THE OUTLINE OF SCIENCE

First Volume

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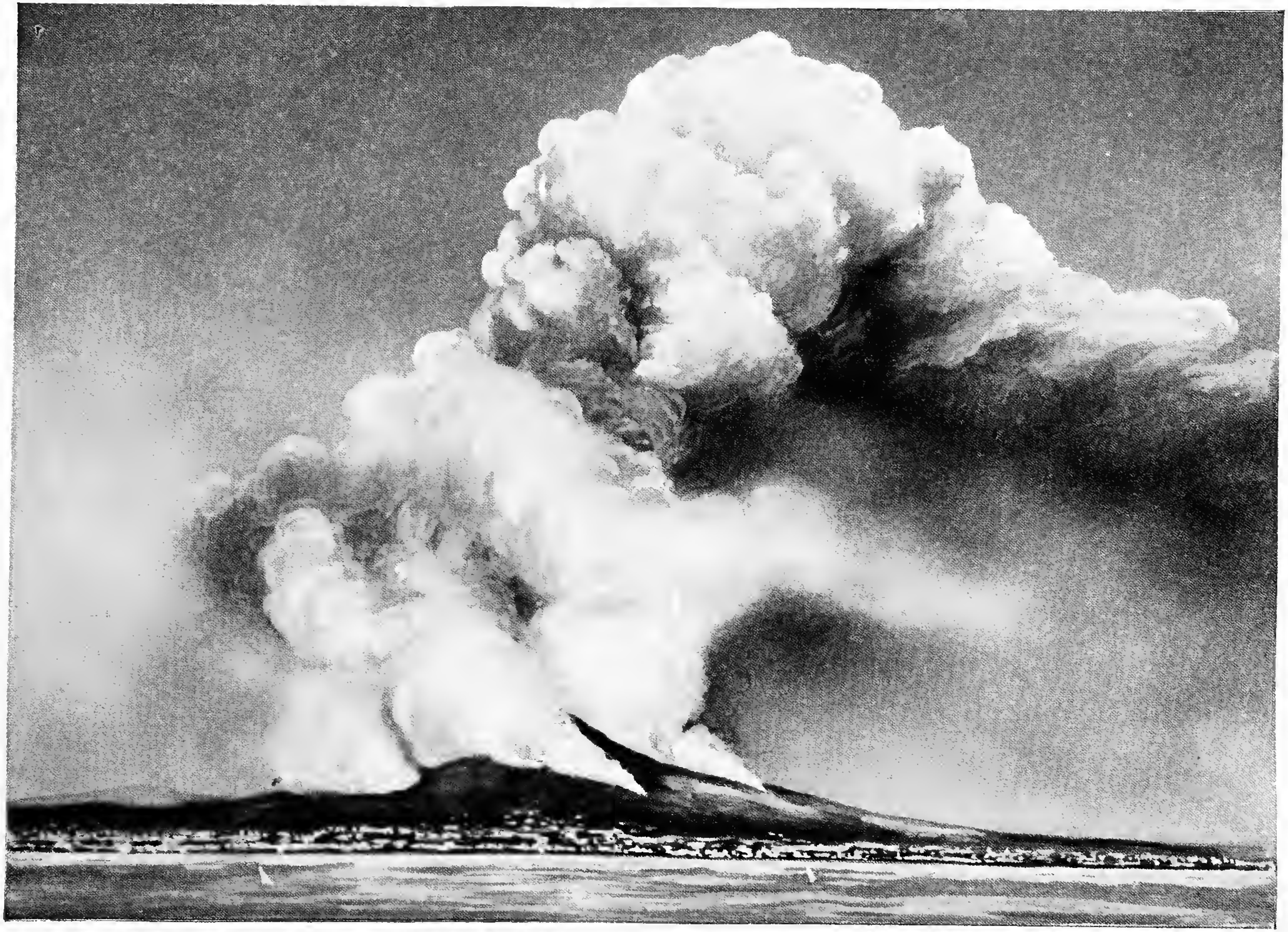

From a photograph by Negretti & Zambra.

VESUVIUS IN ERUPTION

Vesuvius, overlooking the Bay of Naples, was an extinct volcano in early Roman times; the story of its first recorded eruption, when the towns of Pompeii and Herculaneum were overwhelmed, is well known. Since then its activity has varied, and our illustration shows the appearance of the mountain during one of the major outbreaks of recent date (1872-3). At the present time Vesuvius continues in a state of moderate activity.

THE
OUTLINE OF SCIENCE

A PLAIN STORY SIMPLY TOLD

EDITED BY

J. ARTHUR THOMSON

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UNIVERSITY OF ABERDEEN

WITH OVER 800 ILLUSTRATIONS
OF WHICH ABOUT 40 ARE IN COLOUR

IN FOUR VOLUMES

★ ★ ★ ★

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BACTERIA

THE BACTERIA: THE UBIQUITOUS GERMS OF FERMENTATION, PUTREFACTION, AND DISEASE

By Sir E. Ray Lankester

The Early Microscopists

THE microscope is the means by which our modern understanding of the structure and nature of living things—as contrasted with the baseless fancies and blank ignorance of three centuries ago—has been gained. It is a noteworthy fact that even the use of a simple lens of glass or crystal as a magnifier is not recorded by ancient Greek or Roman writers—though it is difficult to believe that some of the minute engravings on ancient gems were made without the use of a magnifying-glass. It is true that Pliny tells us of the concentration of the sun's rays by a glass globe filled with water, and of the use of such a globe as a "burning glass"; but the first records we have of the use of glass lenses as optical instruments date from the early years of the fourteenth century, when they were used by ingenious Italians (some say by Roger Bacon also) to improve the failing sight of old people, and were (as they still are) called "spectacles." In a portrait of Pope Leo X, painted by Raphael in 1520, the Pope is drawn holding a hand-magnifier, evidently intended to enable him to read the pages of a book open before him.

It took two hundred years for learned men to advance from the use of "spectacles" to the first combination of lenses, to form on the one hand "a telescope" and on the other "a microscope."

The first-made "compound microscopes" or adjustments of two lenses—an "ocular" and an "object-glass" mounted in a tube, so as to give great magnifying power—were not so serviceable as a means of exploring the invisible world as were the cleverly-shaped *single* lenses, used by some naturalists. Robert Hooke—the secretary of the newly incorporated Royal Society of London—constructed in 1665 a compound microscope consisting of a cylindrical tube seven inches long, carrying eyeglass at one end and object-glass at the other; this was fixed by a ball and socket joint to a firm upright-support, and could be inclined at any angle. A screw arrangement for focussing and also elaborate illuminating apparatus were provided. Hooke's microscope was an improvement in mechanism upon the Italian instrument of twenty years earlier. One of these is attributed to Galileo, and was the first described.

The main features of Hooke's instrument, though the lenses have been greatly developed and improved, are retained in the latest compound microscopes of our own day. Hooke published a folio volume entitled *Micrographia,* describing his observations, finely illustrated by enlarged drawings of the flea, the louse, the house-fly, the nematoid worms called "vinegar-eels," and of a variety of other objects. His drawing of the appearance of a thin slice of cork, greatly magnified, has become celebrated, since it is the first recorded observation of the cell-structure of plants (Fig. 1). The dried dead tissue, consisting of cell-walls enclosing air-spaces where once was living protoplasm, was compared by Hooke to the honeycomb made by the bees, the minute air-holding cavities resembling the closed "cells" of the honeycomb. Hence the word "cell" came into use for these universal units of plant-structure.

A century and a half later the word "cell" was applied, not to the empty-cell wall, but to its living viscid content by the founders of the "cell-theory" of organic structure and function, Schleiden and Schwann (see Figs. 2 and 3). We now speak of the viscid content of the vegetable "cell" and of its equivalent in the structure of animals as "protoplasm."

Leeuwenhoek's Work

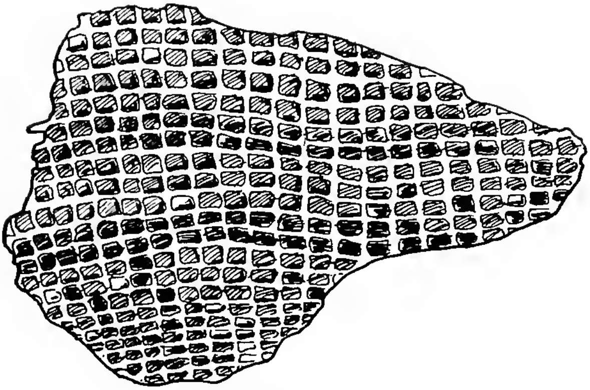
The early "compound" microscope, though giving high magnification, was of much less value as a means of discovery than might be supposed, owing to the distortion and want of clearness of outline in the magnified image which it gave. It was not at first better than, not even so good as, a single lens or simple microscope. In the later third of the seventeenth century Antony van Leeuwenhoek, a merchant of Delft in Holland, who has been called "the Father of Microscopical Discovery," made observations on "animalcules"—living in water, and in the interstices of his own teeth—with a microscope consisting of a single glass lens no bigger than a dried pea, ground into proper shape and curvature by himself, and mounted between two perforated plates of silver. In 1672 he sent descriptions and drawings of his observations to the Royal Society of London—then recently founded. During fifty years, that is, from 1672 to 1722, fifty of his communications were published in the *Philosophical Transactions*. He was made a Fellow of the Society and received from it copies of its publications, including the book by Willoughby on *Fishes,* the cost of which caused such financial difficulty to the Society as to render it unable to undertake the publication of the *Principia* of Isaac Newton.

Leeuwenhoek's observations covered a wide field. They included the discovery of the red corpuscles of the blood of man and birds, the capillaries and the movement of blood along them, the spermatozoa of the dog and of the bird, the banded or cross-striped fibres of muscular tissue, the wheel-animalcules and their survival of desiccation and their "dispersal" as "dust," the structure of yeast as a mass of spherical corpuscles, and many other important things. It required no little skill and patience to make observations with the small simple lenses used by Leeuwenhoek. Though definite facts were thus ascertained the optical imperfections of both the simple and the compound microscope were in these early days such as to give very incomplete and often erroneous notions of the things examined.

Even after the lapse of a century, when O. F. Müller of Copenhagen (born in 1730) described and figured with great skill the freshwater worms and other inhabitants of the ponds and streams of his native land, in publications which are still valued, the microscope was as yet so untrustworthy when high powers of magnification were used, that little value attaches to his drawings of very minute forms, though they are beautifully executed and engraved. He published in 1786 a volume entitled *Animalia Infusoria—fluviatilia et terrestria,* employing the name *Infusoria* (ever since retained in use with important limitations) for the first time for that population of swarming, struggling, multitudinous living things which, otherwise invisible, were revealed by the microscope in *infusions* of vegetable and animal débris. Such infusions occur in natural waters or are purposely prepared in vessels and set aside for observation by the inquiring microscopist.

Leeuwenhoek had already drawn attention to the minute living things thus revealed in their hundreds of thousands in "infusions" which he exhibited with his simple microscope to the Fellows of the Royal Society, to whom also he bequeathed a case containing twenty of his lenses. He wrote of the minute creatures discovered by him as "infusion-animalcules."

It is difficult to identify all the kinds described and figured by Leeuwenhoek with the comparatively feeble and "uncorrected" (that is, "distorting") magnifying-glass used by him, and the consequent want of accurate detail in his figures. But the great successor of Leeuwenhoek and O. F. Müller in this field of study—namely, Ehrenberg—writing in 1838, credited Leeuwenhoek with having distinguished twenty-seven kinds or "species" of Infusoria or "infusion-animalcules"; and O. F.



From Robert Hooke's "Micrographia."

FIG. I.—THE "CELLS" OR CELLULAR STRUCTURE OF CORK, AS SEEN IN A THIN SLICE MAGNIFIED 200 DIAMETERS

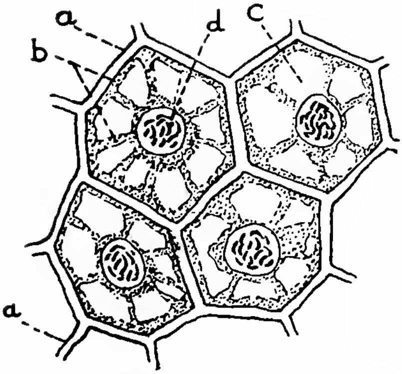


FIG. 2.—SECTION THROUGH VEGETABLE TISSUE SHOWING HEXAGONAL CELLS ENCLOSING "PROTOPLASM"

a, cell-wall; *b*, protoplasm; *c*, liquid-holding space; *d*, nucleus or central "kernel" in each cell.

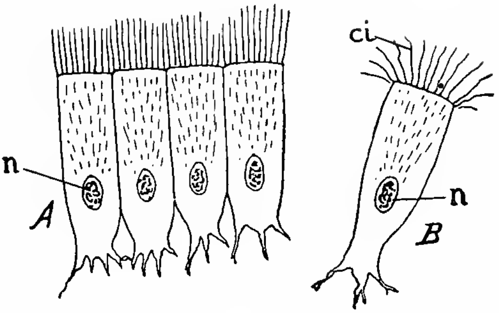


FIG. 3.—COLUMNAR CELLS FRINGED WITH VIBRATING "CILIA," *ci*, AND EACH CONTAINING A "NUCLEUS," *n*

A, a row of such cells; *B*, a single "ciliated cell" detached from the others.

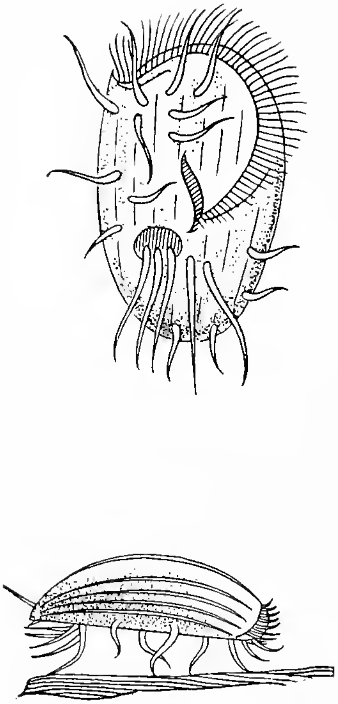
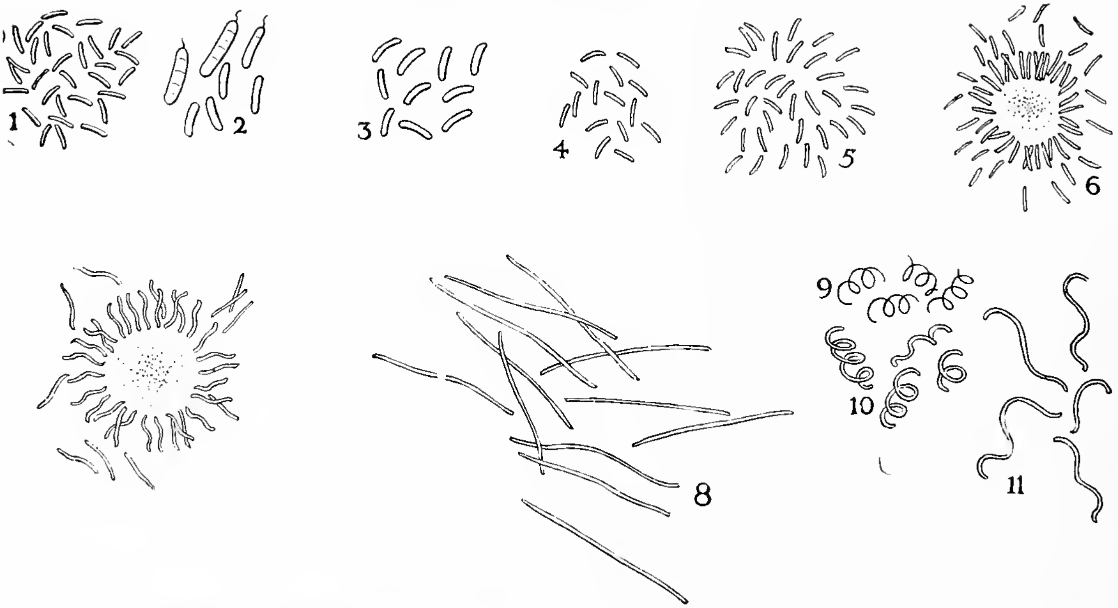


FIG. 4.—THE ANIMALCULE KNOWN AS *Euplotes harpa*

One of the larger "ciliated" Infusoria, provided with delicate cilia along the groove leading to the mouth and with coarser leg-like outgrowths. The lower figure gives a side-view of the animalcule "running" on a piece of weed.



From Plate V. of Ehrenberg's "Infusionsthierchen" (Leipzig, 1838).

FIG. 5

The "species" are named by Ehrenberg as follows: 1 and 2, *Bacterium triloculare* (2 more highly magnified); 3, *Bacterium enchelys;* 4, *Vibrio lineola;* 5 and 6, *Vibrio tremulans;* 7, *Vibrio rugula;* 8, *Vibrio bacillus* (what today would be called a Leptothrix form); 9, *Spirillum volutans* (× 300 linear); 10, *Spirillum volutans* (× 800 linear); 11, less coiled examples of Spirillum.

Müller may be credited with a hundred more. Undoubtedly Leeuwenhoek saw some of the very abundant and excessively minute organisms which are now known by the name BACTERIA, and described their characteristic movements. But he did not give any specific names to the forms which he described nor define them precisely.

§ 1

O. F. Müller's Work

In the work of O. F. Müller a hundred years later the new influence and example of the great Linnæus in introducing the use of generic with specific names and in systematising the nomenclature of living things had its effect. Müller distinguished and named the different "kinds" or *species* of Infusoria which he observed, and sorted the species so named into different *genera*. Each genus so formed received a name and contained species which were held to be more like to one another than they were to the species of other genera. Thus he instituted a genus which he called "Vibrio," and in this genus he placed several "species" which he had observed and of which he gives drawings. Thus we get his *Vibrio lineola, V. rugula, V. bacillus, V. undula, V. serpens,* and *V. spirillum.* They are very minute, almost structureless, thread-like organisms which exhibit a darting and often an undulatory movement and locomotion. We can recognise them to-day by his drawings and still use his names for them.

They comprise a large proportion of those organisms to-day known as *Bacteria.* But Müller was led, by a vague similarity in their shape, to name and enroll in his genus "Vibrio" a number of other small (but not so very minute) worm-shaped creatures revealed by his microscope, which were really, as we now know (as the result of using improved microscopes), of more complex internal structure than, and remote in character from, his other species of Vibrio. Thus he reckoned as forming species of this genus young thread-worms of the sort known as Nematoids; also the wonderful organism which we to-day call by the name given to it by Ehrenberg, "*Bacillaria paradoxa*," and other minute plants—now familiar to "pond-naturalists" as Desmids and Diatoms — besides the swan-necked animalcule called Trachelocerca!

This genus Vibrio, with its strange mixture of species, was placed by Müller with four other genera, viz. Monas, Proteus, Volvox, and Enchelys, as the lowest or most simply organised group of the Infusoria. His genus Monas comprised four species—*M. termo, M. atomus, M. punctum,* and *M. lens*—very minute spherical forms, which it is not possible to identify to-day with certainty. Müller's genus Proteus contains the species of *P. diffluens,* which was described by other observers before him as "the Proteus animalcule." It is to-day known as one of the species of the genus Amœba.

A second species named by Müller *Proteus tenax,* and admirably drawn by him in its changes of shape, is really a species of Astasia—a genus not known by name in Müller's day. Müller assigned to a genus "Volvox" the well-known globular composite organism still known by that name and several other microscopic forms resembling it in general shape but now assigned to separate and widely separated genera. Under his genus Enchelys, Müller placed (and gave specific names to) a number of obscure forms which it is impossible to identify (from his drawings) with any of the microscopic forms which we know to-day. Of larger kinds of Infusorial animalcules Müller defined and carefully figured thirteen genera with a great number of species. Some of them are examples of the group of Protozoa which are to-day called the "Ciliata," because they are beset with vibrating filaments or hairs called "cilia" (see Fig. 3), and for these Ciliata the names used by him still are maintained, since his drawings leave no doubt as to their identity.

Such are the well-known species of "Paramœcium," of "Kolpoda," "Bursaria," and "Vorticella," though Müller erroneously placed in those genera, together with true "Protozoa," many small worms and wheel-animalcules (Rotifera). He established one genus of wheel-animalcules, namely Brachionus, which was excellently figured by him and is still recognised by that name, though he wrongly included other forms (which his drawings show were wheel-animalcules) in his genus Vorticella, together with the bell-animalcules clearly recognisable from his drawings. He knew and figured the attractive group of Ciliate animalcules now called "Hypotricha" with their leg-like locomotive organs (Fig. 4). But he classified along with them in his heterogeneous assemblage of Infusoria also the minute tailed larvæ of the parasitic flukes, to which he applied the name Cercaria, still used for them.

O. F. Müller is not only a pioneer in the history of our knowledge of microscopic life, and the first naturalist to figure accurately and to name the extremely minute organisms which are to-day indicated by the comprehensive group-name *Bacteria;* but he has the credit of entering upon the difficult task of naming these and the many other kinds of Infusoria revealed to him by his microscope in accordance with the binominal method of genus and species introduced by Linnæus. This is all the more noteworthy in that Linnæus himself (as pointed out by Müller) in his *Systema Naturæ* renounced the task, and with what looks like a little outburst of temper assigned these minute organisms to a debatable group of his great class "Vermes," to which he gave the name "Chaos"—*chaos infusoriorum,* as he writes.

Müller made the attempt to reduce this chaos to order, and though naturally enough, as a pioneer must, he failed in some respects, yet the value of his effort is attested by the fact that many of the descriptions given by him are declared to-day to be excellent and accurate as far as they go, and many of the names given by him in his orderly work are honoured and used by the naturalists of to-day.

§ 2

First Use of the Name Bacteria

Fifty years after the date of Müller's work (1786) we find another great microscopist—Ehrenberg—completing his celebrated treatise *Die Infusionsthierchen als volkommene Organismen* (Leipzig, 1838). Ehrenberg (born in 1795, nine years after the death of O. F. Müller) had a much better microscope than that of his predecessor, though the instrument was still far from the perfection to which it was soon afterwards brought by Amici and J. Jackson Lister (the father of Lord Lister the surgeon), through discoveries in the "correction" of the lenses combined to form the "object glass" or chief element of the system.

Ehrenberg had been publishing and accumulating his observations for twenty years when he produced his magnificent folio volumes on "the Infusion-animalcules," with sixty-four plates containing some 1,500 exquisite drawings, many of them in colours, all executed by himself and faithfully exhibiting "animalcules" as shown by his microscope. This treatise is on the same lines as, and is an expansion, as it were, of, the work of O. F. Müller, showing an immense progress in half a century, both in the capacities of the microscope and the increase in the variety and abundance of new kinds of microscopic life now distinguished, named, and classified.

Ehrenberg divided the "Infusoria" or infusory animalcules—in which he included all the minute forms of life to be found in stagnant pools and puddles, streams and seas, whether fresh water or marine—into two classes, "Polygastrica" and "Rotifera." The former were distinguished by him from the latter as possessing an internal structure consisting of many stomachs or digestive sacs, whilst the latter are of larger size and have a more elaborated anatomy, together with the remarkable double or modified wheel-shaped apparatus beset with vibratile hairs (cilia) which Leeuwenhoek had seen for the first time in 1676.

Ehrenberg gives fine and careful drawings of 169 different species of "wheel-animalcules," including most, though not all, of the more remarkable kinds which we know to-day. They form a true and natural group.

But his "Polygastrica" not only are far remote in structure from the Rotifera and far simpler than they are, but are really a most variegated assemblage, including, together with many kinds of "ciliated" animalcules, also whole groups of very simple plants—the Diatoms and the Desmids—as well as the animalcules now called "Flagellata," also the Amœbæ (Proteus) and the Monads and the Vibrions of O. F. Müller.

Whilst it is impossible not to admire the patience and skill of Ehrenberg in producing his great book, it is the fact that he entertained an erroneous theory as to all the lower forms which he called "Polygastrica"—namely, that they possessed numerous stomachs and organs of secretion, etc., which he said are visible in the larger kinds, but can only be distinguished as minute granules in the smallest kinds. This erroneous prepossession affected the accuracy of his descriptions and drawings of many of his "Polygastrica," which have really no such complete system of internal organs, comparable to those of higher animals, as he assumed to be the case in his title *Die Infusionsthierchen als volkommene Organismen.* At the same time it is true that the larger kinds do show some definite elaboration of internal structure. In Ehrenberg's vague heterogeneous assemblage called "Polygastrica," many of which, such as the bell-animalcules, are beautifully figured by him, we find the genus Vibrio of O. F. Müller—the nearly structureless thread-like species of which are amongst the most minute and abundant of "infusory" organisms—included and raised by Ehrenberg to the dignity of a "family," called by him the "Vibrionia." To it are assigned five genera, viz. Bacterium, Vibrio, Spirochæte, Spirillum, and Spirodiscus. (See Fig. 5 and its explanation.)

This, then, is the first appearance in scientific literature of the name BACTERIUM, which has persisted and become a general name for the immense variety of very simple, very minute, rod-like organisms, with which we are in this chapter specially concerned. It has given origin to the name "bacteriology," applied to the special study of these organisms, which, we now have learnt, are immensely important and ubiquitous agents of the chemical processes called "fermentation," "putrefaction," and "disease"! Ehrenberg defined his family "Vibrionia" as "Filiform animals distinctly or apparently 'polygastric,' without an alimentary canal, naked, legless, with the same structureless body as the Monads—forming filiform chains by spontaneous, incomplete, transverse fission." The genus "Bacterium" he defined as "animals of the family Vibrionia assuming by spontaneous division the form of a stiff or firm filiform chain." He recognised three species of Bacterium, namely: *B. triloculare, B. enchelys,* and *B. punctum.* Of the genus Vibrio—differing, according to him, but little from "Bacterium" except in flexibility—he recognised the species *V. tremulus, V. subtilis, V. rugula, V. prolifer,* and *V. bacillus.* The name "Bacillus" was introduced for a species of Vibrio by O. F. Müller. Like the name "Bacterium," it has in the course of years gained a wider and more general signification, and is to-day often used to include a large number of different kinds of rod-like "Vibrions." Serpentine and screw-like forms of these thread-like organisms are placed by Ehrenberg in the genera Spirillum and Spirochæte.

We have thus arrived at the period when, through Ehrenberg, the minute organisms known to him as Vibrionia (for which to-day his generic name "Bacteria" has become universally substituted) were definitely set apart as a group. We have yet to trace their further study by Cohn, Pasteur, Koch, and a whole army of recent investigators, who have shown that these Bacteria are really minute plants, allied to the blue-tinted, thread-like weeds common in fresh waters, and known as the Oscillatoriæ or Cyanophycæ; that they carry on a fundamentally important

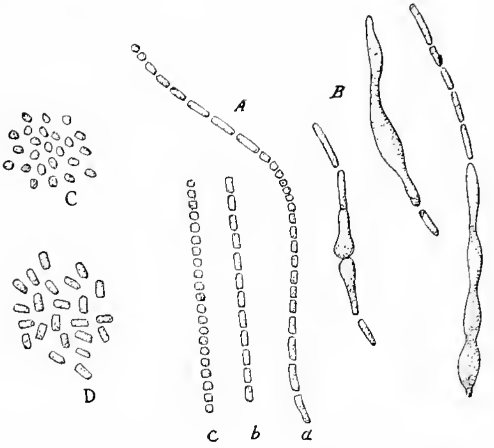


FIG. 6.—THE VINEGAR FERMENT OR ACETIC BACTERIUM (*Bacterium aceti*)

A. The usual filamentous growths, consisting of chains. *a*, long and short constituent rods; *b*, shorter rods; *c*, micrococci. *B*. Distorted growths called "involution forms" which occasionally appear in cultures of this and other Bacteria. *C*. Free micrococci. *D*. Free short bacilli. Magnified 900 diameters.

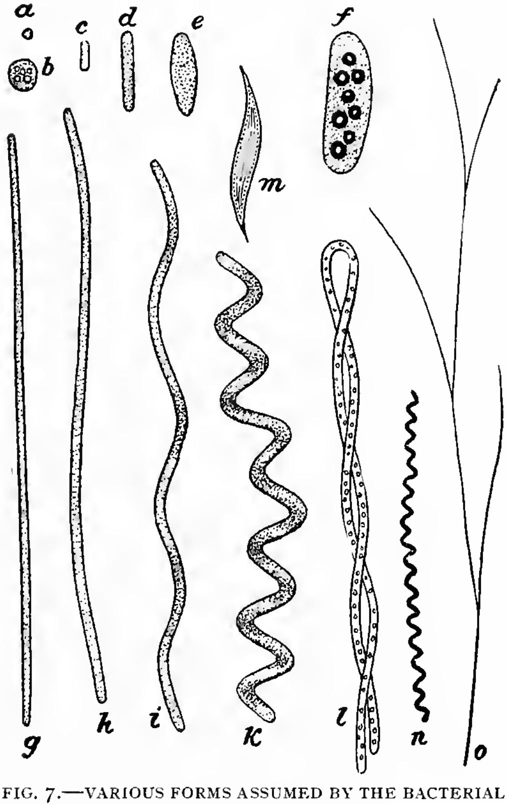


FIG. 7.—VARIOUS FORMS ASSUMED BY THE BACTERIAL "UNIT" OR PLASTID

a, micrococcus; *b*, macrococcus; *c*, short bacillus; *d*, long bacillus; *e*, ovoid form or clostridium; *f*, very large short bacillus enclosing sulphur granules (peach-coloured bacterium); *g*, Leptothrix form; *h*. vibrio form, slightly undulate; *i*, vibrio form, more undulate; *k*, spirillum form; *l*, folded spirillum; *m*, very short spirillum form; *n*, close-set spirillum form; *o*, arborescent form (false-branching) of Cladothrix. All except *o* magnified 1,000 times linear.

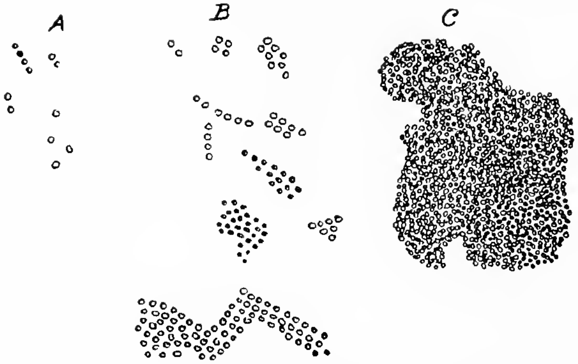


FIG. 8.—GROUPS OF MICROCOCCI MORE OR LESS CLOSELY AGGREGATED

Each micrococcus is about $\frac{1}{50000}$ of an inch in diameter. Abundant in most putrefactions. (After Cohn.)

FIG. 9.—BRANCHING GROWTH OF THE BACTERIUM CALLED *Cladothrix dichotoma*, LIVING IN RIVER WATER

It shows constituent bacillus-like segments and the "slipping" of these (as at *a*, *b*, and *c*) whilst held together by a delicate coat of jelly, so as to form false-branching. Magnified 600 diameters. (After Zopf.)

activity in relation to the nutrition, indeed the very existence, of all living things, being the ubiquitous agents of putrefaction and of a variety of chemical changes in living, or recently living, matter, leading to the production of a large series of chemical substances, many of them important as food to other living things; others valued as flavours or for other qualities by man; many of them poisonous to him and other organisms, and, in fact, the causes of nearly all "infectious" disease.

§ 3

Abiogenesis

Before tracing more of this development of our knowledge of, and interest in, the Bacteria, we shall best get a clear notion of how it has grown up by calling to mind the influence which the discovery of the teeming millions of living things in the natural waters of the earth—suddenly revealed by the microscope in the years following Leeuwenhoek's first observations—had upon the minds of the more thoughtful and speculative "philosophers" of those days.

The immensity of the world of unseen living things suddenly revealed by the microscope was compared by Ehrenberg and others before him to the equally astonishing resolution by the telescope of the pale cloud of the Milky Way into hundreds of thousands of separate stars: a conquest made in the same half-century. Unexpectedly life—as to the origin and nature of which fanciful guesses and romantic traditions had been handed on from remote antiquity—was demonstrated as existing in the form of an almost infinite "dust" of invisible particles, abounding in all the waters of the earth and dispersed far and wide in the dried and pulverised sediment of pools and seas by the wind.

"Spontaneous Generation"

It was held by an English philosopher, Needham (1750), and by others, that this is due to the fact that there is a fertile or productive "principle" in natural waters which gives rise to the Infusoria; whilst others held that water, air, warmth, and the *remains* or *débris* of animal and vegetable substances are necessary for the "generation" of these organisms. These views were largely accepted and discussed at the end of the eighteenth century as two varieties of the doctrine of "spontaneous generation," or *generatio primitiva,* or *generatio equivoca,* as it was called. At the present day the term "Abiogenesis" is used for the theory according to which living organisms arise from not-living matter. It is now held that though in the remote past this must have occurred, there is no evidence to show that it takes place at the present day.

