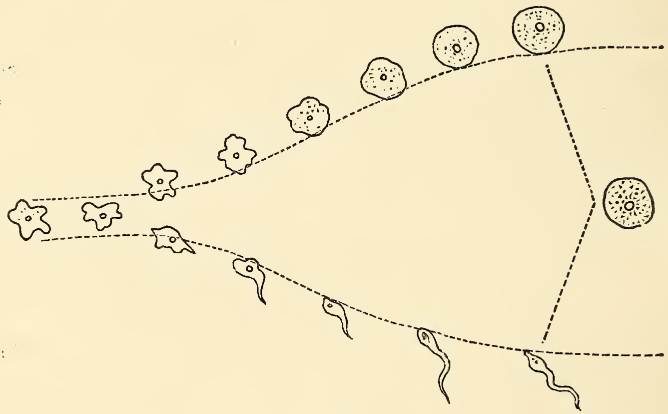


Fig. 3.

in the female and katabolism in the male. It would lead us too far at present from our direct argument to show how this applies to the Protozoa, which exhibit a practical coincidence of cell and organism, and which should be defined not so much as "organisms devoid of sexual reproduction," but rather as "undifferentiated reproductive cells (protosperms or protova, as they may in fact be called) which have not built round themselves a body." Not only do the Protozoa illustrate, in the great lines of their differentiation, and in the phases of their life-histories, the outcome of preponderant or equated anabolism and katabolism; but in the incipient dimorphism of two conjugating individuals or the macro- and microspores of higher forms, we find the primitive expression and fundamental secret of that difference which afterwards comes to saturate the whole body, and to effect what we know as sexual dimorphism. Without entering into detailed illustration, it will be instructive to select the case of Volvox. In this colonial organism, which is best regarded as a multicellular protist, the component cells are at first all alike. They are united by protoplasmic bridges, and simply form a vegetative colony. In favourable environmental conditions this state of affairs may persist, or be interrupted only by parthenogenetic multiplication. When nutrition is checked, however, sexual reproduction makes its appearance, and that in a manner which illustrates most instructively the differentiation of the two sets of elements. Some of the cells are seen differentiating at the expense of others, accumulating capital from their neighbours; and if their area of exploitation be sufficiently large, emphatically anabolic cells or ova result; while, if their area is reduced by the presence of numerous competitors struggling to become ova, the result is the formation of smaller, more katabolic, and ultimately *male* cells. In some species distinct colonies may, in the same way, become predominantly anabolic or katabolic, and be distinguishable as completely female or male colonies. Again we reach the conclusion of a predominant anabolism effecting the differentiation of female elements, and of katabolism as characteristic of the male.

(2) Another illustration may be selected. In the cells of a developing anther an enormous number of crystals may be often observed to occur. Crystals are, however, usually regarded as accumulations of waste products. These anther crystals are, in fact, comparable to urinary deposits. Such accumulations do not, however, occur in the embryo-sac or in the female organs in spite of the homology in male and female development. They occur as signs of katabolism where we would naturally expect them—in the tissue of the *male* organs.

(3) Or, again, in the structure of *Chara* or *Nitella*, there is, as is well known, an alternation between nodal and internodal cells. The internodal cells are actively vegetative, and go on increasing in size; they do not divide, and may be justly regarded as emphatically anabolic. The nodal cells, on the other hand, are much smaller, and do divide. They are to be regarded as relatively more katabolic.

A crucial test of the present theory thus suggests itself. Since the reproductive organs are simply, as every morphologist knows, shortened branch-structures, we should predict that the cell from the segmentation of which the antheridium is derived must correspond in position to a nodal cell (*i.e.*, be based upon an internode), while the corresponding essentially female cell or ovum must be internodal or apical in origin (*i.e.*, based upon a node). It is therefore not a little noteworthy that an examination alike of classical figures and fresh specimens will show that this imperfect homology, but perfect physiological correspondence, is invariably the fact.

(4) Similarly over a larger area, if we take a general survey of male and female forms, noting the distinctions of their form, function, and general habit of life, it will be seen that the males are upon the whole smaller, more active, with higher temperature, shorter life, &c., than the more vegetative, nutritive, and conservative females—the apparent exceptions presented among the higher animals being readily explained when we bear in mind the larger development of the male muscular system necessitated by the exceptional stress of external activities thrown on the male during the period of incubation or pregnancy, &c. Rejecting theories of "inherent" maleness or femaleness, it is yet evident that there must be some cause giving a bias to the general life,—some influence saturating the whole organism,—in fact, some predominant protoplasmic diathesis. An analysis of the differences in detail suggests the previous conclusion that the female is the outcome of preponderant anabolism, and the male of equally emphatic katabolism.

(5) An induction over another wide series of observations also confirms the result already reached. I refer to the researches on the determination of sex,* which, though incomplete, and in many cases divergent, have yet led to a few results which may be considered as fairly well established. Thus, when the male parent is older than the female, when it is in its physiological prime, when the sperms meeting the ova are young and fresh, when the conditions of nutrition and environment both for parent and offspring are defective or unfavourable, the offspring is likely to be *male*. On

* See "Sex," *Ency. Brit.*

the other hand, when the female parent is older than the male, when the female is at its physiological prime, when the ova fertilised are young and fresh, when food is abundant and environment favourable, the chances are distinctly in favour of the offspring being *female.* A few well-known cases may be briefly referred to. Thus old branches of conifers, overgrown and shaded by younger ones, produce only male inflorescences, and some fern prothallia in unfavourable conditions can still produce antheridia, but not archegonia. Male plants of hazel grow more actively in heat than the female, and *Stratiotes aloides* bears only female flowers north of 52° lat., and from 50° southwards only male ones. Caterpillars starved before entering the chrysalis state produce males, while others of the same brood highly nourished come out females. In his well-known tadpole experiments, Yung raised the percentages of females in one brood from 56 in those unfed, to 78 in those fed with beef, and in another from 61 to 81 per cent. by feeding with fish; while, when the especially nutritious flesh of frogs was supplied, the percentage rose from 54 to 92.

Now such conditions as deficient or abnormal food, high temperature, deficient light, moisture, and the like, are obviously such as would tend to induce a preponderance of waste over repair,—a *katabolic* diathesis,—and we have just seen that these conditions tend to result in the production of *males.* Similarly, the second set of factors, such as abundant and rich nutrition, abundant light and moisture, must be allowed to be such as favour constructive processes, and make for *anabolism,* and we have just seen that these conditions result in the production of *females.* The explanation has thus been reached, that in the determination of sex, influences inducing katabolism tend to result in production of males, as those favouring anabolism similarly to increase the probability of females.

B. *Sex—Deductive Interpretation.*—The theory may be confirmed, moreover, deductively as well as inductively, in proportion to the success of its interpretation of the various orders of phenomena, from the reproductive elements themselves to the sexual dimorphism of the entire organisms. Of this deductive rationale, however, only a few illustrative examples can here be given.

(1) In regard to the reproductive elements, numerous empirical results, hitherto little more than curiosities of observation, admit

of being rationalised. Thus, if the ovum be a predominantly anabolic cell, in an environment tending towards the increase of anabolism, the occurrence in so many groups of degenerate ova which are wholly nutritive becomes intelligible. They have passed the limit of normal anabolism, and have become too anabolic to divide. So the various kinds of spermatozoa, from the ordinary ciliated type to the sluggish amœboid form of many Arthropods, may be arranged according to the degree in which katabolism diminishes. The amœboid forms partly equipped with nutriment persist, as is well known, for a prolonged period, which would be quite impossible for the rapidly moribund ordinary types. Experimental researches like those of Zacharias and others on the action of reagents, &c., on sperms, such facts as the artificial reversion to the amœboid type, the attraction of sperms most powerfully to the most nutritive solutions, and so on, acquire a new meaning and importance.

(2) So, too, in the phenomena of maturation, the formation of polar vesicles seems rightly interpreted as an extrusion of the katabolic or male elements from the preponderatingly anabolic ovum. The close parallelism between spermatogenesis and oogenesis, which has been elsewhere insisted upon,* holds good here also. The extrusion of protoplasmic elements at various stages in spermatogenesis, but especially in the sperm mother-cell or spermatogonium, which is homologous with the ovum, may be similarly expressed as a separation of predominantly anabolic material. In this connection it is worth noting how Van Beneden and Julin have, in their researches on oogenesis and spermatogenesis in *Ascaris*, emphasised the exact morphological correspondence of the two processes. A further corroboration of a different character has been afforded in the microchemical demonstration of the similar staining reactions of polar vesicles in ova, and the blastophore remnant in spermatogenesis. Further, in the differentiation of the reproductive elements in most plants, certain elements are observed to be separated off, and these admit of being similarly

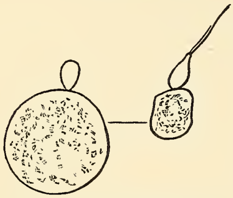


Fig. 4.—Oogenesis and Spermatogenesis.

* "History and Theory of Spermatogenesis," Geddes and J. Arthur Thomson, *Proc. Roy. Soc. Edin.*, 1886.

rationalised. In the history of the pollen grain Strasburger distinguishes the vegetative, apparently non-functional, from the generative or essential nucleus. On the present view, the latter would be regarded as emphatically katabolic, the other half as less so. Similarly, the basal portion of the zoospore-forming cell in certain Algæ, the unused remnant in the antheridium of *Salvinia* and other forms, the "Bauchcanalzelle" separated in the differentiation of Conifers and Archegoniates, and other cases noted by Strasburger and others, admit of being interpreted as separations of anabolic or katabolic portions, as the case may be. That such a separation may take place in cell division is illustrated on the present view, for instance, in the primitive reproductive cell of a *Sagitta*, which divides into two portions, afterwards developing to form ovary and testis respectively.

(3) In regard to fertilisation, which forms, indeed, the central problem of sex, numerous theories have been proposed; some authors, *e.g.*, Strasburger, asserting the absence of any essential physiological difference; while, according to others, like De Bary, the difference is indeed profound. Sachs suggested the analogy between fermentation and fertilisation, while Rolph regarded the process in its nature and origin as distinctly nutritive. It has been already noted, in regard to the origin of fertilisation, that the almost mechanical flowing together of exhausted cells is connected by the stages of multiple conjugation with the ordinary form of the latter, while the respective differentiation of the two elements effects the transition to fertilisation proper. Historically, then, fertilisation is comparable to mutual digestion, and the reproductive process has arisen from a nutritive want. With the differentiation of the elements along anabolic and katabolic lines, the nature of the fertilising act becomes more definite. The essentially katabolic male cell, getting rid of all accessory nutritive material contained in the sperm-cap and the like, brings to the ovum a supply of characteristic katastates, which stimulate the latter to division. The profound chemical differences surmised by some are intelligible as the outcome of the predominant anabolism and katabolism in the two elements. The union of the two sets of products restores the normal balance and rhythm of cellular life. Rolph's suggestion is thus included and defined.

Just as some zoospores may sometimes dispense with conjugation and germinate independently, so may ova develop parthenogenetically. These are to be regarded as incompletely differentiated forms which retain a measure of katabolic (male) products, and thus do not need fertilisation. Such a successful balance between anabolism and katabolism is indeed the ideal of all organic life. That the extrusion of polar globules has been observed in some instances, only shows that some katabolic products are still expelled. Just as in the disappearance of sexual reproduction in parasitic fungi, where surrounding waste products presumably serve the purpose otherwise effected by means of sexual organs, so peculiarities in the development of parthenogenetic ova may explain the retention of the normal balance which makes division possible without the usual stimulus afforded by fertilisation.

(5) The deductive interpretation must, however, be extended from the elements themselves to the associated tissues. In the present state of our knowledge, it is sufficient to suggest the interpretation of the phenomena of segmentation, or of the resemblances and divergences between that of the ovum and that of the spermatogonium. That the different modes of segmentation, in regard to which we barely know the morphological facts, must ultimately depend upon variations in the anabolic and katabolic rhythm is evident, though the nature of these variations is obscure. Nor in regard to later development can we do more than note that the physiological importance of the embryonic layers may be essentially expressed in terms of their respective predominance of anabolism and katabolism.

(6) In reference to the tissues of ovary and testis, tempting applications might be suggested. Hermaphroditism, for instance, is common in the undifferentiated embryonic stages, when the cell-diathesis is still to some extent undecided. Whether it occurs thus, or with casual or constant persistence in the adult, it is due to the local preponderance of anabolism and katabolism in one set of reproductive cells or in one period of their life. Van Beneden and others have suggested that the yolk-bodies (*vitellaria*) of the complex generative organs of many Platyhelminthes are to be regarded as degenerate ovaries. On the present view this seems extremely probable, and is expressible as the result of an over-nutrition resulting in a too completely anabolic preponderance. Other pathological

degenerations of the ovary will doubtless admit of similar description, while the abnormal regions in amphibian testes may be similarly referred to restriction of the area of predominant katabolism.

(7) The application of the conception of anabolic and katabolic rhythm to *organs and functions*, sheds a new light on several familiar processes. If the female sex be indeed preponderatingly anabolic, we should expect this to show itself in distinctive functions, and so it is. Menstruation is thus explained as the means of getting rid of the anabolic surplus in absence of the fœtal consumption. Just as it is intelligible that the process should stop after fertilisation, when replaced by the demands of the fœtal parasite, so the occurrence of lactation as the outcome of a still preponderant anabolism, and the final return of menstruation, become lucid and reasonable. So in a widely different region the distinctly anabolic overflow of nectar ceases at fertilisation, and the surplus of continued preponderant anabolism is drafted into the growing fruit. In the male, too, similar expression is given to preponderant katabolic diathesis. Even associated organs may be influenced by the general tendency. Thus the kidneys of the stickleback, greatly affected by mature testes, are known to produce special waste or katabolic elements in the form of mucous threads, which instinct has subsequently utilised in the familiar nest-building. So, too, various peculiar sexual functions, such as those frequently associated with the maturation of the sexes, will doubtless admit of being explained not merely (and more or less metaphysically) as the result of sexual selection, but really and ultimately as the outcome of anabolic or katabolic preponderance.

(8) The general average difference in *form and habit* between male and female has been already referred to as an inductive argument in support of the theory that the males are predominantly katabolic, and the females as emphatically anabolic. Conversely, the fundamental conception of protoplasm, *i.e.*, life, may be applied to the interpretation of the details both of form and habit. Thus, every one is familiar with cases such as Bonellia, Rotifers, and Cirripedes, where the males are mere pigmies in comparison with the females. Here a long continuance of predominant katabolism has brought its peculiar nemesis. Where the reproduction of the female throws a larger share of energising

on the shoulders of the male, the latter may exceed in size; and the same may result in instances, like that of the drones, where the activities are excessively low. In regard to general features, then, such as higher temperature and greater activities in the males, and in reference also to secondary sexual characters, it is no longer sufficient to explain these teleologically in reference to sexual selection; both essential and secondary peculiarities must be explained as the results of preponderant anabolic or katabolic diathesis in the two sexes.

§ 4. *Heredity.*—Since the theories of heredity will be discussed in a future paper by my friend Mr Arthur Thomson, the subject shall be referred to here only in briefest outline. To explain the likeness of offspring to parent numerous hypotheses, both physiological and physical, have been suggested, which, though perhaps too mystical in their present forms, will yet, to some extent at least, admit of being re-expressed in the more real and definite terms of protoplasmic changes.

An important line of investigation, first noted by Jäger, but recently followed up and corroborated by Nussbaum, and especially by Weismann, emphasises the fact that, in many cases at least, the future reproductive elements are isolated from the germ at an early stage in the development, and, in some cases, before the differentiation of the body-cells. In the direct continuity between the rudimentary reproductive organs of the embryo and the parent ovum, there is a continuity of protoplasm, which is in itself a partial explanation of the continuity in history.

Now, if the reproductive elements start with a specific protoplasm continuous with that of the combined mother ovum and fertilising sperm, that is, with a concentrated accumulation of characteristic anastates and katastates, the simple fact that the products of protoplasmic change must be fixed, definite, and continuous, as in all chemical processes, gives us at once a protoplasmic basis from which to explain the constant and necessary symmetry of segmentation and development.

On the other hand, if there be cases where the superficial characters acquired by the individual parent are transmitted to the offspring, apart from the result of similar environment and experience, it must not be forgotten that all the organs of the body do to a certain extent share mutually in nutriment and in waste products, and that thus, besides the characteristic specific protoplasm acquired through direct continuity, both germinal cells and developing embryo may accumulate a proportion of characteristic anastates and katastates, acquired as it were "pangenetically" from the organs of the body.