In early times Greek, Roman, Hebrew, and Arabic philosophers accepted the popular beliefs that new generations of animals and plants—continually and as a regular every-day occurrence—"spring into existence" by the sudden transformation of the lifeless decaying substance of dead animals or plants. It was also held that often by the sudden "vivification" of the inert, mud-like deposits forming the banks of seas and rivers, birds and beasts of new kinds are produced, and that the waters "bring forth abundantly," by a normal though mysterious process, fish and creeping things, and sometimes larger beasts. Thus there was no difficulty felt in regard to the original creation of life on the earth. It was merely an early operation on a large scale of the same power which (so it was believed) is at work every day in obscure regions of the land-surface undisturbed by man's intrusion.

The poet Milton set forth in splendid verse this conception of the creation of living things. His cotemporary, Sir Thomas Browne of Norwich (1670), states his belief in the "spontaneous generation" of mice in wheat stores, but is sceptical as to their being "bred in putrefaction" in mud or slime, and as to the production of the barnacle goose from barnacles, and of these from timber. Alexander Ross, a cotemporary, wrote of his views: "Sir Thomas Browne may doubt whether, in cheese and timber, worms are generated, or if beetles and wasps in cow's dung; or if butterflies, locusts, grasshoppers, shell-fish, snails, eels, and such like be procreated of putrefied matter—which is apt to receive the form of that creature to which it is by formative power disposed. If he doubts of this let him go to Egypt, and there he will find the fields swarming with mice begot of the mud of Nylus, to the great calamity of the inhabitants." This quotation gives a vivid record of the common opinion of that day on Abiogenesis.

Yet at the very same time Leeuwenhoek was starting the investigation of the vast world of "animalcules" by his microscope, and the Italian Redi made the first step (1668) in the scientific refutation of the popular theory of Abiogenesis by showing that no maggots were "bred" in meat on which, by means of wire-netting, flies were prevented from laying their eggs. It was at this date that the great physician Harvey enunciated, as a final dismissal of the ancient fancies as to spontaneous generation, the law *omne vivum ex ovo,* every living thing comes from an egg—that is, from the reproductive form produced by a pre-existing living thing.

During the eighteenth century, as the result of Redi's experiment and similar observations of a very simple kind, the general belief in Abiogenesis or spontaneous generation, in so far as the larger forms of life are concerned, disappeared.

But it found a new scope when the existence of a world of well-nigh invisible organisms was made known at this critical moment by the microscope. We have seen that Needham and others indulged in large speculations based on the supposed spontaneous generation of the swarming dust of animalcules now discovered. "True!" they said, "the larger forms of life are only produced by parentage; but this newly-discovered world of minute creatures arises by Abiogenesis, and in due course they gave birth to larger organisms." It was an Italian, Spallanzani, who applied to the problem thus restated the same kind of test as that used a hundred years earlier by his compatriot Redi. He demonstrated that if a natural water or an infusion teeming with microscopic animalcules were heated to boiling-point, the animalcules were killed, and if the flask in which the liquid was contained was now hermetically closed, the liquid became clear, and no living things could be found in it, even after it had been thus kept for many weeks. But when the flask was opened and the liquid in it exposed to the inflow of air, then, after a few hours, infusorial animalcules were again found living in thousands in it. Spallanzani drew the conclusion that the "eggs" or "germs" of the animalcules were carried in the dust of the air and so gained admission to the liquid when the flask was opened.

§ 4

A Long Controversy

A controversy thus arose which has continued into our own times, and has led to very important knowledge as to the conditions necessary for the life of the "infusory animalcules" and also as to the many different kinds included under that name, as well as to the means of keeping liquids containing organic matters (such as infusions or solid vegetable and animal substances) altogether protected from the access of "infusory animalcules." Liquids so treated are said to be "sterilised." In order to study the question as to the existence of Infusoria or their reproductive germs as dust in the air, it was necessary to "sterilise" an infusion, such as that of hay or roots, fruits or flesh, which was to be used (like the raw meat in Redi's experiment) to feed or cultivate the air-carried germs should they gain access. The experimenter had to begin by preparing an uninfected "culture-fluid" which, though free from living Infusoria, should yet be capable of affording them nourishment should they gain access to it.

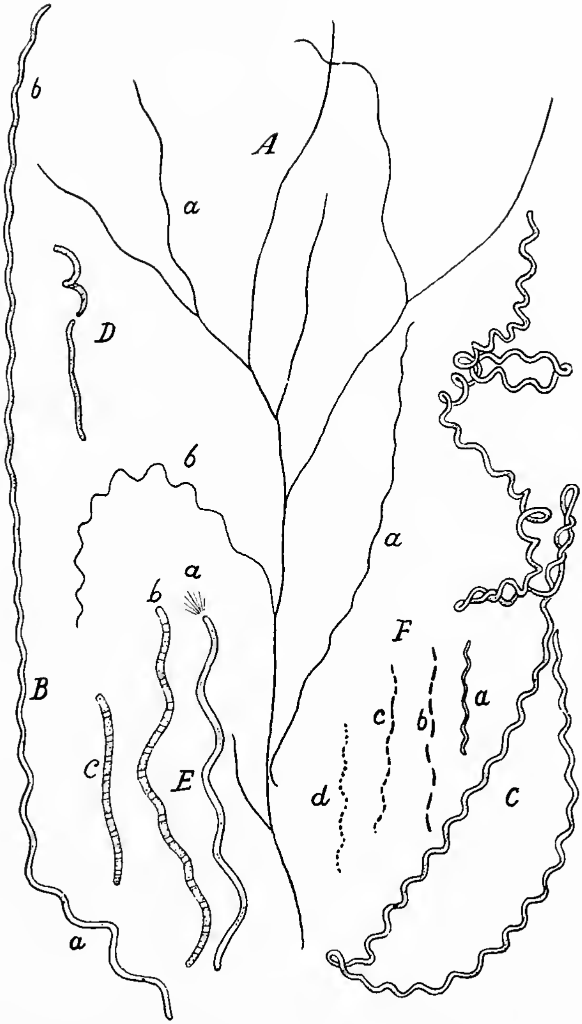
It was agreed, as Spallanzani had declared, that by heating an infusion of any kind to the temperature of boiling water and keeping it at that temperature for five minutes all animalcules or their germs already living in the infusion could be (with rare exceptions) killed. The exceptions were, it was found at a later date by Ferdinand Cohn (1870), due to the existence in some cases of a hard dried condition of those animalcules called Bacteria, or their reproductive spores. These resisting "spores" were destroyed either by an exposure of three hours to the boiling temperature or by soaking in warm water for some hours before the exposure to the temperature of boiling water.

Spallanzani's conclusion that the appearance of animalcules in such boiled infusions could only be accounted for by the access of air-carried germs to the infusion after it had been boiled was met by his opponents with another suggestion. They suggested that the Abiogenesis or spontaneous generation of animalcules depended on a special chemically active condition of the air present in the flasks, which when closed were filled half with liquid and half with atmospheric air. It was supposed that the heating of this air to a high temperature and its consequent rarefaction before the closure of the flask did not act merely by destroying germs floating in it but destroyed its power of *chemical* action on the organic infusion. But it was *not* shown by any well-devised experiment that air when freed of organic germs before admission to the sterilised fluid in the flask by filtration through cotton-wool, possessed nevertheless this vivifying quality. And it *was* shown that the admission of unfiltered air to the flask resulted in the production of animalcules in the infusion. This fact was in accordance with the supposition of Spallanzani, that the unfiltered air brought with it, in the form of dust, the actual living though incompletely desiccated animalcules or their reproductive germs. These were excluded when filtration was used, just as Redi's blow-flies were excluded from access to the meat which he placed under covers of wire-netting.

In the early years of the nineteenth century the controversy of opinion concerning "spontaneous generation" continued without any experimental decision, until in 1837 Theodore Schwann—who was the author of the cell-theory of organic structure and function, also the discoverer of "pepsin," the digestive ferment of the stomach, and the first to apply the experimental methods of the physicist to the investigation of the animal machine—made some well-contrived decisive experiments, confirmatory of Spallanzani's conclusion. Schwann boiled his experimental fusion in a flask with a long tube-like horizontal neck. He did not close the neck, but kept it heated by a flame so that no living particle could pass and enter the flask when air was drawn in by the cooling of the flask. The infusion in the flask remained sterile for many weeks—in fact, so long as the neck was kept nearly red-hot by the flame. But when the flame was removed and unheated air allowed to enter the flask the infusion became turbid and swarmed with Infusoria, since their germs were no longer destroyed on their way inward through the heated portion of the neck.

Schwann completed his experimental inquiry by demonstrating by chemical analysis that the atmospheric air, after passing the heated neck of the flask, contained as much free oxygen gas as does normal atmospheric air, and that it was capable of supplying the respiratory needs of frogs which (he found) lived healthily in a chamber supplied only with such air. The air was cooled and conducted into this chamber after passing the heated region.

By this date (as we have seen) the knowledge of the shape and character of the various kinds of Infusoria when studied with the microscope had become greatly increased owing to Ehrenberg and other writers. It is therefore surprising that Schwann writes of the organisms which appeared in his infusions or were successfully kept out of them simply as "Infusoria." He gives no description of these Infusoria, but draws a sharp



From Zopf, *Die Spaltpilze*, Breslau, 1885.

FIG. 10.—VARIOUS GROWTH-FORMS OF *Cladothrix dichotoma* OF ZOPF—A "PLEOMORPHIC" OR "MANY SHAPED" BACTERIUM

A. Branching plant, the branches tending to be vibrio-like (*a*) and spirillum-like (*b*). *B.* A branch showing both forms of growth. *C.* Very long, closely twisted, spirillar branch. *D.* A branch detaching a free spirillum. *E.* Branches: *a*, unsegmented; *b*, divided into rod-like segments; *c*, divided into micrococcus segments. *F.* Spirillum-like branch: *a*, undivided; *b*, divided into long rods; *c*, short rods; *d*, micrococci.

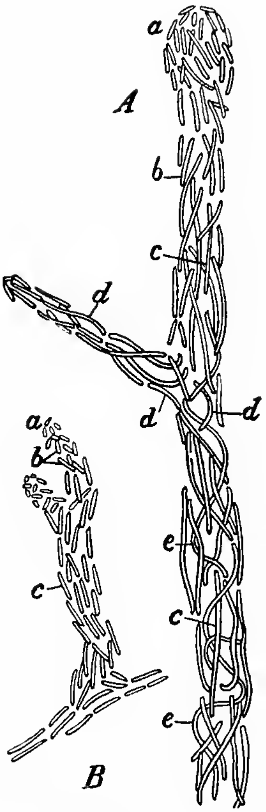


FIG. 10 *bis*.—PART OF AN ARBORESCENT JELLY-MASS OR CŒNOGLÆA, FORMED BY *Cladothrix dichotoma*
(See Fig. 21, F.)

Enclosing division-products of various shapes and sizes. *a*, short rods; *b*, long rods; *c*, Leptothrix or filamentous forms; *d*, vibrions; *e*, spirilla. (After Zopf.)

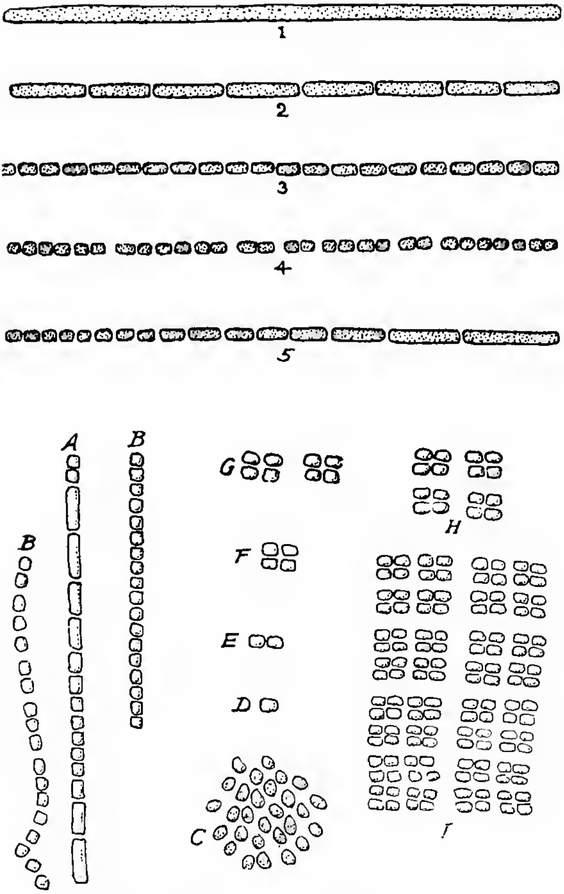


FIG. 11.—PLEOMORPHISM OR VARIETY OF GROWTH-FORMS SHOWN BY THE *Bacterium merismipedioides*

Described by Zopf from freshwater, putrid pond-slime at Berlin. 1, unsegmented filament; 2, long segments (bacilli); 3, short rods (such as used to be distinguished as "bacteria," but can no longer be so named since that word applies to the whole class or group of "Schizomycetes"; 4, cocci or spherical segments; 5, all three forms of segment in one filament. *A*, *B*, *C*, filaments dividing into cocci; *I*, isolated cocci; *D-H*, successive phases in the formation by budding of "tablet-colony"; *I*, a moderate-sized tablet-colony consisting of thirty-two tetrads (groups of four cocci). Compare this with Fig. 17.

line between them and the "moulds" (minute branching, thread-like organisms classed with the Fungi), the spores or germs of which are, he says, liable to appear in infusions exposed to contamination by atmospheric dust. He makes some important observations on what he calls "the well-known granules" of which beer-yeast consists (discovered by Leeuwenhoek one hundred and fifty years earlier). He shows that they are living vegetable organisms, and describes their growth and multiplication by budding.

The important feature in this contribution to the subject by Schwann is that he ascribes the putrefaction of the infusions in which "Infusoria" appear to the *life and nutritional processes* of the Infusoria. He says they take chemical elements from the infusion of vegetable matter as nutrition, and this causes the breaking down or putrefaction of the organic chemical compound which is dissolved in the infusion. Thus, according to him, putrefaction is the immediate outcome of *life* and not of *death,* for without the presence of the *living* Infusoria the infusion would remain clear and unchanged for an unlimited period. And he argues that the conversion of sugar into alcohol by yeast is due in a similar manner to the life and growth of the beer-yeast organism, which takes the elements which it requires from the sugar, so that the chemical combination known as sugar is broken down and the residue forms into alcohol and carbonic acid gas. Thus Schwann for the first time formulated the doctrine that fermentation is due to the action of living organisms, and asserted the general similarity of "putrefaction" to alcoholic "fermentation," the former caused by unnamed "Infusoria," the latter by the beer-yeast. This was the very reverse of the then largely prevalent chemical doctrine that putrefaction was set up by the action of atmospheric oxygen, which, it was supposed, gave rise to the Infusoria accompanying putrescence, by "Abiogenesis" or spontaneous generation.

Closer Study of Infusions

After Schwann had briefly attributed the production of putrefaction to what he called, without discrimination, "Infusoria," the careful study of the Infusoria concerned in that process by means of the improved microscopes of the period 1840–60 was obviously the next step which had to be taken. It was gradually effected. Leeuwenhoek and all the describers of "Infusoria"—including Ehrenberg—had, in searching for these microscopic forms of life, examined both (*a*) natural "infusions," such as the waters and slime of ditches, pools, and ponds, and also (*b*) artificially prepared infusions obtained by letting dead leaves or hay or dead animal matter soak in jars or dishes containing water. The rich population of bell-animalcules, of relatively large Ciliates, swimming and creeping forms, and of Rotifers or wheel-animalcules was obtained from the naturally accumulated infusions of long standing—in ancient ditches and pools, and to some extent also in the artificial infusions kept in vessels *for many weeks* under frequent examination by the microscopist.

But when the occurrence of the spontaneous generation of "Infusoria" was in question artificial infusions were employed, which were first purified or freed from all life by heat. Then being freely exposed to contamination by atmospheric dust or contact with unsterilised objects, such as a glass rod or a man's finger, they became in the course of a few hours charged with a living multiplying cloud of the minutest organisms, and in a day or two were putrid and foul-smelling. It was observed and fully established that the larger "Infusoria" do not appear at once in these rapidly formed growths, and have no part in causing putrefaction. These growths consist exclusively of the peculiar excessively minute rods and threads and spherical forms called Vibrionia and Monadina by Ehrenberg (our Bacteria).

It is not until a later stage of the putrescence of a freshly-made infusion—attained after a period varying from a few days to a month—that the larger "Infusoria" make their appearance. Their germs (spores, eggs, or their desiccated bodies) are not nearly so abundant and ubiquitous as those of "Vibrionia" (Bacteria). They cannot flourish in an infusion until the Bacteria have established themselves and are ready, like the grass-crop in a grazier's paddock, to serve as *the food of the larger forms.* Until the interest in the question of spontaneous generation became very pressing, no one had supposed that the various kinds of microscopic organisms arbitrarily assigned to a group as "Infusoria" (a "chaos" as Linnæus called it) made their appearance in an infusion successively as separate stages of its history, and that the earliest to appear differ from the later in the same ways as plants or vegetables differ from animals.

The Bacteria Removed to the Vegetable Kingdom

It is not possible to give the credit for this observation to any one individual, But the botanists who occupy themselves with the study and systematic classification of Algæ and Fungi, especially with the microscopic forms of filamentous water-weeds and of mildews and moulds, about the years 1840 to 1860, with the general assent of biologists removed the Vibrionia, the Desmids, and the Diatomaceæ from Ehrenberg's "Infusoria" altogether and definitely assigned them to the *Vegetable Kingdom.*

Rabenhorst, Kutzing, and Nägeli were the chief amongst these botanists, who, as a consequence of their very extensive study of the lowest microscopic plants, broke up and rearranged the old "chaotic" group called Infusoria. The most striking fact which they established was that the organisms which cause putrefaction, the Vibrionia or Bacteria, are not "animalcules" at all —are not, in fact, animal in nature or nutrition as previously assumed, but are plants allied to the delicate water-weeds known as "Oscillatoriæ." At the same time zoologists agreed that the Rotifera cannot be associated on structural grounds with the other animalcules classed by Ehrenberg and Müller as Infusoria, but must be classed with the higher group of Annulose animals. In fact, as a result of mere revision the class "Infusoria," so named by O. F. Müller and adopted by Ehrenberg, fell to pieces, resolving itself, when the botanists had taken the Bacteria, the Desmids, and the Diatoms, and the zoologists had removed the wheel-animalcules, into a natural assemblage of microscopic *unicellular animals,* to which, about 1860, von Siebold gave the name "Protozoa."

Pasteur's Early Discoveries

Whilst the new conception of the nature and activity of the Vibrionia was developing, and their many points of resemblance to the delicate thread-like Oscillatoriæ were being demonstrated, an epoch-making impulse was given to their investigation as agents of fermentation by the discoveries of the great French chemist Louis Pasteur and the theoretical views which he established. Pasteur found that the ammoniacal decomposition of urine is due to the growth of it in swarms of a special, very simple kind of Vibrion or Bacterium, and further that the change of wine and beer into vinegar is due to special kinds of acetifying bacterial ferments which multiply in it by the million (see Fig. 6).

The first discovery of a disease-producing Bacterium was made by the French pathologist Davaine in 1854. He found that the blood of sheep suffering from the disease known as splenic fever or anthrax (to which men and other animals are also liable) is occupied by countless swarms of a rod-like bacterial parasite, and concluded that they were the active cause of the disease (see Fig. 23). Later (1863) Pasteur investigated this disease and proceeded to discover and study other "bacterial" diseases (e.g. fowl cholera, silkworm disease or "pebrin," etc.). Pasteur's investigations were always directed to the control of the diseases studied by him and their ultimate banishment from the life of man and his domestic animals, or on the other hand to the control and improvement of process such as brewing and the making of wine and of vinegar, in which living ferments, Bacteria and yeasts, play an important part either helpful or injurious to man's enterprise.

The Steps Leading to our Present Knowledge of the Bacteria

We have now followed in outline the steps by which our knowledge of the Bacteria entered upon its present vast practical and theoretical importance. These steps are indicated by the following epitome: (1) invention and early use of the microscope; (2) theory of spontaneous generation or abiogenesis; (3) discovery of the vast world of microscopic Infusoria or Infusion-animalcules; (4) first use of the name "Bacteria"; (5) experimental rejection of the theory of abiogenesis and discovery that the Bacteria are the living agents of putrefaction; (6) and of many other fermentations; (7) and that many deadly diseases of men and animals are "fermentations" caused by intrusive Bacteria; (8) that Bacteria agree with certain Algæ or aquatic plants (the Oscillatoriæ or Cyanophycæ) in structure and growth and nutrition, and must not be classed as animals.

We shall now, as briefly as the purpose of this "outline" necessitates, give some account of the present state of our knowledge of the Bacteria. This knowledge has grown during the last sixty years from the beginnings above sketched to an almost incredible extent—spreading out into a number of very distinct branches, pursued in great laboratories by thousands of eager, specially trained investigators, led by the ablest chemists, physiologists, hygienists, and pathologists of our time. It has received on account of the importance and novelty which characterise it a special title as a branch of science, viz. Bacteriology.

§ 5

Forms of Bacteria

The Bacteria are now recognised as a group or class of very minute rod-like, spherical, or filamentous aquatic plants.

They are allied to the common blue-green water-plants or Algæ known as the Oscillatoriæ or Cyanophycæ—in their simplicity of structure and form, in much of their physiology and life-history, and also in the fact that they multiply by transverse fission —whence both are called Schizophyta (splitting plants). They are remarkable for their varied chemical activities, including the production of many kinds of "fermentation," but do not agree in structure and life-history with the yeasts and moulds, the agents of the fermentations in which alcohols are produced from various kinds of sugar.

The name Bacteria has reference to the fact that they most commonly occur as swarms of many millions of minute separate rods. Usually, each rod is only 1/50,000 in. (or half a micron) in width and 1/25,000 (or one micron) in length (see Fig. 11). But often the swarms consist of individuals all uniformly seven or eight times longer and a little broader than this. Swarms consisting of individuals uniformly of smaller size than this are frequent. These rod-like units, whether short or long, are now called *bacilli* (Fig. 7, *c* to *f*), the name "bacterium," which was at one time used to distinguish the shorter rods, having become generally applied as a name for the whole group. Instead of dividing into two after moderate growth in length, the *bacilli* of some kinds, under conditions not precisely determined, grow greatly in length so as to form delicate straight filaments, which are called "Leptothrix forms" (Fig. 7, *g*) in allusion to an Oscillatorian of that name. Further, such elongated growths may be not straight but slightly serpentiform, when they are called "Vibrio forms" (Fig. 7, *h-i*). The name Vibrio is that originally given to the whole group of Bacteria by O. F. Müller, but has been now restricted to these undulated forms. The same process of growth or twist carried further gives us screw-like filaments which may be more or less open or else closely turned spirals; these are called "spirillum forms" (Fig. 7, *k* to *n*). These filamentar growths, whether straight or spiral, often show

FIG. 12.—THE LIVING BACILLUS OF TYPHOID FEVER

An instantaneous photograph from life taken with dark-ground illumination by Dr. Commandant (Pathé frères, Paris).

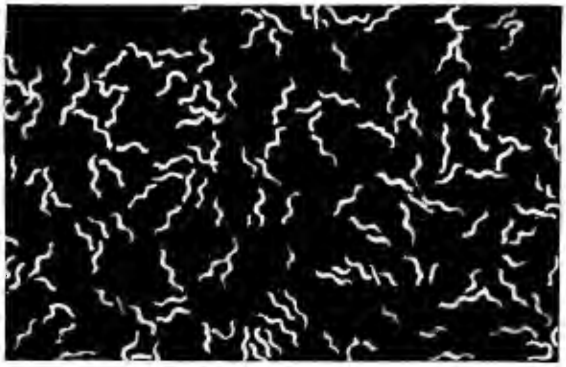


FIG. 13.—LIVING SPIRILLA FROM A DROP OF SEWAGE-WATER

An instantaneous photograph from life with dark-ground illumination, taken by Dr. Commandant, of Paris.

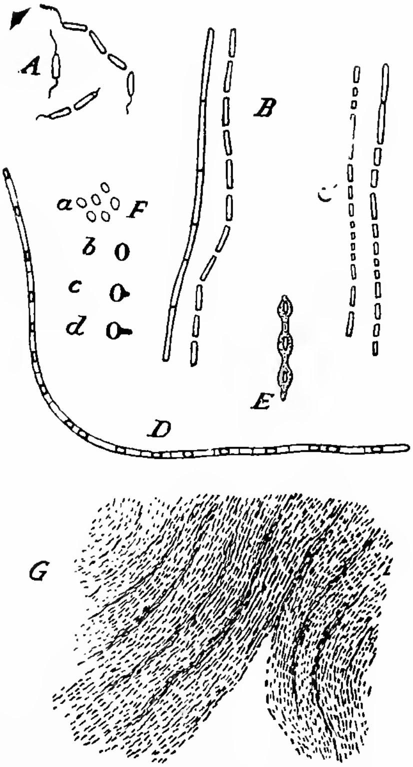


FIG. 14.—THE "HAY-BACILLUS," *Bacillus subtilis*, OF COHN AND SUBSEQUENT WRITERS

A. Free-swimming bacilli, showing a cilium at each end (but see *A* in Fig. 15). *B*. Filament, or Leptothrix form dividing into bacilli. *C*. Similar filament with shorter segments. *D*. Filament in which the segments (bacilli) have formed statospores. *E*. Spores with swollen jelly-like envelope. *F*. Liberated spores: *a*, before, *b*, *c*, *d*, during germination. Note the non-polar lateral position of the new growth or sprout. (Compare with Figs. 23 and 24.) *G*. Membrane-like jelly enclosing rows of the hay-bacillus.

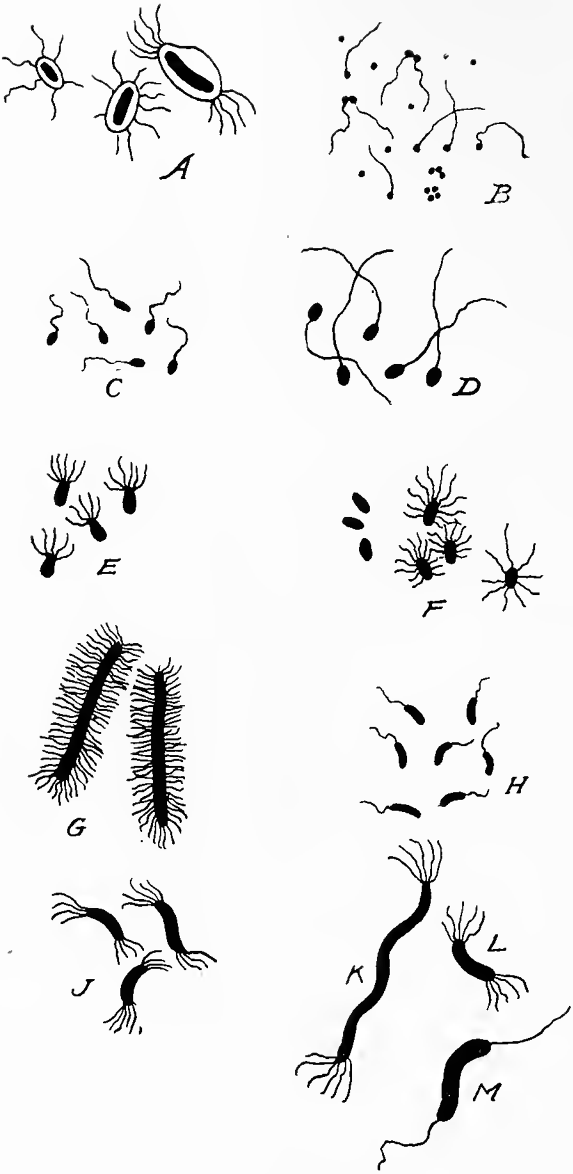


FIG. 15.—DEEPLY STAINED PREPARATIONS MADE IN ORDER TO SHOW THE VARIOUS FORMS OF CILIA AND THEIR ARRANGEMENT IN DIFFERENT KINDS OF BACTERIA

A. *Bacillus subtilis*. *B*. Micrococci with single cilium. *C* and *D*. Larger oval plastids with single cilium from green pus. *E*. A larger kind of colour-producing bacterium, with a bunch of cilia at one pole. *F*. Bacillus of typhoid fever, showing many scattered cilia, not visible during life (see Fig. 12). *G*. A large bacillus with numerous cilia all over its surface. *H*. The comma bacillus of cholera described by Koch (see Fig. 31). *J*, *K*, *L*, *M*. Spirilla of various origin, showing polar cilia.

a jointing or structural division into segments corresponding to long or short *bacilli,* and they may eventually break up into separate pieces of that nature (see Figs. 9, 10, 11, 14). In some of the spirillum forms such a breaking up results in their separation into curved, "comma"-like segments. This is the case with the spirillum, which is the cause of cholera and led its discoverer, Koch of Berlin, to call it "the comma-bacillus" (Fig. 29).

Bacilli, vibriones, and spirilla may, but do not necessarily always, break up by transverse fission and contraction of their substance into spherical units, which are called "micrococci," or "coccus forms" (Fig. 7, *a*). Micrococci multiply rapidly by transverse fission and form immense growths consisting of this form only (Fig. 8). The conditions which determine the formation of micrococci by fission of bacilli or of the filamentar Bacteria are not determined. Probably very many micrococci have become fixed or limited to the production of this form, and whilst they themselves are not constantly or regularly produced from elongate forms they have lost the power of elongating so as to produce bacilli or filaments. They and probably many bacillar forms have all been derived from ancestral stocks which showed, as do *some* of their progeny, a certain freedom of growth ranging from micrococcus to leptothrix and spirillum forms (see Figs. 9 and 10). But just as the simple pullulating yeasts called Saccharomyces are to be regarded as a specialised arrested race budded from the submerged branching threads of a mould of elaborate structure, and can no longer (so far as experimental research shows) grow into the larger form from which they took their rise, so many micrococci and bacilli have lost the capacity for filamentar growth and are restricted to the form of a minute sphere or a short rodlet. Nevertheless, *many* of the Bacteria do show these and other variations in their growth; especially do those which live in open streams and ponds and have not lost their capacity for varied growth by adaptation to special conditions, such as those of parasitism. It is a matter of extreme difficulty to isolate and to cultivate in a variety of conditions a particular Bacterium so as to be able to say with certainty, as a result of direct observation, "this form gives rise by growth to that form." In a few cases it has been done (see Figs. 6, 10, and 11). It is even more difficult to prove a negative and to show that *under no possible change of conditions* does this form grow into that form. Some writers (e.g. Winogradski), having kept a given form of bacterium under observation with the microscope for some weeks during which it grew and multiplied without change of form, have unreasonably put forward the conclusion that such change of form *never* occurs, either in this or any other bacterium, even when exposed to new conditions of nourishment and environment not tested by them.

Strangely swollen and distorted enlarged Bacteria are occasionally produced in unusual chemical conditions of cultivation, and are called "involution forms" (see Fig. 6).

Multiplication and Movements

The rate of growth and multiplication of micrococci and bacilli is a very high one. A common bacillus (Fig. 14), known as "the hay bacillus" because it occurs in infusions of hay, has been observed to double in length and to divide every half-hour. One such bacillus would thus under favourable circumstances produce 1,024 bacilli in five hours, over a million in ten hours, and some millions of millions in twenty-four hours!

Bacilli, micrococci, and spirillum forms of Bacteria are frequently found actively moving and darting through the liquid in which they form a dense swimming cloud (so-called "swarming phase"). They also often abandon this movement and settle down as motionless particles ("resting phase"). Their locomotion is due to the presence on their surface of extremely delicate threads of protoplasm, which keep up a lashing movement. Such are commonly seen on the bodies of aquatic animalcules, and on the structural units or cells of the moist surfaces of higher animals, and are called "cilia" (Fig. 3). The Bacteria shed their cilia when they enter upon a resting or motionless period of life. It is only in recent years, by the use of skillfully applied staining liquids and the highest powers of the microscope, that the cilia of the Bacteria have become, step by step, clearly known. They are so delicate, transparent, and minute as to be invisible unless artificially stained. They are figured as seen when strongly stained—in preparations of different kinds of Bacteria —in Fig. 15. They may be single, few, or numerous, and may exist at one or both ends of the Bacterium, or all about it. The ciliary locomotion of the Bacteria is easily distinguished from the tremulous "Brownian" movement which, like other minute particles suspended in liquid (e.g. gamboge resin), they sometimes exhibit.

The Jelly Phase

A general feature of the life and growth of Bacteria of a varying character is the production of a film of jelly on the surface of each little individual. This jelly may be the thinnest film, and act so as to keep the products of fission in conjunction with one another (Figs. 16 and 17). This is particularly important in the form known as Cladothrix (Fig. 9), where a kind of false-branching results from the side-slipping of the terminal part of a filament, the broken-off part being retained in position by the delicate gelatinous coat. True branching does not occur in the Bacteria. Again, the jelly may form a thick transparent coat (Fig. 18), or the jelly of neighbouring units may be very abundant and fuse into a common jelly in which the jelly-forming Bacteria are embedded (Fig. 19). In that case the jelly may be some inches in area (Fig. 20), and even fill, as a transparent coherent mass, a glass jar in which the Bacteria are growing. The term "zooglœa" is applied to these copious productions of jelly, and botanists speak of the "zooglœa-phase" of the Bacteria. The term "zooglœa" is objectionable because it implies that the jelly is of animal origin, which it is not. "Glœogenous" is the most suitable term to apply to Bacteria which are in this phase of growth, and the jelly itself should be called the "cœnoglœa" or "common jelly" of this or that kind of Bacteria.

Very many different kinds of Bacteria—but by no means all—at one time or other in their growth produce a more or less abundant "common jelly" or "cœnoglœa." Remarkable varieties of shape and density are produced in different cases (Fig. 21). A common form is that of a resisting membrane or skin which forms on the top of the liquid in which the Bacteria are living, or on a submerged surface—this is called a "mycoderma" (Fig. 21, *A*). Ball-like, branching, and net-like forms of the cœnoglœa are known (Fig. 21, *C*). Often Bacteria of different kinds and chemical property become embedded in one common jelly and form a residential colony of reciprocally helpful kinds of Bacteria. The ginger-beer plant, which includes yeast cells in its association, is an example (Fig. 22), so are the "mother of vinegar" and the koumiss ferment. They are symbiotic growths, similar to the lichens in their composite character.

Reproduction of Bacteria

No process corresponding to conjugation has been observed in Bacteria nor has the production of male and female spores. Though all reproduce by the simple separation of the products of fission which resemble one another, yet in a large number of kinds of Bacteria the formation of reproductive spores of an enduring character called "stato-spores" has been observed. Under given conditions of nutrition, not precisely determined, the protoplasm within a bacillus or in a joint or segment of a filamentous "leptothrix-form" or spirillum-form contracts so as to form an oval, dense, highly-refracting body which acquires its own special "coat." These "spores" have the power of resisting desiccation and high temperature to a greater extent than can the unchanged substance of a bacillus or bacillus-like segment. They are "resisting spores" or "stato-spores." Some of these are represented in Figs. 14, 24, and 25. It is not possible to divide the Bacteria into the "spore-producing" and the "non-spore-producing" (as has been proposed), because we do not know enough about the forms which are not known to produce spores to be sure that they never do! The hay-bacillus and the bacillus which produces the disease known as "anthrax" or "splenic fever" are good examples of spore-producing Bacteria, and are very much alike (Figs. 14 and 23). They both, in certain conditions, grow into long filaments (leptothrix-form) in which stato-spores are formed in a row (see Figs. 14 and 24). It was thought (by Buchner) possible that the anthrax bacillus is only a hay-bacillus modified by parasitism in the blood. But a decisive difference was discovered when the germinating spores were observed with the highest powers of the microscope. The new young anthrax bacillus (Fig. 24) sprouts from one end or pole of the oval spore, whilst the hay-bacillus arises from the mid-region of the oval spore (Fig. 14, *F*). Some writers apply the term spore to the swimming free bacilli and micrococci produced by the simple fission of leptothrix-forms or of long bacilli. But this is a misuse of the term spore, which should refer to a bud or seed-like particle specially modified so as to ensure its locomotion or else resistance to destructive agencies and its growth into a new individual, and not to the ordinary abundant fission-products of vegetative life.

§ 6

Protoplasm of Bacteria

The structure of the protoplasm of which the Bacteria, whether cocci, bacilli, or filaments, consist is extremely difficult to determine on account of their minute size. By analogy with other simple organisms (such as the yeast cell), we should expect to find that each of the segments of a filamentous bacterium (and every detached segment called "coccus" or "bacillus") has the structure of a typical *cell;* that is to say, has a "nucleus" or denser central body of a certain definite structure, consisting largely of granules or threads of a readily-stained substance called "chromatin." In typical "cells" (Figs. 2 and 3) the nucleus is surrounded by less dense protoplasm, in which are various granules and vacuoles, or liquid-holding cavities. But it appears from long-continued inquiries into this matter that, contrary to what we find in typical "cells," the Bacteria have not a true nucleus, though many have chromatin granules, and in a few a deeply placed stain-taking body has been observed. The outer region of the Bacterial "plastid" or unit is denser than the deeper part. Granules of chromatin and of other chemical nature, and in one kind (the so-called sulphur-bacteria) granules of sulphur, are scattered in the outer substance (Fig. 7, *f*). The structural units of some of the Oscillatoriæ (allied to the Bacteria) are apparently also devoid of a nucleus, though in others an irregular stainable body, which probably represents the nucleus of a typical cell, is present. The *structure* of the bacterial plastid throws little, if any, light on the very elaborate chemical processes in which it is the active agent; nor on the growth and the shedding of its locomotive cilia.

We have so far summarised what is known as to the *form* and *structure* of Bacteria. Their relations to surrounding physical conditions, and to the chemical nature of the organic infusions in which they flourish, require a brief statement.

The chemical problems involved cannot be discussed without dealing with some of the most novel and difficult questions of Organic Chemistry, which lie far beyond the scope of this chapter.

Influence of Moisture Desiccation

Bacteria, like all living things, owe their distinction from "dead" or "non-living matter" to the presence in them, as a main

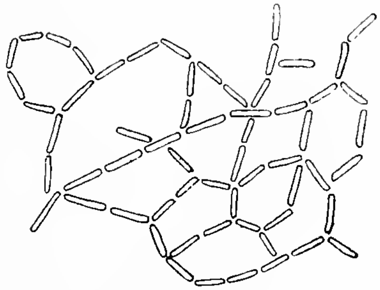


FIG. 16.—MESHWORK LIKE THAT OF THE GREEN FRESHWATER ALGA HYDRODICTYON

Formed by bacilli of the pleomorphic peach-coloured Bacterium (*B. rubescens*). From Lankester, "On a Peach-coloured Bacterium" (*Quart. Journ. Microsc. Sci.*, vols. xiii. and xvi.).

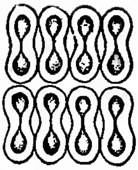


FIG. 17.—THE BISCUIT-SHAPE OR FIGURE-OF-EIGHT PRODUCED BY AN INCOMPLETE DIVISION OF A SPHERICAL OR COCCUS FORM

This was at one time regarded as the typical form of "Bacterium" when that word was used by Cohn as the name of a genus. The figure shows eight of such units or "plastids" adherent to one another in regular tablet form (from a growth of the peach-coloured Bacterium, *B. rubescens*). Original.

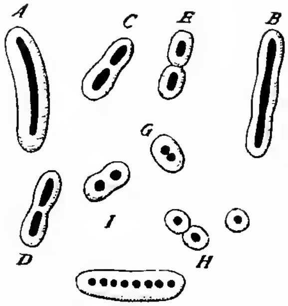


FIG. 18.—THE PATHOGENOUS BACTERIUM WHICH CAUSES PNEUMONIA. (FROM THE LUNG OF A MOUSE)

The thick envelope or coat of a jelly-like character is remarkable. Both elongate (bacillar) and spherical forms are shown. Magnified 1,000 times linear.

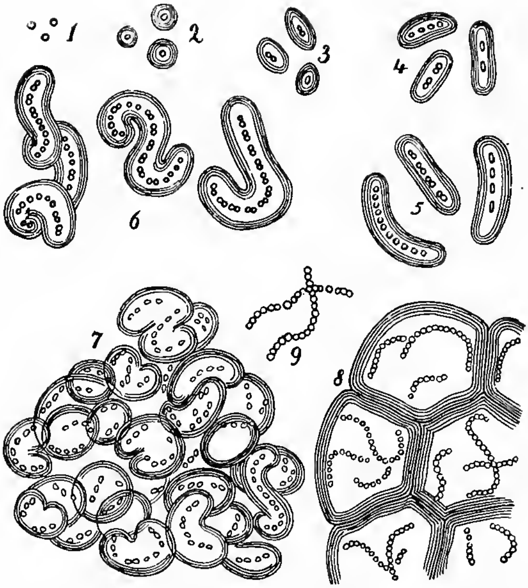


FIG. 19.—*Leuconostoc mesenteroides* (*Cienkowski*)—THE "FROG'S SPAWN" GROWTH—A GLŒOGENOUS BACTERIUM WHICH OCCURS IN THE VESSELS IN WHICH BEET-SUGAR IS BEING EXTRACTED FROM ROOTS

It develops from minute spherical spores (1) which form a jelly-like coat around themselves (2, 3) and divide to form a row of micrococci (4, 5, 6). Large accumulations of the jelly-masses (7, 8) are thus produced and cause a "ropy" condition of the sugar. In 9 two chains of the micrococci are seen with single larger cocci interspersed. Compare with the allied but much larger organisms Nostoc and Anabæna, belonging to the group Cyanophycæ.

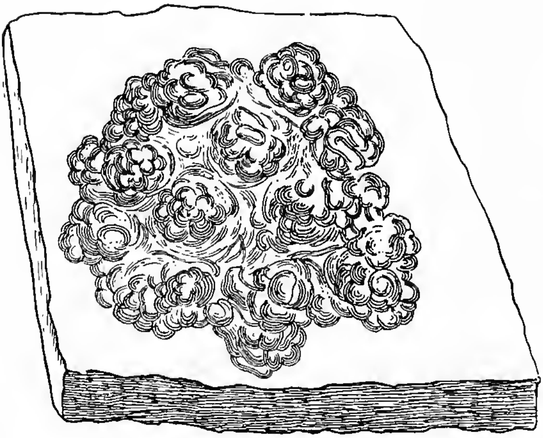


FIG. 20.—ZOOGLŒA OR CŒNOGLŒA, OR JELLY-MASS FORMED BY A BACTERIUM GROWING ON A SLICE OF CABBAGE ROOT

Drawn of the natural size. The bacteria enclosed are grouped in chains which resemble those of Anabæna and Nostoc.

part of their substance, of peculiar compounds of the elements Carbon, Hydrogen, Nitrogen, and Oxygen, with some Sulphur and minute quantities of phosphates, lime, and alkalis. These compounds are combined to form a viscid labile material which is called "protoplasm" or "cell-substance." To be permeated by water—that is, moisture in greater or less quantity—is essential for the active life of protoplasm; but it can survive desiccation—in some instances—in a quiescent state described by the term "suspended animation" (as in the case of the wheel-animalcules and Tardigrades). Thus we find that the Bacteria are active—growing, multiplying, and moving—when in damp surroundings or actually submerged, and that although many of the more delicate kinds are killed by drought others survive desiccation, the formation of hard-shelled resisting "spores" (or stato-spores) aiding that survival.

Influence of Heat and Cold

Many kinds of Bacteria flourish in sea-water at 0° C. It has been found that a very low degree of temperature (e.g. that of liquid hydrogen – 252° C.), whilst suspending their activities leaves them uninjured. On the other hand, most Bacteria are killed when the temperature is raised to about 55° C. Some live in hot-springs and can flourish at 72° C. All non-spore-producing Bacteria are killed almost instantaneously when placed in boiling water (100° C.). But the spores of some of the spore-producing kinds are capable, if old and dry, of resisting exposure to boiling water for three hours, younger spores in a moist condition are more easily killed. These facts as to resistance to heat have especial importance in reference to the preparation of sterile infusions and jellies (that is, pure and free from germs) to be used in the cultivation and separation of different kinds of Bacteria in the laboratory. They are, in fact, the foundation of the science of bacteriology, and also of the successful carrying on of the great commercial enterprises of canning fruit, vegetables, fish, and flesh for use as human food. They are and have been of no less critical importance in the examination of the, now discarded, belief in spontaneous generation (see above). The great poet-philosopher Goethe knew the facts demonstrated by his cotemporary Spallanzani, and also had seen the swarming animalcules revealed by the microscope. We find accordingly that, in a discussion with Faust, Goethe makes Mephistopheles protest in words which are precisely in accordance with modern knowledge of bacteriology:

> In water, in the earth, in air,
> In wet, dry, warm, cold, everywhere,
> Germs without number are unfurled.
> And but for fire and fire alone
> There would be nothing in the world,
> That I could truly call my own.

The translation is Sir Theodore Martin's.

Influence of Light

It has now been definitely demonstrated that direct sunlight has a destructive effect on many kinds of Bacteria. The violet rays are the most deadly. Water exposed in open reservoirs and shallow lakes and streams to the sunlight is freed to a large extent of such disease-producing Bacteria as those causing typhoid, anthrax or splenic fever, and others which are specially liable to destruction by the sun's rays. It was found by Dewar that a liquid containing the Bacteria which cause phosphorescence of butchers' meat and dead fish can be frozen at the temperature of liquid air, and kept solid for some months without injury to the Bacteria if not exposed to daylight. The Bacteria became active and phosphorescent when the liquid containing them was subsequently thawed. No chemical or mechanical agency could injure them when in this hard-frozen condition, yet they were not inaccessible when in this state to the destructive action of the violet rays of sunshine. Though frozen solid and unassailable by all other agencies, it was discovered that light rays could penetrate the solid mass and by their vibrations break and destroy the protoplasmic molecules.

Influence of Gravity

It appears that violent and constant agitation of the liquid in which they are living may be injurious to the life of Bacteria; but also "sedimentation"—that is, the falling of particles through air or water—leads to the freeing of the upper layers of the atmosphere from Bacteria, and also to the purification of large sheets of stagnant water, especially when fine mineral sediment (as in Clarke's process for softening water) helps to carry down the floating Bacteria.

The air at the top of St. Paul's was found to contain eight organisms per litre, when that of the churchyard contained seventy. Not a single microbe was found in 100 litres of air at the top of Mount Blanc. Bacteria do not float long in the air. They are carried with dust by the wind, but where there is little traffic and no wind, as in a quiet room or a meadow in the country, the air is practically free from microbes. On the other hand, they accumulate on all *surfaces,* especially on human fingers and in liquids.

It is usual in examining air for the presence of Bacteria to pass measured quantities of air through a flask of sterilised nutrient liquid mixed with warm (not hot!) jelly, which is then poured out on to a sterilised plate, covered, and allowed to solidify. Each bacterium present in the air becomes embedded in the jelly and multiplies without changing its position, forming a "bead" or minute patch of growth.

The total number of such "patches" thus obtained from the measured volume of air can be counted, and the different kinds thus captured can be distinguished. Similarly the number of Bacteria in measured quantities of water can be estimated.

For accuracy as to the kinds of Bacteria contained in a liquid and their isolation (a matter of the utmost importance to the bacteriologist), the fractional method is preferable to the gelatine plate method. In the fractional method (used by Lord Lister in his study of the bacteriology of milk, when he wished to ascertain what different kinds of Bacteria are present in normal dairy milk and to separate them from one another for study) the number of Bacteria of all kinds present in a cubic millimetre of the liquid under examination is counted by spreading it on a "squared" glass plate under the microscope. Supposing it is found that there are about one thousand organisms present in the cubic millimetre, then we dilute that quantity of the liquid with one thousand cubic millimetres of pure sterilised water and agitate the mixture. Now we have produced a liquid containing one organism to every cubic millimetre of its bulk. If a cubic millimetre be removed by a graduated dipping-tube, it will probably contains a single organism. Fifty such measured cubic millimetres may be consecutively removed and placed each in a tube of sterilised nourishing or culture fluid. In some no infection will take place, in a few others an infection by two or even three kinds. But in a large majority the experimenter will obtain infection by a single microbe, and therefore a *pure* culture of that one kind, which he can proceed to study and to cultivate. In the foregoing lines we have given a rough indication of one of the methods of the bacteriologist. The difficulty of his work consists in the need for perpetual and unsparing care to avoid contamination and to leave nothing to chance.

The Influence of Chemical Agents

Apart from the question of nutrition, Bacteria are checked in their growth, or actually destroyed, by various substances even when present in small quantities. Certain Bacteria cannot flourish in liquids giving even a slightly acid reaction; others are not so checked. Quick-lime, carbolic acid, free chlorine and iodine, and various metallic salts and aniline dyes act as "antiseptics," as they are termed. They kill Bacteria. They do not occur in ordinary natural circumstances, but are made use of by man for arresting the destructive action of Bacteria. A bactericidal substance has recently been found in the lachrymal secretion and other fluids of the human body by Fleming (*Proc. Roy. Soc.* 1922).

The presence of free oxygen gas is indispensable for the life and consequent chemical activities of some Bacteria, which are therefore called "aërobic" or, better, "aërobiontic." On the other hand, another large series of Bacteria only flourish in the absence of free oxygen, and are called "anaërobic" or "anaërobiontic." The chemical action of the Bacteria on the carcasses of dead animals and plants and the organic matters contained in the soil and infusions (pond water, sludge, etc.) in which they live is largely bound up with their dependence on, or their independence of, free oxygen gas.

§ 7

The Action of Bacteria on their Surroundings and especially on Organic Matter

The historic case of the chemical activity of Bacteria is that of their causation of the decomposition of the "proteids"—complex compounds of the five elements Carbon, Hydrogen, Nitrogen, Oxygen, and Sulphur, which constitute the flesh and softer parts of the bodies of animals and plants. Schwann showed that the "putrefaction" of decoctions or infusions of these "proteids" such as occur naturally in pools or soil or may be prepared as "broths," takes place only in the presence of certain minute organisms living and multiplying in them which were called, by him and others, "Infusoria," but are now distinguished from other kinds of microscopic organisms as the "Bacteria." Prominent features of this putrefaction are the production of foul-smelling substances and the rapid growth and multiplication of the Bacteria. The decomposition effected by the Bacteria is a step towards the nutrition of those minute plants, and may be compared to the digestion of proteids in the alimentary canal of animals. The Bacteria in order to grow and multiply must take up into their living protoplasm and assimilate the organic elements Carbon, Hydrogen, Oxygen, Nitrogen, and Sulphur, and build new protoplasm from them. These elements exist in a stable "mineral" state in the atmosphere as water-vapor and the gases Oxygen, Nitrogen, and Carbonic Acid gas (CO_2), whilst dissolved in all natural waters are Carbonic Acid gas, Ammonia (NH_3), Carbonate of Ammonia, and Sulphates. All living things require the five organic elements as food, but only the green plants are able to take them up in this stable mineral condition and assimilate or build them up to form elaborated compounds, the chief of which are "proteids." This special property of green plants is shown experimentally to be dependent on the action of sunlight on the green parts of plants, the green grains or corpuscles of chlorophyll or leaf-green being essential agents in the process, and the liberation of free oxygen, necessary for the life of protoplasm, a part of it. No animals can build up the organic elements from their simplest condition into proteids. Animals are absolutely dependent for the organic elements which they require, upon the "proteids" already formed by other animals on which they prey, or else on the proteids built up as leaves, fruits, and roots by green plants, which also liberate during their life perennial supplies of free oxygen gas. Thus chlorophyll and sunshine are the indispensable intermediary agents bringing the free or lowly combined stable or mineralised organic elements into the elaborated condition of proteids and protoplasm, whether of plants or of animals, while replenishing the atmosphere with free oxygen.

Ferments

The Bacteria, like the animals, are totally unable to feed upon Carbonic Acid and Ammonia. It is found that there are some Bacteria which can get their carbon and their nitrogen

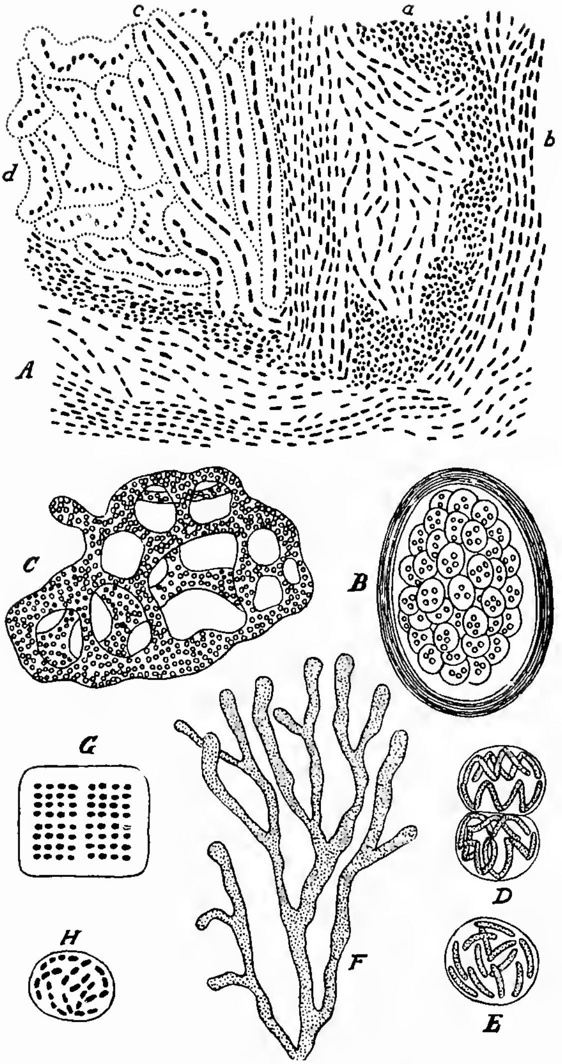


FIG. 21.—VARIOUS FORMS OF JELLY-LIKE MASSES ("ZOOGLŒA" OR "CŒNOGLŒA") PRODUCED BY ENCLOSED BACTERIA

A. A pellicle or skin-like growth enclosing various forms of bacteria; at *a* and *d* micrococci, at *b* and *c* rod-like forms (short bacilli). *B*. Egg-shaped cœnoglœa or jelly enclosing large cocci of the peach-coloured Bacterium. *C*. Net-shaped cœnoglœa of the same species. *D*. Spirillum form in jelly. *E*. Curved forms (Vibrio) in jelly. *F*. Arborescent jelly-form of Cladothrix with enclosed micrococci. *G*. Tablet form of growth of *Bacterium merismopedioides* enclosed in jelly (see Fig. 11). *H*. Jelly enclosing spirillum broken into short segments.

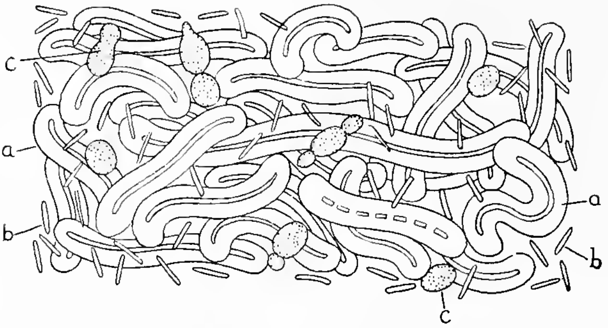


FIG. 22.—A FRAGMENT OF "THE GINGER-BEER PLANT"

Magnified about 600 times linear. It shows (*a*, *a*) curved rods and chains of short bacilli, enclosed in jelly, very like the sugar-loving "frog-spawn" bacterium called Leuconostoc (Fig. 19); also free bacilli (*b*, *b*) and yeast-cells (Saccharomyces) (*c*, *c*). It is a symbiotic association of three distinct organisms.

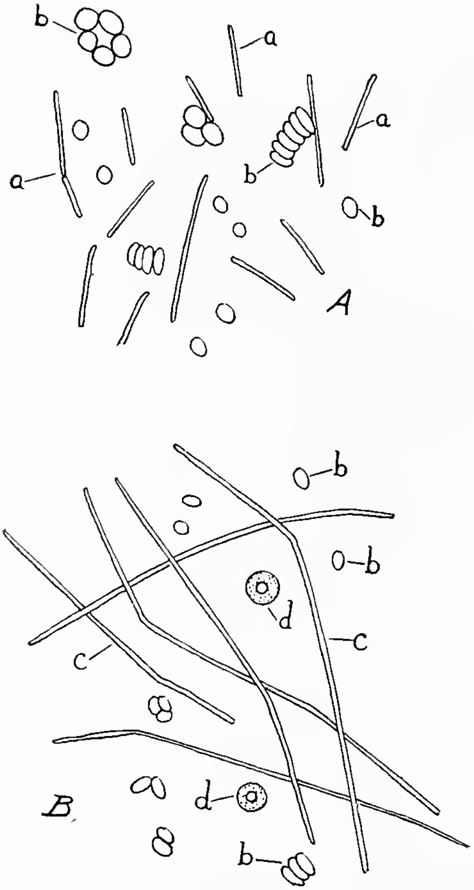


FIG. 23.—*Bacillus anthracis*, THE PARASITE OF MALIGNANT PUSTULE OR WOOL-SORTER'S DISEASE (AFTER ROBERT KOCH)

a, bacilli (free, but not motile); *b*, red blood corpuscles; *c*, filamentous or Leptothrix growth-form; *d*, colourless blood corpuscles. *A*. From a drop of blood of an infected rabbit. *B*. From the same after three hours cultivation in a drop of aqueous humour.

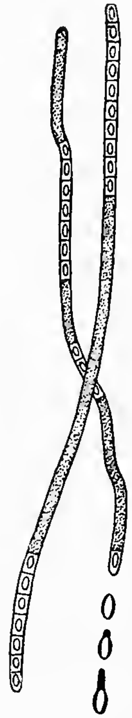


FIG. 24.—THE FILAMENTOUS GROWTHS OF *Bacillus anthracis* PRODUCED BY CULTIVATION OUTSIDE THE ANIMAL BODY BECOME SEPTATE, AND EACH SEGMENT GIVES ORIGIN TO AN OVAL STATOSPORE (OR "ENDURING" SPORE)

Three separated spores are seen on the right; two are germinating by a sprout from the apex or pole of the spore. Contrast with this the germination of the spores of the Hay-bacillus (Fig. 14), which is *lateral*.

from a compound so little elaborated as that called Ammonium Tartrate; but most of them (as do animals) attack higher compounds—breaking them down or digesting them—by the aid of " ferments " or " enzymes," which are similar in their action to the digestive ferments, pepsin, trypsin, etc., poured out by the cells lining the digestive cavity of animals. The flesh eaten by an animal is taken into a stomach and surrounded by ferment-producing cells, which cause its chemical breakdown. We cannot here enter into the questions connected with the nature of enzymes and the mode of their action. We must frankly dismiss that inquiry to another chapter, merely stating that the ferments or enzymes are elaborate chemical compounds of the organic elements Carbon, Hydrogen, Oxygen, and Nitrogen, and act as what chemists call " catalysts." The minute Bacteria cannot *get* their undigested food *into* them, since they have no stomach. But conversely they *get into* their food, and act upon it by ferments diffused from their living surfaces, breaking it down in various degrees and by various chemical reactions according to the kind of bacterium at work and the exact chemical nature of the food to be digested. One of the results of this digestion, and the most important, is that the food is brought into a soluble condition, and the necessary organic elements—in the form of "diffusible" compounds less elaborate than proteids—soak into the bacterium and are assimilated by its protoplasm which grows and reproduces itself.

Putrefaction

It appears that in the putrefaction of a dead body, or say a piece of meat, there are many kinds of Bacteria at work *successively*. Each is appropriate to a certain step in decomposition and produces its special enzyme or ferment. The first stage is the production by special Bacteria of compounds from the proteids of the meat which are little less elaborate than those proteids. No foul smell accompanies their production. They are called "ptomaines," and some act as virulent poisons when swallowed by man. A further breaking-down effected by other Bacteria—apparently always ready at hand for this work—now leads to the production of foul-smelling compounds—poisonous to most animals—known as indol, scatol, etc., the chemical composition and properties of which have been carefully ascertained. Following upon this grade of decomposition, we find other Bacteria entering into action. These produce ammonia, sulphuretted hydrogen, and carbonic acid. The proteid is thus brought down to the condition of low, simple (that is, not complex), compounds, chiefly carbonic acid and ammonia. The Bacterium causing the ammoniacal decomposition of urine belongs here. Finally, by the action of yet other Bacteria the ammonia is oxidised to form nitrites and these to form nitrates, so that now the organic elements are restored to the stable mineral condition in which alone, be it noted, they can serve as food for the green plants.

Circulation of the Organic Elements

Thus we see that the Bacteria serve an absolutely indispensable service in the general circulation of the organic elements. Were it possible to remove from existence all Bacteria, the earth's surface would be encumbered by the highly elaborated proteids forming the dead bodies of animals and green plants, and the organic elements would be "locked up" in them. The existing "mineral" or "stable" carbonic acid and ammonia would in due time be used up and none would be available for the food of green plants. Accordingly, no more proteids would be formed and no more oxygen liberated to replace that lost by oxidising action. The existing proteids would remain undecomposed though dead, and the chain of life would be broken. The Bacteria, by their putrefying activity, perform the unique part of returning the organic elements from their elaborated combination as proteids to the simpler stable condition in which green plants can again take hold of them and build them into proteids whilst replenishing the vital atmospheric gas—oxygen—continually diminished by its union with all kinds of oxidisable material.

The various Bacteria concerned in proteid putrefaction have been to a large extent isolated and their forms and special chemical activities determined; but a great deal is still uncertain, owing to the minute size of the organisms, their intermixture, and interactions.

Species of Bacteria

We cannot yet conclusively arrange the Bacteria into a series of well-defined species and genera, and assign to each species its special activities and life-cycle. The bacteriologist has, at present, to be content with stating that a given chemical change is accompanied by the presence of a longer or shorter or straight or spiral bacterium—a micrococcus, a bacillus, a leptothrix, or a spirillum, which he has isolated in pure culture, and as to which he has determined that it does or does not liquefy gelatine when growing on it; is or is not "aërobic"; does or does not produce spores; does or does not produce colouring matter, fluorescent or not so; does or does not produce heat or phosphorescence. Further he notes with what reagents it can be stained; and how its motile cilia, if it have any, are grouped.

For convenience a name is assigned to the bacterium in each case. The list has become a very large one, comprising, according to authorities of moderate views, more than a thousand "species" and thirty genera. But at present no theory is possible as to the origin of these forms, and as to whether they all have the persistent character which the *species* of higher plants and animals possess. Nor is there any suggestion as to the *advantage* given to each kind or putative "species" of Bacterium by the special and distinctive kind of chemical activity which characterises it. The survival in the struggle for existence of this or that form or strain cannot at present be accounted for by those distinctive activities.

§ 8

Manifold Activity of Bacteria

It is not possible here to do more than mention a few of the more striking examples of bacterial activity, especially in so far as they affect human welfare. In recent years the investigations of specialists in various fields of industry and sanitation have resulted in an enormous increase of the kinds distinguished and named. Besides proteid putrefaction, many other similar processes are accomplished by Bacteria. The decomposition of cellulose, the woody fibre of plants, is the constant work of certain kinds of Bacteria in ponds and marshes where vegetable refuse accumulates, and is accompanied by the liberation of marsh gas (CH_4), of sulphuretted hydrogen, and sometimes of phosphoretted hydrogen (Fig. 25). The formation of acetic acid or vinegar from wine and beer (that is, from dilute alcohol) is another bacterial activity (Fig. 6); so, too, is the formation of butyric acid from milk, and of lactic acid from certain sugars. In each case the bacterium concerned is known and pictured, and a knowledge of methods of controlling its activity has now become essential to the carrying on of great industries, such as the manufacture of vinegar, and the protection of wine and beer from "souring." The butyric and the lactic ferments are of essential importance in the dairy industries—souring of milk, and manufacture of butter and of cheese. The butyric bacterium a few years ago attacked a valuable collection of sea-shells in the Manchester Museum, and destroyed many by reducing them to a powder, which was found to be butyrate of calcium.

Many Bacteria produce coloured substances as they grow. Usually the colours are obscured by mixture, unless the Bacteria are grown in pure cultures. Some Bacteria become themselves coloured; as, for instance, the *Micrococcus prodigiosus,* which grows on bread and gives it the appearance of having been stained with blood. It spreads over all the bread in an infected locality and causes much alarm. Other kinds cause reddening of dried cod-fish and of cheese. Another self-coloured kind is the Peach-coloured Bacterium, *Bacterium rubescens,* which is common on dead leaves and twigs in old ponds and also in pools above tide-mark on the seashore. Bacteria diffusing yellow pigment with a green fluorescence into the jelly, on which they are cultivated, are common in river water, and others which produce blue, violet, and green pigments diffused in the nutrient medium in which they are cultivated. One such is responsible for the blue-green colour of pus.

Certain essential chemical changes in the extraction of indigo blue from the indigo plant are due to a bacillus which naturally occurs on the leaves of the plant. So, too, the peculiar fermentations which give special flavours to different kinds of tobacco are due to special Bacteria; as are also the much valued flavours of tea and of cocoa. These Bacteria can be encouraged or checked by appropriate treatment.