§ 5. Much of the above interpretation may be summed up in reference to the genealogical tree. Starting from one of the familiar diagrams (*a*) expressing the genetic relationships of the various forms, the accompanying figures represent magnified fragments of the tree. The second figure (*b*) expresses the continuous alternate series of sex-cell and organism, the latter becoming less and less distinguished from its parent cell until the two practically coincide in the Protozoa. The parallel one (*c*) shows how the continuous immortal stream of protozoan life, which Weismann has so well described, is continued by that of the reproductive cells among higher animals. The gradually enlarging leaves of the tree, which represent individuals, express in their relation to the base the gradual differentiation of the reproductive process, which is at first coincident with the disintegration and reintegration of the entire organism, but becomes as we ascend more and more localised, the individual life also surviving more and more completely the katabolic and at first fatal act of reproduction. To represent the two sexes, a second

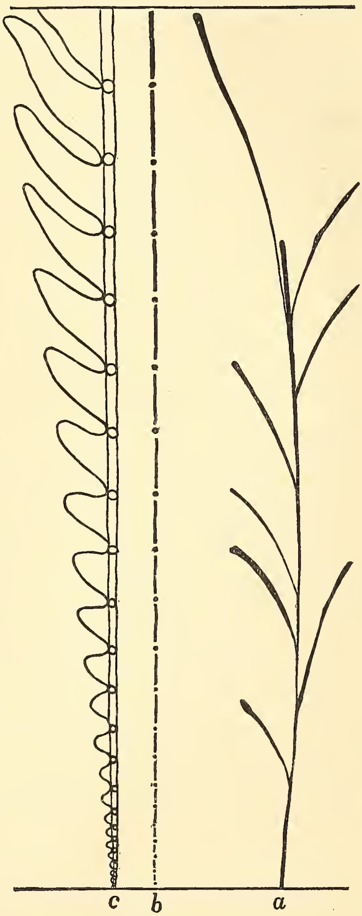


Fig. 5.

set of "leaves" should be added, and thus to fig. *c* there should be apposed another similar figure, yet divergent enough to express the difference between the sexes. The mode of representing the process of "alternation of generations," already explained at p. 918, will readily suggest itself.

In short, then, when the genealogical tree has thus been magnified until we can study the succession of organisms which compose it, we find that the explanation of the morphological and physiological phenomena which this succession presents and involves (*i.e.*, those of growth, reproduction, sex, and heredity) becomes raised from the plane of detailed, un-coordinated, and empirical observations and hypotheses, to that of a generalised and verified rationale or *law*, by the deductive application (which the historic survey of the preceding paper showed to be at once legitimate, urgent, and profitable) of that simple principle which is fundamental in biology.

We thus come to understand the phenomena of heredity and growth, of reproduction and sex, as a continuous series of expressions of whole activities of the organism; and thus the marvellous phenomena of sex are seen to be no isolated ones, but, in animal or plant alike, the highest outcome, the literal blossoming, of the individual life.

At this point the present exposition naturally closes, since its obvious applications to the problems of human life cannot be entered on within the present paper. Yet a new and vaster deductive application of the same principle must be indicated. For if the details of the genealogical tree be thus explained, so also may the curves, the general direction, nay, the very origin, of its branches; *i.e.*, the problem of those variations which we know as sexual, leads us to the problem of variations in general; it enables us to look forward to the solution of the problem of ætiology in deeper terms than those of "natural selection" alone, as illustrations of a continuous rhythm of anabolic and katabolic change.*

NOTES.

1. (P. 917.) A thoroughly parallel instance of the association between a specially anabolic environment and the non-occurrence of sexual reproduction is afforded by the recent observations of

* See "Variation and Selection," in forthcoming volume of *Ency. Brit.*

Jaworowski on "Chironomus" (*Archives Slaves de Biologie*, 1886). He finds that by rupture of the ovarian membrane the ova fall into the body-cavity, and there develop rapidly to form larvæ without fertilisation. "The great abundance of nutritive material replaces the effect of fertilisation."

2. My attention has recently been called by Mr H. B. Brady to the phenomenon of "Dimorphism" exhibited by certain Foraminifera, and which has been hypothetically interpreted as possibly of sexual nature by De la Harpe. An inspection of De la Harpe's figures seems to me to render it clear that this explanation is just (the objection of Munier-Chalmas that sex is unknown in Protozoa notwithstanding). The form named *Nummulites Lamarckii*, as better grown and less modified, with fewer partitions, and a *grand loge central*, seems to me distinctly the anabolic or female; the other, *N. lævigata*, since smaller and more modified, the male.

3. I have finally to record my obligations for much help, both in the discussion and preparation of the present paper, to my friend Mr J. Arthur Thomson.

PRIVATE BUSINESS.

Mr Robert Kidston, F.G.S., and the Rev. H. G. Bonavia Hunt, Mus.B., &c., were balloted for, and declared duly elected Fellows of the Society.

Monday, 19th July 1886.

ROBERT GRAY, Esq., Vice-President, in the Chair.

The following Communications were read:—

1. On the Colours of Thin Plates. By the Right Hon. Lord Rayleigh.

2. Ueber algebraische Knoten. Von Dr Franz Meyer a. o. Professor in Tübingen. (Plates XXXI., XXXII.)

Die ersten Untersuchungen von Herrn Tait über "Knoten," zusammengefasst in der grösseren Arbeit,* *Phil. Trans. of Edin-*

* Auf diese beziehen sich die im Texte gemachten Verweisungen.

burgh, 1877, veranlassten mich, im Jahre darauf, auch *algebraische* Curven vom *topologischen** Gesichtspunct aus zu studiren und zu classificiren (Münchener Dissertation, in Commission bei Mayer und Müller in Berlin).

Zunächst boten sich die rationalen ebenen Curven dar, und unter ihnen wiederum diejenigen vierter und fünfter Ordnung, welche lauter *reelle* Doppelpuncte mit reellen Zweigen besitzen. Nicht bloss die von H. Tait aufgestellten Eintheilungsprincipien der Knoten, sondern auch seine Schemata waren dabei für mich von Nutzen.

Seitdem sind die topologischen Untersuchungen von Herrn Tait (*loc. cit.*, 1884, 1886), Kirkman (*loc. cit.*, 1884, 1886), und Little (*Trans. of the Connecticut Academy*, 1885) fortgesetzt, indem ebene Knoten mit 8, 9, 10 crossings hereingezogen wurden. Von anderer Seite her haben namentlich Simony (*Mathem. Annalen*, von Klein u. Mayer, xix., sowie eine fortlaufende Reihe von Publicationen in den Wiener Sitzungsberichten) und Koller (*Wiener Berichte*, 1885) neue topologische Gesichtspuncte entwickelt. Auch die Arbeit von Weith (Züricher Dissertation, 1876) brachte einige neue Bemerkungen. Endlich hat Brill (*Mathem. Annalen*, von Klein u. Mayer, xviii.) einen topologisch-algebraischen Beitrag zur Verschlingung von Raumcurven geliefert.

Wenn diese Arbeiten auch keinen directen Bezug auf meine damalige Studie hatten, so zeigen sie doch, wie das Interesse für dieses Gebiet der Anschauungs-Mathematik seitdem gewachsen ist. Sie boten daher die Veranlassung, meine damals mehr auf *empirischem* Wege gefundenen Resultate einer sorgfältigen Neubearbeitung zu unterziehen. Diese lieferte einmal einige Berichtigungen und nicht unwesentliche *Ergänzungen* (über welche weiter unten), vor Allem aber eine *strengere, algebraische Begründung.*

Im Folgenden erlaube ich mir, einen kurzen Auszug meiner Untersuchungen vorzulegen. Um aber die ursprüngliche topologische Natur derselben nicht zu sehr zu verwischen, habe ich mich in den *algebraischen* Zugaben auf das Nothwendigste beschränkt.

In § 1 findet man eine gedrängte Zusammenstellung der *topologischen* Sätze und Methoden, die bei Behandlung *algebraischer* Knoten zu Grunde zu legen sind. Es folgt sofort die Anwendung auf die

* Dieser Name ist der grundlegenden Arbeit von Listing (Göttinger Studien, 1847) entnommen.

rationalen Curven vierrte (§ 2) und fünfter Ordnung (§ 3). Auf diesen Theil beziehen sich die drei Schemata-Tabellen, wie die Figurentafeln, welche am Schlusse angehängt sind: nur die letzten 15 Figuren gehören zu § 4.

Diese Betrachtungen werden in § 4 *umgekehrt*, und so eine neue *algebraische* Darstellung der einfachsten Tait, schen Knoten gewonnen.

Der zweite Abschnitt bringt die *algebraischen* Hülfsmittel behufs Erbringung der Beweise für die *Existenz* der vorher aufgestellten Typen. Dies geschieht einmal mit Hülfe von *quadratischen Transformationen* (§ 5). Zweitens aber—und dies ist der Weg, auf dem die *gezeichneten* Curventypen erhalten worden sind—unter Anwendung eines einfachen *Deformationsprocesses*, welcher lehrt, wie man von *zerfallenden* rationalen Curven zu *eigentlichen* in continuirlicher Weise gelangt. Diese Deformationen lassen sich, gerade für den Fall der Curven vierter und fünfter Ordnung, wiederum auf *quadratische Transformationen* (§ 6) stützen, in allgemeinerer und durchsichtigerer Art jedoch auf ein *Projectionsverfahren* (§ 7).

Die Combination beider Methoden liefert in § 8 eine dritte, welche zu den Resultaten des § 4 führt.

Zum Schluss werden gewisse *algebraische Relationen* entwickelt, welche den inneren Grund dafür enthalten, dass bei den rationalen Curven *fünfter* Ordnung eine ziemliche Anzahl von Typen *nicht existiren können.*

I. Algebraisch-topologische Knoten.

§ 1. *Die Schemata algebraischer Knoten.*

Wir recapituliren in Kürze* die Modificationen, welche die von H. Tait im Jahre 1877 über ebene "topologische" Knoten entwickelten Begriffe und Sätze zu erfahren haben, wenn ihre Uebertragung auf *algebraische* Curven stattfinden soll.

Es liege ein ebener, geschlossener Curvenzug C vor, der auch mehrmals *durch's Unendliche* laufen darf, mit den Knotenpuncten A, B, C. . . . . Diese werden beim Durchlaufen von C in einer gewissen *Folge* passirt, etwa :—

ACBACBD . . .

die das "*Stellenschema*" von C heissen soll.

* Ausführlicheres findet man in meiner Dissertation von 1878.

Dabei sollen auch "Schleifen" von der Form AA (die auch durch's *Unendliche* gehen können), und überhaupt die von H. Tait so genannten "*nugatory crossings*," wie BDFEDFEB* *gestattet* sein.

Ist C ganz im *Endlichen* befindlich, so sind nach H. Tait je zwei gleiche Buchstaben, wie A, A durch eine *gerade* Anzahl anderer getrennt. Dann ist es erlaubt, die Bezeichnung so zu wählen, dass an erster Stelle des Schema's A steht, an dritter B, an fünfter C, etc. und man kann das Schema auf das der *geraden* Stellen, "*reduciren.*"

So ist das Schema ACBACB des "trefoil Knot" (*loc. cit.*, pg. 153) reducibel auf CAB.

Es gilt nun der Satz: "*Läuft die Curve C eine ungerade Anzahl von Malen durch's Unendliche, so ist ihr Stellenschema ein reducibles.*"

Man unterwerfe nemlich die Curve C einer Inversion (*i.e.*, Transformation durch reciproke Radien), deren Mittelpunct O nicht auf der Curve liege. Dadurch geht die Curve C, die $(2l+1)$-mal durch's Unendliche gehen möge, über in eine Curve C mit $(2l+1)$ fachem Punct in O, die aber, von letzterem abgesehen, dieselbe Folge der Knotenpuncte aufweist, wie C. Variirt man jetzt die Curve so, dass sich der $(2l+1)$-fache Punct O zerspaltet in $(2l+1)\frac{2l}{2}$ einfache Knotenpuncte, so trägt jeder von den durch O gehenden Zweigen nach der Variation eine *gerade* Anzahl (nemlich $2l$) von Knotenpuncten. *Streicht* man daher im Stellenschema der *endlichen* (variirten) Curve C′ diejenigen Buchstaben, welche den aus O hervorgegangenen Knotenpuncten zugehören, so bleibt es ein *reducibles* (*q.e.d.*).

Läuft dagegen die Curve C eine gerade Anzahl, 2m, von Malen durch's Unendliche, so kann man ihr Stellenschema im Allgemeinen erst dadurch zu einem reduciblen machen, dass man es *ersetzt* durch das der variirten Curve C′.

Für $m=1$ tritt auf diese Weise nur *ein* weiterer Knotenpunct in das ursprüngliche Schema ein (Dieser Fall tritt in § 2 ein).

Wir wenden das Gesagte auf diejenigen algebraischen Curven an, die den geschlossenen topologischen am nächsten stehen, nemlich auf die (aus *einem* reellen Zuge bestehenden) *rationalen*, ebenen

* D. h., wo zwischen zwei gleichen Buchstaben, wie B, B, jeder andere Buchstabe zweimal auftritt.

Curven n^{ter} Ordnung "R_n" mit *lauter* reellen, eigentlichen (d. i. mit reellen, getrennten Tangenten versehenen) Doppelpuncten A, B, C, . . . Jedem einfachen Punct von R_n kommt ein, und nur ein reeller Zahlwerth λ,* sein "*Argument*" zu, das ihn repräsentirt: jedem Doppelpuncte, z.B. A, zwei Argumente A_1A_2. Trägt man diese in das Stellenschema von R_n ein, so geht es über in eine gewisse *Folge von reellen Zahlwerthen.*

Wir sagen, die Curve R_n besitze a unzerstörbare "*Asymptoten,*" wenn a die *Minimalzahl* von reellen Schnittpuncten ist, welche R_n im Schnitte mit einer Geraden aufweisen kann.

Dann kann man sie nemlich stets in eine solche zweite Curve R'_n mit gleichem Stellenschema projiciren, so, dass R'_n nur a-mal durch's Unendliche geht.

Ist a ungerade, so ist das Stellenschema von R_n ein reducibles; ist aber a gerade, so substituiren wir das reducible Stellenschema der nach obiger Methode invertirten und variirten Curve.

In beiden Fällen setzen wir das Schema in der *reducirten* Form voraus. Treten K Knotenpuncte im reducirten Schema auf, so kann dasselbe in 4 K Formen (von denen auch verschiedene identisch sein können) gebracht werden. Denn es kann das Zeichen A succ. *jedem* Doppelpuncte beigelegt werden, und von jedem kann man in vier verschiedenen Richtungen längs der Curve fortgehen. Da diese 4 K Formen nur aeusserlich verschieden sein können, so setzen wir fest:

"Zwei R_n sollen zu demselben '*Stellentypus*' gehören, wenn ihre reducirten Schemata demselben Systeme von 4 K Formen angehören."

Die Untersuchungen von H. Tait zeigen, dass die weit überwiegende Mehrzahl von Schemata nicht durch wirkliche ebene Knoten *realisirt* werden können. Entsprechendes gilt für die R_n: hier ist aber der Grund dieser Thatsache unmittelbar ersichtlich.

Denn zwischen den $\frac{(n-1)(n-2)}{2}$ Argumentenpaaren der Doppel-

* Ein solches "Argument" λ kann auch für jeden Punct eines *topologischen*, endlichen (oder auch unendlichen) Knotens construirt werden. Ist nemlich l die Länge der Curve, s der von einem festen Ausgangspunct längs ihrer gemessene Bogen, so spielt jede eindeutige, einfach-periodische Function von s (mit der Periode l) genau die Rolle von λ. Einen unendlichen Knoten *invertirt* man zuvor in einen endlichen.

puncte einer R_n herrschen gewisse algebraische Relationen: *jede Folge der Argumentenpaare, die diesen Relationen genügt, ist realisirbar und umgekehrt.*

Neben dem Stellenschema hat H. Tait noch ein "Felderschema" aufgestellt. Durch eine geschlossene, endliche, ebene Curve wird die Ebene in eine Anzahl von *Feldern* eingetheilt, deren *Ecken* von den Knotenpuncten gebildet werden. Ueberschreitet man den Contour der Curve in einem einfachen Puncte, so gelangt man von einem *positiven* Feld in ein *negatives* u. umg.