The manufacture of cheese is dependent on the action of lactic-acid-producing Bacteria upon the curd produced by "rennet." In the later stages of "ripening" both of cheese and of butter special flavours are developed by various special kinds of Bacteria. Over one hundred species of Bacteria (bacilli and micrococci) have been described and distinguished which can produce lactic acid in milk. Special cultures of Bacteria, giving special qualities and flavour to milk or to cream, are carefully prepared and used by manufacturers. Bacteria are further important to the dairy industries owing to the fact that serious defects such as "bitter cheese," "red cheese," "putrid cheese," and also "poisonous cheese," as well as similar defects in butter such as "turnip flavour," "oiliness," and bitterness, are due to certain kinds of them, and can be avoided by adequate knowledge of what favours and what arrests the growth of the several kinds. The flavours of cheese characteristic of this or that locality are due to the combined activity of many kinds of Bacteria, and of some moulds, a combination differing in each locality and practically peculiar to it. As many as eighty different species of Bacteria have been described by one investigator as occurring in one kind of cheese.

"Tanning"—the soaking of raw hides in liquid by which they are converted into leather—is another industry in which different Bacteria have at different stages of the process an all-important action. They have been very imperfectly studied.

The cases above cited are a few samples of the many industries connected with the preparation of food or animal or vegetable substances for manufacturing purposes, in which Bacteria are of essential importance, and are being more and more studied and brought under control.

Two very definite and obvious results of bacterial activity are (*a*) the production of heat; and (*b*) the production of *light* without heat, commonly called phosphorescence. The heating of hay and of cotton-waste and of malt is often set up in the chemical processes of bacterial fermentation, and under certain atmospheric conditions may be so intense as to result in conflagration—as it were, a "spontaneous combustion."

Luminous Bacteria

On the other hand, phosphorescence—the production of light without heat—is caused by the life and growth of some kinds of Bacteria. Many marine organisms, such as the minute Noctiluca, jellyfish, sea-worms, crustacea, and shell-fish, as well as insects such as the glow-worms and fireflies, are phosphorescent. From any sample of sea-water it is easy by appropriate methods of cultivation to obtain a crop of phosphorescent bacilli, which may be kept alive in a flask for an indefinite period, and will make the liquid (a meat broth) in which they are growing, glow brightly like a lamp when shaken up with atmospheric oxygen. Different "species" of phosphorescent Bacteria are distinguished. All appear to be marine or of marine origin. Occasionally, all the meat in the butchers' shops at a

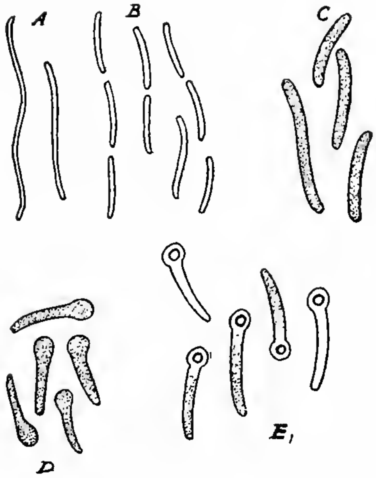


FIG. 25.—*Vibrio rugula,* A FERMENT OF VEGETABLE SUBSTANCES, DISSOLVING THE FIBRE-FORMING CELLULOSE OF THEIR HARD PARTS

Magnified 1,000 times linear. *A, B, C.* Slightly undulate, freely swimming. *C, D, E.* Three stages in the formation of the statospore, which gives a club-like shape to the organism.

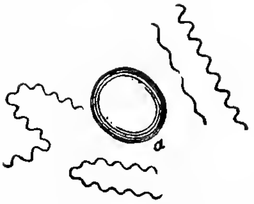


FIG. 27.—*Spirillum obermeieri,* THE CAUSE OF RELAPSING FEVER

Living specimens in human blood. *a,* a red blood corpuscle. Magnified 1,000 times linear.

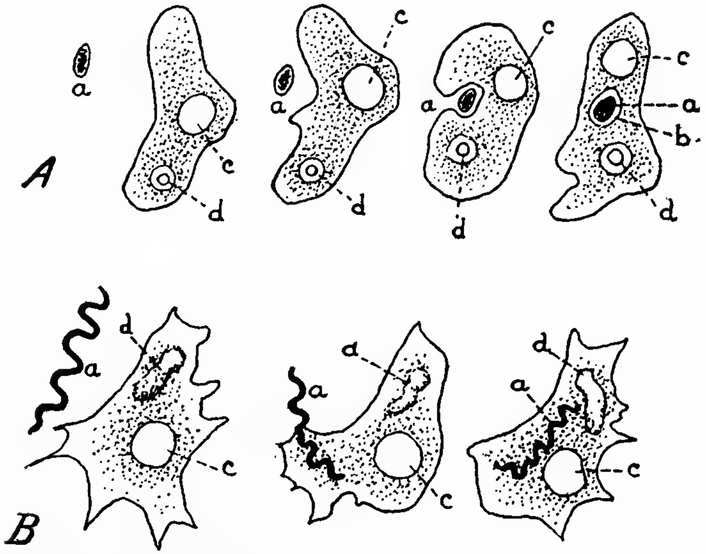


FIG. 26—(A) THE ANIMALCULE AMŒBA AND (B) A PHAGOCYTE OR COLOURLESS CORPUSCLE OF THE VERTEBRATE'S BLOOD COMPARED

In both cases a food-particle *a* is seen, and its "engulfing" in the living protoplasm of the microscopic cell—there to be dissolved and digested by "enzymes" or "ferments"—is shown. The food-particle taken up by the Phagocyte is a spirillum—possibly a disease-causing one which is thus destroyed. *b,* liquid surrounding the food-particle engulfed by the Amœba; *c,* vacuole or liquid holding space in the protoplasm; *d,* the cell-nucleus.

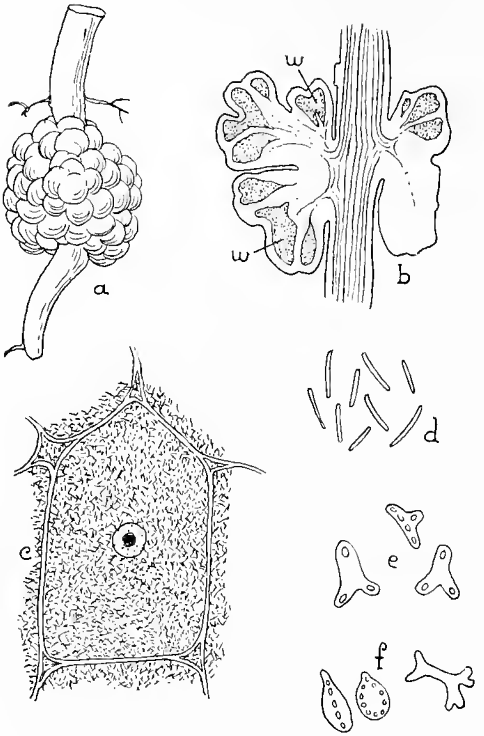


FIG. 28.—THE INVASION OF THE ROOTS OF THE PEA AND BEAN FAMILY BY BACTERIA

a, root nodule of the lupin of the natural size, caused by *Bacterium radicicolum; b*, longitudinal section through the root and nodule, showing *w*, the tissue infected with bacteria; *c*, cell from that tissue, highly magnified, showing dense infection by bacteria; *d*, bacillus-shaped bacteria (*B. radicicolum*) from the infected cells, magnified 900 diameters; *e* and *f*, irregularly-shaped bacteria often present.

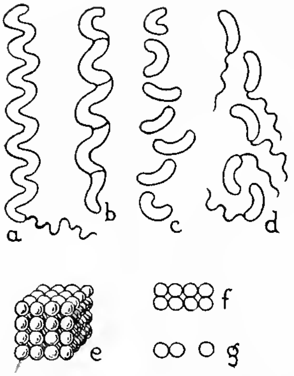


FIG. 29.—THE CHOLERA SPIRILLUM, OR COMMA-BACILLUS OF KOCH

a, spirillum stage of growth, with vibrating flagellum, by which it is driven along with screw-like movement; *b*, the spirillum has lost its flagellum, and is motionless; it is marked off into separate segments; *c*, the segments have separated from one another as comma-shaped pieces, hence the name "comma-bacillus" given to it by Koch; *d*, a number of comma-bacilli of cholera which have developed tails of vibratile protoplasm (like a single cilium), and are swimming about, being driven by the lashing of these tails. *e*, a cubical packet of the bacterium called *Sarcina ventriculi*, which is found to favour by its presence the growth of the cholera bacillus in man's intestine; *f*, a double row of the spherical units (cocci or micrococci), which form a sarcina-packet; *g*, similar cocci separated.

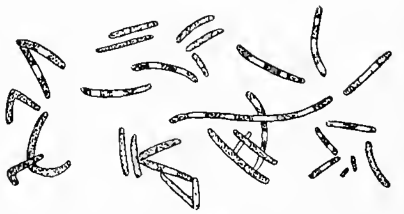


FIG. 30.—THE *Bacillus tuberculosis* OF KOCH

The drawings are 3,000 times the length of the actual specimens, and are made from a section of a human tubercular growth stained and clarified for microscopic examination. They illustrate the report of a lecture on "The Warfare against Tuberculosis," given by Prof. Metchnikoff before the National Health Society, 53 Berners Street, London, W.

seaside town gets infected and glows in a ghostly way by night. Bones and bits of meat lying on a dust-heap become, in warm, damp weather, infested in patches with these phosphorescent growths. A very curious case is that of the infection of sand-hoppers living above tide-mark on a weed-strewn shore by one species of phosphorescent bacilli. They were first observed near Boulogne and later at Ouistreham on the Normandy coast; but have not been hitherto reported from the British shore. The phosphorescent bacilli make their way into the blood of the "sand-hoppers," and multiply there to such an extent that the little shrimps shine at night like glow-worms, and are, indeed, mistaken by casual observers for such. A dozen or so may be picked up on a summer's night as one walks along the sands. They are all the more easily picked up since they have become almost incapable of crawling, let alone hopping, owing to this wonderful luminous infection. The phosphorescent Bacteria cause chemical changes in the blood of the sandhoppers of a poisonous nature, in fact a disease; and the infected sandhopper rapidly dies. It is a puzzling fact—from the point of view of "the origin of species by the selection of favoured races in the struggle for existence"—that the two points in which this phosphorescent bacterium, which gets into and multiplies in the sandhopper's blood, arrests our attention as differing from any ordinary bacillus, are its power of producing phosphorescent or light-giving material and also of producing a poison—deadly to those little shrimps. Yet it assuredly requires greater ingenuity than has been applied to the case to show that it is of any advantage to the bacillus to glow like a glow-worm or to poison the harmless shrimp. How, then, did these faculties become fixed in this parasitic race of bacilli, faculties which seem likely to be as injurious to its own life as favourable to it? It is no advantage to these phosphorescent Bacteria (nor indeed to other marine luminous organisms) to attract attention to themselves by "lighting up." All that they require in life is a moderate supply of their accustomed food, which they find in a shrimp's juices. They do not even profit by killing their host. Very few parasites do; they are likely to perish with their host. In most cases of parasitism—after a certain period, a sort of balance is effected between parasite and host—the former does not multiply so as to seriously injure the latter, since it is not the host's death which is beneficial to the parasite, but rather the perennial provision by the host of nourishment for his guest. We must leave the phosphorescent death-dealing parasite of the sandhopper as a puzzle for future inquirers.

The Bacteria of the sea comprise some kinds peculiar to it. The matter has not been very carefully studied, but it has been stated that the water of great ocean depths is free from Bacteria, and that putrefaction does not occur in those regions because there is not a sufficient supply of putrescible matter to maintain "a seething pot," or witches' cauldron, of endless varieties of Bacteria such as are the soil and the more shallow waters of the globe.

Disease-carrying Bacteria; Bacteria Causing Disease

The poison-producing quality of the phosphorescent bacillus brings us to a momentous subject, that of pathogenic Bacteria, the study of which has developed of late years into a vast and most important branch of medical inquiry. It now appears that nearly all "infectious" diseases of men and animals, and many of plants, are due to the parasitism in the living body of Bacteria of many different kinds. A very few infectious diseases, such as "malaria," are traced to equally minute parasites which are regarded as Protozoa—that is, of animal nature, rather than vegetable. Spreading wherever their special nourishment—dead organic matter—occurs, many species of Bacteria infest the skin and surface secretions of animals, but beyond causing foul-smelling decompositions do no harm. Various kinds have spread from the surface into the alimentary canal by way of the mouth, some into the bladder and the air passages by way of their external apertures. The contents of the intestines form a rich culture-ground for putrefactive species of Bacteria. Nearly half the bulk of the intestinal contents in man and other animals consists of Bacteria, including a very large number of distinct kinds, all requiring much further study and experiment. Most of these do not cause any injury to the host, but may even assist in the process of digestion. Poisonous products are often formed by them in small quantity and tolerated by the infected host; but from time to time (owing to special condition of the host, or to the entrance of special malignant species) active poison-producing Bacteria multiply in excess in the intestine, and cause deadly disease. Typhoid or enteric fever, oriental cholera, dysentery, and various kinds of diarrhœa have been thus traced to definite intrusive species of Bacteria (Figs. 12, 15 *F*, and 30). Bacteria (bacilli, leptothrix, and spirilla) abound in the mouth and are the active causes of the decay of the teeth and toothache. The bacterium which causes the ammoniacal fermentation of urine sometimes establishes itself in the bladder and produces disease; the deadly tubercle bacillus is taken into the lungs, though also entering by the alimentary canal; and a putrefactive bacterium makes its way through the nose into the air passages in the bones of the face!

To prove the agency of a particular bacterium as the cause of a disease, it is accepted by bacteriologists as necessary to obtain in the first place a *pure culture* of the suspected bacterium and then to inoculate with it a perfectly healthy animal previously free from it. Then, if the bacterium is found to multiply and flourish in the inoculated animal, and the symptoms of the disease supposed to be caused by the bacterium appear in the animal, the conclusion that the bacterium is the cause or agent of the disease is rendered highly probable. But this is not finally accepted until it has been confirmed by many trials under varying test conditions. Many pathogenous Bacteria are able to live, either as spores or in active growth and movement, for a greater or less length of time, in the soil or water, and so spread from one victim to another. This is true of the Bacteria causing typhoid, cholera, and anthrax (or malignant pustule), and of others; but the presence of common putrefactive Bacteria is often antagonistic to the life of specialised pathogenous species. Some of the latter require the co-operation of other species; e.g. the deadly tetanus or lockjaw bacillus, which gets into wounds polluted by rich soil, is killed by the phagocytes (see Fig. 26 and explanation) of the blood and fails to produce its terrible poison unless it is accompanied (as it usually is) by septicæmic Bacteria, which attract the phagocytes and so enable the tetanus bacilli to multiply in the wound and produce their poison, which is rapidly absorbed. Another wound-infection, called "gas-gangrene," which was frequent in the Great War, arises from the co-operation of three and possibly of four distinct species of bacillus. Lister discovered that the dangerous putrefaction of wounds, whether resulting from necessary surgical operations or from accident or from hostile assault, is due to the growth in the wounded tissue of "septic" or poison-producing Bacteria. He introduced with world-famous success the use of antiseptic dressing and great cleanliness for the purpose of excluding such Bacteria from the wounded surface.

§ 9

How Bacteria are "Carried"

The mode of access of pathogenic Bacteria to the animal body is a matter of prime importance. The living tissues are protected by the skin, and those Bacteria which cannot gain access through the natural apertures to the cavities of the body lined by soft penetrable "mucous membrane," have to pass through the dry horny skin by way of accidental cracks and scratches or else by attaching themselves to the parasitic insects which pierce the skin for the purpose of blood-sucking, such as fleas, flies, bugs, ticks, and lice. The germ which causes hydrophobia has not yet been satisfactorily identified; but it is established that it is brought into man's body through wounds inflicted by the teeth of dogs or other animals suffering from the deadly infection of rabies. The hydrophobia germ is present in the rabid animal's saliva. The organism causing typhus or jail fever has been shown by experiment to be introduced into man by the louse, although it also has not yet been isolated. Yellow fever is due to a microbe, probably a bacterium, which is injected into man by the stab of a species of gnat, the *Stegomya fasciata,* but the microbe has not been isolated. The bacterium causing trench fever is carried by the louse. Relapsing fever (famine fever) is caused by a motile Spirillum (Fig. 27), which is carried by the common bedbug and is introduced into man by its bite. The most terrible of these insect-carried pathogenous Bacteria—looking as it does like an ordinary short bacillus with nothing peculiar about it—is that which causes the historic disease known as Plague. It is carried by a wandering species of flea, the *Pulex cheopis,* from the rat to man.

Pathogenous Bacteria are sometimes "carried" by higher animals, to which they are innocuous. The carrier becomes, as it were, a reservoir of a dangerous bacterium injurious to man or other animals, but not to the carrier. Such is the history of the bacterium which causes "Malta fever." After its discovery by General Bruce it was shown that it infects the goats from which the milk-supply of Malta is obtained, and whilst doing them little or no injury passes in their milk to the human population, especially to the sailors and soldiers in the Government hospital. The discovery has led to the supervision of the goats and the practical suppression of the dangerous and disabling fever. Not unfrequently men and women become insusceptible to the poison of typhoid or, in other instances, of cholera bacilli. Such persons are found then to act as "carriers" of these deadly germs and spread them and infect other persons though they are themselves immune. Blood-poisoning of various kinds (pyæmia) is shown to be due to specific Bacteria; so are erysipelas, diphtheria, glanders, various kinds of "catarrh," and influenza. In the last case the bacterium is not yet precisely known and we are consequently not so well able to deal with it as we may hope to be in the future. The disease called "syphilis" is due to a spirillum-like form. The bacillus of tubercle (Fig. 30), discovered by Koch in 1882, infects various tissues and organs, and multiplying to excess causes destruction of the lungs, glands, and other organs invaded. It is not rapid, though it is sure, in its destructive action. Allied to the bacillus of tubercle is that of leprosy, even more slow in its growth. It was discovered by Hansen of Bergen in 1871—eleven years earlier than the tubercle bacillus. The bacillus of leprosy enters the human body from infected persons through wounds or ulcerous surfaces. The broken skin-surfaces through which it enters are due to a scorbutic condition set up by defective diet, such as dried fish, absence of fresh meat and vegetables. Wherever the diet of a population has improved in these respects, leprosy has died out. Forty years ago there were 250 lepers in the leper-house of Bergen (Norway), now there are only some forty or fifty and these are all the cases known in Norway. Formerly, in Western Europe, including the British Isles, leprosy was abundant. "Leper-houses," and special lepers' doors in the churches, were very generally provided. There is hope that tubercle (phthisis and its other forms) may eventually disappear in a similar way.

It is not possible to find space here for more than the bare enumeration of some of the chief bacterial diseases of man given above. Scarlet fever, smallpox, and measles are almost certainly bacterial diseases also, but as yet the bacterium responsible in these fevers has not been seen and isolated for study.

§ 10

Bacteria of the Soil

Finally, three classes of Bacteria, very important in their chemical action upon water and the soil, must be mentioned.

They are the Sulphur, the Iron, and the Nitrogen Bacteria. The "Sulphur Bacteria" are remarkable for their dependence on sulphuretted hydrogen, the gas liberated together with marsh-gas in ponds and marshes by the action of the abundant Bacteria (above mentioned) which attack and break up the "cellulose" or woody matter of vegetable refuse. The Sulphur Bacteria flourish by oxidising the sulphuretted hydrogen in such waters, taking up the sulphur and storing it as granules in their own protoplasm. Peach-coloured or purple Sulphur Bacteria of many varieties of form and growth are abundant in stagnant pools, forming wine-coloured sheets of encrustation. There is urgent need for further study of these peach-coloured Bacteria. Colourless Sulphur Bacteria of large size and very distinct shape and growth, including a large range of *form*, viz. coccus, leptothrix, and spirillum (known as Beggiatoa), are abundant in natural warm springs, which bubble with sulphuretted hydrogen gas. The great deposits of pure sulphur in the Tertiary strata of Sicily are due to these Sulphur Bacteria.

The black mud of stagnant pools is due to the production of black iron sulphide by the action of sulphuretted hydrogen upon iron salts in the soil. "Iron Bacteria" are described which flourish in natural waters containing the soluble bicarbonate of iron. The Bacteria become thickly encrusted with a reddish-brown deposit of ferric hydroxide, and sometimes the supply pipes of water-works become clothed with this deposit, due to a chemical attraction and oxidation exercised by a special "species" of Bacteria.

The "Nitrogen Bacteria" are of supreme importance in relation to the supply of nitrogen in the form necessary as the food of green plants. They are one of the chief agents in natural waters and in the "soil" and must be regarded as the basis of agriculture and all cultivation of green plants. One set called the "nitroso-Bacteria" are the agents of the conversion into *nitrites* of the ammonia (NH_3) which is a final term of proteid putrefaction. But nitrites are not what the green plant needs. It must have *nitrates.* A distinct set of soil Bacteria—the nitrato-Bacteria—are to hand, and it is they which are concerned in the oxidation of nitrites into nitrates. But the green plant's need for nitrogen is yet further met by another and most remarkable kind of Bacteria, which can actually seize *free uncombined nitrogen* from the atmosphere, and convert it into compounds capable of feeding the green plant. These nitrogen-seizing Bacteria are widely present in "arable" soil. And further, they attack the roots of the great food-producing order of plants, the Leguminosæ (which includes our Peas and Beans, Vetches, and Clover), and entering there cause the growth, on the rootlets, of characteristic nodules (Fig. 28) in which they accumulate. They are known as *Bacterium radicicolum,* and enable the Pea and Bean plants to seize and assimilate free atmospheric nitrogen, when there is a deficient supply of nitrates from other sources. This has been proved experimentally on a large scale. The nitrogen-seizing bacterium of the nodules can be cultivated independently of the green plant in appropriate solutions, and has been prepared in quantity as a commercial article to be introduced into soils deficient in nitrogenous salts. It yet remains to note in this connection that another distinct set of Bacteria is known, and is at present the subject of experiment, which has the power of *deoxidising* nitrates in the soil, and yet more remarkable, of liberating ammonia and *free nitrogen gas.*

Sewage as Manure and as Pollution

These two subjects each occupy the life-work of many accomplished chemists employed in large public institutions. Great works are erected for the purpose of bringing crude sewage into the best form for the nourishment of plants by the activities of a succession of Bacteria—the putrefactive, the cellulose-destroying, the ammonia-forming, the nitrous and the nitrate kinds, of which we have briefly written above. That is one vital and constantly growing industry.

Another line of work arises from the necessity of preserving some considerable portion of the waters of our streams and rivers in such a state of purity as is needful to render it unlikely to produce disease when used as the daily drink of a dense population of human beings. The water drawn from rivers for human consumption is liable to contain pathogenous Bacteria, such as those of typhoid, cholera, dysentery, etc., especially when the excreta of the populations of large towns situated on its banks are conveyed by sewers or otherwise into the river. Legislation has done much to prevent the excess of such contamination, which once was general. Nowadays the river water supplied by water companies is, to a great extent, protected from pollution (under Act of Parliament) by the separate treatment of sewage in special works; and the water is freed from an excess of Bacteria by sedimentation, by precipitation (Clarke's process), by filtration, and by exposure in great tanks to sunlight. In some difficult cases chemical purification by ozone or by chlorine has been used. The number and kinds of Bacteria present in the water at different stages of its passage through the reservoirs of the pumping stations are recorded with precision, and especial attention is given to the number present (per cubic centimetre) of certain indicative Bacteria due to contamination by human and animal excreta. Such are the *Bacillus coli communis* and the *B. enteritidis sporogenes.* The possible carriage, by water thus humanly contaminated, of the Bacteria of typhoid, cholera, and other diseases derived from the sewage of a town or village where those diseases are present, but not yet notified, is a very real danger, and steps are taken by the authorities to prevent the contamination when discovered.

§ 11

The preceding pages may serve to give the reader an outline of the extraordinarily varied and vitally important branches of knowledge which have grown up, and are still developing, around the "infusion-animalcules" of Schwann—the "Vibrionia" of Ehrenberg. The practical demands of human industry and sanitation have led to the production of an immense body of detailed knowledge as to the chemical activities and life conditions of many special kinds. But the investigation of those kinds not concerned in disease nor in manufacturing processes has been comparatively neglected. It is the study of these less specialised kinds of Bacteria which will in the future help us to a better understanding of the origin and "natural history" of these astonishing and ubiquitous organisms.

BIBLIOGRAPHY

The reader who wishes to go further into this subject will find the article "Bacteriology" in the eleventh edition of the *Encyclopædia Britannica,* written by the late Professor Marshall Ward, the best general statement in English, with very full references to earlier important works. He should also read Lankester's articles on "A Peach-coloured Bacterium" in vols. xiii. and xvi. (1873 and 1876) of the *Quarterly Journal of Microscopical Science.* The *Spaltpilze* by Zopf (Breslau, 1885) is a short but well-illustrated treatise of great value, whilst the *System der Bakterien* by Migula (Jena, 1901) is still the most detailed work on the subject, giving full references to all the literature. Special handbooks dealing with the technical and commercial aspects of Bacteriology are published in England and the United States.

Note.—Pasteur did not distinguish by name and description the various kinds of organisms producing the fermentations which he studied. He called them all "microbes"—an abbreviation of "micro-bionta"—a convenient term which has come into general use.

XXVIII

THE MAKING OF THE EARTH AND THE STORY OF THE ROCKS

THE MAKING OF THE EARTH AND THE STORY OF THE ROCKS

THE EARTH'S INTERIOR—VOLCANIC ERUPTIONS

Origin of the Earth

IN the opening chapters of this work the modern theories regarding the origin of the earth and its early history were briefly discussed. It may be regarded as certain that the earth was originally part of a larger mass from which it, and other planets, were heaved off in the form of knotted spiral nebulæ, like many of those to be observed in the heavens to-day.

One of the two main theories of the origin of the earth and the other planets is that of Laplace, according to which the planets were formed by the nebulæ throwing off gaseous rings. Professor Chamberlain pictures this hypothesis thus:

> Starting as a gaseous globe, an early passage into a molten sphere wrapped in a hot vaporous atmosphere was logically assigned the earth. The atmosphere was made vast to contain all the water of the globe and the volatile matter that the heated conditions were presumed to have generated. At a later stage a crust was assigned to the cooling globe, and the waters, condensing on this, gave the infant earth the swaddling bands of a universal ocean. On further cooling, shrinkage and deformation were supposed to follow, the waters to be gathered into basins, the land to appear, and the formation of earth strata to begin.

Another view is the Meteoric theory, according to which the more primitive stage of the nebulæ was gaseous, but later the nebulæ condensed into scattered meteorites, and such bodies as the planets were formed by passing through a stage of small scattered solid bodies. We quote Professor Chamberlain again:

> Quite in contrast with the older pictures of the primitive earth, the planetesimal hypothesis—and this is entitled to be taken as the type of theories based on concentration from a scattered orbital state—postulates a solid earth, growing up slowly by accessions and coming to be clothed gradually with an atmosphere and hydrosphere. The earth, the air, and the water are made to grow up together from smaller to larger volumes without necessarily attaining a very high temperature. The sources that at first had furnished the body of the ocean and the air, though they fell off as time went on, still continued to serve as means of replenishment, and to act as an offset to the familiar agencies of loss, far down into the later ages.

The material of the earth is similar to that of many of the other members of the Solar System, though of course the materials may not exist in the same proportion. In its primitive stage, the earth in its outer parts was liquid or gaseous; it was from its outer part that the moon was detached and became a separate body. As we have seen in a previous chapter, the friction of the tides has carried the moon farther and farther away from the earth. The primitive earth, it is estimated, had a diameter of about 5,500 miles; it grew larger by drawing into itself more nebulous materials or meteorites (called planetesimals by Professor Chamberlain) until it had a diameter of 8,100 miles at the end of its growing period.

After *the growing period* was over, the earth began to lose volume. To-day it has a diameter of 7,900 miles. It was cooling, and that usually means becoming smaller. It was also consolidating internally. On the surface the earth was probably like a mass of lava, alternately passing from crust-making to boiling over. The boiling process must have brought about a sorting

Photo: Underwood & Underwood

A SAN FRANCISCO PAVEMENT TORN BY THE EARTHQUAKE

The result demonstrates the tension and strain produced in the earth's crust by these movements.

Photo: E. N. A.

THE EFFECT OF AN EARTHQUAKE IN JAPAN

A remarkable view of the Nagara-Gawa Bridge on the railway line between Gifu and Ogaki.

Photo: E. N. A.

THE RUINED BIWAJIMA BRIDGE ACROSS THE RIVER SHONIGAWA, JAPAN

The bridge now lies in the bed of the river in a curious serpent-like twisted form.

of materials, the lighter materials coming to the top and the heavier sinking to lower levels. The more acid, granitic materials would rise; basaltic materials would sink. Thus, roughly speaking, arose the rigid, rocky, relatively cool shell of the earth, perhaps fifty miles thick, shutting in the internal heat. The continents are, on the whole, built of the lighter materials, e.g. granites, while the depressions that form the floor of the oceans have more of the heavier basaltic rocks beneath them. In any case a rocky shell or lithosphere was formed, and the romance of the rocks is concerned with the permutations and combinations of the materials of the earth's crust.

In all probability, the earth contains a metal core embedded in a mantle of rocks some 50 miles thick. The centre of the earth is about 4,000 miles beneath us; the deepest shaft ever bored reached a depth of only some 6,500 feet, or less than one and a half miles. For a knowledge of the conditions existing in the interior of the earth, therefore, we must depend on the resources of scientific investigation. It is probable that the rocky crust of the earth changes in its nature at a uniform rate, as the temperature rises, down to a certain depth, and beneath that there is a sudden change in the conditions; we reach the beginning of the metal core which is enveloped by the earth's mantle of rocks.

§ 1

The Interior of the Earth

We owe a great deal of our knowledge of the interior of the earth to earthquake waves and to volcanic eruptions. From earthquake waves we are able to infer something of the elastic properties of the earth's substance. From such phenomena we learn that rigidity increases towards the centre of the earth. This is due to the effect of the pressure of the earth's outer layers, which forces the molecules closer together in the most central part of the earth. In earthquakes, the earth tremors, starting from the focus of the quake, pass through the body of the globe as elastic waves. The "principal waves" which are felt in a severe earthquake, and which cause the greatest oscillations of the ground, pass along the earth's surface and do not reach a great depth; such waves are known as transverse waves and have only half the velocity of the longitudinal waves, which are the first waves to arrive, and are called "first precursors." It is these "precursors" which tell us most about the conditions of our globe. Their behaviour shows that their paths lie through the *body* of the earth, and from observations it is possible to trace their paths through the depth of the globe. There are many seismologic stations at different places with instruments so fine, and so carefully watched, that the earthquake phenomena can be studied with utmost precision. By studying the manner of the propagation of earthquake waves it is possible, with the aid of mathematical reasoning, to calculate their paths in the interior of the earth, and the velocity of their propagation. By such means the condition and the composition of the earth's interior is ascertained; it is found, as already stated, that the rocky mantle or crust of the earth extends down to about 50 miles; below that there is a central core of quite different and denser metallic material. It is possible that beneath the outer solid crust, there exists, at no very great depth, a thin molten layer, so thin, comparatively, as not to produce in any perceptible degree diminution of the earth's rigidity.

It is unlikely that the substratum of the crust is liquid; it is merely "plastic." Mr. Bailey Willis, in discussing "What is Terra Firma?" says, "On what do mountains, continents, and ocean basins rest? Are there any rocks firm enough to bear the weight of mountains or continents without crushing?" Among mountains there are many that are more than three miles high and some that exceed five miles. The weight of such a column would crush its base.

> Asia is so high that its weight must exceed the load which can be supported by rocks, as we know them. The same is true

> of other continents. It seems reasonable to think [Mr. Willis says] that the foundations or rocks beneath the continents may approach a crushed condition, or may actually be crushed. . . . The crushed condition is not, however, that of rocks which fall apart when crushed, for the foundations of continents and ocean beds are part of the solid earth and are continuous all about the sphere. There is, therefore, no space into which any crushed mass can crumble. The strength of the rocks may be overcome, but they cannot fall apart. This condition has been reproduced experimentally, and it has been shown that marble and even the firmest granite may be forced to change form, yet to be held a coherent solid. The rock under these conditions may be compared to wax, if only we bear in mind that it remains all the time a very strong solid.

That the temperature of the interior of the earth is very high, is shown by the existence of hot springs and volcanoes, and by the rapid rise in temperature observed in mining operations, tunnelling and drilling. The temperature in the interior of the earth, it is reckoned,

> attains some thousands of degrees Centigrade; that the material of the earth, nevertheless, does not become liquid or even gaseous at such high temperatures, but is proved to be very rigid, must be attributed to the extreme pressure which packs the molecules together and robs them of their mobility. Keeping this in mind while trying to ascertain the physical behaviour of bodies with increase of temperature, we may infer that the temperature in the interior of the earth must certainly remain below 9,000 degrees; in all probability it does not even reach 4,000 degrees.[1]

§ 2

Distribution of Land and Water

The question of the *plan of the earth,* and the distribution of land and water over its surface, is a very fascinating one. More

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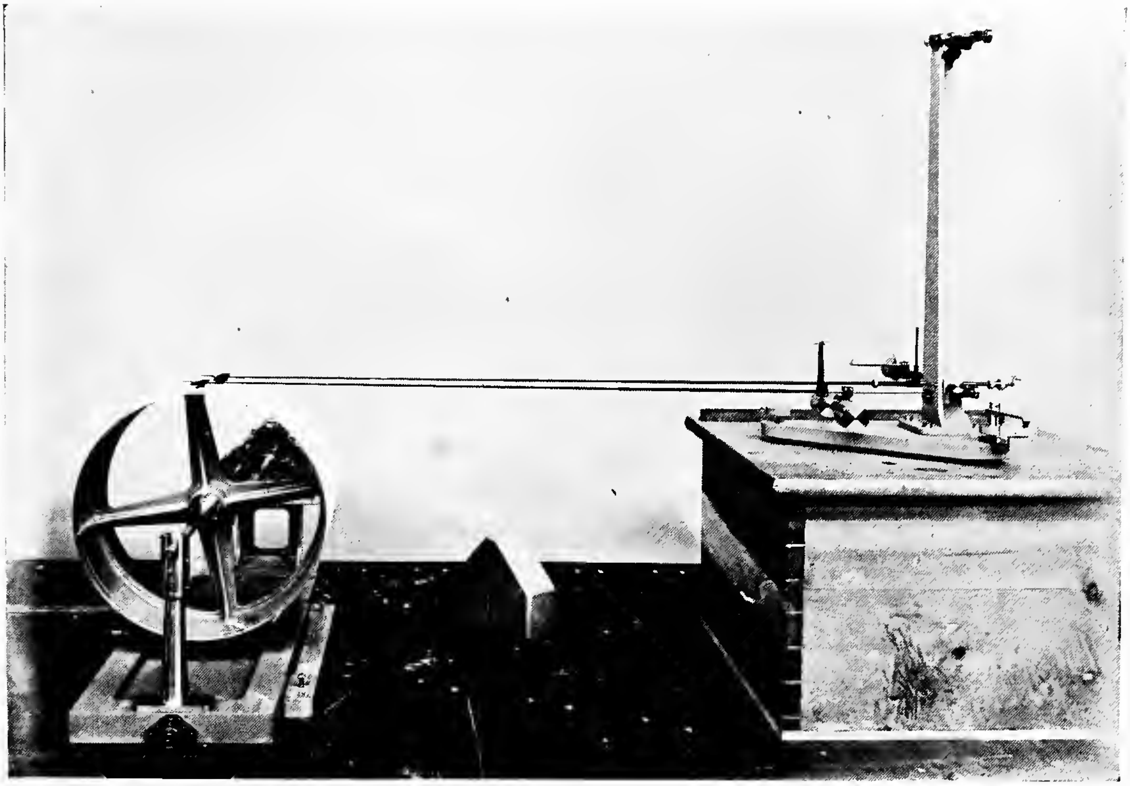
[1] Professor Gregory, *The Making of the Earth.*

than forty years ago, Lothian Green pointed out that the continents correspond in position to the edges and solid angles of a tetrahedron—a figure with four triangular faces. The flat faces would be occupied by the Atlantic, Indian, Pacific, and Arctic Oceans. It was shown mathematically that if water could be held by gravity on the surface of a tetrahedron, so as to cover five-sevenths of the area, it would correspond in plan to the oceans of the world. It was further pointed out that a sphere, like the earth, which was shrinking in volume without changing the area of its surface, would assume the form of a tetrahedron; although, in the case of a rapidly revolving body like a planet, the angles would be very much rounded off. This theory deservedly enjoys a great popularity.

When we consider that animals and plants of the same families and even of the same species are found in equal abundance in widely separated regions, and that this is true of all geological ages, we are forced to conclude that continents now separated by oceans must once have been connected by bridges of land. Oftener than once, dry land has disappeared below the surface of ocean water; the bed of oceans has been raised above the surface and become dry land; but some areas have continued as land throughout nearly the whole of geological time. The fabled continent of Atlantis was supposed to have existed in the North Atlantic Ocean. Whether Plato's description of prehistoric Atlantis—and the high state of the civilisation of its inhabitants—is credible or not, there is little doubt that in very remote times there was a large land mass between the Eastern and Western Continents.

It is well established that in the course of time there has been a frequent interchange between land and sea areas. Nearly every part of England has undergone such changes, land areas have been submerged beneath the sea, and alternately the floor of the sea has been raised and become dry land. At the time when the Coal Measures were formed in Europe, there flourished in



By courtesy of Messrs. R. W. Munro, Ltd.

THE SEISMOGRAPH

By means of these highly sensitive instruments, placed in observatories all over the world, earthquake tremors of even a very slight character are recorded. The study of the propagation of these tremors through the earth has yielded information about the physical state of the interior of the globe that was unobtainable by direct means.

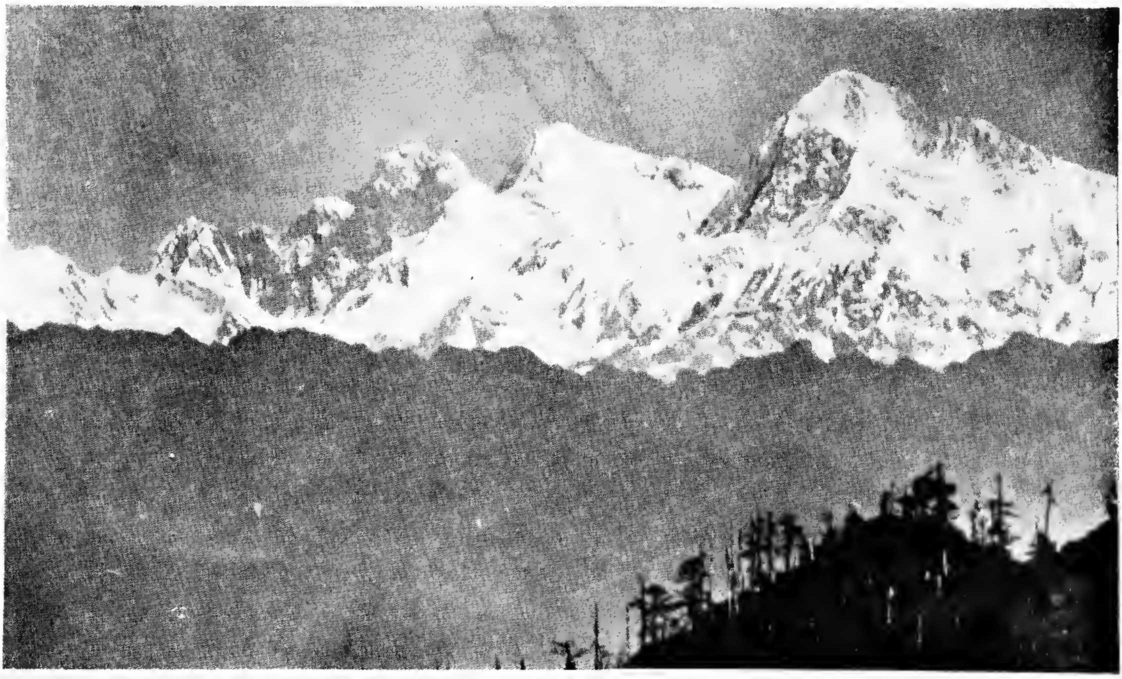


Photo: L. E. A.

THE HIMALAYAS, SHOWING MOUNT EVEREST

The summit of Mount Everest, the highest mountain in the world, is 29,002 feet above sea-level. The figure for the greatest depth of ocean is rather more. All the heights and abysses which mark the earth's surface are thus comprised within a vertical space of about twelve miles, an insignificant fraction of the radius of the globe.

Green, Belfast.

MARINE EROSION ON THE IRISH COAST

ine.

ARTHUR'S SEAT, EDINBURGH

n shows a typical example of a rock-mass of volcanic origin. The originally molten substance has solidified into a very
able to withstand the action of the eroding agents which have removed the formerly surrounding rocks of softer natures.

Australia, India, South Africa, and South America alike, a number of distinctive forms of plants. It was therefore concluded that all these regions then formed part of an immense continent which has been called "Gondwana Land." But an interesting new theory has quite recently been advanced by Professor Wegener, who suggests that in past ages these continents were very much nearer to each other than at the present time. South America, Antarctica, Australia, and India can readily be fitted round South Africa, like pieces of a jig-saw puzzle, so as to form a single land-mass of far less astounding size than the vast "Gondwana Land." Professor Wegener regards the continental masses as blocks of lighter granitic rock, floating, like an ice-floe in water, upon a sphere of heavier basaltic rock, which lies below the floors of the great oceans. In the Tertiary epoch, not very long ago in geological time, these blocks became separated, and America drifted westwards away from the Old World. At the present day, Greenland at least is moving away from Europe as much as 50 feet in a year. In front of the moving continent, the rocks were deformed and folded into the great mountain chains of the Rockies and the Andes, and with this were associated great outbursts of volcanic activity.

Volcanoes

We in the British Isles have little experience of earthquakes and none of volcanoes. It was not always so. There are many records of volcanic eruption in this country; indeed, these Islands furnish a great body of evidence regarding volcanic action in prehistoric times. Many of the Western Isles of Scotland are partly built of volcanic rocks. Central Scotland at one time was the centre of intense volcanic activity; North Berwick Law marks one of the chief vents; a great volcano built up Arthur's Seat and the Castle Rock at Edinburgh; so also with the Eildon Hills in Roxburgh and the Cumbraes in the Firth of Clyde, to mention only a few. The Cheviot Hills and the Lake District, ages ago, were also volcanic zones; and in Wales, Snowdon and Cader Idris were built up around volcanic centres.

Throughout geological history there have been great outbursts of volcanic activity alternating with prolonged intervals of rest.

The crust of the earth is subject to strain and stress due to the cooling of the earth and to its revolution, while in addition the other heavenly bodies may exert an attractive force. Disturbances of the earth's crust often produce a movement of the strata along fractures or "faults," a fault being a displacement by which rocks are broken across and sink or rise to different levels. Rift valleys have been formed by areas settling down to a lower level than that of the surrounding region; the Western Mediterranean, the Dead Sea, the Red Sea, Tanganyika and other African lakes, lie in such areas where depressions have been formed in remote times. The upward and downward movements of the earth's crust have given rise to the main configuration of the earth.

> The variations in volcanic intensity during successive geological periods [Professor Gregory says] may be explained as due to the alternation of periods of violent disturbances of the earth's crust with periods of slight and gentle movements. As the earth shrinks in size the crust sags gently downward. For a time the crust may easily accommodate itself to the internal contraction, and volcanic activity is dormant. As the shrinkage proceeds the crust becomes deformed and unstable; and the earth ultimately recovers stability by great readjustments of the surface. During these movements the crust is fractured and parts of it sink, and at such places the pressure on the underlying rock is especially heavy. This extra weight on the superheated plastic rock and the opportunity given for its escape through the fractures occasion fresh periods of volcanic activity.

Photo: James's Press Agency.

FINGAL'S CAVE, STAFFA

A magnificent example of an igneous rock divided by "joints" into columns. The rock is a dark-coloured, fine-gr
It was not poured out as a lava at the surface of the ground, but made its way between layers of older rocks as a sheet or
arch at the entrance is 60 feet high and the cave is 80 yards in length.

J. Shepstone.

COX'S CAVES, CHEDDAR, SOMERSETSHIRE

ground caverns are characteristic of limestone formations and are found in many parts of the world. The constant percola-
rip of water saturated with lime causes the formation of long *stalactites* depending from the roof like icicles; drops fall on the
cavern until in time this deposit of carbonate of lime becomes an upright rod called a stalagmite. Sometimes the stalactites
mites ultimately join and form complete pillars.

Volcanoes are closely related to the earth movements which result in the fracturing of strata and folding of the earth's crust. Amongst the examples of periodically active volcanoes to-day is Vesuvius. The earliest recorded eruption of Vesuvius (79 A.D.) destroyed Pompeii, leaving it "a heap of hardened mud and ashes." Stromboli has been constantly active since the time of Homer.

Sir Ray Lankester, as an eye-witness, has vividly described Vesuvius in eruption:

Vesuvius in Eruption

> The crater or basin formed by a volcano starts with the opening of a fissure in the earth's surface communicating by a pipe-like passage with very deeply-seated molten matter and steam. Whether the molten matter thus naturally "tapped" is only a local though vast accumulation, or is universally distributed at a given depth below the earth's crust, and at how many miles from the surface, is not known. It seems to be certain that the great pressure of the crust of the earth (from five to twenty-five miles thick) must prevent the heated matter below it from becoming either liquid or gaseous, whether the heat of that mass be due to the cracking of the earth's crust and the friction of the moving surfaces as the crust cools and shrinks, or is to be accounted for by the original high temperature of the entire mass of the terrestrial globe. It is only when the gigantic pressure is relieved by the cracking or fissuring of the closed case called "the crust of the earth" that the enclosed deep-lying matter of immensely high temperature liquefies, or even vaporizes, and rushes into the up-leading fissure. Steam and gas thus "set free" drive everything before them, carrying solid masses along with them, tearing, rending, shaking "the foundations of the hills," and issuing in terrific jets from the earth's surface, as through a safety valve, into the astonished world above.

The eruption he proceeds to describe was that of 1871.

> We walked up towards the Observatory in order to spend the night on the burning mountain. We found that

two white-hot streams, each about 20 yards broad at the free end, were issuing from the base of the cone. The glowing stones thrown up by the crater were now separately visible; a loud roar accompanied each spasmodic ejection. The night was very clear, and a white firmly-cut cloud, due to the steam ejected by the crater, hung above it. At intervals we heard a milder detonation—that of thunder which accompanied the lightning which played in the cloud, giving it a greenish illumination by contrast with the red flame-colour reflected on to it by red-hot material within the crater. The flames attributed to volcanoes are generally of this nature, but actual flames do sometimes occur in volcanic eruption by the ignition of combustible gases. The puffs of steam from the crater were separated by intervals of about three minutes. When an eruption becomes violent they succeed one another at the rate of many in a second, and the force of the steam jet is gigantic, driving a column of transparent superheated steam with such vigour that as it cools into the condition of "cloud" an appearance like that of a gigantic pine-tree seven miles high (in the case of Vesuvius) is produced.

We made our way to the advancing end of one of the lava-streams (like the "snout" of a glacier), which was 20 feet high, and moved forwards but slowly, in successive jerks. Two hundred yards farther up, where it issued from the sandy ashes, the lava was white-hot and running like water, but it was not in very great quantity and rapidly cooled on the surface and became "sticky." A cooled skin of slag was formed in this way, which arrested the advancing stream of lava. At intervals of a few minutes this cooled crust was broken into innumerable clinkers by the pressure of the stream, and there was a noise like the smashing of a gigantic store of crockery ware as the pieces or "clinkers" fell over one another down the nearly vertical "snout" of the lava-stream, whilst the red-hot molten material burst forward a few feet, but immediately became again "crusted over" and stopped in its progress. We watched the coming together and fusion of the two streams and the overwhelming and burning up of several trees by the steadily, though slowly, advancing river of fire. Then we climbed up the ash-cone,

> getting nearer and nearer to the rim of the crater, from which showers of glowing stones were being shot. The deep roar of the mountain at each effort was echoed from the cliffs of the ancient mother-crater, Monte Somma, and the ground shook under our feet as does a ship at sea when struck by a wave.
>
> As we ascended the upper part of the cone the red-hot stones were falling to our left, and we determined to risk a rapid climb to the edge of the crater on the right or southern side and to look into it. We did so, and as we peered into the great streaming pit a terrific roar, accompanied by a shuddering of the whole mountain, burst from it. Hundreds of red-hot stones rose in the air to a height of 400 feet, and fell happily in accordance with our expectation, to our left. We ran quickly down the sandy side of the cone to a safe position, about 300 feet below the crater's lip, and having lit our pipes from one of the red-hot "bombs," rested for a while at a safe distance and waited for the sunrise. A vast horizontal layer of cloud had now formed below us, and Vesuvius and the hills around Naples appeared as islands emerging from a sea.

Sir Ray Lankester also witnessed the great eruption of the following year. The great lava stream reached six miles down the mountain in the flat country below, destroying two villages—its course, narrow where it started, widened to 3 miles. After ten days "this river, with all its waves and ripples, was turned to stone and greatly resembled a Swiss glacier in appearance. A foot below the surface it was still red-hot, and a stick pushed into a crevice caught fire." [1]

Earthquakes and Geysers

Some earthquakes are produced as a result of volcanic eruption, but many of the most severe earthquakes have no immediate connection with volcanic activity; they are due to a shifting of the

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[1] Sir E. Ray Lankester, *Secrets of Earth and Sea.*

earth crust, to a movement of the strata along the fractures or "faults" to which we have referred.

Geysers, which are hot springs in which the water is forced fountain-wise into the air, exist in volcanic areas, deriving their heat from volcanic sources. The most famous are in the Yellowstone National Park, Wyoming, U.S.A. From one of these springs the water is shot to a height of nearly 150 feet. Many geysers, in America, in Iceland, and in New Zealand—the regions where they are best known—do not flow continuously, but squirt out jets of boiling water at intervals, which may be remarkably regular. The presence of geysers is an indication that the volcanic activity of the district is gradually dying away.

§ 3

The Making of Mountains

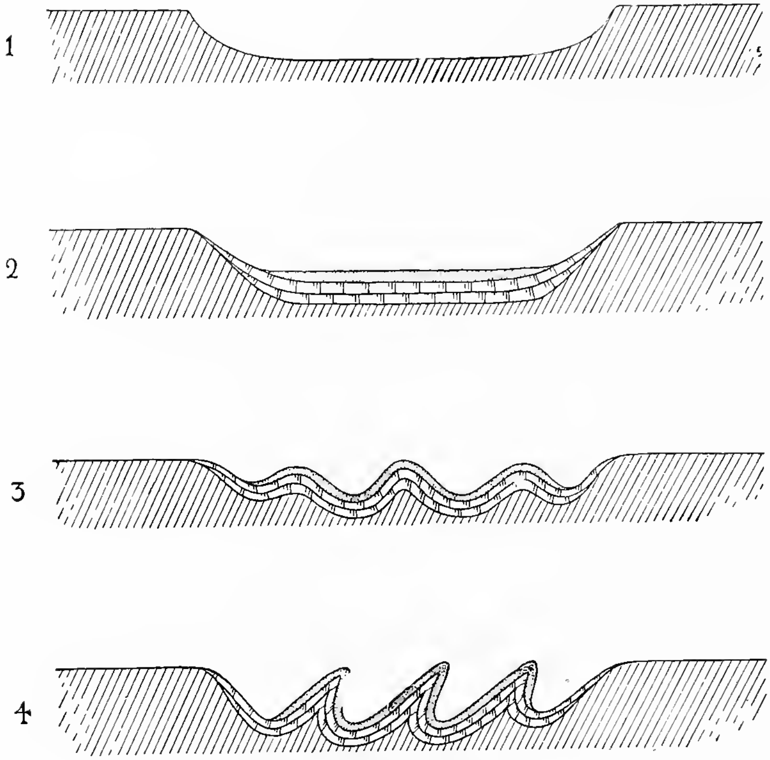
We shall see when we come to consider the story of a piece of sandstone, how the forces of running water and frost break up rocks into fragments, and how the streams sweep these fragments down into the sea; and we shall see, too, that these forces act more powerfully in the mountains than anywhere else. If these forces could go on unchecked, they would in time wear down the surface of the earth's rocky crust until it was quite flat. We know, too, that the sea covers a much greater area of the earth than the land does, and that the highest mountains could be completely drowned in the greatest depths of the sea. What is it, then, that has saved the earth from being worn into a uniform ball, covered all over by a shallow, level-floored sea? The answer is that the earth still has a vast store of energy, and as fast as the old mountains are worn away new ones arise to take their place.

There are several ways in which mountains may be built. The simplest are those which are mere heaps of material on the surface of the earth, and these are called *accumulation* mountains. A volcano, for instance, will build up round its mouth a

By permission of the New Zealand Government Office.

WAIMANGU GEYSER, NEAR ROTORUA, NEW ZEALAND

Geysers, or hot springs, are characteristic of regions where former volcanic activity is dying away, and they are fo
notably, in North America, Iceland, and New Zealand. The column of water shown in the photograph is 1,500 fe
high.



FIVE STAGES IN THE MAKING OF A MOUNTAIN CHAIN

1. A depression forms between two continents. 2. Sediments accumulate. 3. The newly made rocks are folded. 4. The folds become more marked. 5. The folds have broken and slipped over each other. The next stage is the raising of the folded rocks out of the sea.

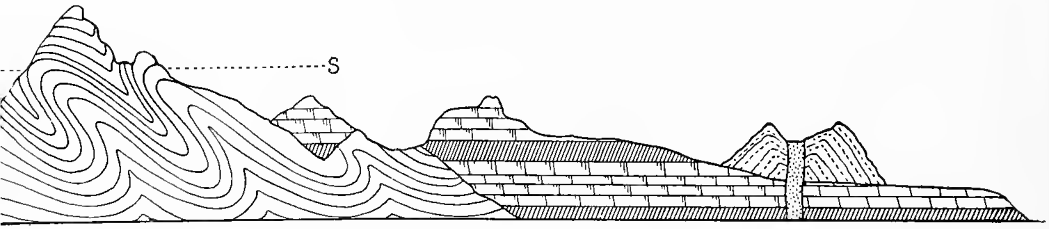


DIAGRAM SHOWING TYPES OF MOUNTAINS

e history of the imaginary country shown above in section is as follows: First was formed a range of *folded mountains*, whose re-
re seen on the left. This range sank till the sea reached the level S, and new horizontal beds were formed. The country rose
d the horizontal beds formed a plateau, which was cut up into *relict mountains*. To the left remains an original folded mountain,
mpletely under water; then come two relict mountains. Further to the right a younger original accumulation mountain has
med where a volcano has burst through the flat beds of the plateau.

cone consisting of layers of dust and cinders and rock-fragments, with perhaps sheets of lava which have welled over the lip of the hollow or crater thus formed. In this way are built the stately cones of Teneriffe, of Fujiyama in Japan, and many others. But a volcano is an uncertain and capricious builder, and is at all times liable to blow away in a single explosion the accumulated ashes of a century of smouldering fires. This has happened more than once in the story of Vesuvius in Italy, round whose slopes lie the ruins of an older and larger cone. A volcano which has become inactive may be so worn away by weathering, that nothing remains but the plug or *neck* of rock which hardened in the pipe leading down to the molten mass in the interior of the earth. Volcanoes are the chief builders of accumulation mountains, but small examples may be formed by the piling-up of stones at the foot of a glacier, where the ice-stream which carried them melts; and if a geologist be allowed to make a mountain out of a molehill, it is in this group that he must classify it.

More important mountains, and especially mountain *chains,* are formed, not by the heaping-up of materials on the surface of the crust but by warpings and pinchings of the crust itself. Sometimes, where the crust is hard, a block of solid rock is raised up or tilted all in one piece, as a loose brick may stick up out of its place in a brick floor. At other times, where the rocks of the crust are newer and more yielding, they are bent and folded into a series of waves.

Folded mountains arise from the crumpling and folding along special lines of weakness in the earth's crust. In front of a firm land-mass or continent, the surface sinks, so as to form a trough-like depression, which is of course occupied by a sea. Into this sea the rivers of the continent which form its shore sweep sand and mud washed from the surface of the land. The floor of the sea is covered by thick deposits of sandstone and clay, and limestone derived mainly from the shells and skeletons of marine animals: but the wrinkle in the earth's surface goes on deepening, so that the trough is never quite filled. In this way is formed a great sheet of sediments, young, soft, and pliable.

In the next stage this sheet of new rocks is crumpled or folded. This is due to pressure, not from above or below, but from the sides. When we wish to bend a sheet of cardboard, we do not dent it in the centre, we press the two edges towards each other till it buckles. If the pressure be only moderate, the folds form a series of wave crests and troughs, like those of corrugated iron. But if the pressure be very great, the folds are squeezed together, they become tall and narrow, and arch over to one side like the breakers on the sea-shore. In the end they may lean over upon the next fold, so that the whole becomes pleated. The folds may even be broken by the strain, and slide over one another.

The Making of the Alps

The most important folded mountains of Europe are the Alps. The first steps in their formation began at the beginning of the Secondary era, when a trough-like sea formed where they now stand. Throughout that incalculable length of time, the era of the first birds and mammals, of the early flowering plants, and of the giant extinct reptiles, this sea was becoming charged with enormous layers, thousands of feet thick, of sandstones, shales, and limestones. In the next (the Tertiary) era, the continent to the south sank below the waters of what is now the Mediterranean. This movement was the signal for intense folding to begin in the Alpine region. The folds leant over to the northwest, and formed sheets of rock lying almost horizontally on top of each other.

The enormous pressures which accompanied these crumplings had their effect upon the nature of the rocks. The clays and shales were changed by squeezing into slates and schists; the granites were crushed so that their minerals became arranged in parallel bands.

After the folding, the last step was for the crumpled rocks

Photo: A. Landsborough Thomson.

GIANTS OF THE PENNINE ALPS

Monte Rosa (15,217 feet), the second highest summit in the Alps, is seen on the left, the Lyskamm (14,889 feet) in the centre, and the Breithorn (13,685 feet) on the extreme right. From the slopes of these huge mountains descends the great Gorner Glacier (left). The view is taken from below the Matterhorn, looking eastwards.

Photo: A. Landsborough Thomson.

THE MATTERHORN

This famous Alpine peak is 14,705 feet high. Great glaciers descend from its sides, and the sharp outlines of its upper ridges are characteristic of the shattering action of frost. For long deemed inaccessible, the summit was first reached in 1865 under the leadership of Edward Whymper, but at the cost of four lives during the descent. The mountain is now frequently ascended, but its sudden storms, in particular, still lead to fatalities from time to time.

to be raised out of the sea to their present height. Immediately the forces of weathering set to work. Already, in what is geologically a relatively short time, the surface is transformed. The highest summits of the Alps (Mont Blanc, the Matterhorn, and others) are formed out of very old rocks, which must have been covered by great thicknesses of younger sediments; but, because of their hardness, these older rocks have more successfully resisted weathering. Only here and there do the crests of the mountains correspond with the crests of the folds. The relief of the country is determined almost entirely by the sculpturing action of the streams of ice and water.

The ultimate fate of a range of mountains, if the attacks of weathering go on unchecked, is to be worn down into a plain. Plains may, however, also be formed by the accumulation of even, undisturbed layers of sediments; the great plain of Russia, the oldest landmark on the map of Europe, is an example. But however flat and regular a plain of either kind may be it will not yield uniformly to weathering. If a plain be raised up by earth-movements into a plateau, its flat surface will soon be cut up by river valleys. In the course of time only some surviving peaks and ridges will remain. Mountains formed in this way are called *relict* mountains; they are the remains of what was once a tract of high land.

The Mountains of Scotland

The mountains of Scotland and of Norway are of this type. At the beginning of geological history they arose first as a chain of folded mountains like the Alps of to-day. Several times since then, however, have they been worn down and raised up anew. Although the rocks of which they are built are among the oldest in the world, the mountains are at the same time very young, since they were raised to their present height in the last geological period, later even than the Alps. In some disturbance of the earth's crust, these old mountain masses, too tough and hard to be folded, were tilted up in one vast block. We can see, by the lengths of the rivers, that in general the Atlantic side of the block is shorter and steeper than the European side. But in both Scotland and Scandinavia, the mountains owe their shape to the action of streams of ice and water.

We see, then, that there are two principal ways in which mountains are made. Firstly, there are those mountains which are actually *built up,* and are known as *original.* They include such types as volcanic cones, which are mere heaps of material, like a child's sand-castle on the beach; and also there are the folded mountains, which are portions of the earth's crust squeezed and warped like clay under the hands of the modeller. Secondly, there are the *relict* mountains, which are the remains of former high land; they may be considered as monuments of weathering, cut from the solid rock.

The Destruction of Mountains

Mountains are invariably the scene of intense weathering. Rock-fragments once broken off will not accumulate upon steep slopes, so that there is no protecting layer of soil, and therefore no vegetation. Moreover, isolated peaks are very much exposed to all attacks. Lightning may split the rocks of the summits: Leslie Stephen, speaking of a shoulder of Mont Blanc, says "the lightning's strokes have covered numbers of stones with little glass-like beads, showing that this must be one of its favourite haunts." But the chief splitter of rocks is frost. Water which has penetrated the cracks and joints of the rocks expands in freezing, with tremendous force. The angular fragments called "scree," which litter the slopes or fill the gullies below the crags, are almost all split off in this way. Frost-riven summits, like the Coolin Hills of Skye or the "Aiguilles" of Chamonix, are sharp and spire-like.

In the Alps and elsewhere, where the snow lies throughout the year in great masses, it becomes hardened and compacted, partly by melting and freezing and partly by its own weight, into ice. Mountaineers distinguish between the "black" ice formed by the freezing of pools and streams, and the granular "blue" ice made of compacted snow. By its own weight and by the pressure of the masses of snow, this blue ice begins to creep from the snow-fields, down the mountain slopes, down the valleys, in the great rivers of ice called *glaciers.* Not a pile of broken fragments, but a solid mass, always welded together by fresh meltings and freezings, the glacier fills the valley from wall to wall. It is too solid to be readily melted, and so it creeps down into the green valleys far below the snow-line. It moves infinitely slowly, ten thousand times more slowly than water, often no faster than the minute hand of a watch. From the valley walls blocks of stone fall on to the glacier and accumulate there in long heaps called *moraines;* the ice bears them down to the foot of the glacier, where it melts, and there the stones are dropped and form great heaps. Much of the finer material is washed away by the river which the melting ice supplies; a stream which springs from a glacier is always exceedingly muddy.

The action of a glacier in sculpturing the valleys through which it makes its way is very different from that of a river. A mountain stream cuts a valley, like a furrow cut by a knife in a wooden board; narrow at the foot, with sloping sides, V-shaped, often very sinuous. The great mass of a glacier acts principally by grinding the stones which it carries against the rocks which surround it, like a gouge; the valley is U-shaped, with steep sides and a wide floor, and no sudden curves. Moreover, a glacier rounds off the outlines, and polishes, but at the same time scratches the surface of the rocks it passes over.

All of these features, as well as the abandoned moraines, can be recognised in countries where no glaciers now exist, for example in the Highlands of Scotland. For in the last geological period, the great Ice Age, all Northern Europe, including the whole of Britain north of the Thames, and all Canada were covered by a vast sheet or sea of ice, like the Antarctic Continent or Greenland to-day. The causes of these changes in the climate remain obscure.

We have seen, then, that the regions where the breaking-up of rocks proceeds most rapidly are the mountains, the deserts, and the cliffs of the sea-shore. On the cliffs, the fiercest attack is that of the waves and the pebbles which they carry; in times of storm, tremendous blows are struck, and pressures of over two tons per square foot are recorded. In the deserts, the rocks crack under the influence of the blazing sun alternating with the cold of the nights, and under the ceaseless grinding of wind-blown sand they are shaped and polished. In the mountains, the cold and the freezing of water strike the first blows. Gravity alone, or the slow glaciers, or the summer rains, or the water that streams from the melting snow when the sun shines or the warm *Foehn* wind blows, carry the fragments away. With long periods of rest, as they lie upon level ground or at the bottom of lakes, they make their way down to the sea. In the sea, at last, they are spread and sorted and hardened into rocks. From the sea-floor, they may again be lifted and crumpled into a new range of mountains. The weathering will recommence; the particles lifted up in the folded strata, ranked and filed in their orderly battalions, will find their way back to the sea as a horde of stragglers.

And so mountains are built up and worn down in endless succession. There are three stages of mountain-making: the forming and hardening of the rocks, the folding, the uplifting. There are three stages of mountain-destruction: the splitting, the transport of particles, the forming of new rocks; and the last stage of the one is the first stage of the other. One generation of mountains follows another. To what end? Does the earth shrink each time? Is it becoming less round and more angular? Are the continents moving away from each other? We cannot be sure. Mountains are insignificant wrinkles at best:

Photo: A. Landsborough Thomson.

A TYPICAL GLACIER VALLEY

Looking down the Nicolai Valley from above Zermatt, the Matterhorn being behind the camera. Whereas a valley cut by a river is narrow, V-shaped, and tortuous, one gouged out by a glacier is broad, U-shaped at the bottom, and comparatively straight. The ice has retreated from this part of the valley, which is now occupied only by the Visp River, fed by the Gorner Glacier and other ice-streams which still fill the upper reaches.