Das "*Felderschema*" giebt an, wieviel Ecken jedem der positiven resp. negativen Felder zukommen. So z. B. für den "trefoil knot":—

$$\left\{\begin{matrix} 3,\ 3 \\ 2,\ 2,\ 2 \end{matrix}\right\}$$

Unter dem "*Felderschema einer R_n*" soll dasjenige der invertirten (aber nicht weiter variirten) Curve verstanden werden. Es tritt im Folgenden nur in zweiter Linie, und als Ergänzung auf. Wir gehen jetzt über zur speciellen Behandlung der einfachsten Fälle $n = 4$ und 5.

§ 2 *Die Typen der R_4.*

Die R_4 hat drei Doppelpuncte (α_i, β_i) $(i = 1, 2, 3)$, Die 6 Argumente α_i, β_i sind ganz willkürlich (*cf.* § 9). Man erhält 5 Typen (*cf.* die Schemata der Tabelle III. und die Figuren, Blatt I.), die sich bereits bei H. Brill * befinden. Jedem Stellenschema gehört nur *ein* Felderschema zu, und umgekehrt. Die reducirten Schemata der beiden Typen (4) und (5) mit zwei Asymptoten sind:—

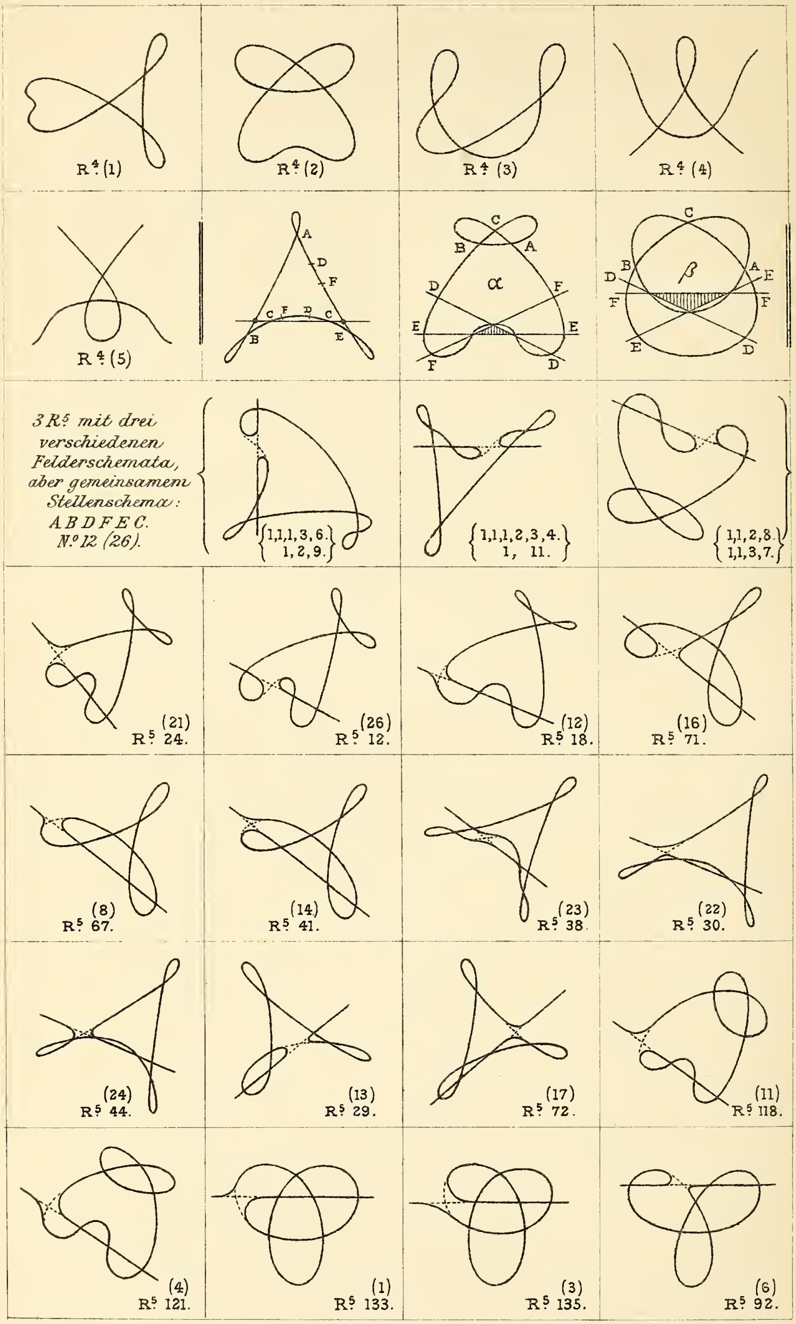
(4) A D B C

(5) C D A B

wo in (4) D den, die beiden unendlich fernen Puncte der Curve repräsentirenden, Doppelpunct angiebt, während dies in (5) jeder der 4 Buchstaben leistet. *Umgekehrt* zeigt man leicht, dass alle aus 4 Buchstaben herstellbaren reducirten Schemata (die auch Schleifen aufweisen können), wenn sie R_4 darstellen sollen, nur zu (4) und (5) führen.

Für die Aufstellung der Typen der R_5 (*cf.* § 3) ist es unbedingt erforderlich, sich von der *Existenz* und *Lage der reellen Wendepuncte* bei den R_4 Rechenschaft zu geben.

* *Mathem. Annalen*, von Klein & Mayer, XII.



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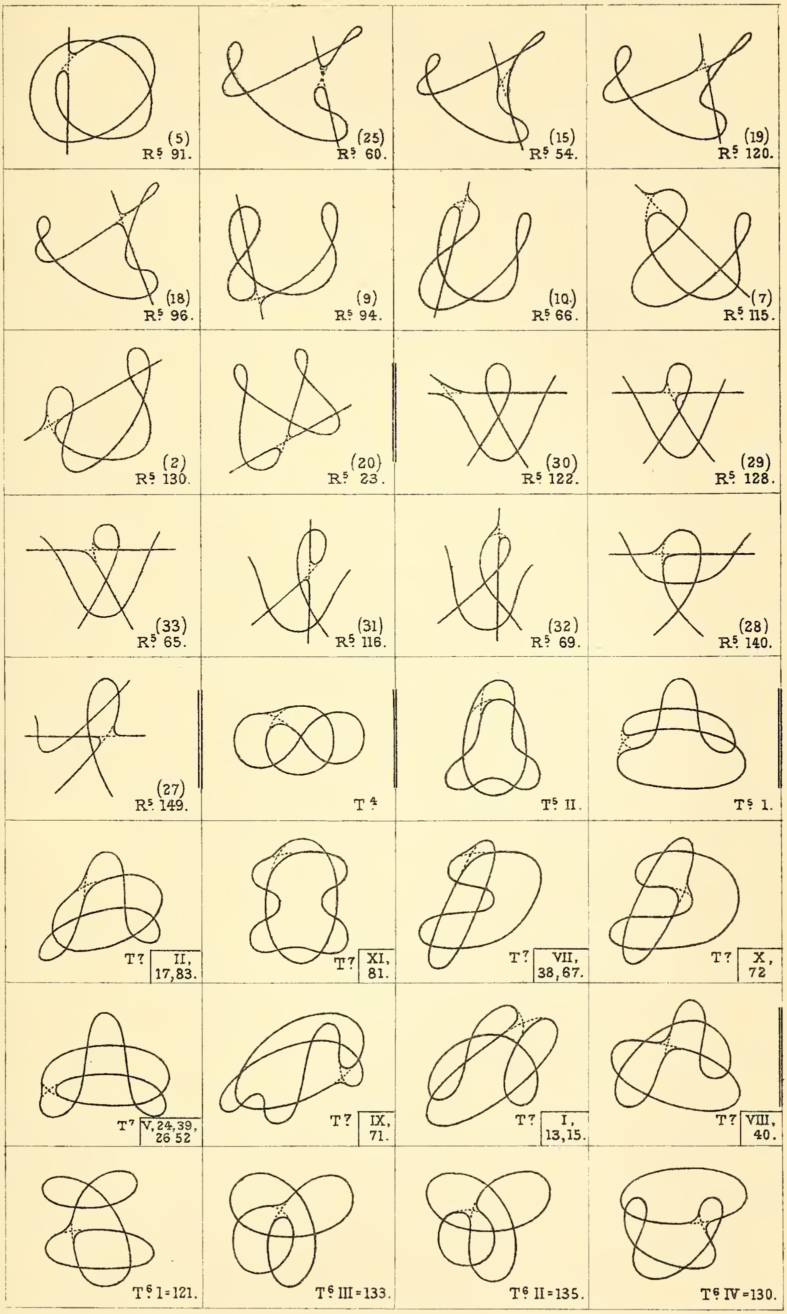

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Nach der von H. Klein * aufgestellten allgemeinen Formel besitzt die R_4 entweder zwei reelle Wendepuncte, oder keinen (und dann eine isolirte Doppeltangente).

Mittelst der im zweiten Abschnitt entwickelten algebraischen Methoden lässt zich zeigen, in welchen Fällen zwei reelle Wendepuncte auftreten können, und auf welchen Zweigen der R_4 sie sich dann befinden.

So z. B. kann der eine der beiden Wendepuncte im Typus (3) auf einer Schleife liegen, oder auf einem der übrigen (passend gewählten) Verbindungszweige.

Dadurch wird es möglich ALLE *Lagen einer Geraden, die vier reelle Schnittpuncte mit der R_4 gemein haben soll, einer R_4 gegenüber zu bestimmen d.h. man kann* GENAU *angeben, welche Zweige der R_4, und wie oft jeder einzelne, von einer Geraden getroffen werden können.*

Nur dadurch gelingt es, *alle* Typen der R_5 mit Hülfe des (unten erörterten) Auflösungsprocesses aus den R_4 herzuleiten.

§ 3. *Die Typen der R_5* (*cf.* die Figuren auf Blatt I., II.).

Eine R_5 hat eine oder drei Asymptoten. In beiden Fällen sind die Stellenschemata der sechs Doppelpuncte von vorn herein reducirte. Man hat daher *alle* reducirten Schemata für sechs Buchstaben aufzustellen, und nachzuweisen, welche von ihnen realisirbar, und welche es nicht sind. Das Letztere wird öfters eintreten, da (*cf.* § 9) zwischen den sechs Argumentenpaaren der Doppelpuncte drei Relationen herrschen.

Die Zahl der Schemata ohne Schleifen (*cf.* Tabelle II.) ist 80, wie auch H. Tait angiebt. Diese ziehen sich aber auf nur 9 wirklich verschiedene zusammen (die in der Tabelle durch einen *Stern* markirt sind). Von diesen sind 4 die Schemata der von H. Tait aufgestellten endlichen Curven, nemlich No. 121, 130, 133, 135. Diese führen zu R_5 mit einer Asymptote, während aus vier weiteren, nemlich No. 122, 128, 140, 149 R_5 mit drei Asymptoten hervorgehen.

Nur ein einziges Schema No. 127 ist nicht realisirbar: dieses ist in der That nicht einmal als endliche Curve, die noch ausserdem einen dreifachen Punct besitzt, zu construiren.

Die Zahl der Schemata mit Schleifen beträgt in erster Aufstel-

* *Mathematische Annalen* von Klein & Mayer, X. pg. 200.

lung 5 ! = 120 (*cf.* Tabelle I.), da man *einer* Schleife stets die Bezeichnung AA beilegen kann.

Diese ziehen sich auf 44 wirklich verschiedene zusammen. Von diesen sind 25* realisirbar, davon 3 durch R_5 mit drei Asymptoten. In der That sind die letzteren, No. 65, 69, 116 überhaupt nicht realisirbar durch *endliche* Knoten.

Kein realisirbares Schema (von den 33, die es thun) *führt gleichzeitig zu einer* R_5 *mit* EINER *und* DREI *Asymptoten.*

(Dies gilt nicht mehr für R_n, wo $n > 5$).

Die 33 *Stellentypen der* R_5 *besitzen auch* 33 *verschiedene Felderschemata* (die in dieser kurzen Mittheilung unterdrückt sind). Umgekehrt aber kommt es häufig vor, dass einem *einzigen* Stellentypus *mehrere* Felderschemata zugehören.

So z. B. kann der Stellentypus No. 12 (26) † durch *drei verschiedene* Felderschemata repräsentirt werden (*cf.* Blatt II.).

§ 4. *Algebraische Darstellung topologischer Knoten.*

Im Vorhergehenden haben wir algebraische Knoten auf topologische (endliche) Knoten zurückgeführt: jetzt soll das Umgekehrte geschehen. Wir können nemlich nach solchen endlichen algebraischen Knoten fragen, welche die gleiche Verschlingung aufweisen, wie ein *gegebener* topologischer (endlicher) Knoten. Diese Aufgabe ist für die (von H. Tait aufgestellten) Knoten mit 3, 4, 5, 6, 7 Knotenpuncten mit Hülfe des weiter unten geschilderten Auflösungsprocesses unschwer lösbar.

Und zwar sind jene Knoten (die mit T_3, T_4, T_5, T_6, T_7 ‡ bezeichnet seien) *sämmtlich* NOCH *als endliche* R_6 (die T_3 noch als R_4) *darstellbar*, wobei natürlich die letzteren ausser dem reellen Curvenzug noch eine Anzahl isolirter resp. imaginärer Doppelpuncte besitzen. Die Figuren (auf Blatt II.) zeigen jene Knoten gerade in der Gestalt, wie sie aus einer, in eine R_4 und einen Kegelschnitt R_2 *zerfallenden*

* Diese sind gleichfalls (in Tabelle I.) durch einen *Stern* ausgezeichnet.

† Die 33 Typen der R_5 sind *doppelt* numerirt, einmal nach der Zahl, die sie in den Tabellen I. II. angiebt, sodann in Tabelle III. in natürlichen Reihenfolge, durch in *Klammern* eingeschlossene Zahlen. Von diesen Typen waren No. 23, 29, 60, 65 in meiner Dissertation noch *nicht* enthalten.

‡ Die T_3 (das "trifolium") findet sich unter den R_4 als (2): die T_5, T_6 sind nach der Reihenfolge, in der sie bei H. Tait auftreten, mit römischen Indexziffern versehen: endlich sind die den T_7 beigegebenen Ziffern *genau* die von H. Tait selbst gewählten.

Curve durch eine einfache *Variation* (bei der einer der reellen Schnittpuncte von R_4 und R_2 verschwindet) als R_6 hervorgehen.

Damit ist auch, wie der zweite Abschnitt lehrt, eine Darstellung jener Knoten *durch algebraische Gleichungen* ermöglicht.

II. Algebraische Hülfsmittel.

§ 5. *Beweis für Existenz der Typen der R_4 und R_5 mittelst quadratischer Transformation.*

Es erübrigt noch, für die Richtigkeit der in I aufgestellten algebraischen Knoten, sowie des in den Figuren vorgenommenen Deformationsprocesses die strengen algebraischen Beweise nachzuholen.

Die 5 Typen der R_4 bedürfen, wie schon in § 2 bemerkt, keines weiteren Existenzbeweises (soweit es nur auf ihre Verschlingung ankommt); will man sich jedoch von ihrer Entstehung genauere Rechenschaft geben, so unterwerfe man die Puncte in der Ebene der R_4 einer quadratischen, involutorischen Verwandschaft * T_2, deren drei Fundamentalpuncte in die Doppelpuncte der R_4 fallen. Dann geht die R_4 über in eine R_2 d.h. einen Kegelschnitt, und umgekehrt erhält man vermöge passender T_2 aus einer beliebigen R_2 z. B. einem Kreise, ohne Weiteres alle Typen der R_4.

Gehen wir zu den Typen der R_5 über, so handelt es sich um zweierlei, einmal um die *Existenz* der aufgestellten 33 Typen, andererseits um die *Nichtrealisirbarkeit* der 20 noch verbleibenden Stellenschemata (*cf.* § 3). Beides ist mittelst der Transformationen T_2 ausführbar.

Nimmt man nemlich drei Doppelpuncte der R_5 zu Fundamentalpuncten einer T_2, so transformirt sich die R_5 in eine R_4, von der diese drei Puncte einfache Puncte sind. *Umgekehrt lassen sich für jeden der* 33 *Typen der R_5 R_4 mit drei auf ihr gelegenen Fundamentalpuncten einer T_2 so wählen dass die R_4 in die verlangte R_5 übergeht.* (§ 6 weist nach, wie dies am einfachsten ausführbar ist.)

Versucht man nunmehr *dasselbe* Verfahren für die 20 restirenden Schemata, so erweist sich jedesmal die Ausführung als *unmöglich.* So z. B. zeigt die Figur der R_4 mit dem Schema: ABE (Blatt II.)

* Diese ist z. B. ausführlich behandelt in Salmon's *Higher plane curves.* Am einfachsten wird sie repräsentirt durch die Verwandtschaft zwischen den beiden Brennpuncten der einem Dreiecke einbeschriebenen Kegelschnitte. Die Ecken des Dreiecks sind die Fundamentalpuncte der Verwandtschaft.

unmittelbar, wie eine T_2 gar nicht existiren kann, die die R_4 in die R_5 mit dem Schema: A B F C E D (No(20)) überführe. Die entsprechende Durchführung für die 19 weiteren Schemata unterbleibe hier: sie stützt sich auf die genaue (in § 3 erörterte) Kenntniss aller möglichen Lagen einer Geraden zu einer R_4.

Die Methode dieses § genügt so zwar völlig dem Zwecke der Auffindung aller Typen der R_5: behufs einer wirklichen Anschauung derselben ist sie indessen viel zu zeitraubend. Wir bedienen uns daher eines andern Processes, der auch sonst in der Lehre von den Gestalten algebraischer Curven eine Rolle spielt, nemlich des *stetigen Ueberganges zerfallender Curven in nicht-zerfallende*, oder des sog. "*Auflösungsprocesses.*"

§ 6. *Der Auflösungsprocess mit Hülfe quadratischer Transformationen.*

Sei wieder das Fundamentaldreieck einer T_2 einer R_4 einbeschrieben. A sei einer der Eckpuncte, a die gegenüberliegende Seite, die noch die reellen Puncte A_1, A_2 aus der R_4 ausschneide.

Jetzt bewege sich A auf der R_4, bis er mit einem Doppelpuncte der R_4 zusammenfällt. In diesem Augenblick zerfällt die (sich mit A bewegende) R_5 in eine R'_4 und die Gerade a.

Verlassen wir umgekehrt den Doppelpunct, indem der Punct A längs eines der vier vom Doppelpuncte auslaufenden Zweige fortschreitet, so vereinigt sich die R'_4 mit der Geraden a zu einer R_5, und zwar "*löst sich*," jenen vier Richtungen entsprechend, entweder der Punct A_1, oder der Punct A_2, je in einem der beiden * möglichen Sinne, "*auf.*"

Soll sich daher eine gegebene R_4 mit einer Geraden R_1 so zu einer R_5 vereinigen, dass sich ein bestimmter der vier reellen Schnittpuncte von R_4 und R_1 auflöst, so verfahre man, wie folgt:

"Man nehme zwei der weiteren Schnittpuncte von R_4 und R_1 nebst einem Doppelpuncte A der R_4 zu Fundamentalpuncten einer T_2. Vermöge der T_2 geht die R_4 über in eine R'_4 mit Doppelpunct in A. Variirt man nunmehr die T_2 dadurch in eine T'_2, dass an die Stelle des Fundamentalpunctes A ein in passender Richtung auf R'_4 benachbarter Punct A′ tritt, so verwandelt sich die R'_4 vermöge T'_2 in eine R_5, die die vorgegebenen Bedingungen erfüllt."

* Diese beiden Sinne der Auflösung erhellen unmittelbar aus der Anschauung einer, aus einem Geradenpaar hervorgehenden Hyperbel.

Auf diese Weise haben sich die Figuren für die Typen der R_5 sämmtlich ergeben: in der Nähe des aufgelösten Punctes sind die R_4 und R_1 PUNCTIRT.

Man hätte den Punct A′ noch um eine *endliche* Strecke auf der R'_4 vorwärts bewegen können, ohne dass die successive so entstehenden R_5 ihre Verschlingung geändert hätten. Man ersieht daraus, wie sich der in § 5 geschilderte Uebergang einer R_4 in eine R_5 in mannigfaltigster Weise bewerkstelligen lässt.

Es kann sich freilich ereignen, dass, wie z. B. Figur α auf Blatt I. lehrt, von den drei Fundamentalpuncten der T_2 keiner längs der R_4 in die Lage eines Doppelpunctes rücken kann, ohne dass nicht inzwischen die R_5 ihren Typus gewechselt hätte. Dagegen zeigt Figur β ebenda, wie man diesen Missstand (stets) vermeiden *kann.*

Ganz ebenso lassen sich die Typen der R_4 durch Auflösung aus der R_3 gewinnen: dies erweist sich zugleich thatsächlich als der einfachste Weg, um über die in § 2 besprochenen Lagen der beiden reellen Wendepuncte Aufschluss zu erhalten.

§ 7. *Der Auflösungsprocess mit Hülfe der Projection.*

Der im vorigen § vorgenommene Process der Auflösung einer R_n und R_1 hört auf, anwendbar zu sein, sobald $n > 4$. Wir theilen daher noch ein anderes Verfahren mit, das allgemein für ebene (auch räumliche) R_n brauchbar ist.

Man kann nemlich eine *gegebene* R_n auf die mannigfaltigste Art als Projection einer rationalen Raumcurve C_{n+1} ($n+1^{ter}$ Ordnung) von einem ihrer Puncte P aus, erscheinen lassen.

In der That, wenn die R_n dargestellt ist durch die Gleichungen,

$$(1)\ x_1 : x_2 : x_3 = f_1(\lambda) : f_2(\lambda) : f_3(\lambda),$$

wo die x Punctcoordinaten, und die f ganze Functionen n^{ten} Grades von λ bedeuten, so liefert, wenn $\phi(\lambda)$ eine ebensolche Function vom Grade $n+1$ ist, das Gleichungssystem (bei beliebigem, reellem a):

$$(2)\ x_1 : x_2 : x_3 : x_4 = f_1(\lambda)(\lambda - a) : f_2(\lambda)(\lambda - a), : f_3(\lambda)(\lambda - a) : \phi(\lambda),$$

immer eine C_{n+1} von der gewünschten Art. Dabei ist P der Raumpunct $x_1 = o$, $x_2 = o$, $x_3 = o$. Ist t die Tangente in P, und P′ ein, zu P benachbarter, *nicht* auf C_{n+1} gelegener Punct, und projicirt man jetzt die C_{n+1} von P′ aus auf die Ebene $x_4 = o$ *d.i.* die Ebene der R_n, so gelangt man zu einer R_{n+1}, die *durch Auflösuug des Punctes* $\lambda = \alpha$ aus der R_n und derjenigen Geraden hervorgeht, welche von der durch t und P′ gelegten Ebene aus der Ebene der R_n ausgeschnitten wird.

Dies ist geometrisch evident. Daraus folgt umgekehrt die Regel: "Soll eine R_n und eine R_1 durch Auflösung eines ihrer reellen Schnittpuncte A continuirlich in eine R_{n+1} übergehen, so fasse man die R_n auf als Projection einer räumlichen C_{n+1}, von einem ihrer Puncte, P, aus. Deren Tangente t in P geht nothwendig durch A. Ist dann Q ein beliebiger Punct auf R_1, und schreitet man von P aus in einer der beiden Richtungen PQ um ein beliebig kleines Stück zu einem Puncte P′, so ist die Projection der C_{n+1} von P′ aus eine R_{n+1} der gewünschten Art, die zudem noch die Gerade R_1 im Puncte Q berührt."

Wir unterlassen die genauere algebraische Verfolgung dieses Projectionsprocesses, und gehen sogleich über zu der in § 4 benützten Vereinigung einer R_n und R_2 zu einer R_{n+2}, wiederum mittelst Auflösung einer ihrer reellen Schnittpuncte.

§ 8. *Die Deformation einer $R_n + R_2$ in eine R_{n+2}.*

A sei der reelle Schnittpunct beider Curven, in dem die Auflösung vor sich gehen soll. Wir greifen noch drei weitere reelle * Schnittpuncte der R_n und R_2 heraus, A_1 A_2 A_3. Dann geht vermöge einer quadratischen Transformation T_2 mit den Fundamentalpuncten A_1 A_2, A_3, die R_n über in eine R_{2n-3} mit $(n-2)$ fachen Puncten in A_1, A_2, A_3; die R_2 dagegen in eine durch den Punct A laufende R_1.

Löst man jetzt nach der Regel des § 7 den Punct A auf, so dass aus dem Aggregat R_{2n-3} & R_1 eine R_{2n-2} hervorgeht, so besitzt diese gleichfalls drei $(n-2)$ fache Puncte in der Nähe der früheren, wir wollen sagen, in A'_1, A'_2, A'_3.

Dann verwandelt sich vermöge einer neuen Transformation T'_2 mit den Fundamentalpuncten in A'_1, A'_2, A'_3 die R_{2n-2} in eine eigentliche R_{n+2}, die, wie verlangt wurde, der $R_n + R_2$ benachbart ist.

Wir bemerken am Schlusse dieser Betrachtungen nur noch kurz, dass man ganz allgemein algebraische Processe angeben kann, die das Aggregat aus einer R_n und R_m continuirlich in eine R_{+n} überführen, sobald nur einer der Schnittpuncte von R und R_n reell ist.†

* Von diesen könnten auch zwei conjugirt imaginär sein.

† Dabei zeigt sich vor Allem—und dies gilt natürlich im Besondern von

Um aber den Character dieser Mittheilung als einer topologisch algebraischen zu wahren, sei es nur noch gestattet, einen Blick auf die in § 3 erwähnten Relationen zwischen den Doppelpuncts-argumenten einer R_5 zu werfen.

§ 9. *Die Relationen zwischen den Doppelpunctsargumenten einer* R_5.

Wir bezeichnen die zwölf Argumente mit (α_i, β_i), (α'_i, β'_i) $(i=1, 2, 3)$. Wie in § 6, führen wir die R_5 vermöge einer Transformation T_2, mit den Fundamentalpuncten in den drei ersteren Doppelpuncten, über in eine R_4, die darstellbar sein muss durch die Gleichungen :

$$(1)\ \rho y_i = (\lambda-\alpha_k')(\lambda-\beta_k')(\lambda-\alpha_l')(\lambda-\beta_l') = f_i(\lambda) (i, k, l=1, 2, 3),$$

wo ρ ein Proportionalitätsfactor, und die y_i lineare homogene Functionen der Coordinaten sind.

Die drei (α_i, β_i) repraesentiren jetzt irgend drei Punctepaare der R_4 *die allein der Forderung zu genügen haben, auf den Seiten irgend eines, der* R_4 *einbeschriebenen Dreiecks zu liegen.* Die Anzahl der gesuchten Relationen ist demnach drei.

Seien a_i, a_k, a_l, die Argumente der Eckpuncte des Dreiecks, so hängen a_k, a_l, ab von der quadratischen Gleichung :

$$(2)\ G_i = \frac{1}{(\lambda-\alpha_i)(\lambda-\beta_i)(\alpha_i-\beta_i)} \left| f(\lambda), f(\alpha_i) f(\beta_i) \right| = o (i=1, 2, 3),$$

wo die beiden verticalen Striche eine dreireihige Determinante bedeuten. Ist R_{ik} die Resultante von G_i und G_k, so sind die oben aufgestellten Bedingungen erfüllt durch die drei Gleichungen :

$$(3)\ R_{ik}=0\ (i,k=1, 2, 3).$$

Es ist aber leicht nachweisbar, dass die R_{ik} noch einen, der Frage fremden Factor enthalten. So ergiebt sich :

$$(4)\ R_{ik} = \Delta R'_{ik},$$

wo $\Delta=0$ gesetzt, bedeutet, dass die R_4 einen dreifachen Punct erhält. Unsere gesuchten drei Relationen lauten daher in der einfachsten Form :—

$$(5)\ R'_{ik}=0.$$

den im Texte benützten Deformationen der R_3+R_1, und R_4+R_1—dass man deutlich übersieht welche von den beim Uebergang von den zerfallenden Curve in die eigentliche *neu auftretenden Singularitäten reell* sind.

I. *Tafel* der* 120 *Stellenschemata für* 6 *Doppelpuncte, incl. Schleifen.*

(1)	BCDEF	(41)*	CEFBD	(22)= (81)	ECDBF
(2)	BCDFE	(29)=(42)	CEFDB	(12)= (82)	ECDFB
(2)= (3)	BCEDF	(41)=(43)	CFBDE	(68)= (83)	ECFBD
(4)	BCEFD	(44)*	CFBED	(54)= (84)	ECFDB
(5)	BCFDE	(38)=(45)	CFDBE	(23)= (85)	EDBCF
(6)	BCFED	(12)=(46)	CFDEB	(44)= (86)	EDBFC
(2)= (7)	BDCEF	(44)=(47)	CFEBD	(24)= (87)	EDCBF
(8)	BDCFE	(30)=(48)	CFEDB	(30)= (88)	EDCFB
(4)= (9)	BDECF	(5)=(49)	DBCEF	(71)= (89)	EDFBC
(4)=(10)	BDEFC	(29)=(50)	DBCFE	(72)= (90)	EDFCB
(11)	BDFCE	(11)=(51)	DBECF	(91)*	EFBCD
(12)*	BDFEC	(11)=(52)	DBEFC	(92)*	EFBDC
(5)=(13)	BECDF	(53)	DBFCE	(92)= (93)	EFCBD
(11)=(14)	BECFD	(54)*	DBFEC	(94)*	EFCDB
(6)=(15)	BEDCF	(6)=(55)	DCBEF	(95)	EFDBC
(12)=(16)	BEDFC	(30)=(56)	DCBFE	(96)*	EFDCB
(17)	BEFCD	(12)=(57)	DCEBF	(97)	FBCDE
(18)*	BEFDC	(8)=(58)	DCEFB	(98)	FBCED
(19)	BFCDE	(54)=(59)	DCFBE	(99)	FBDCE
(20)	BFCED	(60)*	DCFEB	(20)=(100)	FBDEC
(20)=(21)	BFDCE	(17)=(61)	DEBCF	(71)=(101)	FBECD
(22)	BFDEC	(41)=(62)	DEBFC	(72)=(102)	FBEDC
(23)*	BFECD	(18)=(63)	DECBF	(98)=(103)	FCBDE
(24)*	BFEDC	(29)=(64)	DECFB	(104)	FCBED
(2)=(25)	CBDEF	(65)*	DEFBC	(20)=(105)	FCDBE
(26)	CBDFE	(66)*	DEFCB	(6)=(106)	FCDEB
(8)=(27)	CBEDF	(67)*	DFBCE	(44)=(107)	FCEBD
(12)=(28)	CBEFD	(68)	DFBEC	(30)=(108)	FCEDB
(29)*	CBFDE	(69)*	DFCBE	(71)=(109)	FDBCE
(30)*	CBFED	(54)=(70)	DFCEB	(44)=(110)	FDBEC
(4)=(31)	CDBEF	(71)*	DFEBC	(72)=(111)	FDCBE
(12)=(32)	CDBFE	(72)*	DFECB	(30)=(112)	FDCEB
(4)=(33)	CDEBF	(19)=(73)	EBCDF	(23)=(113)	FDEBC
(2)=(34)	CDEFB	(41)=(74)	EBCFD	(24)=(114)	FDECB
(11)=(35)	CDFBE	(20)=(75)	EBDCF	(115)*	FEBCD
(8)=(36)	CDFEB	(38)=(76)	EBDFC	(116)*	FEBDC
(11)=(37)	CEBDF	(67)=(77)	EBFCD	(116)=(117)	FECBD
(38)*	CEBFD	(69)=(78)	EBFDC	(118)*	FECDB
(12)=(39)	CEDBF	(20)=(79)	ECBDF	(96)=(119)	FEDBC
(26)=(40)	CEDFB	(44)=(80)	ECBFD	(120)*	FEDCB

* Aus Raumersparniss ist bei diesen 120 Schemata überall der *erste* Buchstabe A *fortgelassen.* Im Uebrigen vgl. § 3.

Im Texte siud die 200 Schemata in Tafel I. und II. *ohne* Klammern citirt, zum Unterschiede von der Klammerbezeichnung der Tafel III.