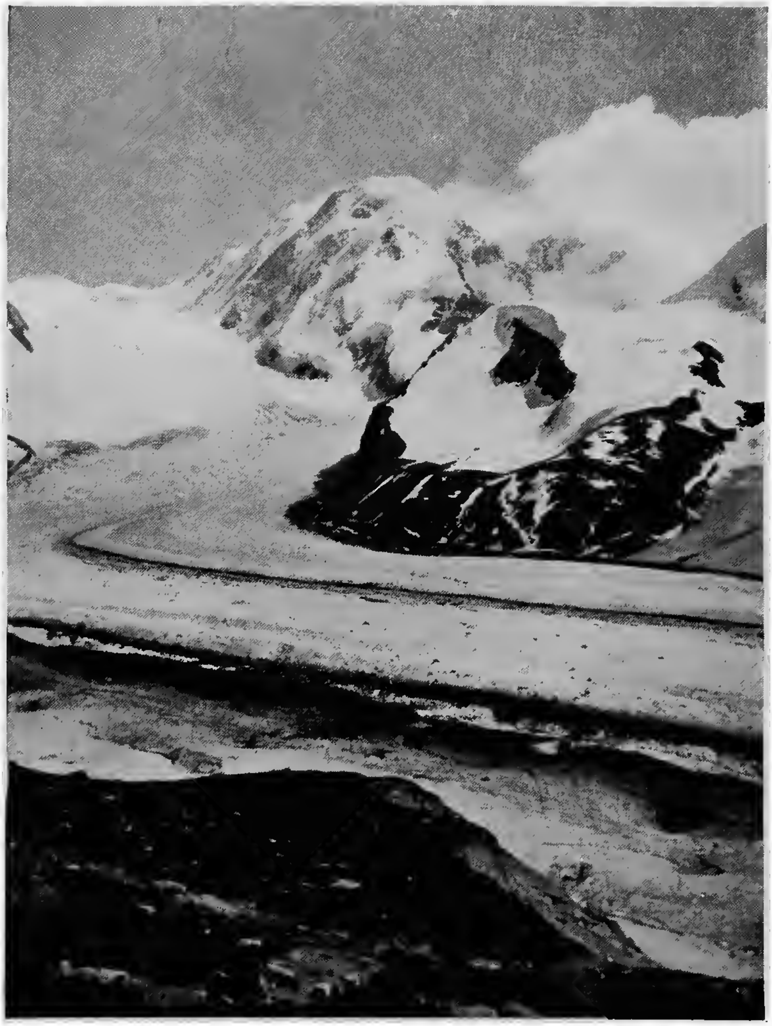


Photo: A. Landsborough Thomson.

THE GORNER GLACIER

Where the snow lies throughout the year it becomes hardened and compacted, by repeated melting and freezing, into ice. This, by its own weight and by the pressure of the masses of snow creeps down the slopes and valleys in great rivers of ice called glaciers. The illustration shows the second largest glacier in the Alps, about a mile wide at this point.

the highest make no more difference to the earth's diameter than a woollen sock makes to a man's height: but that they play their part in the story of the earth as a whole is certain. Four times, since geological history begins, have new generations of mountains risen in Europe. There is no reason to suppose that the oldest of the four belongs to the first of the great cycles of growth and decay in the earth's history; there is no reason to suppose that we ourselves are living in the last.

§ 4

A Piece of Granite

Much of the building material of the continents consists of granite, and many of the mountains of the world, such as Mont Blanc, are granite mountains. We are all familiar with the clean, hard appearance of the stone in granite buildings. Let us see what the story of this granite is.

When we look carefully at a piece of granite, the first thing we notice about it is that the rock is made up of a number of different minerals. As the mixture is rather a coarse one, it is not difficult to recognise the more important of these. There are little glittering scales and specks of white and black *mica;* there is a great deal of opaque grey or pink *felspar,* which gives its colour to the whole rock; and there are irregular grains of clear, glassy quartz. From the chemical point of view these three minerals, mica, felspar, and quartz, are compounds of the element *silicon* with oxygen and, in the first two cases, with metals such as sodium, aluminium, and iron. Although the rock is such a coarse mixture, it is, as we know from our granite buildings, exceedingly strong; the minerals cannot be separated from each other; they are firmly welded together, as the granite worker well knows. This welding suggests that the granite rock was formed by the cooling and solidification of a mass of liquid rock which had been melted by some intense heat.

Under the solid crust of the earth with which we are more or less familiar, there lies a layer of rock so hot that whenever the pressure is not too great it assumes the molten or liquid condition. From time to time, for reasons not well understood, this molten rock invades the solid crust above it, and pushes its way out towards the earth's surface. It may reach the surface and be poured out as molten lava in a volcanic eruption; or its upward rush may be arrested, and it may slowly cool and harden deep down in the solid crust of the earth. This hidden eruption may be laid bare long afterwards by the gradual wearing away of the rocks above: a concealed episode is thus brought to the light of day.

Crystal Making

When such a molten mass cools and becomes solid, the minerals in the rock form crystals. A crystal is an orderly grouping of the molecules or smallest possible particles of the mineral upon a definite plan; every mineral when crystallised has its molecules arranged upon its own particular plan, from which it never departs, and which is shared by no other mineral. As a result of this systematic arrangement of their minutest particles, all crystals have certain properties in common; for instance, a ray of light passing through a crystal is very often split into two, so that an object seen through a transparent crystal, say of Iceland Spar, will appear double. But the amount by which the two rays of light are separated depends upon the particular kind of mineral; and if the amount of separation could be accurately measured, *the mineral could be recognised by this property alone.*

When a crystal can develop freely in every direction it grows in a definite geometrical form, a number of flat faces separated by definite angles, and by these angles the mineral can be recognised. On our piece of granite the light is reflected from the smooth flat crystal faces of the mica. But when a molten rock solidifies, the crystals will rarely be able to grow quite freely; they will retain all their properties except their shape, and will grow as far as

Photo: W. A. Green, Belfast.

EVIDENCE OF GLACIAL ACTION

The slab shows, in a characteristic manner, the polishing effect of the passage of moving ice and the scratching caused at the same time by particles of harder stone carried by the glacier. The specimen is from the Carboniferous Limestone of County Down and is thus evidence of a Glacial Period in the British Isles.

Photo: W. A. Green, Belfast.

THE GIANT'S CAUSEWAY, COUNTY ANTRIM, SHOWING THE GRAND CAUSEWAY

This famous Causeway consists of basaltic rock which originated in Eocene times as a molten lava welling up through huge fissures and overflowing the land surface. The striking prismatic formation so well seen in the picture has been the subject of much controversy, but it is doubtless due to contraction strains taking place during the cooling of the mass. Each column is also jointed traversely.

Photo: W. A. Green, Belfast.

THE PLEASKINS, GIANT'S CAUSEWAY

Layers of columnar basalt are seen, the results of successive overflows of molten lava. In between are beds of Red Ochre, formed by the decay of vegetation in the long epochs which intervened.

they can to meet each other in the firmly welded unbreakable joints, which we have already noticed in the extraordinarily strong granite.

The size which the crystals attain will depend principally on the rate of cooling; the more slowly the molten mass solidifies, the longer time will the molecules have to come together and take up their positions, and the larger the crystals will be. When a molten mass is poured out at the surface in a volcanic eruption, it cools very quickly and the crystals may be too small to be seen with the naked eye. Sometimes under such conditions crystals are not formed at all, and the rock solidifies as a *glass,* in which the various minerals have not separated out. So we can argue that glassiness without crystals means rapid cooling—perhaps a hundred million years ago.

On the other hand, since our piece of granite shows crystals of large size, we may infer that granite must have cooled very slowly. The fact is, it can never have reached the earth's surface at all; and wherever a mass of granite is found to-day, we may be sure that it must once have been covered by great thicknesses of other rocks, which have been worn away *since* the molten granite welled up into its present place from the white-hot interior of the earth. This, then, is the scientific romance of the piece of granite. It burst out of the earth's internal furnace; it was arrested by the crust; it cooled so slowly that its crystals are very big; and they were so crowded that they dovetailed into one another, so that granite is difficult to break.

A Piece of Sandstone

When a mass of granite is laid bare, after unthinkably long ages of burial, it will, of course, be attacked in turn by the weathering agencies which wore away the overlying rocks. In a mountain region, for instance, where the granite becomes much exposed to the action of the weather and is not much protected by a covering of soil and vegetation, the rock will be split and shattered by the action of frost and perhaps of lightning, it will be worn away by wind and running water, and it may be ground to dust by the slowly moving ice of glaciers. We must remember, moreover, that water may act upon the rocks chemically as well as physically, especially if the water contains dissolved acids, such as those derived from plant remains rotting in a peat-bog. Thus the felspar in a granite rock may be slowly altered into a powder which is washed away as mud, while the quartz, which is more resistant, will be broken into minute fragments and become *sand.* Below a granite block protruding beside a mountain path, we often find a heap of coarse fragments; a little further off angular grains of sand lie upon the ground; these are the first stages in the breaking down of the rock.

In a desert region the broken-down particles cannot be washed away; but they are blown away by the wind, and the sand grains become worn and rounded. Under ordinary conditions the rain sweeps the particles into runlets, which lead to streams, and these make rivers which bear the weathered particles to the sea. In countries with a temperate climate, rivers are by far the most important factors in shaping the surface of the land; they operate not only by eating away their own floors and banks, but, by removing the loose particles, they expose the bare rock to the action of the weather. As the amount of mud and sand which a river can carry along depends on the size and rapidity of the stream, it often happens that a river cannot carry as much in the lower part of its course as it does higher up where the current is stronger. Thus a portion of the load falls to the bottom, though the greater part is swept out into the sea where it is deposited, together with other material which the sea itself has torn from the coastal rocks.

All materials laid down under water, by gravity, are called *sediments.* They do not usually accumulate in a continuous way. For, after a certain layer of sediment is laid down, all over a considerable area of the floor of the sea, and of much the same thickness throughout, there may be an interruption or a change in the supply of material, and the layer next laid down will be distinct from the one below it. These distinct layers are geologically known as beds or *strata.* The body of a dead animal, lying on the floor of the sea, will be gradually buried by the deepening sediments, and its skeleton or shell at least may not have rotted away before it is completely entombed. Even inside the rock, if the sediment becomes a rock, the hardest parts of animals are liable to be dissolved away in the course of time, but an impression or mould will be left; or the original material may be replaced, molecule by molecule, by some resistant mineral such as *silica* (of which quartz is the crystalline form). Such *fossils* are of great value to the geologist; for the occurrence of a fossil in a rock shows that the animal thus preserved was living at the time the bed was formed; and in this way the age of the bed of rock can be told, in some cases with great precision.

We are now able to understand what sandstone is. It is a compacted deposit of grains of "sand," worn off the surface of some other and older rock (such as a granite), very possibly far inland, and carried down by the rivers to be laid upon the sea-floor in beds or strata. The loose grains of sand become compacted together partly by being cemented by mineral matter dissolved in the water, partly by the weight of later sediments above them. A sandstone contains, then, two kinds of deposit, the grains and the cement. The grains are very largely of quartz, angular fragments broken off crystals, and, though completely irregular in arrangement, retaining their crystal properties; grains of felspar, mica, and other minerals also occur. The cementing material may be muddy, limy, or of silica, and it is very often stained red, yellow, or green; the colour being frequently due to iron, which may be derived from many minerals, such as black mica. A whole town may have a "local colour," depending on the nature and staining of the sediments on the floor of an ancient sea which once occupied that area.

Everyone recognises that sandstone is practically very different from granite. It is a plastic building stone, while granite cannot be coerced. The textures of the two rocks are as different as they well could be. And yet the *minerals* in a sandstone may be the same as those in a granite. This shows clearly that the difference in result must be due to the difference in the mode of formation.

Rocks such as granite, which are first formed as molten masses *below* the surface of the earth, are known as *Igneous* rocks. Rocks which are formed *at* the earth's surface, as aggregations of solid particles, are called *Derivative;* and if, as in the case of sandstone, the particles are directly derived from the wearing-down of some older rock, the derivative rock thus formed is said to be *detritic.* It is made up of rock-debris, or detritus.

§ 5

A Piece of Coal

To the geologist, coal is a rock, just as much as granite or sandstone; playing a smaller part than either of these in the formation of land masses, but of great economic importance. It is a derivative rock, that is to say it is formed upon the surface of the earth; but, unlike sandstone, it is not detritic—not made up of the fragments of previous rocks. It consists chiefly of the compressed and altered remains of plants, and all rocks which are formed through the intervention of plant or animal life are said to be *organic* in origin. Chemically, coal consists chiefly of carbon, combined with hydrogen and other gases, and it differs from unaltered vegetable matter in containing more carbon and less of the other constituents. When coal is burnt in air, the compounds of hydrogen and carbon break up; the oxygen of the air combines with the carbon to form carbonic acid gas, and with the hydrogen to form water; in each of these reactions, chemical energy is set free in the form of heat. Where did this energy come from? It was stored up by the plants from which the coal is formed; and the plants in these far-off times lived as plants do to-day, by

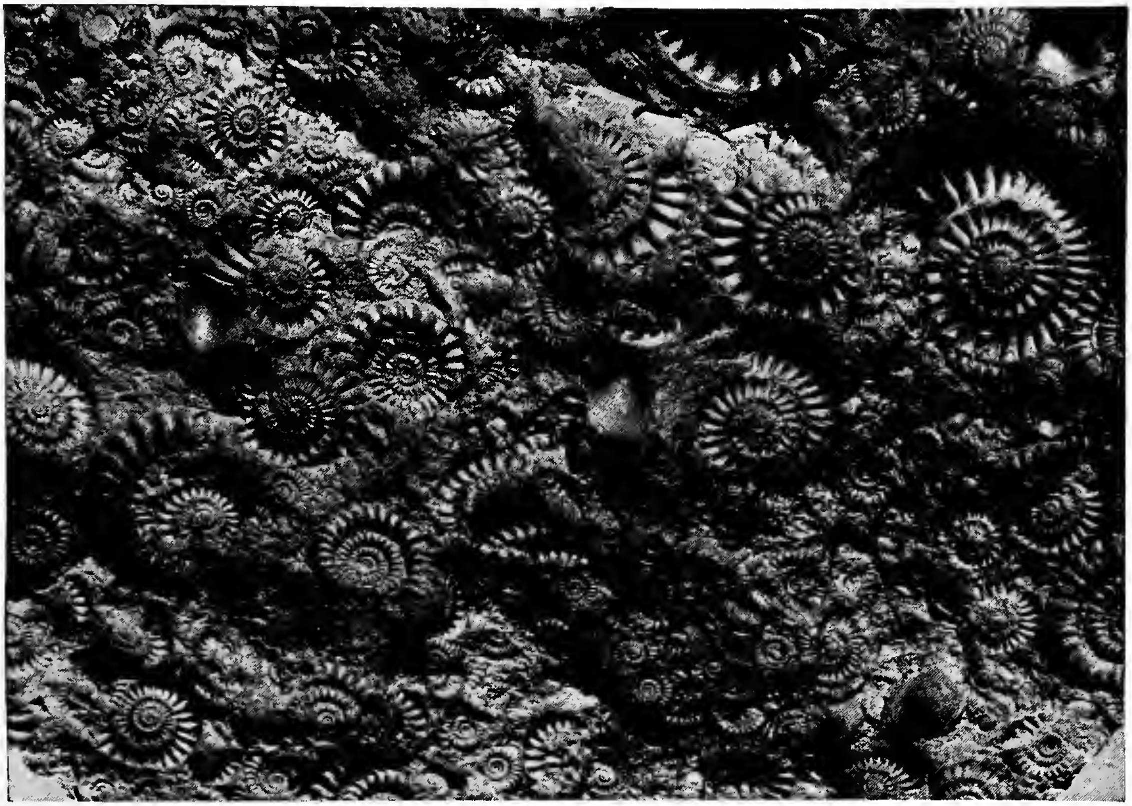


Photo: W. A. Green, Belfast.

A MASS OF AMMONITE SHELLS

A piece of rock from the Liassic strata at Whitby, Yorkshire. It is largely composed of the fossil remains of Ammonites, an extinct group of marine animals belonging to the same class of Molluscs as the *Nautilus* and the Cuttlefish of today.

Photo: W. A. Green, Belfast.

A FOSSIL SPECIMEN

Extracrinus briareus, from the Liassic rocks at Lyme Regis. The Crinoids, or "Feather Stars," are well-known marine animals of the present day, but the surviving species are greatly outnumbered by the fossil forms which have been found.

Photo: J. J. Ward.

"FOSSIL HORSETAILS" OR CALAMITES

Parts of the stem. These extinct relatives of the modern horsetails attained their maximum development in the Carboniferous period, attaining tree-like dimensions and contributing considerably to the formation of coal. It will be seen that the stem is longitudinally fluted, with transverse lines at intervals. From these transverse nodes side branches arose in whorls. It should be noted that one of the modern horsetails, a South American species, sometimes reaches a height of 30 feet, recalling the extinct giants.

trapping the energy of the orange-red rays of the sunshine. George Stephenson said of one of his early railway engines, that it was the light of the sun that drove it.

Ordinary household coal is not the only fuel resulting from the transformation of vegetable remains. Peat, for example, consists of little-altered vegetable residue fermenting in the bogs where the plants actually grew. In Lignites the structure of wood is still recognisable. Cannel coals and Boghead coals are dull in appearance, break irregularly, and are clean to handle. Anthracite is also clean, but is shining and metallic, and difficult to ignite. These types form a series becoming progressively heavier and richer in carbon. But it must not be thought that Anthracite, for instance, the heaviest of all, has in its formation passed through all these stages. Rather are these different types of coal derived from different assortments of plant remains.

The chief plants of the coal measures were ferns, and giant tree-like forms represented to-day by the horsetails and club-mosses. Modern horsetails and club-mosses are mostly small plants, pigmies compared wtih their predecessors in the Carboniferous age. Flowering plants were just beginning when the coal measures were formed. Coal often shows bands parallel to the bedding plane, alternately bright and dull or charred. The dull bands consist probably of altered wood and the bright bands of leaves and cones. In many cases the coal-seams rest upon beds of fireclay, known as the "underclay," which contains fossilised roots and other remains of the plants of which coal is made up. Limestones, sandstones, and ironstones are also associated with coal, and in some places lumps of limestone, known as "coal-balls," and containing very fine fossils, are found in the coal.

Although coal is best known from the Carboniferous period, scattered deposits occur in rocks of nearly every age.

The ancient plants which formed the coal measures possibly grew in swamps near the sea, like the Everglades of Florida to-day. The fallen tree-trunks accumulated, and vegetable matter may have been carried into the swamp by rivers. The land gradually sank, and the swamp was invaded by the sea, and beds of sandstone and other sediments were laid down on top of a layer of plant remains which became coal. Then the land may have risen again, a new forest sprung up on the site of the old one, and in time a second seam of coal may have been formed above the first one. Sometimes, however, coal may have been formed from driftwood, or by the choking of a freshwater pool with vegetation.

Whatever be the origin of the coal, the romance is the same. The rough, dirty lumps are the memorials of a silent forest of strange trees. They contain the stored energy of the sun which shone on these primitive plants. As we saw in a previous chapter, they can yield us dyes of all the colours of the rainbow; chemically, they are nearly akin to the clear, sparkling diamond.

A Piece of Chalk

Chalk is a soft, white, earthy rock, almost pure carbonate of lime, but mixed sometimes with various mineral impurities. It is made up of the broken skeletons of molluscs, sea-lilies, sea-urchins, and the like, but especially of the shells of some of the simplest of living creatures, belonging to the group of the one-celled animals or Protozoa, and included in the class *Foraminifera.* Their shells are often smaller than pin-heads, but they are extraordinarily beautiful. Chalk is therefore an organic rock: but it differs from coal in being made of compounds of lime, not of carbon; and in being derived from the remains of marine animals, not of plants. There is very little carbonate of lime dissolved in sea-water, but there is a much greater amount of sulphate of lime, and various kinds of marine animals, such as Foraminifera, are able to transform the one to the other, under certain conditions. Animals which require a great deal of carbonate of lime are confined to clear water and to the warmed parts of the globe.

When we look at the chalk cliffs of Dover, we are looking at the results of the lives of minute Foraminifera, which lived in great part floating on the surface of an ancient sea. When they died their shells sank slowly to the sea-floor, and there formed a deposit. A similar deposit is being formed to-day by similar animals over wide areas of the ocean floor, and in another article reference has been made to the interest and importance of the ceaseless rain of tiny dead creatures that drift down into the abysses.

The Building of a Coral Island

Other kinds of limestone, less pure than chalk, being usually mixed with mud worn off from rocks and stones, consist mainly of the remains of molluscs, sea-lilies, and corals, or of Foraminifera different in habit from the chalk-formers. The building of a coral island has been described by Professor J. Arthur Thomson (*The Study of Animal Life*): "We see a multitudinous life rising like a mist in the sea, countless millions of microscopic creatures often enclosed in beautiful shells of flint and lime; myriads of them are always being killed at the surface by vicissitudes of temperature and the like; they sink gently through the miles of water to find a grave in the abysmal ooze. The submarine volcano top, which did not reach the surface, is slowly raised by the rainfall of these countless minutiæ. Inch by inch for myriads of years, the snowdrift of dead shells forms a patient preparation for the coral island. The tiniest, hardly bigger than the wind-blown dust, form, when added together, the strongest foundation in the world. The vast whale skeleton falls, but melts away till only the ear-bones are left. Of the ruthless gristly shark nothing stays but the teeth. The sea-butterflies (Pteropods), with their frail shells, are mightier than these, and perhaps the microscopic atomies are strongest of all. The pile slowly rises, and the exquisite fragments are cemented into a stable foundation for the future city of corals. At length, when the height at which they can live is reached, coral germs moor themselves to the sides of the raised mound, and begin a new life on the shoulders of death."

The living coral is a branched colony of individuals all connected together and with their soft bodies encased in strong shells of carbonate of lime. Each individual or polyp is little more than a stomach, with a mouth surrounded by tentacles; each is sheltered in a little cup of the limy skeleton which invests the whole colony. The branching skeleton assumes beautiful, flower-like forms.

The coral reef builds upwards and outwards. The central part is often suffocated, while the edges grow freely, so that when the reef reaches the surface of the water it may form a ring-shaped island. On this island weathering forms a scanty soil, the waves cast up drifted material, the birds rest: in time the new land is peopled with animals and plants. "It is a strange and beautiful story, dead shells of the tenderest beauty on the rugged shoulders of the volcano; the slowly laid foundation for the reef-building polyps; at last plants and trees, the hum of insects and the song of birds, over the coral island."

Chemically Formed Rocks

When a pool of sea-water dries up, the salts dissolved in it are deposited on the floor of the basin, and a deposit is formed, including common salt and sulphate of lime, or gypsum. On a big scale this has often occurred in the past, and we may call the results chemically formed rocks. The valuable deposits of mixed salts at Stassfurt, in Germany, were formed in this way.

A peculiar example of a chemically formed rock is found in the flints of the lower beds of the chalk itself. Flint is an impure form of silica (of which quartz is the crystalline form), deposited from water trickling through the chalk. The water derives its silica, not from quartz, which is nearly insoluble, but from the flinty skeletons of animals such as certain Sponges and the

Photo: W. A. Green, Belfast.

FOSSIL PLANTS OF THE COAL MEASURES

Remains of the vegetation of former times which have gone to make the coal of today: portions of a root and stem (*Sigmarilla elegans*) from the coal measures of the Carboniferous Sandstone at Ballycastle, County Antrim.

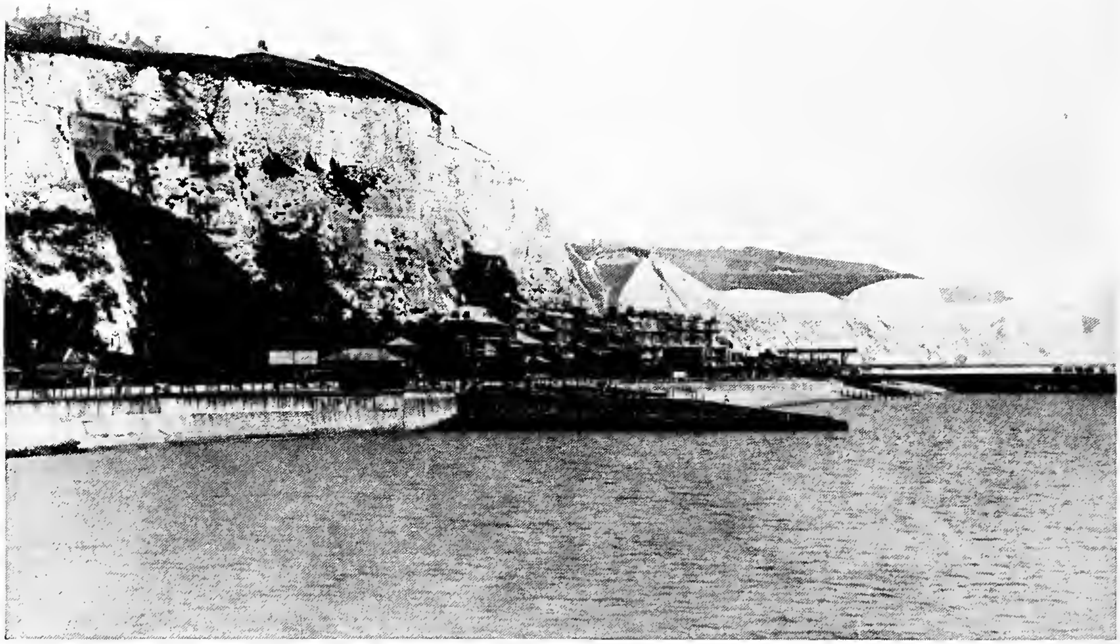


Photo: Topical Press Agency.

THE CLIFFS OF DOVER

A characteristic example of a chalk formation originally laid down at the bottom of a bygone ocean. The cliffs are largely made up of the chalky shells or skeletons of countless generations of marine organisms.

Radiolarians (another group of the one-celled animals or Protozoa, whose skeletons are more delicate, latticed, and pointed than those of the Foraminifera). Very little silica is present in sea-water, but these animals possess the power of transforming particles of clay (impure silicate of aluminium) into flint, of which they build their skeletons.

We are now able to attempt a rough classification of the derivative rocks, namely the rocks made up of materials derived from elsewhere. Firstly, according to their composition, there are five main types, made up (1) of grains, usually of silica; (2) of finer particles of clay; (3) of carbon compounds; (4) of lime compounds; and (5) of silica, in solid, flinty masses; with various others, less important, chiefly of chemical origin. Then we recognise three great modes of formation: (A) the detritic, i.e. built from inorganic rock debris; (B) the organic, i.e. from remains of plants or animals; and (C) the chemical: all are closely linked together. These classifications make for clearness of thinking but Nature seems to set them at defiance, mixing and mingling, in a medley which is at once a puzzle and a fascination.

A Piece of Slate

Derivative rocks, too, may be found in greatly altered forms. Slate is a rock which can be split into thin slices, and, as everyone knows, it can be made smooth enough to write on. Slate is a hardened and altered form of clay; and so its classification is with the clays and sandstones we have already discussed: it is a detritic, derivative rock, made of fragments worn off older rocks. Clay is formed by the chemical alteration of felspar, one of the most important constituents of granite. The weathering of the granite allows water to carry off the altered felspar, and the river or the glacier deposits clay in beds. The clay, which ought to consist of silicate of aluminium, is usually full of impurities, such as grains of sand, and lime. The deposited clay very often hardens in the form of shale, a rock which can be split into very thin sheets parallel to the plane of the beds or strata in which the sediment was laid down.

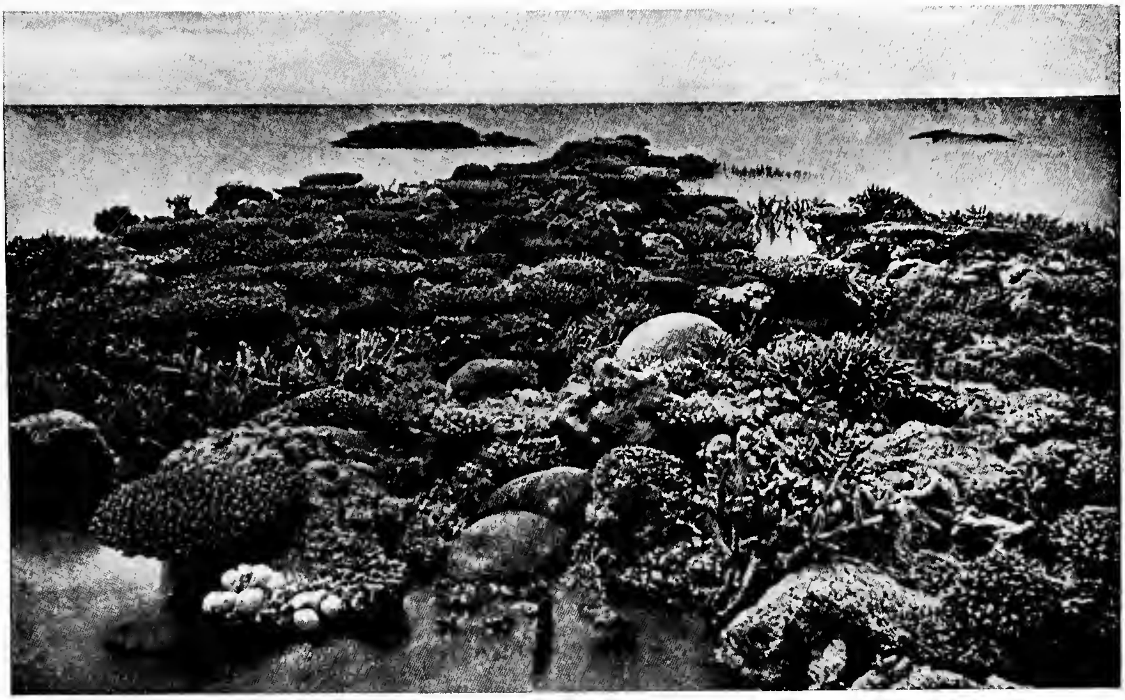
Slate is a clay or shale in which the original bedding has been obliterated by great pressure, in movements of the earth's crust. The mineral particles have been re-arranged in sheets by squeezing, so that the rock can split into thin flakes. Such rocks are called "metamorphic."

The clays, it may here be mentioned, have a special importance. They are impermeable to water, and therefore hold up rainwater which would otherwise sink to such depths below ground as to become unavailable. The clays also, by reason of their softness, readily decay, with the result that beds of rich soil are formed.

§ 6

Precious Stones

When we turn to Precious Stones we are dealing with rocks no longer, but with individual minerals. We have considered minerals hitherto simply as constituents of rocks; but when we consider them by themselves, we take up a new point of view. In rocks, the minerals are usually in small crystals; they are often impure; they are not free to develop equally in all directions, and consequently their shape is irregular. But in studying individual minerals, and particularly Precious Stones, we take as our types the finest, the purest, and the best-shaped examples to be found. We have seen already that when a mineral crystallises, the molecules or smallest possible particles of the mineral arrange themselves upon a certain definite plan, and this gives certain definite properties to the crystals of each mineral. In the study of rocks, the properties which are of most use for the recognition of minerals are those concerned with the effect of the crystal upon rays of light; but in the study of individual minerals, more account is taken of the *shape* which the mineral assumes. So the study of minerals and of Precious Stones is largely a study in crystallography.



From the Smithsonian Report, 1917.

A CORAL REEF

The illustration shows Crescent Reef, outer barrier, Great Barrier Reef of Australia. A fine example of active rock-building by huge colonies of coral animals. How the living corals build up coral islands is explained in the text.

Photo: W. A. Green, Belfast.

THE CASTLES OF KIVVITAR, MOURNE MOUNTAINS, IRELAND

These "castles" are pillars of naked granite standing on the hillside. Atmospheric weathering has picked out and revealed the natural joint planes of the rock.