II. *Tafel der* 80 *Stellenschemata für* 6 *Doppelpuncte, excl. Schleifen.*

(121)*	CABFDE
(122)*	CAEFBD
(121)=(123)	CAEFDB
(122)=(124)	CAFBDE
(122)=(125)	CDAFBE
(121)=(126)	CDBFAE
(127)	CDEFAB
(128)*	CDFABE
(122)=(129)	CDFBAE
(130)*	CEAFBD
(122)=(131)	CEAFDB
(122)=(132)	CEBFAD
(133)*	CEFABD
(128)=(134)	CEFADB
(135)*	CEFBAD
(128)=(136)	CFABDE
(122)=(137)	CFBADE
(135)=(138)	CFEABD
(122)=(139)	CFEADB
(140)*	CFEBAD
(122)=(141)	DABFCE
(128)=(142)	DAEFBC
(122)=(143)	DAEFCB
(135)=(144)	DAFBCE
(140)=(145)	DAFCBE
(133)=(146)	DEAFBC
(135)=(147)	DEAFCB
(128)=(148)	DEBFAC
(149)*	DEFABC
(133)=(150)	DEFACB
(133)=(151)	DEFBAC
(128)=(152)	DEFCAB
(133)=(153)	DFABCE
(135)=(154)	DFACBE
(130)=(155)	DFBACE
(122)=(156)	DFBCAE
(133)=(157)	DFEABC
(130)=(158)	DFEACB
(135)=(159)	DFEBAC
(122)=(160)	DFECAB

(128)=(161)	EABFCD
(122)=(162)	EABFDC
(133)=(163)	EAFBCD
(130)=(164)	EAFBDC
(135)=(165)	EAFCBD
(122)=(166)	EAFCDB
(135)=(167)	EDAFBC
(140)=(168)	EDAFCB
(122)=(169)	EDBFAC
(133)=(170)	EDFABC
(135)=(171)	EDFACB
(130)=(172)	EDFBAC
(122)=(173)	EDFCAB
(149)=(174)	EFABCD
(133)=(175)	EFABDC
(133)=(176)	EFACBD
(128)=(177)	EFACDB
(133)=(178)	EFBACD
(135)=(179)	EFBADC
(128)=(180)	EFBCAD
(127)=(181)	FABCDE
(128)=(182)	FAEBCD
(122)=(183)	FAEBDC
(122)=(184)	FAECBD
(121)=(185)	FAECDB
(128)=(186)	FDABCE
(122)=(187)	FDACBE
(122)=(188)	FDBACE
(121)=(189)	FDBCAE
(128)=(190)	FDEABC
(122)=(191)	FDEACB
(122)=(192)	FDEBAC
(121)=(193)	FDECAB
(133)=(194)	FEABCD
(135)=(195)	FEABDC
(130)=(196)	FEACBD
(122)=(197)	FEACDB
(135)=(198)	FEBACD
(140)=(199)	FEBADC
(122)=(200)	FEBCAD

III. *Haupt-Tafel für die Stellenschemata der* R_4 *und* R_5.

I. 5 Schemata der R_4:

(*a*) mit keiner Asymptote.	(*b*) mit zwei Asymptoten.
AABBCC (1)	AABCBC (4)
ACBACB (2)	ABCACB (5)
AABCCB (3)	

II. 33 Schemata* der R_5.

(*a*) 26 mit einer Asymptote.

Keine Schleife.	Zwei Schleifen.
133. CEFABD (1)	18. ABEFDC (12)
130. CEAFBD (2)	29. ACBFDE (13)
135. CEFBAD (3)	41. ACEFBD (14)
121. CABFDE (4)	54. ADBFEC (15)
	71. ADFEBC (16)
Eine Schleife.	72. ADFECB (17)
91. AEFBCD (5)	96. AEFDCB (18)
92. AEFBDC (6)	120. AFEDCB (19)
115. AFEBCD (7)	
67. ADFBCE (8)	**Drei Schleifen.**
94. AEFCDB (9)	23. ABFECD (20)
66. ADEFCB (10)	24. ABFEDC (21)
118. AFECDB (11)	30. ACBFED (22)
	38. ACEBFD (23)
Vier Schleifen.	44. ACFBED (24)
12. ABDFEC (26)	60. ADCFEB (25)

(*b*) 7 mit drei Asymptoten.

Keine Schleife.	Eine Schleife.
149. DEFABC (27)	116. AFECBD (31)
140. CFEBAD (28)	69. ADFCBE (32)
128. CDFABE (29)	65. ADEFBC (33)
122. CAEFBD (30)	

* Diese sind sämmtlich in "reducirter" Form angegeben (*cf.* § 1), wie auch diejenigen in Tafel I. & II.

3. On Amagat's *Manomètre à Pistons libres*. By Professor Tait.

4. On the Electrical Properties of Hydrogenised Palladium. By Professor Knott.

5. Electro-Chemical Reactions between Metals in fused Salts. By Thomas Andrews, F.R.S.E., F.C.S., Wortley Iron Works, near Sheffield.

Electro-Chemical Reactions between Metals in fused Salts.—The present communication contains some results of a furthur study of electrical reactions at high temperatures in fused salts.

The interchanges of electro-chemical position between such metals as platinum and copper and platinum and iron in fusing salts, noticed by the author, led to an investigation as to the effect on the metals of varied intensified temperature in different parts of the same fusing salt.

A number of repeated experiments were conducted as follow:—

A salt was maintained at its fusing-point in a state of quiet liquefaction in a large flat-bottomed platinum crucible, the ends of two platinum wires A and B (0·063 inch diam.) cut from the same piece, were immersed in the fusing salt, and the other extremities were connected with an astatic galvanometer of known resistance and constants. Whilst the salt was in this condition of even fusion no current was produced. On increasing the temperature of one

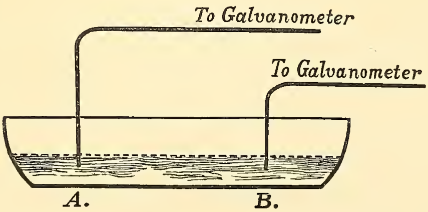


Fig. No. 1.

portion of the fusing salt, in some cases where allowable, by a powerful blowpipe blast applied just under the end of the platinum wire A, the following reactions were obtained; the platinum wire A (in the part of the salt having the highest temperature), becoming metal positive. On reversing the action and increasing the temperature in the same way adjacent to the other wire B (fig. No. 1), the exact reverse result occurred in every experiment.

When a copper wire was substituted for one of the platinum wires, the copper was metal positive during the quiet fusion of the salt at one even temperature throughout; but on locally intensifying the heat as above, under the platinum wire only, that metal at once assumed the positive position compared with the copper, and by thus varying the conditions of temperature alternate interchanges of electro-chemical position between the metals could be produced at pleasure in the same fusing salt.

The results of numerous repeated experiments are summarised in table A.

General Remarks.

Potassium Carbonate (Table A, Division 1).—This experiment was six times repeated, giving same results, and on equalising the temperature throughout the fusing salt, alternating currents continued for a few moments until thermal equilibrium was again restored.

Pctassium Carbonate (Table A, Divisions 2 and 3).—This experiment was thrice repeated with same results. The positive position of platinum and E. M. F. was maintained steadily for ten minutes, or as long as the extra heat was applied under the platinum wire. During equalisation of the temperature throughout the fusing salt, alternating electro-chemical positions between the metals occurred for a short time.

Potassium Nitrate (Table A, Division 3).—This experiment was six times repeated with the same result each time. On equalising the temperature throughout the fusing salt, the metals resumed their original positions, copper being positive.

These experiments indicate that, by apportioning the heat applied to two dissimilar elements, such as platinum and copper, in the same fusing salt, it is possible to produce equipotential in an electrical sense between them, and by pursuing this still further, a complete abnormal interchange of electro-chemical position is obtainable, amounting not unfrequently to 0·343 of a volt or even greater. These intensified electro-chemical effects are of an interesting

TABLE A.

Salts in Igneous Fusion.	Two Platinum Wires as Elements in fusing Salts.			Platinum and Copper Wires as Elements in fusing Salts.						
	Division 1.			Division 2.			Division 3.			
	Electro-chemical position of Platinum in hottest part of fusing Salts.	Deflection of Galvanometer in Degrees.	Electro-motive Force in Volt.	Electro-chemical position of Platinum with fusing Salt at uniform Temperature throughout.	Deflection of Galvanometer in Degrees.	Electro-motive Force in Volt.	Electro-chemical position of Platinum when in hottest part of fusing Salt, Copper in cooler part.	Deflection of Galvanometer in Degrees.	Electro-motive Force in Volt.	Electro-motive Force representing Total Deviation of Platinum from Normal position in Volt.
Potassium carbonate,	P	15	0·054	N	55	0·271	P	20	0·072	0·343
Potassium nitrate,	P	10	0·038	N	35	0·132	P	10	0·038	0·170
Potassium chlorate,	P	3	0·014							
Potassium chloride,	P	40	0·221							

The E.M.F. was ascertained from the known constants of the galvanometer in connection with the ascertained resistance of the fusing salts in repeated experiments.

character. An explanation is doubtless found in the fact that the metallic element whose molecules acquired the greater activity owing to the increased temperature (consequently becoming more liable to attack from oxidation and corrosion), would, under the continuance of such circumstances, be likely to remain the positive metal. When, however, by the reduction of temperature, its molecular rigidity increased, compared with that of the other element, an interchange of electro-chemical position might be expected to occur. This cause appears sufficient at these high temperatures to produce complete interchanges and reversals between metals of such apparent general stability as platinum and copper or platinum and iron during the continuance of abnormal and unequal thermal conditions. The great difference of temperature which obtained in different parts of the same fusing salt would also cause it to act on the metals after the manner of two dissimilar solutions. Thermo-electric and inversion effects at these very high temperatures are probably also involved in the explanation.

6. The Hygrometry of Ben Nevis. By H. N. Dickson.

The observations tabulated in the present paper were taken at Ben Nevis Observatory, chiefly during August 1885. In a note communicated to the Society at the end of last session, a description was given of some observations of air-temperatures and humidities at Granton Marine Station, and it was stated that the work was to be continued at Ben Nevis. At present we confine ourselves to the hygrometrical work: it is hoped that the results of the temperature observations will be communicated to the Society early next session.

The extreme dryness of the atmosphere which prevails at Ben Nevis during anticyclones, makes the Observatory an unusually favourable station for such investigations, and it is believed that the appended tables afford exceptionally good material for rediscussing the whole question of the hygrometry of the atmosphere.

The observations here given were for the most part taken during an anticyclone which lasted from 18th to 28th August. They include all the regular hourly observations taken during that time, except when the air was saturated, besides a large number of extra observations, given at the end of the table of hourlies. Through the kindness of Mr Omond and his assistant Mr Rankin, I was able to make the observations continuous, and also to add a considerable number of observations at low temperature, taken during the past winter.

The readings of wet and dry bulb thermometers given were taken with the instruments in daily use at the Observatory. These thermometers are by Messrs Adie and Wedderburn, and are sufficiently delicate for all the purposes of the investigation. The diameter of the spherical bulbs was 0·40 inches. The wet bulb was covered with thin muslin, as served out by the Scottish Meteorological Society, and every care was taken to ensure its being properly moistened. The thermometer screen was an ordinary double-louvred Stevenson, open below, and of the usual size. The observed readings have been corrected in accordance with the Kew certificates attached to the instruments, and checked by comparison with the readings of one of Aitken's screens.

The direct hygrometer used was Professor Chrystal's, described in the note referred to (*Proc. R. S. E.*, vol. xiii. p. 199). After a little practice this instrument can be made to give very satisfactory results, deposits having been obtained on the silvered surface at temperatures as low as 1°·5 F., by using mixtures of salt and snow.

The dew-point was in each case taken to be the temperature at which a uniform coating of moisture was deposited on the silvered surface, when its temperature was being reduced. The box containing the thermometer was first cooled quickly to within a few degrees of the point where deposition was expected to take place, then its temperature was allowed to fall slowly till moisture began to appear and disappear in irregular patches, when the cooling was still further checked. Almost immediately after, and at a quite definite point, a uniform deposition made its appearance, varying slightly at its outer edges; the reading was then taken. Readings taken from the clearing off of the deposit were of course unsatisfactory, as the moisture deposited may take some time to evaporate, during which the thermometer may rise considerably.

The deposit appearing and disappearing in patches may have been due to the unequal temperature of the mixture in the box of the hygrometer, but as this took place even when the temperature was allowed to fall with great slowness, I am disposed to think it was caused by incessant small fluctuations of the actual dew-point. If the temperature of the hygrometer is kept constant for a time near the dew-point, evaporation and condensation take place on the surface in quick succession, and the dew-point may vary within a considerable range in a very short time. This obviously increases the difficulty of making accurate comparative observations.

The hygrometer, with it reservoirs, tubes, &c., was mounted on a stand about six feet away from the thermometer screen, and the thermometers were read immediately after checking the rate of cooling of the hygrometer, as described.

Considerable difficulty was at first experienced in finding a suitable method of comparing the observations of dew-points by the direct hygrometer with the readings of wet and dry bulbs. After several trials, the following graphic method was found to be satisfactory.

Taking rectangular coordinates, temperatures were measured along the x axis, and vapour pressures in inches of mercury (taken from Regnault's Tables, as given in "Glaisher's Hygrometrical Tables," 6th edition, 1876) along the y axis. Each observation with wet and dry, and the corresponding hygrometer observation, was then treated separately. First a point was taken whose abscissa corresponded to the temperature of the wet bulb and ordinate to the vapour pressure at that temperature. Another point was then taken with abscissa corresponding to the temperature of the dry bulb and ordinate to the vapour pressure at the temperature of the dew-point, as given by the direct hygrometer. These two points were then joined by a straight line.

Plotting all the observations we get a diagram formed of straight lines, and by taking the *general trend* of these lines we are able to see the relations existing between the wet and dry bulb readings and the dew-point obtained from direct observation.

First we note that on the whole the lines near each other are almost parallel, from which it at once appears that with a given reading of the wet bulb the excess of the air temperature above that of the wet bulb is not proportional to the excess of the *temperature* of the wet bulb over that of the dew-point, but to the vapour pressure corresponding to those temperatures. That is to say, given the temperatures of the dry and wet bulbs, their difference is proportional not to the difference between the *temperatures* of the wet bulb and the dew-point, but to the difference between the vapour pressures corresponding to these temperatures.

The fact that as a whole the lines near each other in the diagram are nearly parallel, whatever their length, justifies their being drawn *straight* lines, and in addition there are at least six cases of observations with the same temperature of wet bulb where the lines exactly coincide, although their length, *i.e.*, the differences between wet and dry, are very different.

It is of course to be observed that a very large number of the lines in the diagram are quite irregular in direction. This is obviously due to errors of observation, which are necessarily large both in the working of the wet and dry, and in the direct hygrometer. On the whole, however, the irregularities are fairly well distributed on both sides of the mean direction of the lines, except in cases where the air was nearly saturated. Under these circumstances the action of the wet bulb is extremely sluggish, and the actual dew-point is below that to be expected from the wet and dry. This is further shown by observations taken when, as occasionally happens, the wet bulb reads *above* the dry, as in dry fog. The dry bulb thermometer then acts as the more perfect wet bulb, the hygrometer showing that the dew-point temperature is really below that of the air. This is of course apart from cases where a sudden change of temperature has just taken place, as the wet bulb covering prevents its adapting itself to changes as rapidly as the other. Sometimes the wet bulb thermometer continues to read above the dry for a considerable time, but I have invariably found that in these cases the so-called dry bulb was being kept wet, either by water dripping from the screen, or by driving fog depositing moisture on it, the air being all the time slightly dry.

Comparing observations extending over a large range of temperature of wet bulb, we find that the lines in the diagram are not really parallel, but that they tend to become slightly steeper as the temperature of the wet bulb is lower. From this it appears that the factor by which we must multiply the difference of the temperatures of the wet and dry to obtain the difference between the vapour pressures at the temperatures of the wet bulb and of the dew-point, is not a constant, but tends to increase as the temperature falls.

Again, at a wet bulb temperature of 32° F., we find a sudden change in direction, the lines becoming much steeper. This change is apparently discontinuous, but as the wet bulb temperature continues to fall the slow increase in steepness continues as before.

These results lead to the linear equation

$$f' - f'' = (t - t')K,$$

where f' is pressure of vapour at temperature of wet bulb, f'' is pressure of vapour at temperature of dew-point, t temperature of air, t' temperature of wet bulb, and K the factor before referred to, whose values are to be determined.

It is certainly premature to attempt to give any definite values of K, but by drawing lines in the diagram at those temperatures of wet bulb at which any considerable number of observations appear, as nearly as possible in the mean direction indicated by the observations, the following roughly approximate values have been obtained:—

Temperature of Wet Bulb.		K	Temperature of Wet Bulb.		K
45° F.	...	$\frac{1}{108}$	33° F.	...	$\frac{1}{94}$
40°	...	$\frac{1}{106}$	[31°	...	$\frac{1}{67}$]
39°	...	$\frac{1}{106}$	[30°	...	$\frac{1}{58}$]
38°	...	$\frac{1}{106}$	[29°	...	$\frac{1}{54}$]
37°	...	$\frac{1}{104}$	[28°	...	$\frac{1}{49}$]
36°	...	$\frac{1}{103}$	[25°	...	$\frac{1}{45}$]
35°	...	$\frac{1}{101}$	[20°	...	$\frac{1}{44}$]
34°	...	$\frac{1}{99}$	[17°	...	$\frac{1}{44}$]

Until more continuous observations are made these values must not be taken as more than a first approximation. Below 32° they are probably too small.

The next step was to compare the dew-points given by the hygrometer with those calculated from the wet and dry bulb thermometer readings by the two methods in most common use. Glaisher's "Hygrometrical Tables" (6th edition, 1876) and "Apjohn's Formula." For this purpose it was only necessary to fill in the diagram lines calculated by these two methods.

Glaisher's tables are constructed from factors obtained chiefly from the Greenwich Observatory observations with wet and dry

Hourly Observations, 1885.

Date.	Hour.	Dry.	Wet.	Dew Point. Chrystal's Hygro-meter.	Date.	Hour.	Dry.	Wet.	Dew Point. Chrystal's Hygro-meter.
Aug. 18.	13	47·0	36·4	16·3	Aug. 20.	15	48·8	43·7	39·4
	14	46·7	37·8	19·3		16	47·2	42·8	38·0
	15	47·5	35·5	...		17	46·3	41·9	39·0
	16	47·0	37.4	20·3		18	45·9	41·7	38·7
	17	47·1	39·9	32·9		19	43·9	41·1	39·3
	18	47·0	39·1	26·9		20	43·0	40·0	38·0
	19	44·9	40·2	36·3		21	42·0	40·0	38·3
	20	43·3	40·1	37·7		22	40·8	39·0	37·3
	21	44·1	37·1	28·4		23	41·1	36·0	32·3
	22	45·7	35·1	22·5		24	40·7	35·4	29·3
	23	47·0	34·0	*10·3*	Aug. 21.	1	41·9	38·5	35·3
	24	45·3	32·3	...		2	42·3	39·0	35·0
Aug. 19.	1	45·1	32·0	*14·5*		3	42·1	39·1	34·4
	2	45·1	32·0	*14·3*		4	45·0	41·0	35·3
	3	44·9	32·1	*8·8*		5	45·9	42·0	35·4
	4	44·9	34·0	13·0		6	45·0	42·0	38·7
	5	45·0	34·1	...		7	43·6	41·3	40·8
	6	46·0	34·3	12·7		8	45·0	41·7	40·3
	7	46·6	39·1	28·8		9	45·3	41·7	40·3
	8	47·2	40·2	31·9		10	46·2	42·1	40·6
	9	48·6	41·0	32·4		11	46·2	42·4	39·3
	10	49·0	41·8	34·3		12	47·1	43·0	41·3
	11	49·9	42·4	35·5		13	48·0	43·2	40·5
	12	50·0	43·1	36·7		14	49·1	44·5	41·5
	13	52·6	45·2	38·6		15	50·2	45·1	41·4
	14	52·4	45·2	38·3		16	9·9	45·5	42·9
	15	50·5	43·3	35·9		17	49·3	45·1	41·9
	16	50·0	43·4	37·5		18	47·9	44·0	41·6
	17	49·0	42·1	36·2		19	46·4	43·6	41·2
	18	47·7	41·1	35·2		20	45·4	43·1	42·2
	19	46·1	42·1	39·2		21	45·4	42·0	39·1
	20	45·5	42·1	40·0		22	44·8	41·9	38·9
	21	45·2	40·9	36·4		23	46·2	40·0	33·3
	22	44·0	40·1	37·1		24	46·5	40·4	36·1
	23	44·0	40·0	36·3	Aug. 22.	1	46·4	40·2	34·7
	24	43·1	39·2	35·4		2	46·3	40·5	35·2
Aug. 20.	1	43·8	40·0	36·7		3	45·9	41·0	35·5
	2	43·1	36·0	26·6		4	44·0	40·6	37·5
	3	43·2	37·2	29·7		5	44·5	41·0	37·5
	4	42·3	36·2	29·4		6	45·3	40·8	37·3
	5	42·5	37·8	30-5		7	44·8	40·6	37·7
	6	41·3	37·1	30·9		8	44·3	40·8	37·7
	7	43·3	38·2	31·6		9	43·4	41·3	39·3
	8	43·3	39·2	30·8		10	44·1	43·0	42·4
	9	42·9	40·0	37·3		11	44·0	43·0	42·3
	10	45·1	40·4	36·5		12	44·9	44·5	42·7
	11	44·6	40·7	37·5		13	46·8	44·8	43·6
	12	45·6	41·1	36·6		14	47·3	45·8	45·2
	13	47·8	42·8	38·3		15	45·7	44·9	44·3
	14	46·0	42·0	38·2		16	45·7	45·2	...

Hourly Observations—continued.

Date.	Hour.	Dry.	Wet.	Dew Point. Chrystal's Hygrometer.	Date.	Hour.	Dry.	Wet.	Dew Point. Chyrstal's Hygrometer.
Aug. 22.	17	46·0	44·4	44·6	Aug. 26.	4	36·1	35·0	30·8
	18	45·5	44·7	44·3		5	33·5	33·3	29·3
	19	44·8	44·0	44·4		6	33·8	33·4	33·2
	20	43·4	43·3	43·7		7	35·0	34·3	31·3
	21	43·1	43·0	42·2		8	34·9	34·3	33·7
	22	43·0	42·5	42·5		9	35·0	35·0	34·6
	23	42·0	41·9	...		10	36·6	35·7	33·3
	24	44·8	41·9	38·3		11	37·2	36·3	35·3
						12	38·0	36·5	34·2
Aug. 23.	1	45·8	41·2	37·2		13	38·3	36·4	34·3
	2	44·9	40·2	36·3		14	39·2	37·0	34·1
	3	44·4	40·1	36·7		15	38·5	36·1	32·8
	4	44·0	40·5	36·3		16	37·6	35·7	33·3
	5	43·8	40·1	36·4		17	36·9	35·3	33·8
	6	44·1	40·2	34·3 (?)		18	35·1	34·4	33·5
	7	44·7	41·1	38·5		19	34·9	33·6	31·4
	8	46·1	42·0	39·3		20	33·0	32·2	30·7
	9	47·4	43·1	40·0		21	32·0	32·0	32·2
	10	47·8	42·1	38·3		22	31·9	31·7	31·3
	11	48·6	40·9	34·2		23	31·0	30·9	31·3
	12	50·0	43·2	37·0		24	29·7	29·2	28·8
	13	50·6	46·4	43·5					
	14	48·7	46·5	46·3	Aug. 27.	10	30·0	29·9	29·4
	15	49·0	46·2	43·5		11	31·9	30·9	28·6
	16	48·0	46·1	45·5		12	33·2	31·4	29·6
	17	48·6	45·8	42·6		14	33·5	32·0	30·5
	18	49·0	45·9	42·5		15	34·0	32·3	30·4
	19	46·5	44·7	43·1		16	32·9	31·9	29·3
	20	45·9	44·5	42·3		17	32·8	31·9	29·4
	21	45·2	44·8	44·4		18	32·2	31·7	30·4
						19	32·0	31·0	29·4
Aug. 26	3	36·8	35·2	31 4					

Extra Observations.

Dry.	Wet.	Dew Point. Chrystal's Hygrometer.	Dry.	Wet.	Dew Point. Chrystal's Hygrometer.	Dry.	Wet.	Dew Point. Chrystal's Hygrometer.
35·1	34·0	29·5	40·0	37·8	32·7	41·7	36·0	28·9
35·4	35·0	31·2	40·6	37·3	33·7	41·0	36·0	30·3
38·9	38·4	37·4	40·7	37·8	35·2	40·9	35·4	29·5
39·0	38·7	38·2	41·7	36·7	30·6	41·0	35·4	30·1
39·2	37·5	35·8	41·9	37·4	32·0	42·7	34·0	21·2
39·1	37·7	36·0	41·2	38·0	33·3	41·6	33·8	22·1
39·1	38·1	37·2	41·0	38·2	34·2	41·3	34·3	25·7
40·0	37·1	32·	40·9	38·0	34·4	40·9	34·1	23·5
39·8	38·0	32·4	40·2	38·9	36·6	40·6	34·0	23·8
40·0	3 ·5	33·0	41·3	36·4	30·5	40·3	34·1	21·3
40·0	38·2	34·1	42·0	35·2	26·0	40·0	34·0	24·3

Extra Observations—continued.

Dry.	Wet.	Dew Point. Chrystal's Hygrometer.	Dry.	Wet.	Dew Point. Chrystal's Hygrometer.	Dry.	Wet.	Dew Point. Chrystal's Hygrometer.
40·6	33·2	20·2	43·6	36·7	38·0	20·2	20·0	18·7
40·4	32·7	20·1	48·4	41·8	34·5	20·1	20·0	18·7
40·0	33·0	21·5	49·8	42·4	34·3	23·8	23·7	17·7
40·0	33·0	20·2	49·2	42·8	36·1	22·1	22·0	15·8
40·6	32·0	17·3	50·8	44·0	37·6	22·2	21·9	21·8
40·0	32·2	18·6	52·2	45·0	37·4	21·9	21·4	17·7
40·1	32·2	19·3	52·0	44·0	36·3	21·2	20·5	15·7
40·2	32·1	19·1	50·0	45·0	40·1	21·1	20·0	13·5
40·9	33·1	20·7	47·4	40·8	34·4	20·2	19·3	15·7
44·1	36·4	22·5	47·1	41·9	37·2	20·2	19·1	12·3
46·0	36·6	20·5	46·2	42·4	39·8	20·1	19·0	16·4
46·2	36·5	21·3	45·0	41·1	37·8	19·9	19·0	13·5
46·0	35·2	18·2	43·5	39·8	35·3	19·1	18·6	16·5
46·0	35·0	16·3	44·1	41·0	37·7	15·2	15·0	14·3
47·0	36·4	16·3	51·7	44·0	36·8	15·2	15·1	12·2
46·6	35·5	15·7	44·5	41·1	38·3	15·2	15·0	9·6
47·0	36·0	14·9	46·6	41·7	38·0	15·9	15·0	8·3
47·0	37·8	19·3	47·1	42·4	37·3	15·8	15·0	9·5
46·7	36·9	19·6	48·0	43·7	39·0	16·0	15·5	9·3
45·8	37·1	24·3	47·4	43·0	38·3	19·0	16·0	4·5
46·0	36·3	25·2	47·0	42·1	38·4	21·8	19.3	7·6
47·5	36·0	18·1	46·5	41·6	37·6	19·5	19·2	16·9
46·9	36·9	24·7	43·2	40·2	37·5	20·3	19·2	13·3
47·2	36·1	16·1	43·0	39·6	36·4	19·8	19·3	14·5
47·0	37·4	20·3	46·1	42·6	41·3	22·9	19·3	6·3
47·8	39·3	27·2	46·0	42·4	41·3	21·1	19·2	13·3
47·2	39·5	31·3	44·2	43·0	41·9	21·1	19·0	11·2
47·0	37·8	24·3	44·4	43·7	43·3	22·5	19·1	7·5
47·1	39·9	32·9	45·0	43·9	43·3	21·9	19·1	11·4
47·8	39·0	26·3	46·4	45·0	44·1	22·6	19·7	7·3
47·9	38·1	24·6	46·7	45·2	44·4	22·7	19·4	9·6
47·3	37·9	26·7	33·4	29·9	19·2	24·1	19·9	7·3
47·0	39·1	34·3	33·0	29·7	20·7	23·0	19·8	8·2
46·3	38·1	27·3	32·6	29·0	18·9	22·7	19·9	9·7
46·1	39·0	34·3	32·5	28·3	12·5	19·1	18·4	13·4
46·9	37·7	26·3	33·8	27·3	16·5	18·1	17·8	12·7
44·9	40·2	36·3	32·3	28·1	9·7	18·1	17·5	14·8
45·0	40·8	37·1	30·7	30·0	25·7	18·1	17·9	14·9
44·0	40·7	37·3	29·8	27·7	19·7	17·4	17·1	13·0
44·0	40·2	38·4	30·4	28·0	24·2	17·3	16·9	12·7
44·0	39·7	35·3	30 8	27·1	23·9	18·6	18·0	14·0
43·3	40·1	38·1	30·6	28·8	22·7	20·1	19·8	16·9
43·1	40·5	39·1	28·0	27·2	23·7	29·6	22·1	1·5
44·1	38·0	30·3	31·0	30·3	26·6	33·0	23·0	3·3
44·1	38·0	30·9	32·1	31·0	26·8	33·0	23·1	3·4
44·1	37·1	28·4	21·0	20·0	10·7	36·1	25·0	2·1
43·8	37·0	38·3						

bulb thermometers used in conjunction with Daniell's and Regnault's direct hygrometers, extending from the year 1841 to 1854. The difference of temperature between the wet and dry bulbs is multiplied by the factor corresponding to the temperature of the dry bulb, and the result subtracted from the dry bulb temperature gives the temperature of the dew-point. This obviously gives us in the diagram a line involving the curve connecting temperature with vapour pressure. Taking the wet bulb temperature as constant, and gradually raising that of the dry bulb, we have at first a part of the curve closely approximating to a straight line, and the higher the temperature taken for the wet bulb the closer is this approximation, and the longer is the part of the curve. As we continue to raise the temperature of the dry bulb the curve becomes less steep, and eventually we have a point of inflection, after which, as the dry bulb rises, the dew-point given also rises, until another point of inflection is reached.

The only part of the curve which has to be looked at, however, is that first mentioned. We find this to be nearly straight, starting in a direction steeper than the hygrometer lines, gradually lessening in steepness till it crosses them, and then going on above them. Hence it appears that the dew-points given by these tables are at first lower than those found by the hygrometer, the difference first increasing to a maximum, and then diminishing to zero. After the point of coincidence the calculated dew-points are *above* those got directly, and the differences go on increasing rapidly. The first differences referred to, where the calculated dew-points are the lower, are smaller the higher the temperatures concerned, and the points at which the lines cross are further from the commencement of the curve. Hence Glaisher's tables are practically nearly accurate until the point of the crossing of the lines is reached, and this is rarely done at the temperatures and with the humidities ordinarily experienced at low levels in this country, although it is often passed at Ben Nevis Observatory.

It is to be remarked that the results deduced from Glaisher's tables, used within the limits above mentioned, do not on the whole agree so well with direct observations at high levels as with those low down. In observations at Granton Marine Station it was found that in most cases the dew-point derived from both sources agreed almost perfectly; while at Ben Nevis the hygrometer tended to give higher results. As a rule the differences do not exceed the limits of errors of observation, and are only shown by the general direction of the lines in the diagram.

The expression given by Dr Apjohn is of the form

$$f'' = f' - m\delta\frac{P}{30},$$

where f'' is the vapour pressure corresponding to the temperature of the dew-point, f' that to the temperature of the wet bulb, δ is difference of temperature between wet and dry, P the atmospheric pressure at the time of observation, 30 being mean sea-level pressure, and m a coefficient depending on the specific heat of air and the latent heat of aqueous vapour. Dr Apjohn communicated the details of the investigation which led him to the above formula to the Royal Irish Academy, and the paper was published in the *Transactions* in 1834. He afterwards verified his results by experimental investigations (*Trans. R. I. A.; Phil. Mag.*, 1835, vii. p. 266; *Brit. Assoc. Rep*, 1843, p. 36). In the course of these, by heating air, of which the point of saturation was known, he obtained very great differences of wet and dry, and found his formula to give accurate results.