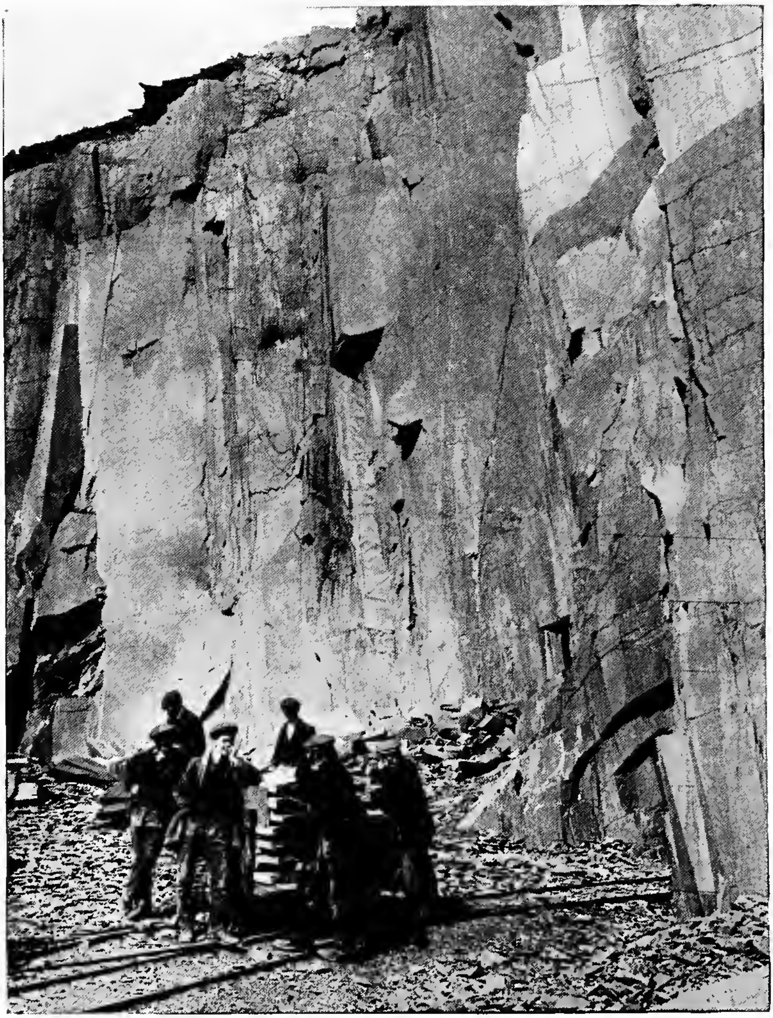


Photo: Topical Press Agency.

A SLATE QUARRY (DINOWRIE)

This mass of slate was originally a bed of clay, formed from the break-down of older rock but was converted into a hard rock by tremendous pressure; its particles have been so rearranged that it can be split into thin sheets or slates.

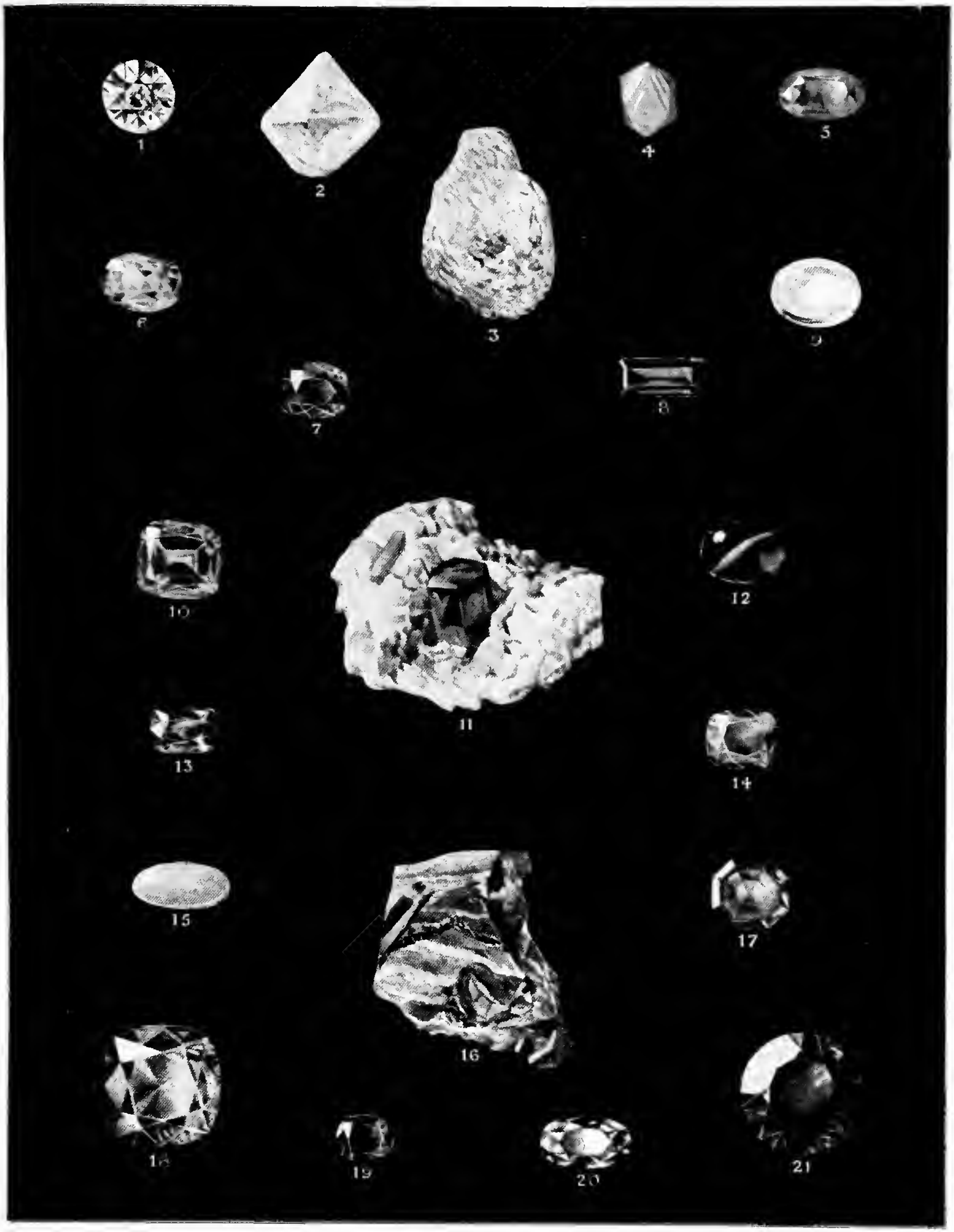
What is a Precious Stone? What are the characters that give a mineral a commercial value? Generally speaking, and making allowance for certain exceptions, they are these: perfect purity, and freedom from cracks or inclusions of liquids or of other solids, is essential. Transparency, brilliant sparkle, and good colour are important; hardness, and the power of resisting chemical as well as physical wear, are usually required; and lastly, if the stone is to have any market value, it must occur sometimes, but only rarely, in fine specimens suitable for cutting. It matters not what the chemical composition may be: gems range from the Diamond, which is pure Carbon, to the Tourmaline, of which Ruskin said that "the chemistry of it is more like a mediæval doctor's prescription than the making of a respectable mineral." It matters not if the gem be but a variety of a mineral which in some other form enters into half the rocks of the world, as Amethyst is a variety of quartz; or if it be a strange combination of rare chemical elements, to be found only in three or four places in the world, like the Emerald.

Certain stones, which possess the qualities of hardness, brilliancy, and rarity in a marked degree, like the diamond, ruby, and sapphire, are always highly prized. But among the less outstanding gems, vogue and value are largely dictated by fashion, and many very lovely minerals are ignored. Among the "semi-precious" stones, the varieties of quartz play an important part.

Silica, the oxide of the element silicon, occurs most commonly in the form of crystalline quartz, which is, as we have seen, an important constituent of acid igneous rocks and of all sands. In granite, however, it usually forms crystals of extremely irregular outline and is often very far from pure. Curious cavities, which at one time probably contained gases, are of common occurrence in igneous rocks, and they are often lined with large, well-shaped crystals. Ordinary or milky quartz is valueless; but the perfectly clear Rock Crystal, the purple Amethyst, and the brown Cairngorm are all used as gems. Along with quartz, in these cavities of igneous rocks, there often occur rarer minerals, in whose formation the contained gases have probably played a part. Amongst these is the valued Topaz, a hard, almost diamond-like stone, which may be clear, or of almost any colour except the rose-pink with which jewellers not infrequently stain their specimens in response to the dictates of fashion. Tourmaline, a stone of variable colour as of variable composition, a "little of everything," also occurs in this way. Pink and green specimens are the most valued, and black is the commonest; while specimens occur which show two colours, as red and green, blending into each other. Topaz and tourmaline are alike in possessing remarkable electrical properties; when heated, they will attract fragments of ash or scraps of paper, just as a vulcanite rod or the cap of a fountain pen will if it be rubbed.

Silica occurs not only as quartz, but also combined with water, as Opal. Some varieties of this are used as gems and are exceptions to the usual rules of gem-qualities; for opal is neither very hard nor very resistant, nor is it crystalline. Its play of colours, like that of mother-of-pearl but more bright and fiery, is due to the presence of a multitude of little cracks, whose angles break up the light reflected off the surface. This is called "physical" colour, and would, of course, be destroyed completely if the opal were ground to powder. The colours of mother-of-pearl, or of the golden Iron Pyrites, or of a parrot's red and blue feathers, or of a film of petrol on a pool of water, all depend on the breaking up of white light by an irregular surface. But the colour of an amethyst, like the colour of blue eyes, is due to the presence of a recognisable coloured substance. The amount of an impurity necessary to give a tint to a clear stone is so small as almost to defy analysis; but we know that it is manganese that gives the purple tint to amethyst, and nickel that is responsible for the green of Chrysoprase.

Agate is a beautiful variety of chalcedony, another form of silica, which consists of successive layers of different colour laid



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PRECIOUS STONES

1. Diamond.
2. Diamond (Crystal).
3. White Opal.
4. Ruby (Crystal).
5. Ruby.
6. Yellow Sapphire (Oriental Topaz).
7. Sapphire.
8. Emerald.
9. Moonstone.
10. Topaz.
11. Emerald (Crystal in Matrix).
12. Cat's-eye.
13. Tourmaline.
14. Fire Opal.
15. Turquoise.
16. Black Opal.
17. Peridot.
18. Alexandrite.
19. Balas Ruby.
20. Aquamarine.
21. Amethyst.

down round the walls of a cavity from solution in water. Coat after coat is applied, building inwards towards the centre, which is not infrequently filled by a few quartz crystals. Cut across. the agate shows fine concentric lines, and variations in colour, corresponding to each successive layer of material. Onyx is an agate with alternate parallel bands of black and white.

Pearls

The minerals of derivative rocks are largely the same as those found in igneous rocks, but worn and shattered by their adventures in the rivers and the sea. New minerals are formed, however, by the action of plant or animal life, and a few of these are valuable. Red Coral is allied to the reef-building corals. Amber is the hardened, fossil resin of pine-trees; Jet is a variety of coal. But of all the organically formed gems, one is supreme and outstanding, and worthy of a place with the diamond and the ruby. In the form of chalk, of limestone, or of marble, carbonate of lime is one of the commonest of minerals; but in the form of *Pearl,* its value is as surpassing as its beauty. Pearls are globules of carbonate of lime laid down layer by layer by an oyster or mussel round some foreign body within its shell (see Colour Plate, facing p. 650). They were prized in ancient Egypt, India, China, Peru: "In all ages, pearls have been the social insignia of rank among the highly civilised," writes W. R. Cattelle in *The Pearl.* And yet the pearl is soft, easily damaged, and easily tarnished. So great is the demand, none the less, that long researches have been devoted to furthering the production both of artificial or imitation pearls, and of "culture" pearls in the preparation of which a foreign substance is introduced into the shell of the mollusc, round which it may be induced to form a genuine pearl.

Aristocrats among Jewels

Four gems may be classed along with the pearl as the aristocrats among jewels: Emerald, Sapphire, Ruby, and Diamond.

All are true "precious stones," intensely hard, clear, sparkling. It is a mistake to suppose that, weight for weight, the diamond is the most valuable of these; but the diamond occurs sometimes in large, perfect crystals of enormous worth.

Emerald is a bright-green variety of the mineral Beryl, another variety of which is Aquamarine. Large stones of good quality are rare; indeed, even small stones of absolute purity are very uncommon. Emeralds often show curious variations in the colour, which may be much deeper at one part of the stone than at another. Many stones sold as emeralds are in reality garnets, tourmalines, or other minerals.

Rubies and Sapphires are varieties of the same mineral, *corundum,* which is the oxide of aluminium. Rubies are deep red, while sapphires may be any colour, but are usually blue. Both are very hard and rather heavy, and both, like emeralds, occur frequently in rocks greatly altered by heat or pressure. Rubies vary in colour from rose to carmine, and are most valued when they possess the tint of "pigeon's blood"; the colour varies according to the direction in which the stone is cut. A perfect ruby of good size is worth three times as much as a diamond of the same weight.

The Diamond

The Diamond undoubtedly reigns king of all precious stones. Not only its great worth and its romantic associations, but also its chemical and physical properties give it the lead. Its properties of reflecting and refracting light yield an inimitable sparkling lustre. It is the hardest substance yet discovered; but it is decidedly brittle, and can be burnt away completely, though not melted, in the tremendous heat of the electric arc. Formerly, however, it was believed to be capable of resisting every attack, and received its name of Adamant, or "The Unconquerable." Chemically, the stone consists of the element Carbon, pure and uncombined. It is strange indeed that the premier gem of the world should be of the same material as the soot of a lamp-chimney or the

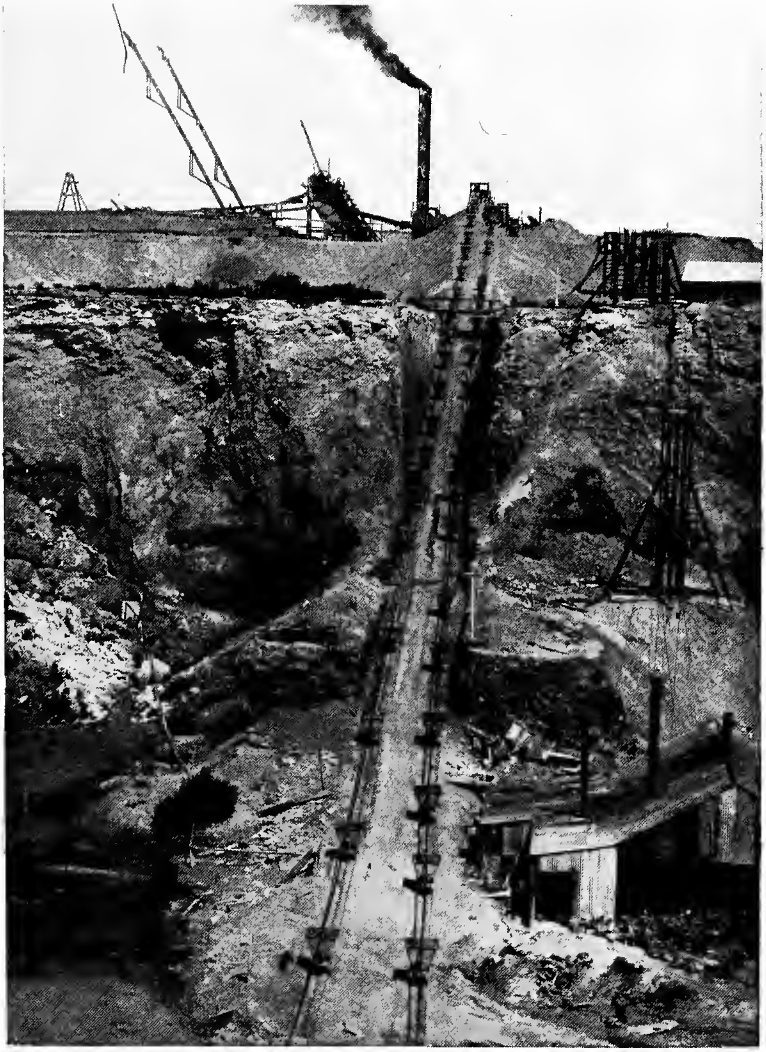

Photo: H. J. Shepstone.

DESCENT TO THE DIAMOND MINES, KIMBERLEY

The diamonds are here found in the co-called "Blue Ground," a loose, crumbling rock consisting of ashes and lavas of volcanic origin.

Photo: H. J. Shepstone.

SORTING THE GRAVEL FOR DIAMONDS AT THE KIMBERLEY MINES

The stones are simply picked out from the gravel resulting from the breaking down of the "Blue Ground" excavated from the mines. A diamond is a crystal of carbon, pure and uncombined: it has thus the same chemical composition as lamp-black and as the graphite used in pencils, but a different arrangement of the molecules gives it an entirely different physical structure and appearance.

graphite of a lead-pencil, only crystallised—that is, with its molecules arranged in a different way! Carbon enters into the formation of every "organic" compound, and the number of its compounds known to science is far greater than the number of all other known substances put together. Each one of us breathes out enough carbon every hour, in the form of carbonic acid gas, to make a diamond of 100 carats, worth anything over twenty thousand pounds!

Naturally, the question arises, How is this every-day element carbon induced to take up this precious form? By difficult and costly processes, small diamonds have been produced artificially, and the experiment has shown quite clearly that enormous pressures must play a part in the transformation. In South Africa, diamonds occur in a strange igneous rock, a mixture of fragmental ashes and lava, which fills old volcanic pipes. It is supposed that diamonds were formed during the cooling within the pipe of the molten materials thrown up from great depths by the volcanic forces. This rock, called "Blue Ground," is of very basic character, and is a remarkable assortment of minerals. It is very tough, and after being dug up is exposed to the action of weathering for twelve months, so that it becomes broken up and the diamonds can be picked out. Some authorities hold, however, that the diamonds are deposited from water and are derived from organic compounds.

In other cases the diamonds occur in sedimentary rocks, as in sandstone in Brazil, or in loose sand in some parts of Africa. We can readily suppose that the diamond resists weathering which breaks up the rock in which it was formed, and that it was rolled down as a pebble to take part in the formation of the sediment.

Diamonds in their natural state do not display their full fire and beauty, but are irregular in shape and often somewhat cloudy or frosted in appearance. To bring out their qualities they require to be "cut." For this purpose they are first split with a diamond knife, and then ground on wheels coated with diamond dust. The stones are cut into various shapes, such as the "rose" and "brilliant," with different numbers of angular facets. These shapes have, of course, nothing to do with the natural crystal shapes, which are often eight-sided double pyramids. In addition to its brilliance and hardness, the diamond has certain remarkable properties, such as that of phosphorescence, or glowing after being rubbed or being exposed to light: in the opinion of Sir William Crookes, it is the most sensitive substance for ready and brilliant phosphorescence. Diamonds are not all clear white; they may be of any colour, even deep red or deep blue, though these are very rare.

Remarkable Histories

The story of diamond-mining abounds in curious incidents. The first Brazilian diamonds were used as counters for cardplaying; the first South African diamond was a child's plaything. Diamonds have been discovered in the walls of houses, and in the throats of poultry; more than one fine gem has been thrown away as worthless.

Not less remarkable are the histories of individual stones. The huge "Great Mogul," once the property of the Emperors of Hindustan, has been totally lost; the Koh-i-noor, or "Mountain of Light," from the same treasury, was hidden and protected by one royal owner after another, even in the torture chamber; but its power for evil appears to have passed away, for it now reposes among the Royal Jewels at Windsor. Too many diamonds, like the Pitt or "Regent," have a history of bloodshed and cruelty. We remember how, in Kipling's story, the "King's ankus," the jewelled elephant-goad, killed six men in a night. Even in later days, in South Africa, the diamond has not been untainted; but at least the two largest diamonds in the world, the "Excelsior" and "Cullinan," have had a more fortunate history. The Cullinan was found in the Transvaal in 1905; it weighed, in the rough state, 3,250 carats, or almost *one and a half* *pounds* avoirdupois! It measured 4½ by 2¼ inches. It was cut and ground into nine large and about a hundred smaller stones, and the two first parts are by far the largest cut diamonds in existence. It is the property of the British Crown.

Round the diamond, as round all precious stones, strange legends and beliefs have gathered. The toad was anciently supposed to carry a jewel in its head; the dragons which were believed to inhabit the Alps were similarly adorned, and the lucky man who found a dragon asleep had only to cut out the stone, and run the risk of wakening the dragon, to make himself rich for life. Gems had all sorts of supernatural properties: they cured all manner of diseases, they were charms in love, in battle, in peril of all sorts. They were lucky or unlucky, but never merely neutral. There were stones for the days of the week, for the signs of the zodiac, for the months of the year, for all the saints of the calendar. The only element of romance which was overlooked was the scientific romance of the origin and properties of crystals.

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XXIX

THE SCIENCE OF THE SEA

THE SCIENCE OF THE SEA

The Making of the Sea

THERE was a time in the earth's history when there was no sea. The surface of the young earth was too hot to allow the accumulation of water in basins. More than that, *there were no basins,* for the surface of the young earth must have been at any one place as flat as a pancake. If the young earth was uniformly spherical (apparently flat at any point) there could be no separate *seas.* If the young earth had on its surface a high temperature, there could be no *sea:* the water would evaporate. But there is another factor, which requires more explanation than this Outline admits of (see Chamberlin in the Bibliography), that the growing earth was originally *too small* to hold even a gaseous envelope (the atmosphere), still less an aqueous envelope (the hydrosphere). As the earth gradually grew in diameter it acquired an atmosphere—differing from that of to-day in having but little oxygen. For the oxygen of our air is mostly due to the activity of green plants. As the earth reached its limit of growth and began to cool and shrink, a rocky shell (or lithosphere) was formed, seething and swaying at first, but gradually gaining stability. The probability is that as the result of surface boilings lighter materials rose higher to form CONTINENTS, while heavier materials sunk lower to form OCEAN BEDS. It is probable that over-weighting of vast areas resulted in the formation of ocean basins, which have become steadily larger as the quantity of water on the earth has increased. Over limited areas the floor of the sea has sometimes been raised into dry land,

and a large part of a continent has sometimes sunk down and formed the floor of a sea, but the trend of opinion among geologists seems to be in favour of the view that the present positions of the great masses of land and water have remained on the whole the same since continents and ocean basins were first established. But this is a much discussed question. It should also be noticed that some suppose that there was a universal ocean over the earth before there was any dry land.

To the natural question, Where did all the water come from? geology answers, "From the earth itself." When we visit hot springs or watch the clouds of steam rising from volcanoes, we probably get more than a hint of how the water of the sea began. It is supposed that from a quarter to a half of the present-day volume of the seas was in existence before the Cambrian period. The rest has been added since—expressed from the earth itself. There is, of course, an endless circulation of water, on which the economy of Nature largely depends. The mist rises from the sea and clouds are formed which condense into rain or snow on the cold mountains or in cool strata in the air. The rain falls, the springs are fed, the streamlets become rivers, and these return to the parent sea. And it is the sun that keeps this water going round; for without the sun we could not have either rain or rivers.

Why is the Sea Salt?

On an average there are 3½ pounds of salty material to every 100 pounds of sea-water; and the great bulk of this has been dissolved out by the rain from the rocks of the dry land. In a very real sense the continents are always flowing into the sea. When there is an elevation of part of the floor of the sea, to form the chalk cliffs of Dover or the like, we may speak of a restitution of material from the sea to the dry land; and a better illustration of recoupment going on now may be found in the formation of a coral island on the shoulders of a submarine volcano, to which reference has been previously made. All the coral-rock, which is gradually elevated and in part piled up above the sea-level, consists of carbonate of lime which coral-polyps and ancillary animals have extracted from the soluble lime-salts of the sea-water. But all that the sea has restored to the dry land is little compared with what it has filched or with what the fresh waters have surrendered.

There are dissolved salts and other solids in the water of rivers and lakes just as there are in the sea, but those in the latter are nearly 200 times as abundant as those in the former, so we speak of *fresh* water and *salt* water. More than three-fourths of the salts in the sea consists of common salt (sodium chloride), which forms 77.7 per cent. Magnesium chloride forms 10.8 per cent., and the same percentage is made up of the sulphates of magnesium, calcium, and potassium. That leaves only 0.7 per cent. for calcium carbonate, magnesium carbonate, magnesium bromide, and traces of other salts. There are so many marine animals with heavy shells of carbonate of lime—think of oysters and periwinkles alone—that one is surprised to find so little of this salt (0.3) in solution in the sea. The explanation is that the carbonate of lime used in shell-making is largely formed, as the result of some process of chemical change in the tissues of the animals, from the fairly abundant calcium sulphate (3.6 per cent.). There is a far smaller proportion of silica in sea-water than in river-water, and the explanation must be that the silica gets locked up in the siliceous skeletons of flinty sponges and of the beautiful microscopic plants called diatoms which float near the surface.

In 100 lb. of average sea-water there are 3½ lb. of salts, and this is the "average salinity." But different parts of the surface of the sea differ markedly in salinity, for it will increase where evaporation is great (as in the Red Sea); it will decrease where the rainfall is heavy; it will decrease where there is little wind and much precipitation. In a general way, the salinity corresponds with the climate.

A very interesting fact in regard to the salts of the sea is their correspondence with the salts in the blood of land animals! If the percentages of sodium, magnesium, calcium, potassium, and chlorine in sea-water be compared with the percentages in blood serum, the figures are respectively 30.5 and 39; 3.79 and 0.4; 1.2 and 1.0; 1.11 and 2.7; 55.27 and 45.0. There are striking resemblances especially in the proportion of potassium and calcium to sodium. So it has been suggested by Macallum and Quinton that in Cambrian times an equilibrium was established between the living matter of marine animals and the composition of the surrounding water. To use Sir William Bayliss's words: "When vertebrates with a closed circulatory system took to the land, they took with them a blood of the same composition, as regards salt, as the sea-water which they left behind." And as to the differences which the percentages we have quoted also reveal, these may be interpreted in terms of the changes in the composition of the sea since the close of the Cambrian period. The composition of our blood is a tell-tale relic.

The Depth of the Sea

The total surface of the globe occupies about 197,000,000 square miles, and about 71 per cent. of that (namely 140 millions) belongs to oceans, seas, and lakes. The great mirror of the sea seems very uniform to the landsman's eye, but it is really very heterogeneous. For there are shallows and depths, and apart from the floor the surface has its ups and downs. This is due to a variety of causes, but notably to the gravitational pull of the continents, which implies a heaping-up of the waters round the shores. The surface of the *Mid* Indian Ocean is thus *lowered* by the Himalayas.

Thousands of soundings have been taken all over the navigable globe, and we know that the average depth of the sea is about 2½ miles. Only 16 per cent. of the ocean-floor lies between the shore-line and 1,000 fathoms; more than half the entire

Photo: Copyright, Daily Mail.

HIS SERENE HIGHNESS ALBERT, PRINCE OF MONACO (b. 1848)

A veteran Oceanographer, who has conducted many marine expeditions, the results of which have been published in a monumental series of monographs. He has founded an Oceanographical Institute in Paris and a magnificent museum and laboratory at Monaco. He has made great contributions to the science of the sea.

Photo: Elliott & Fry, Ltd.

THE LATE SIR JOHN MURRAY

One of the naturalists on board the *Challenger*, and afterwards editor of the great series of *Challenger Reports*. A strong personality, instinct with the scientific temper, resolute and indefatigable in overcoming difficulties, he must be reckoned as one of the founders of Oceanography. He discovered the valuable deposits of Christmas Island and was a generous patron of scientific endeavours, such as the Millport Marine Station. He was the greatest authority on Deep Sea Deposits. His *Oceanography* in the Home University Library is a remarkable piece of work, and his *Depths of the Sea* (along with Dr. Hjort) is also outstanding.

Reproduced by courtesy of the purchaser, the Prince of Monaco, and the artist.

A NEW WORLD FOR THE LANDSCAPE PAINTER—AT THE BOTTOM OF THE SEA—HAS BEEN OPENED UP BY AN ARTIST, MR. ZARH PRITCHARD, WHO PAINTS UNDER WATER IN DIVING DRESS

The picture shows pointed rocks at the bottom of the sea, a submarine "landscape" from a study in oils painted 16 feet under water.

floor is covered by depths between 2,000 and 3,000 fathoms. Sir John Murray gave the name "deeps" to holes and basins, troughs and trenches, with a depth of over 3,000 fathoms. Thus there is the "Challenger Deep" (5,269 fathoms) in the north-west Pacific, and the "Swire Deep" (5,348 fathoms) off Mindanao. Of this tremendous abyss—400 feet more than six miles—Sir John Murray wrote: "If the highest known mountain (Mount Everest in the Himalayas, 29,002 feet) could be placed in this area of the Pacific, its summit would be covered by the waters of the ocean to a depth of 3,087 feet." From the bottom of the "Swire Deep" to the top of Mount Everest would be a vertical distance of 61,091 feet, or over 11½ miles. This is surely the limit in the irregularity of the Earth's crust.

§ 1

Temperature of the Sea

Heat rays are lost at about 250 fathoms, and even in the tropics the upper stratum of warmish water is comparatively thin. The great bulk of the water in the oceans is relatively cold. There is an automatic regulation at the surface, for when the temperature rises there is increased evaporation which checks the rapidity of the rise; and if the temperature is lowered a blanket of water-vapour forms over the surface which checks the rapidity of the fall. From one place to another there is great diversity of temperature, but at any given place there is, apart from the surface stratum, great constancy of temperature year in year out. Murray and Mill write:

> At the depth of 50 fathoms it is probable that the temperature does not change by so much as 2° F. at any one place throughout the year; and below the depth of 100 fathoms there is no evidence of any annual change of temperature whatever.

Sir John Murray calculated that on the average all the water in the ocean deeper than 500 fathoms may be said to have a temperature below 40° F., and that this would include about 87 per cent. of the entire ocean. But in the great depths the temperature is lower still; it is just a little above the freezing-point of fresh water (32° F.). Eternal winter reigns. "The ooze dredged from the ocean floor in the tropics is so cold that it cannot be handled without discomfort." This low temperature is mainly due to a slow northward "creep" of the ice-cold waters of the Antarctic.

Pressure in the Sea

When a piece of wood is weighted, lowered to a great depth, and pulled up again, it will no longer float. All the minute cavities in the wood have been burst in and filled with water. The log of wood is thoroughly waterlogged, and gives one a hint of the enormous pressure at great depths. It is calculated at 2½ tons on the square inch at a depth of 2,500 fathoms. And yet we know that a frail skeleton like that of Venus's Flower-basket (see Figure facing p. 121) stands like a fairy palace on the floor of the deep sea, and that it is surrounded by the delicate shells of creatures that once lived on the surface. How is the apparent contradiction explained?

The pressure is due to the weight of the water which packs the molecules a little more closely together. If an open glass vessel is lowered into the water it at once fills, and as the pressure of the water is the same inside as outside nothing happens. If a corked bottle not quite full be lowered to a great depth, one of two things will happen—the cork will be stove in or the bottle will be shivered.

What is known as "Buchanan's experiment" is very instructive in this connection. It arose out of the fact that two thermometers lowered from the *Challenger* (1873) in 3,873 fathoms collapsed owing to the great pressure. Mr. J. Y. Buchanan, the physicist on board, took a glass tube, sealed at both ends, wrapped it in a cloth, and enclosed it in a cylindrical copper case with the ends pierced with holes to let the water in. The case was sent down to a depth of 3,000 fathoms and then pulled up. The copper case looked as if it had been struck with a hammer at the portion occupied inside by the sealed glass tube. And as for that glass tube, it was represented inside the cloth by what looked like snow—the glass reduced to fine powder!

Let us quote the explanation given by Sir John Murray, who witnessed the experiment.

> It seems that the sealed glass tube, while sinking, had held out long against the pressure, but this at last had become too great for the glass to sustain, and the tube had suddenly given way, being crushed by the violence of the action to a fine powder. The collapse had been so rapid and complete that the water had not had time to rush in through the holes at either end of the copper cylinder and thus fill the empty space caused by the collapse of the glass tube, but had instead crushed in the copper wall and thus brought about equilibrium. The process, which is exactly the reverse of an explosion, is called an "implosion."

When a body of any kind sinks to a great depth any cavities it may contain will be quickly filled with water; but if there are cavities which cannot be quickly reached, like water-tight compartments, they will be imploded, and the form of the body will be altered correspondingly. There is no warrant at all for the common sailor's belief that ships and men sink till they "reach their level" and there remain suspended! Everything sinks to the bottom.

When a deep sea fish rises in pursuit of its prey above its usual zone, the decrease of external pressure brings about an expansion of the gases in the swim-bladder, and the specific gravity of the fish is greatly reduced. The result is that, in spite of its efforts, the fish "tumbles upwards" to the surface, killed sooner or later by the distension of its organs. This is an explosion.

§ 2

Movements of the Sea

The sea is eternally restless. Even when there is no wind at all, there may be a "swell," for the perfect elasticity of the water keeps it throbbing long after the storm is past, just as the gong continues quivering long after the blows have fallen. Attention has already been given to the tides (p. 290), which are due to the gravitational attraction of the sun and moon, sometimes acting together, sometimes against one another. The familiar ebb and flow of the tides, two low tides and two high tides in every 24 hours 50 minutes, are coastal expressions of two worldwide tidal waves, which ceaselessly chase one another round the globe. In equatorial waters the tidal wave would travel at the rate of 1,000 miles an hour if there were no obstructions, but it must be clearly understood that what travels so quickly is the undulation, not the water. "The waving grain, as it bends to the breeze, causes an undulation that travels across the field faster than you can run; but the stalks are rooted; they only sway backward and forward to the breeze. So is it with the deep sea and its swell" (Maury and Simonds). The tidal undulation and the familiar rise and fall must be distinguished from tidal currents produced near the shores and often attaining so great a speed (6–11 miles an hour) that people use the word "race."