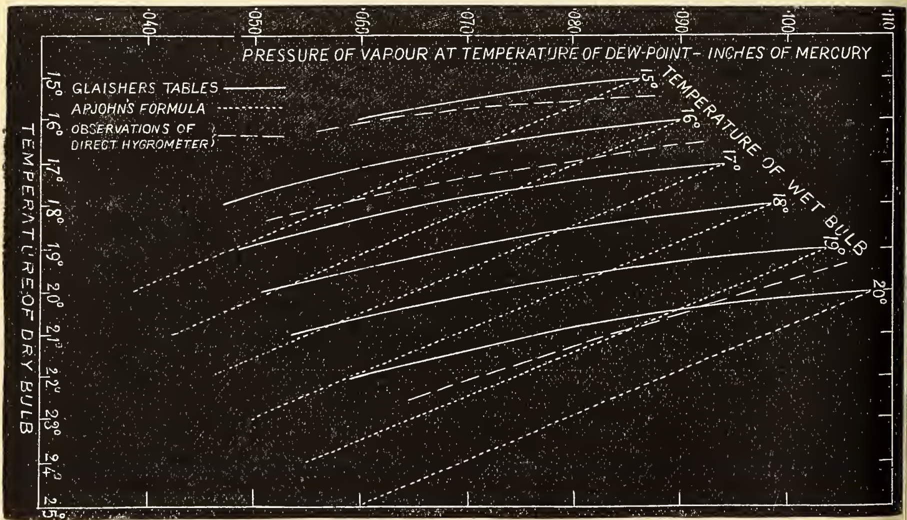
Without discussing objections to Apjohn's methods (for which see his original paper, also Clerk-Maxwell in *Ency. Brit.*, art. "Diffusion," 9th edition), we may simply take the form given with the value $\frac{1}{87}$ for m. Putting into the diagram lines formed by taking fixed values of f', and increasing δ, the value of P being as 25·300 throughout, being the mean barometric pressure for the time over which the observations extend, we get a system of parallel straight lines. Comparing these, as before, with the hygrometer lines, we find that at high temperature of wet bulb the dew-points ascertained by Apjohn's formula are on the whole too low, *i.e.*, the lines representing them are slightly steeper than the hygrometer lines. As the wet bulb temperature is lowered the differences between the two results diminish, and with wet bulb readings between 35° F. and 40° F. Apjohn's formula agrees with the hygrometer within limits of observational error, even with differences of wet and dry amounting to over 10° F. When we come to temperatures below 32° F., the results deduced from Apjohn's formula are too high, there being no change in the direction of the lines. In most works on Meteorology we find that for temperatures below 32° F. the value $\frac{1}{96}$ is given for m, but I have not been able to discover the origin of this, and it is not stated whether the change is to be made with reference to the temperature of the dry bulb or of the wet bulb. Using this value we get dew-point differing still further from my own observations, and also from Glaisher's tables.

The empirical formula deduced from the diagram is simply that of Apjohn, the factor denoted by k being equivalent to $\left(m\frac{P}{30}\right)$.

The value of $\left(m\frac{P}{30}\right)$ is

$$\frac{1}{87}\cdot\frac{25{\cdot}3}{30{\cdot}0}=\frac{1}{103},$$

and the temperatures at which the formula is found to give most accurate results are those at which the value of K is nearest $\frac{1}{103}$.



It is obviously impossible to reproduce the diagram in full, but a specimen is given for wet bulb temperatures between 15° F. at 20° F. The lines for Glaisher's tables (solid) and Apjohn's formula (dotted), are given for each degree of temperature of wet bulb, and the mean direction given by the hygrometer observations is shown for wet bulb temperatures of 15°·5 F., 16°·5 F., and 19°·4 F.

7. The Temperature of Loch Lomond and Loch Katrine during Winter and Spring. By J. T. Morrison, B.Sc. Communicated by Dr J. Murray.

8. Note on the Surface Temperature near a Tidal Race. By the Same.

9. Further Remarks on Dew. By John Aitken, Esq.

10. On the Objective Cause of Sensation. Part II.—Taste. By John B. Haycraft, M.B., B.Sc., &c., Professor of Physiology in the Mason Science College and the Queen's College Medical School, Birmingham.

Much knowledge has already been gained regarding the nature of light and sound, and much is known as to the functions of both the eye and the ear. Little, however, has been learnt concerning the production of smell and taste, which is not the intellectual property of every educated man. The views of Hobbes and Hartley have been during late years rendered more acceptable by the remarkable discovery that the end-organs of special senses are all built up on the same plan. Developed as they are on the same lines from simpler, practically identical, ectodermic cells, we are forced with Herbert Spencer to look for similarities in the agencies which develop them. In the case of sight and hearing, it is already known that the quality of the sensation produced depends upon the nature —rapidity, complexity—of the vibrating stimulus. The particles of a liquid, as well as particles dissolved in water, are in constant and characteristic vibration. It has been my endeavour to discover whether in the case of taste also it will not be possible to connect the quality of the sensation with the nature or character of the vibration of the sapid particle.

In the first place, it may be well to determine whether or no there is any relationship between taste sensation and the gross molecular weight of a sapid particle.

If we take the molecular weights of acid substances, we shall find in the case of hydrochloric acid a weight of 36·5, in the case of sulphuric acid 98. Lithium chloride, molecular weight 42·5, and potassium sulphate, molecular weight 14·4, are saline. Many other examples might be adduced from bitter and sweet compounds to demonstrate that we cannot tell by the molecular weight alone anything about the taste of a substance. In the above example an acid may have a lower or a higher molecular weight than a salt.

We shall see hereafter that molecular weight is not without its importance, and even at this stage of our inquiry it may be well to allude to a series of facts in this relationship. Bodies which have the greatest molecular weight of any, such as albumens, albumenoids, starches, gums, &c., are totally without taste; nor need it be urged that a ready explanation of this is at hand. No doubt many of these substances are not readily miscible in water, and in consequence they will not readily permeate the viscous layer of saliva covering the tongue and the surface of the gustatory end-organs. Some albumens, such as serum and egg-albumen, are fairly soluble, and they may all be converted by appropriate ferments into allied products called peptones, which are soluble and readily diffusible, and nevertheless devoid of taste. In like manner starch may be converted into dextrine, a substance readily diffusible in water, and tasteless.

We find also among the list of tasteless bodies all those of very small molecular weight. Water, molecular weight 18, is an example. The simple gases dissolved in water are tasteless, but when we examine a substance with a molecular weight over 30, we find that when dissolved in water it is capable of producing some taste or other. Sulphuretted hydrogen, molecular weight 34, is very slightly acid to the taste; hydrochloric acid, molecular weight 36·5, is very acid; and nitrogen monoxide, molecular weight 46, is sweet. It is true that the monatomic alcohols, such as ordinary commercial alcohol, have molecular weights over 34, and are tasteless, so that the same rule does not apply to all the carbon compounds; but even here we are struck with the fact that these alcohols are the lowest of a series, all the polyatomic and more complex alcohols being sapid and sweet in character.

There seems then to be some analogy between taste on the one hand and sight and hearing on the other. The substances of lowest molecular weight, and therefore of most rapid vibration—like the ultra-violet rays of the spectrum—are incapable of producing sensation. In like manner there are substances of very great molecular weight, and of the most sluggish molecular vibration, like the vibrations of the ultra-red, also incapable of effecting the sensorium.

Let us turn again to our study of sapid substances, restricting ourselves in the first case to the investigation of inorganic compounds. A large number, perhaps the greater number of inorganic compounds, are insoluble in water, and are therefore tasteless, so we are confined to those which are soluble, which are chiefly the salts of certain metals.

Many elements are so closely related that they may be classed together. New and curious relationships have recently been discovered by Newlands, Lothar Meyer, Mendelejeff, and Carnelley. In the groups of elements shortly to be mentioned we find the presence of common physical and chemical properties. It has been shown by Dr Lauder Brunton that elements with similar physical properties have similar actions on protoplasm generally. It will be my endeavour to show that they are capable in the same way of stimulating the end-organs of the gustatory nerve, and producing similar sensations.

The nature of the Periodic Law is now so well known, thanks to the many recent publications of Professor Carnelley, that it would be superfluous to attempt more than roughly to sketch its main features. If we arrange the elements in the order of their atomic weights, beginning with that which has the lowest, and passing to that which has the highest, we shall find that there is a periodical recurrence of function or property in the series. The first element is a monad, the second a dyad, the third a triad, and the fourth a tetrad. Then we find the fifth a triad, the sixth a dyad, and the seventh once more a monad. Then follows a second series of seven elements, showing the same variation in atomicity, and this repeats itself right through the list of elements. This periodic recurrence is seen not only with the atomicity, but with the atomic volume, the fusibility, the electrical and other properties of the elements. There is then a general resemblance in physical properties between the first, eighth, fifteenth, &c.; between the second, ninth, sixteenth, &c., and so on. Mendelejeff has arranged the elements in a very convenient tabular form, which brings out these and some other important facts.

MENDELEJEFF'S TABLE.

Groups.	I.	II.	III.	IV.	V.	VI.	VII.	Group VIII.
Series.	Monads.	Dyads.	Triads.	Tetrads.	Triads or Pentads.	Dyads or Hexads.	Monads or Heptads.	
1.	H = 1							
2.	Li = 7	Be = 9	B = 11	C = 12	N = 14	O = 16	F = 19	
3.	Na = 23	Mg = 24	Al = 27	Si = 28	P = 31	S = 32	Cl = 35·5	
4.	K = 39	Ca = 40	Sc = 44	Ti = 48	V = 51	Cr = 54	Mn = 55	Fe = 56 . Co = 59 . Ni = 59 . (Cu = 63)
5.	Cu = 63	Zn = 65	Ga = 69	EkaSi = 72(?)	As = 25	Se = 79	Br = 80	
6.	Rb = 85	Sr = 87	Yt = 89	Zr = 90	Nb = 94	Mo = 96	...	Ru = 104 . Rh = 104 . Pd = 106 (Ag = 108
7.	Ag = 108	Cd = 112	In = 113	Sn = 118	Sb = 120	Te = 125	I = 127	
8.	Cs = 133	Ba = 137	La = 139	Ce = 142	Di = 147	Tb = 149(?)	...	—— —— —— —— (——)
9.	...	...	...	...	Er = 166(?)			
10.	...	...	Yb = 173	...	Ta = 182	W = 184	...	Os = 193 . Ir = 193 . Pt = 195 . (Au = 197
11.	Au = 167	Hg = 200	Tl = 204	Pb = 207	Bi = 210			
12.	...	...	...	Th = 234	...	U = 240	...	—— —— —— —— (——)

Those elements, which resemble one another and which we can pick out, taking every eighth one from that one we start with, from what he calls a *group* (see table). In vertical series are arranged the *groups* of similar elements, and the *series*, each of seven elements, are seen on the horizontal lines. There is one other point of importance; it is that the elements of a *group* which are in an *even* series are especially related one to another in these properties. So, in like manner, elements belonging to the same group of odd series are especially related. Thus Li, Na, K, Cu, Rb, Ag, Cs, Au have all of them properties in common; but in this group, Na, Cu, Ag, Au are most alike, and Li, K, Rb, Cs also, in like manner, are specially related.

By far the greater number of sapid substances contain elements found in Groups I., II., and VII., and these I accordingly studied. The salts of Group I. and II. most easily obtained are the chlorides and sulphates, and of Group VII. I selected the combinations these elements form with sodium and potassium. As it was very necessary to use salts as pure as possible, many were prepared for me with great care by Mr Harris the chemist, but for the greater number I have to thank my colleague Dr Nicol, who placed at my disposal a large collection of very pure salts prepared by himself for his own well-known investigations on solubilities. In the subjoined tables are the results of an investigation of Groups I., II., and VII. We have then to see whether the same taste sensations are produced by the chlorides, &c., of elements having similar physical properties.

Group I.

Metal.	Chloride.	Sulphate.
L	Salt.	Sal. Bit.
Na	Salt.	Sal. Bit.
K	Salt. Sal. *Bit.*	Sal. Bit.
Cu	Insol.	Sal. Bit. Ast.
Rb	Salt. Sal. *Bit.*	———
Ag	Insol.	Sal. Bit.
Cs	Salt. Sal. *Bit.*	———
Au	Salt. Ast.	———

It will be seen that all the soluble chlorides are salt like table salt, although with the higher numbers we have the taste becoming more saline, A very slight bitter taste also develops. Some salts are astringent, as will be seen in a study of this and of other groups. I do not think this astringency is generally looked upon as a taste at all, depending, as it does, upon the formation of insoluble albuminates. It is purely a local action on the mucous membrane of the tongue, and will not be again discussed.

The sulphates are saline, not salt at all, and in addition they are distinctly bitter. I have not been able to obtain the sulphates of cæsium and rubidium.

GROUP II.

Metal.	Chlorides.	Sulphates.
Be	———	Acid. Sweet Ast.
Mg	Bit. Sal. Wrm. Pung.	Bit. Sal.
Ca	Bit. Sal. Wrm. Pung.	Insol.
Zn	Bit. Sal. Wrm. Pung.	Bit. Sal. Ast.
Sr	Bit. Sal. Wrm. Pung.	Insol.
Cd	Bit. Sal. Wrm. Ast.	Bit. Wrm. Ast.
Ba	Bit. Sal. Pung.	Insol.
Hg	———	———

In Group II. the chlorides are all bitter salines, with in nearly every case a warm pungent flavour. They are very disagreeable to taste, and it is long before the flavour leaves the mouth. Beryllium chloride with the sulphate is described as sweet. I have not tasted the chloride; the sulphate is distinctly acid and astringent as well. Beryllium salts then come out as a well-marked exception to the other salts, giving, as they do, such constant taste sensations. The atomic weight of beryllium was long an open question. I am informed on competent authority that there is now no doubt on this head, and I am at a loss therefore to explain its action as a sapid substance. The soluble sulphates are saline and bitter.

GROUP VII.

Element.	Sodium Comp.	Potassium Comp.
F	Salt.	Salt. *Sal.*
Cl	Salt.	Salt. Sal. *Bit.*
Mn	———	———
Br	Salt. *Sal.*	Salt. Sal. *Bit.*
I	Salt. Bit.	Sal. Bit.

In Group VII. we have tastes produced which are in the main salt. In the case of both the sodium and potassium compounds there is a tendency to the production of the saline and bitter among the higher members of the group, and this is sooner seen in the case of potassium—itself a higher member—than in the case of sodium, a lower member of Group I.

From a study of these groups we may learn many important facts. It will be seen that much depends upon the electro-negative group with which the element is combined. Thus sodium combined to form a chloride has a different taste from the sulphate of the same element.

With the same electro-negative group similar elements give similar tastes, but with a curious and very uniform change, as we pass from an element of low to one of high atomic weight. As we shall soon see, a change in physical property may, in like manner, be seen as we pass from a lower to a higher member of a group.

So far then we have reduced taste to a *function* of elements and then compounds, and we see that it obeys laws which are the same for so-called physical properties of these elements; just as from a knowledge of the components of a compound we can account for its physical properties, so we have to take to pieces the sapid substance before we get the clue to relationship between its nature, as indicated by its chemical and physical properties and the sensation it produces.

This is much already to learn, but can we go a step further, and ask "in what *essentials* are elements alike that produce similar tastes." We turn naturally to the question with which we started, and ask, Do these elements *vibrate* in any way that is similar?

Rapid advances are being made in the more exact and extended inquiry, How do the ultimate particles of matter move? In a few years, no doubt, the investigations into the ultra-red and ultra-violet spectrum will shed a flood of light on this question, and will enable us to come to more definite conclusions than at present. Still much is known, and it may not be premature even now to make use of this incomplete knowledge.

No one would expect to find very closely allied spectra when comparing elements even of the same group, and for this reason. Suppose potassium and lithium to have each a fundamental tone and a series of upper partials each in an exactly similar inharmonic ascending scale, the tones of the heavier—potassium—would all be of lower pitch than the lighter—lithium. An absorption line of potassium in the visible spectrum will correspond in this case to one of lithium in the ultra-violet. Thus all attempts to establish exact mathematical relationships between the wave lengths of similar metals are for the present out of the question. We can but hope to find rough points of similarity, and these are forthcoming. The chloride of the alkaline earths are nearly related. The lithium and sodium spectra have some points of similarity, especially in their extreme simplicity; also potassium and rubidium, each with their five groups of lines. Then again the chlorides, bromides, and iodides of calcium and barium are nearly related, the lines shifting towards the red end of the spectrum in a way which is nearly proportional with the increase of atomic weight.

Many salts absorb light of different wave lengths, and are in consequence of a definite colour. The colour is an index to this absorption and to the state of molecular vitiation of the salt molecules. In a paper on the colour of chemical compounds, recently published in the *Philosphical Magazine*,* Professor Carnelley demonstrated a relationship between salts of metals of the same group in respect to colour. The salts, say the chlorides, of a group of metals are much of the same colour, except that as you pass to the higher members of a group this changes somewhat, shifting uniformly towards the end of the spectrum. This is illustrated by the following diagrams taken from his paper, in which only these metals of a group are given in alternate series :—

Metal.	Cl.	I.	Metal.	CrO_4.	AsO_4.
Na	White.	White.	Mg	Lemon Yellow.	White.
Cu	White.	Cream.	Zn	Yellow.	White.
Ag	White.	Light Yellow.	Cd	Orange Yellow.	White.
Au	Yellow White.	Golden Yellow.	Hg	Red.	Yellow.

The striking analogy between the above tables and those of taste already alluded to needs scarcely to be pointed out; it is obvious. But what does this shifting towards the red end of the spectrum indicate

* *Phil. Mag.*, July 1884.

in the case of these coloured salts? Probably the colourless ones have vibrations of high pitch in the ultra-violet; with a higher atomic weight and slower vibration they gradually absorb the rays of the visible spectrum. The blue rays are first absorbed, and the salt appears yellow; then the green giving orange, and then the yellow and orange rays, all also absorbed, giving red. In the case of tellerium chloride all are absorbed, and the salt is black. Carnelley has therefore demonstrated that the salts of a group have molecular vibrations, which are similar, which absorb light and give rise to *colour sensations*, which are similar, changing uniformly, however, with increasing atomic weight. If a curve be constructed in which the ordinates represent the atomic weights of the positive elements, and the abscissæ a chromatic scale rising from blue, green, &c., to black, we shall obtain a curve, indicating that the colours of the compounds are a periodic function of the elements arranged in atomic series. This is best seen in the case of the normal iodides. Upon the pitch of the vibration depends the colour sensation, as every one would admit; we find in the case of taste a result which in every way is the same.

This has been an induction from the study of the inorganic compounds, but a whole field of inquiry has been untouched. As yet no allusion has been made to the carbon compounds, many of which are sapid.

One of the most important and interesting facts in connection with the chemistry of the carbon compounds is that they have what may be termed a *structure*. Thus the formula for common alcohol is C_2H_6O, but one of the hydrogen atoms is found to be especially related to the oxygen, and it is written $C_2H_5 . OH$. In this case, then, there is one group (compound radical), C_2H_5, united with another group, OH. Now those groups play the same part that elements do in inorganic compounds, and it is necessary to know this so-called structural formula, in order to understand the property of an organic substance. Just as we can replace the hydrogen in water with potassium and form another substance of different properties depending upon the nature of the substance you add, so, in like manner, we can replace the C_2H_5, or the OH, by other compound radicles or even elements, and produce a substance whose properties will depend upon the nature of the radical added.

There are then two points for investigation. In the first case, can we find in sapid substances having, say a sweet or a sour taste, compound radicals always present, and from whose presence we may say that the taste-sensations result? Just, in fact, as the chemist associates certain properties with the presence of a certain radical in a substance, can we find similar associations with taste sensation?

In the second place, do we find that a compound radical, in the various combinations which it may form, preserves the character of its vibration, as shown by the spectroscope, unaltered in any marked degree?

The answer to the first question can be readily given, for it will be sufficient to obtain a list of substances giving a definite taste, and to search for some common or similar radical. If a radical common to all be found, we may safely answer it in the affirmative.

There are among the carbon compounds many substances having an acid taste; here is a list of the most familiar ones:—

Acetic acid, ...	$CH^3 . CO . OH.$
Oxalic acid, ...	$CO . OH.$ | $CO . OH.$
Succinic acid, ...	$CH_2 . CO . OH.$ | $CH_2CO . OH.$
Glycolic acid, . . .	$CH_2 \langle {OH. \atop CO . OH.}$
Glyceric acid, . . .	$CO . OH$ | $CHOH$ | CH_2OH
Lactic acid, ...	$CH_3 . CH \langle {OH. \atop CO . OH.}$
Tartaric acid, ...	$CH(OH) . CO . OH.$ | $CH(OH) . CO . OH.$
Benzoic acid, ...	$C_6H_5 . CO . OH.$

Malic acid, ...	$CH(OH).CO.OH$ | $CH_2.CO.OH.$
Glyoxylic acid, . . .	$CHO.$ | $CO.OH.$

The above ten examples of substances possessing distinct acid tastes are taken from various classes of organic acids, and they will be seen to have in all cases a common group of elements. This group is a compound radical $CO.OH.$ which is combined in all cases with a different molecule. We have then the same right to impute to this radical the capacity of producing a given taste sensation as the chemist has of looking upon it as related to certain physical properties of the compounds in which it may be found.

Among sweet substances we find the following :—

Glycol, ...	$CH_2.OH$ | $CH_2.OH.$
Glycerine, ...	$CH_2.OH$ | $CH \quad OH$ | $CH_2.OH.$
Mannite, ...	$C_6H_8(OH)_6$
Glucose, ...	$C_6H_{12}O_6$
Inosin, ...	$C_6H_{12}O_6$
Saccharin, ...	$C_{12}H_{22}O_{11}$

These are all alcoholic bodies, glycol, glycerine, mannite, being respectively a diatomic, triatomic, and hexatomic alcohol. The rational formulæ of the last three, and other nearly related substances, such as levulose, maltose, &c., are not at present definitely settled; but it is certain that they are alcoholic or ether bodies, and contain a radical $CH_2.OH$ found in the first three substances. Thus the formula of glucose, according to Colley, is $CH_2.OH - CH.OH. - CH.OH - CH.OH - CHOH - CHO.$

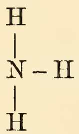
Monatomic ethyl alcohol is tasteless, and has been alluded to already. It is the simplest alcohol, the polyatomic alcohols referred to having a sweet taste.

We see here again that, with a definite molecular structure, with the presence of certain groups of elements, a definite taste sensation is produced. A chemist examining the rational formula of a substance will predict its properties to an extent which will vary with the extent of his knowledge. We too can predict a property, that of producing a particular sensation, when applied to the tongue.

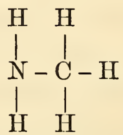
There is a large number of organic compounds having a bitter taste. Such is quinine, quassia, strychnia, &c., but inasmuch as so little is known as to the chemical nature of these substances their investigation would be of little use.

We have seen that in the inorganic compounds the physical, chemical, and taste properties vary with the nature of the elements in the sapid substance; with similar elements similar properties are associated. So, too, we have seen among the carbon compounds that the physical, chemical, and taste properties vary with the compound radicals present in the sapid substance. The question now to be determined is, whether or no the compound radicals behave as elements, vibrating in a characteristic and definite way, not materially disturbed by altering the combination. This may be determined by the eye, with or without the aid of the spectroscope. We know that chromic acid has an orange-red colour; combine it with metallic elements to form chromates, and we find that these are coloured, the colour varying very slightly with the metal.

Picric acid is a coloured solid, and it probably owes its colour, at any rate in part, to the presence of a radical (NO_2). Its salts, too, are coloured, the absorption shifting towards the red end of the spectrum. In his interesting researches into the spectra of colourless fluids, observed through a considerable length of tube, Dr W. J. Russell finds that ammonia gives certain well marked absorption bands. If an atom of hydrogen in the ammonia be replaced by methyl forming a substance methylamine, the ammonia bands are still seen, shifted, however, slightly towards the red end of the spectrum.



Ammonia.

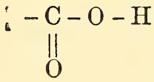


Methylamine.

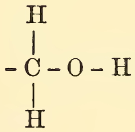
Replace the hydrogen by the higher group C_2H_5, or Ethyl, to form ethylamine, and the shifting continues towards the red.

With a series of alcohols, such as methylic, ethylic, propylic alcohol, we find that, as we pass to the more complex, heavier, but similarly constituted molecule, a shifting of equally characteristic bands towards the red end of the spectrum. It is very much (and here we may recall the colour experiments of Professor Carnelley) as if we took an instrument, say a violin, and kept loading its strings. The notes would be heard deeper and deeper in tone, but it would be still recognised as having the tone or quality of the violin.

I have mentioned the above instance, though many others might have been adduced, to demonstrate the same fact. We have every reason then to believe that the radical



and the radical



of the acid and sweet substances are both in constant and characteristic vibration, although this vibration does not affect the rays of the visible spectrum. Not only so, but we know that this vibration will not be altered in character (from the analogy with the ammonia radical in methylamine) being merely shifted to a small extent in pitch, when its combinations are changed.

This is, however, the analogy which we have sought. Both in the case of sight, hearing, taste, and, as I hope afterwards to prove, in the case of smell, we have these analogous phenomena. On the side of sensation we have variations in what we may call quality, on the objective side we have matter in vibration,—these vibrations vary in character, and it is possible to connect the quality of the sensation with the character of the vibration.

It may be urged that, inasmuch as an acid like hydrochloric acid produces much the same taste as oxalic acid, there is no such definite connection between vibration and sensation. There are, too, some sweet substances having no relationship to an alcohol. We know, however, that one can get the same colour sensations from a solution of either a picrate or a chromate, two substances absolutely dissimilar in chemical properties; the reason is, that they both give a group of vibrations in the same part of the solar spectrum. It would then be reasonable to expect that instances would be forthcoming of substances of dissimilar nature and chemical composition with similar tastes. It would seem probable, then, that there is a scale of vibrations which may stimulate the taste organs analogous to the visible spectrum. If a substance vibrates in a definite part of this scale, a definite taste will be produced.

One must always remember that the tongue has, like the eye and unlike the ear, no power of analysis. It may be that just as a colour, say orange, may be produced by either a simple vibration, or a combination of vibrations, some higher and some lower in pitch than that of the simple one, so the same taste may, in like manner, be produced by a simple vibration or a compound one made up of simple vibrations of higher and lower pitch.

In conclusion, it will be necessary to state very emphatically that it is analogy that this paper proves,—analogy in the production of the senses. It would be premature definitely to say how the vibrations of common salt produce irritation of the gustatory nerve. Is it by setting up a sympathetic vibration, as in the ear, where the sonorous waves set in motion the end-organs of the labyrinth? Upon such a question I have no wish to hazard what could only be an opinion. In the eye vibrations stimulate the cones. How is this done? It is quite conceivable that this is by setting up sympathetic vibrations, but many suppose it to be a chemical action. If we ask what is a chemical action, no adequate reply will be forthcoming, though many would hesitatingly affirm that even so-called chemical actions may have a vibratory and mechanical interpretation. When we say that we *understand* the manner in which the end-organs of the ear are stimulated, we mean that we can prove an analogy between the sympathetic vibration of a tuning fork, and of the organ of Corte, when effected by the same wave motion. This is nothing, however, but an analogy. The production, on the other hand, of end-organ irritation by light or molecular vibration has no sufficiently definite analogue in the laboratory of the experimenter.

All that I claim to have proved is, that the body is surrounded by vibrating matter, stimulating its sensitive surface. That in all cases the process of stimulation with the production of a consequent sensation is the same to this extent, that the quality of the sensation is dependent upon the character (pitch and complexity) of the vibrating matter, just as a certain class of salts of allied chemical and physical properties vibrate in a similar way, and stimulating the eye, produce the same colour sensation ; just as certain strings of definite length and consistency vibrate in a similar way and produce the same sound ; so, in like manner, the similar sapid compounds (containing similar elements or the same compound radicals) vibrate in a similar way and produce the same taste.

Concluding Address by Robert Gray, Esq., Vice-President.

In reviewing for a moment the business of the Session now about to be closed, I think we may fairly congratulate ourselves on the satisfactory results ; indeed, I may venture to say that at no period of its history has the Society shown so much vitality, or such a capacity for solid scientific work. Since the opening meeting in December last, ninety-one communications have been submitted at the ordinary meetings, the number being nineteen higher than last Session, and greatly in excess of the average of previous years. These papers may be classed under the following heads :—Physics, 30 ; Mathematics, 7 ; Hydrology, 5 ; Chemistry, 10 ; Geology, 2 ; Mineralogy, 1 ; Meteorology, 10 ; Biology, 4 ; Botany, 2 ; Physiology, 13 ; Anatomy, 5 ; Anthropology, 2.

Thirty-six Fellows have joined the Society during the past Session, and four deaths have taken place. The total number of Fellows on the roll at present is 462. With regard to the deceased Fellows they will receive due mention by competent writers in our Obituary Notices ; but I may meanwhile be permitted to say that in Bishop Cotterill, whose deeply affecting message to his clergy and his people, when he learned the nature of his last illness, will not soon be forgotten, the Diocese of Edinburgh has lost an able administrator, a learned theologian, and an earnest teacher; in Dr

Angus Macdonald, one of the most distinguished of the many celebrated physicians of this city, a gentleman whose skill and conscientiousness marked him as one of the most able and devoted of the profession to which he belonged; while in Dr Williamson, Leith has lost one of its most eminent men, who discharged with universal acceptance the important duties connected with the various medical offices which he held.

It would not be easy for me, nor would it be desirable, to enter into a critical estimate of the value of the papers that have been submitted to us during the Session that is past, and their bearings upon the progress of science in this country; yet it may not be out of place to say that they will contrast favourably with those issued by kindred societies in other parts of the world, and quite justify the impression that under the present administration of the Society's affairs still greater results in the future will be obtained.

Those who have taken part in our proceedings cannot fail to have observed that some of our physicists have dealt, and successfully dealt, with problems of surpassing difficulty, requiring for their solution the utmost resources of mathematical analysis, and the results thus obtained with so much thought and labour constitute real advances in the progress of science, which will at once facilitate the work and guide the steps of future inquirers. Others, again, of our physicists have preferred to investigate the causes of some of the grandest phenomena of nature by the aid of experiments of extreme simplicity, but not on that account less fruitful in results, and have shown to us that costly and elaborate apparatus and laboratories filled with mechanical resources are not indispensable for lifting the veil from the secrets of nature, when the investigator is guided by the zeal which animates and the disinterestedness which pursues truth as its own highest reward.

With regard to the biological papers of this and past Sessions—many of which are of considerable value and interest, coming from what I may venture to call a distinguished school of biology which has grown up among us—I may remind the Society of the services of Dr John Murray, Director of the "Challenger" Expedition Commission, through whom, directly and indirectly, much valuable material has been contributed to our publications. From my own point of view this has been very gratifying, because it has happened within my recollection as a Fellow of the Society that, owing to the entire absence of such papers one of the Society's important prizes (the Neill Prize) could not be awarded; while now the Council sometimes experience a difficulty in selecting one, or a series, out of many papers of great excellence for this distinction.

It is particularly gratifying to remark on an occasion like this, the excellent work now being done by the younger Fellows of the Society, who are rising into notice, and I cannot but think it fortunate for science in Scotland, not only that we have such workers amongst us, but that our Society has the command of funds that have enabled it to publish *Proceedings* and *Transactions* with a liberality, and wealth of illustration, which has probably not been exceeded by any scientific Society throughout these realms. But, gentlemen, we have in our midst original thinkers engaged in active research, which can only be carried on at considerable personal cost, but which it is quite beyond the province of this Society to meet, or even to mitigate; and in mentioning this, I cannot but regret that a Society holding the position of the Royal Society of Edinburgh, should not be entrusted with a share of the Government annual grant for the prosecution of scientific research in this country. The distribution of even a small share by this Society among local applicants, or those residing in other parts of Scotland, whose claims could be better considered here than by the judges of a distant tribunal, would, I feel assured, lead to the best results. Hitherto the difficulty may have been a want of information on the part of the London Committee in charge of the fund, as to the applicants from Scotland, and the nature of their work, and hence, no doubt, their refusal in many cases to give grants in aid of investigations which would have been of real service. But there would be little or no difficulty were a committee of this Society empowered to deal with such applications; and I trust that a strong effort will be made in the proper quarter to bring about an arrangement so desirable, as I am satisfied it would confer a positive benefit upon science at large.

As an office-bearer and member of Council, now of some years' standing, I have taken but a very small personal share in the work of the Society, and on that account I am, perhaps, all the more privileged to refer to the services of others. There never was a time probably in the history of the Society when there was so much activity in the executive Council, the members of which are carrying on the Society's affairs with a zeal and discrimination which it is not the lot of all societies to experience. But beyond all question, the recent and present prosperity of the Royal Society of Edinburgh is mainly due to the distinguished services of our much-esteemed General Secretary, Professor Tait. Besides giving the Society the fruits of his own brilliant research in the many papers contributed by himself during every Session, he has by his great tact and administrative ability, gathered around him a band of fellow labourers, well chosen and effective; and so long as such services are given, so long the Society's influence will continue to be felt both at home and abroad.

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OF THE

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SESSION 1884–85.

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