When a sea is shut off by a narrow entrance or by a breakwater of islands from the influence of the almost worldwide tidal wave, there will be little ebb and flow, as is well illustrated by the practically tideless Mediterranean. When the configuration of the coasts heaps up the tidal current interesting phenomena may result, such as the 70-feet tides of the Bay of Fundy and the 40-feet tides of the Bristol Channel. In rushing into a river the tide may form a dangerous "bore" or "eagre," a wall of foaming water, sometimes over 10 feet in height (see the picture of the Trent eagre facing p. 290).

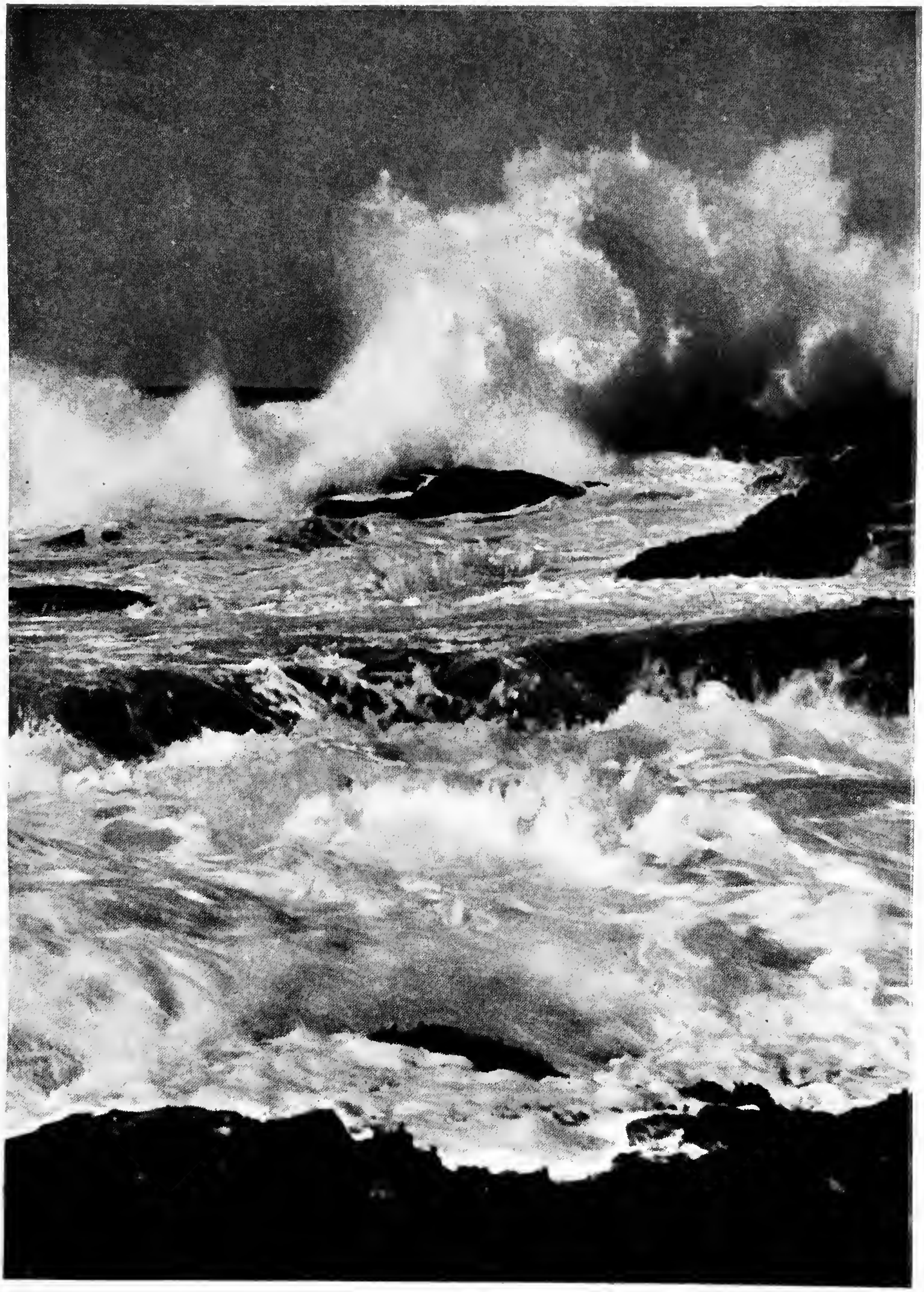


Photo: Frith & Co.

HELL BAY, SCILLY ISLES

Few sights are more beautiful than the waves of the sea breaking on the shore, and their scientific interest is great. The wind striking the surface of the water depresses part of it, and the adjacent region is forced up. But gravity tends to restore the level, and a succession of waves has to result, spreading over the surface of the sea. On entering a shallow the lower part of the water in contact with the bottom is slowed down and the upper part topples over in white foam. In many cases the wind blows the tops off the waves as spin drift. But the whole business is more intricate and more fascinating than can be briefly suggested. See Dr. Cornish on Waves.

We cannot leave the tides without noticing that they have engrained their periodicity in the constitution of some of the shore animals—a fact of special importance since many of the great stocks of animals seem to have served an apprenticeship in the littoral area. Ages of reacting to the tidal rhythm have left their mark on many a shore animal, and probably on some that have long since passed beyond the sound of the sea. The small green worm Convoluta comes up on the flat beach at Roscoff when the tide goes out, and disappears into the sand when the tide comes in. Removed to the laboratory and placed in tall vessels half filled with sand and half filled with water, the little creatures continue for a considerable time moving up and down as the tide outside ebbs and flows. The rhythm of the tides has become an organismal rhythm.

When a tidal current is split into two by a rocky island, and these meet again, a whirlpool is sometimes formed—a vast vortex of angry water. One of the best examples is Corrievrekin in the Sound of Jura, where two rapid currents, from the north and the west, meet around a pyramidal rock which rises rather abruptly from a depth of 100 fathoms to within 15 feet of the surface. There is a true vortical movement, such as we see in miniature in an eddy on the downside of a rock which breaks the current in a river. Whirlpools have taken a grip of man's imagination, and their terrors have been exaggerated. The famous Charybdis, in the Straits of Messina, which thrice a day sucked down the water of the sea and anything that sailed thereon, is not a whirlpool at all, but a "chopping sea" due to the oblique action of the wind on a tidal race or rapid which changes its direction with each ebb and flow. Of course it remains dangerous enough, but it is not a whirlpool. The same remark applies to the not less famous Maelstrom between two of the Lofoden Islands; it is a race, not a vortex, and it is habitually navigated. Edgar Allan Poe's description of its down-sucking powers is a splendid piece of exaggeration.

§ 3

Circulation in the Sea

Almost as important as the circulation of the blood to the body is the circulation of the sea-water to the welfare of the globe. Through the direct and indirect influence of the sun, producing changes of temperature, density, and wind, the waters of the ocean are in ceaseless circulation. This is an extremely difficult subject, and it may be enough here to distinguish the slow *vertical* movements in the mass of water and the more rapid horizontal movements of the surface stratum in drifts and currents. The Gulf Stream is a much-talked-of instance of an important oceanic current, which, as Dr. H. R. Mill says, "is often spoken of as if it were a phenomenon by itself, whereas it is really only part of a great system of surface circulation, the water whirling as if stirred in the direction of the hands of a watch in the northern Atlantic, and if stirred in the opposite direction in the southern part of the ocean." The almost resting centre of the North Atlantic whirl forms "the calm, weed-hampered water" of the Sargasso Sea. It embraces several hundred thousand square miles and is covered with a flotsam of seaweed wrenched off from distant shores. It remains to-day where it was when Columbus encountered it on his first voyage to America. There are four other great weed-hampered areas of little motion, but this is *the* Sargasso Sea.

Storms at Sea

It seems almost a bathos to write in cold blood of storms at sea.

> Part of the water surface [as Dr. Mill puts it] yields to the stress of the wind striking it obliquely, and is depressed, thereby ridging up the neighbouring portions and orginating a wave, the form of which advances as a line of rollers before the wind. Only the form advances, for while the particles of water in the crest of the wave are moving rapidly forward,

Reproduced by courtesy of the artist and the Galeries Georges Petit, Paris.

ANOTHER SUBMARINE "LANDSCAPE," SHOWING A BASALT TUNNEL ON THE SEA-BED

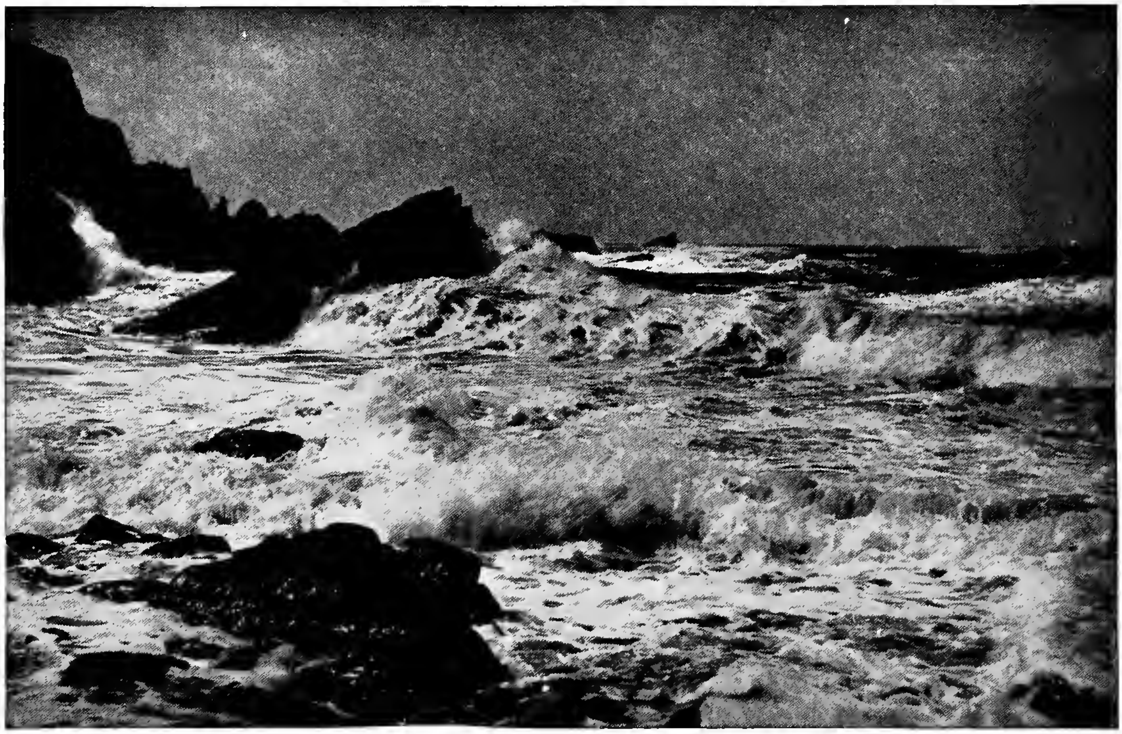


Photo: L. E. A.

AT CAPSTONE HILL, ILFRACOMBE

On a quiet day the waves of the incoming tide seem to rush in, but in most cases it is only the wave form that advances. Particular masses of water merely rise and fall. On entering a shallow area near the coast a tidal wave may be changed into a current. Moreover, the lower zone of the water is retarded by contact with the bottom, and the upper part breaks in spray. A breeze often blows the crests off the waves, and a steady wind may cause a stratum of water to slip before it. With this horizontal movement there will also be associated vertical movements in the sea.

> those in the trough move back to almost exactly the same extent. Thus rollers merely lift and lower the vessels that float upon them.

When these waves "reach" a shallow the lower part in contact with the floor is retarded, and the upper part curves into what often looks like a flinty cave and then breaks into spray. These breakers have great eroding power—blasting and hurling off huge pieces of rock or carving the cliffs with a battery of gravel. Dr. Mill gives a quarter of a mile as the greatest length of a wind-wave from crest to crest, and fifty feet as the maximum height. But the bell of a lighthouse on one of the Isles of Scilly was wrenched off by a breaker at a height of 100 feet. It should be noted that even the largest waves are very shallow in their grip and have hardly any appreciable effect below 100 fathoms.

There are other storms due to the wind driving a thin stratum of the surface water before it, either inshore or offshore. Earthquakes and volcanic eruptions may also raise huge waves. A whirlwind is an aerial vortex or eddy caused by the meeting of two winds, and a whirlwind at sea may cause a *waterspout.* This consists of a pillar of cloud rising from sea to sky, whirling on its axis, round a core of low pressure, and moving over the surface of the deep. The water at its base is fiercely agitated as if it were boiling, but there is no sucking up of more than the spindrift from the waves.

§ 4

The Floor of the Sea

A comprehensive survey of the globe leads us to distinguish three great areas. First, there is the *continental area,* including (*a*) the elevated plain, with an average height of about 2,250 feet above sea-level, (*b*) the shallow water shelf around the continental islands which are insulated parts of the mainland, as distinguished from oceanic islands which originate as volcanoes from the floor of the sea, and may become the foundations of coral reefs. (See THE MAKING OF THE EARTH AND THE STORY OF THE ROCKS.)

Second, there is the *continental slope,* from the shallow water shelf down to the bottom of the sea, occupying about one-sixth of the total superficial area of the globe.

Third, there is the *abyssal area,* the floor of the deep sea, a prodigious plain of about 100 millions of square miles. It seems to be on the whole a monotonous plain, with undulating slopes like sand-dunes, interrupted by occasional volcanic cones rising towards or even to the surface, and by occasional troughs and basins—the "deeps" already referred to.

It is believed that the earth's crust (or lithosphere) beneath the oceans, like that of the continents, is superficially "parcelled out into great earth-blocks, separated from each other by faults and fissure lines, along which volcanic action and gaseous emanations take place, and through which massive outflows of molten matter occur" (Murray). The continental crust has been explored by borings and mines to depths of several thousand feet, and geologists consequently know a great deal in regard to what is hidden below the surface. As to the abyssal crust, however, the dredge cannot penetrate beyond the deposits, and the nature of the submerged crust has been inferred rather than observed. Some information is afforded by comparing the materials ejected from oceanic and from continental volcanoes; the former appear to be heavier and more basic, the latter lighter and more acid in composition. (See THE MAKING OF THE EARTH AND THE STORY OF THE ROCKS.) The continental earth-blocks tend to rise; the abyssal earth-blocks tend to subside.

Deep-sea Deposits

In the shallow water, or comparatively shallow water, of the littoral area and the upper parts of the continental slope, the deposits on the floor are very diverse, varying from place to place according to the nature of the shore rocks, the materials the rivers bring down, and the character of the marine vegetation and animal life. Thus there are gravels, sands, muds, and masses of organic matter.

On the floor of really deep water there is an accumulation of fine-grained ooze, consisting very largely of the calcareous and siliceous remains of minute organisms which have sunk down from the surface. Thus there is "Globigerina ooze," predominantly made up of the pinhead-like shells of surface Foraminifera, comparable to those that formed a great part of chalk deposits in the distant past. This Globigerina ooze has a pale-grey colour, sometimes reddened with iron oxide, or tinged brown with manganese. It is said to cover an area of 47,752,000 square miles at a mean depth of 12,000 feet. In other areas there is a predominance of the shells of "winged snails" (Pteropods), or of siliceous Radiolarians, or of siliceous diatoms—all derived from the surface waters overhead—and thus there are different varieties of ooze. Along with the remains of organisms, both from the surface and from the floor itself, there may be, of course, particles of volcanic dust and meteoritic iron, as well as minute fragments from the land-rocks and precipitations from the sea-water.

Over an immense area of 55,000,000 square miles, almost equal to the whole land-surface of the globe, there is a slowly accumulating deposit of "red clay"—the insoluble residue and final form of all the sea's dust. No "red clay" has been recognised among continental sedimentary rocks; indeed, chalk is the only continental rock which can be traced back to an ancient ooze. What should be inferred from these facts is still uncertain.

§ 5

The Life of the Sea

There is probably far more living matter in the sea than there is in all the rest of the world. Spenser was right in speaking of the sea's "abundant progeny, Whose fruitful seede farre passeth those on land." As the animals of the sea have been discussed in the chapter dealing with adaptations to environment (p. 115), we need not now do more than make the general economy clear. The visible rays of the sun can penetrate to 500 fathoms, and the actinic rays further, so there is a vast area within the sun's appreciable influence, and this is the area of productivity. Here are the great floating sea-meadows. No doubt, there is great importance, especially in the shallower waters, in the organic fragments which are broken off from the larger shore seaweeds and from the sea-grass (Zostera), or borne down by rivers, but the microscopic green algæ of the open waters play a fundamental part. By their photo synthesis they set agoing the upbuilding of complex carbon compounds from the raw materials of air and sea. They are devoured by small animals, and, as we have seen, there is a long ladder of incarnations—from diatom to mackerel. There is also a ceaseless rain of moribund animalcules and of sea-dust from the surface-zones downwards to the abyssal ooze. Nor can we forget the part that green organisms play in helping to oxygenate the surface waters of the sea, thus making it a possible home for ordinary animals like crustaceans and fishes.

The most important impression is that of the abundance of minute forms of life, linked together in nutritive chains. Sir William A. Herdman writes:

> It may be recorded that Brandt found about 200 diatoms per drop of water in Kiel Bay, and Hensen estimated that there are several hundred millions of diatoms under each square metre of the North Sea or the Baltic. It has been calculated that there is approximately one Copepod [a minute Crustacean] in each cubic inch of Baltic water, and that the annual consumption of these Copepods by herring is about a thousand trillion; and that in the 16 square miles of a certain Baltic fishery there is Copepod food for over 530 millions of herring of an average weight of 60 grammes.

Well might Spenser say: "So fertile be the floods in generation,
So huge their numbers, and so numberlesse their nation!"

The Bacteria of the Sea

As is made clear in Sir Ray Lankester's article on BACTERIA, these microbes play a very important part in the economy of the sea. They are inconceivably numerous wherever there is abundant organic matter, except, perhaps, in the great depths, for we know almost nothing of deep-sea bacteria. They are, in any case, least abundant in deep and cold water, and most abundant in shallow water or where cold and warm currents meet. One of their headquarters is certainly the thickly peopled "mud-line," where at a certain distance off shore the organic sea-dust settles down to form fine mud.

The marine work of bacteria is in the main threefold. Some of them—by putrefaction and fermentation—convert the excretions and dead fragments of animals into carbonate of ammonia. This may be utilised by marine plants, but it becomes more readily available when changed by oxidation into nitrites and nitrates. This is the work of the nitrifying bacteria, and where there is abundance of them the minute marine algæ flourish in the waters. But there are other bacteria which reverse what is done by their neighbours. They reduce nitrates to nitrites, nitrites to ammonia, and ammonia to free nitrogen. So their work lessens the amount of nitrogen that can enter into the cycle of life. For there are only two or three ways, e.g. by the root-tubercle bacteria of certain plants, that free nitrogen can be utilised by living creatures.

Colour of the Sea

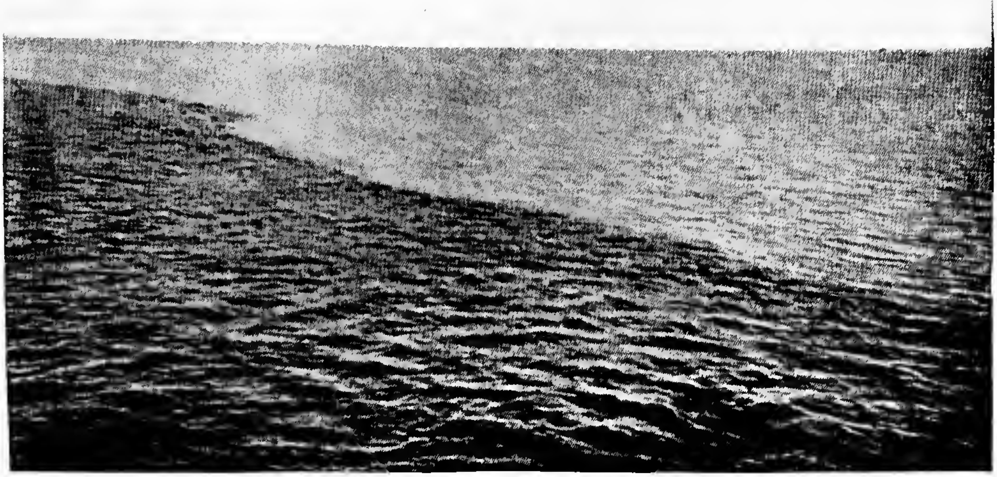
Part of the fascination of the sea is in its changeful colouring. It is "eternally new." To some extent the colour is due to reflection from the sky; "but the fact that blue and even indigo blue may be seen with overcast sky, while the deep blue is not observed in the Arctic waters, even with bright sunshine, proves that this is not the sole cause" (Tarr and Martin, p. 653). A long tube of distilled water has a blue colour, and the addition of impurities changes this to green. It is probable, therefore, that the bluest sea, e.g. of the Gulf Stream, is the purest, and that the greenest, e.g. of the Arctic Ocean, contains most extrinsic material. It is all a question of the reflection of different wave-lengths of the white light. The extrinsic material consists of the minute organisms of the Plankton, e.g. reddish Algæ in the Red Sea, and suspended sediment brought down by the rivers, e.g. in the Yellow Sea off the Chinese coasts. The colour may also be affected by differences in the salinity and in the amount of dissolved gases. In shallow water, e.g. among the coral reefs, reflection from the coloured floor will also count.

In the article on ELECTRIC AND LUMINOUS ORGANISMS, attention has been directed to the frequent "phosphorescence" of the sea both on the surface and in the depths. There is often a welter of sparks in the wake of the vessel, and the oars of the rowing-boat drip fire in the summer darkness. Apart from some phosphorescent bacteria, the light-producing organisms of the sea are all animals—of every degree up to fishes; and the display often beggars description. There is a suggestion of it in "The Ancient Mariner," but the term "sea-snakes" must not be taken literally:

Beyond the shadow of the ship,
  I watched the water-snakes;
They moved in tracks of shining white,
And when they reared, the elfish light
  Fell off in hoary flakes.

Within the shadow of the ship,
  I watched their rich attire,
Blue, glossy green, and velvet black,
They coiled and swam; and every track
  Was a flash of golden fire.

In the well-investigated case of the small open-sea crustacean called Cypridina, the luminescence is associated with the action



THE GULF STREAM HAS CLEARLY DEFINED "BANKS" OF WATER

Observe the dividing-line between the Gulf Stream and the colder ocean water. It leaves the Gulf of Mexico through Florida Strait as a river of very salt warm water, fifty miles wide, with a velocity of five miles an hour. Off Cape Hatteras it curves eastwards and spreads across the Atlantic. Branches diverge northwards and reach the British and Norwegian coasts, while the main body passes southwards to join the north equatorial current off the Canaries. This north equatorial current is due to the Trade Winds blowing from the coast of Africa.

Photo: J. W. Knight.

A WATERSPOUT

When a whirlwind occurs on the sea, the result is a "waterspout"—a whirling pillar of cloud stretching from sea to sky and moving along like a dust-whirlwind on land. At the base of the great aerial eddy the sea is violently churned as if it were boiling, and spray may be carried up. It is a popular fallacy that the sea-water is sucked up in a solid mass. A waterspout on land is usually a torrential shower.

1 2 3

DEEP-SEA DEPOSITS; THE SHELLS OF MINUTE CREATURES, KILLED AT THE SURFACE, SUNK INTO THE OOZE OF THE OCEAN FLOOR

1. Pure chalk ooze made of the sunk shells of pinhead-like animals (Foraminifera) which live at the surface.
2. Mixed ooze consisting of a variety of shells and fragments of shells.
3. Pure Radiolarian ooze—the flinty shells of small creatures which live at the surface and sink down as they are killed by vicissitudes of temperature and the like. The living matter that remains associated with the minute shells forms an important part of the outside food-supply of the abyssal animals.

AN ENLARGEMENT OF A YOUNG FORM OF AN ABYSSAL FISH (STYLOPHTHALMUS) FROM VERY DEEP WATER IN THE INDIAN OCEAN

The eyes are borne on the end of long stalks; the optic nerve and four of the eye-muscles show a similar elongation. The dark spots shown on the front of the head are probably the nostrils. The adult form of the fish is not known, but it is probably one of a family (Stomatidæ) which have "telescope eyes," i.e. with the axis of the eyes considerably elongated.

of a ferment, *luciferase,* which operates upon and brings about the rapid oxidation of a light-producing substance, *luciferin.* But we do not know what this means in the physiological economy of the animal's body, or what use, if any, the light may have in the creature's everyday life.

Ice in the Sea

In the Far North the winter sea is covered with ice, heavier than freshwater ice because of the salts, but still able to float and to bear the sleds of the Eskimos and the explorers. Tidal and other currents break the sheet into *pack ice,* which may be piled up into little mountains. In the Arctic summer when the sun does not set, the ice-plain breaks up into *floe ice,* which drifts southwards in a long procession and gradually melts. Both in the Arctic and in the Antarctic an *ice-foot* is formed as a fringe along the land, partly marine and partly terrestrial in origin. Quite different are the icebergs, which are the broken-off lower ends of glaciers and are therefore fresh. These huge masses may rise 100–200 feet above the water, but that is only one-sixth to one-seventh of their total height. When the submerged part melts much more rapidly than the exposed part, the iceberg may become top-heavy, and "turn turtle." As the icebergs drift southwards they become a menace to ships, the most terrible of the many tragedies being the wreck of the *Titanic* (April 14, 1912), when 1,517 persons lost their lives. It must be realised that icebergs are often great floating islands, several miles across, and that they play an important part in transporting sediment, and in affecting the salinity and temperature of the sea as they melt. Their climatic influence penetrates far inland in countries like Labrador and Nova Scotia.

The Uses of the Sea

In many ways the sea makes the earth more liveable. It absorbs the heat of the "tropical sun" and distributes it far and wide. It tempers the great heat by currents of ice-cooled water from the Poles, and by cold water rising from the wintry depths. It is the cradle of many of the winds which do so much for good as well as ill. It is the central depot in the incalculably important circulation of water; it is the beginning and the end of rivers. Its give and take—absorption and restoration—of atmospheric gases makes for uniformity in the composition of the air. It is the universal clearing-house, the universal cleanser. In the sea all waste is reduced to its common denominator, and the results of the wear and tear of the earth are laid down in deposits which *might* again become rocks. Finally, the sea yields man a rich harvest; it has always been one of his great schools; and it binds together much more than it separates.

The End of the Sea

There was a time, as we have seen, when there was no sea. The elements that unite to form water (H_2O) were imprisoned in the mineral matter of the molten crust, and later on there was water-vapour in the hot atmosphere. Gradually the earth passed into what has been called the terraqueous phase of its evolution or development. But if the supply of heat from the sun becomes in the course of ages less and less, the earth will become cold like the moon, and colder. The sea will become as hard as rock, frozen from top to bottom, "and over this will roll an ocean of liquid air about forty feet in depth." Unless, indeed, something else happens to this earth of ours.

§ 6

Denizens of the Sea

In the chapter on ADAPTATIONS TO ENVIRONMENT something has been said of the animal life and the plant life of the sea. As has been explained, there are littoral, pelagic, and abyssal marine animals, peopling the shore-area, the open sea, and the deep sea respectively. Similarly, as regards plants, there is the very important shore-vegetation of seaweeds and sea-grass (Zostera), the broken fragments of which are borne seawards to serve as a fundamental food-supply for multitudes of fishes, molluscs, crustaceans, and worms on the floor of relatively shallow waters. On the other hand, there is the pelagic population of floating Algæ, more or less microscopic, on which the daintier open-sea animals, like crustaceans, feed, while others sink down, as they die, to the plantless abysses.

In this chapter on the science of the sea we must bring in the animals again—the sea's abundant progeny; and we begin with the OPEN SEA.

Open-sea Animals

Our first picture may fittingly be devoted to whales. Every age has had its giants, and the giants of to-day are the whales, for the Sperm Whales and the Right Whales may be fifty feet long, and there are others larger still. It does not seem certain that the Toothed Whales and the Whalebone Whales form one order, which would mean that they have had a common ancestry; for the fact is that a superficial resemblance is apt to blind us to a multitude of detailed structural differences. It is possible that whales evolved *twice*. But whether once or twice, they almost certainly evolved from terrestrial ancestors, as their vestiges of hind-legs, for instance, seem to indicate. Suckling the offspring, as whales of course do, could not have *begun* in the sea. But the adventure of the Cetacean pioneers, which led to a change of habitat from shore to sea, must have begun millions of years ago, the whale's adaptations to marine life are so numerous and so penetrative.

What a bundle of fitness is a whale: the torpedo-like shape, the almost frictionless skin, the tail turned into a propeller with horizontally flattened flukes, the balancing flippers made out of fore-limbs, the blubber that conserves the precious animal heat and makes the great mass of the body more buoyant, the position of the valved nostrils on the top of the head so that air may be more readily inhaled when the creature comes to the surface of the sea, the relatively huge chest-cavity and lungs, the almost invariable reduction of the number of offspring to one at a time, and the special milk reservoirs which give the young one a big mouthful at once.

The toothed whales feed on true fishes and on cuttlefishes; but the whalebone whales feed on small open-sea animals, such as the lightly built molluscs known as sea-butterflies, which are caught in the great cavern of the open mouth on the frayed edges of the baleen plates. In rushing through the water with the mouth gaping the baleen whale would be apt to drown itself, were it not that it is able to shunt forward the spout-like opening of the windpipe into the posterior opening of the nasal passage on the roof of the mouth. Thus no water can go down the wrong way!

At first sight a whale seems hairless, but in most cases groups of hair can be seen about the snout, jaws, and skin. As some embryo whales show numerous hair-rudiments on the front part of the body, it seems safe to conclude that the ancestors of modern whales had hair like other mammals. And the interesting point is that the hairs which remain are sometimes more than tell-tale evidences of the past; they are actually of use as tactile structures. In the Right Whale they are extraordinarily well ennervated, four hundred nerve-fibres sometimes going to a single hair. They illustrate the conservatism of evolution—that an ancient structure may be kept hold of as long as it is of use. On the other hand, when the use has quite gone the structure may entirely disappear, as has probably been the case with the whale's ear-trumpet and third eyelid. In some embryo whales there are two button-like projections that look like the last traces of externally projecting hind-limbs; and it is impressive to see the deeply buried vestigial thigh-bone of a North Atlantic Right Whale—it is only 5 inches long!

On a sea voyage the "spouting" of whales is a familiar sight. It means that the used-up air is blown out very forcibly from the nostril, perhaps half a dozen times in rapid succession, and that the water-vapour in the breath condenses into drops in the cold air, sometimes accompanied by a little spray borne up by the blast. Spouting water is of course impossible, and Milton was not very happy in his remark "And at his gills draws in, and at his trunk spouts out, a sea." A Right Whale may remain under water for twenty minutes, which is a marvellous feat for an air-breathing animal. Of the creature's vast strength some indication may be obtained from the record of one which was struck in the early morning off Nantucket, and, heading out to sea, towed a boat with six men in it for seven hours and eventually got free. It took the men five hours' hard pulling to get home.

§ 7

Marine Birds

From among the marine birds we may select two—the penguins and the puffins. Quainter creatures than penguins it is hard to find, but their adaptiveness is not less striking. They have sacrificed their wings to form the powerful swimming flippers which strike the water like springy oars, and enable the birds to dive to a depth of ten fathoms; they can toddle on the ice, toboggan on the snow, and climb a cliff to a height of 700 feet; they can fast for four weeks when they are nesting; they can survive for several weeks within a snow-drift; year after year they find the Antarctic shores from afar although their flightlessness keeps them on the surface of the sea.

Another bird that spends much of the year on the Open Sea is the puffin, a quaint member of the well-defined family of auks.

> The puffin [Dr. Townsend writes] is a curious mixture of the solemn and the comical. Its short stocky form and

> abbreviated neck, ornamented with a black collar, its serious owl-like face and extraordinarily large and brilliantly coloured bill, suggestive of the false nose of a masquerader, its vivid orange red feet and legs, all combine to produce such a grotesque effect that one is brought almost to laughter on seeing these birds walking about near at hand.

They come to our steep shores at the beginning of summer, to mate and breed, and in one locality in the Hebrides Professor Newton estimated the attendance at about three millions. One egg, white in colour, is laid in the recess of a yard-long burrow; it hatches in about a month and the young bird has to be fed for four or five weeks. We see the parents bringing fishes in their bills (shaped like the coulter or foreiron of a plough), and it is difficult to understand how the number is added to without losing previous captures. It may be that the tongue and some spines in the mouth keep hold when the jaws are opened.

There are reptiles of the Open Sea, notably certain fish-eating turtles like the Hawksbill, the Loggerhead, and the Leathery Turtle, all of which have to go back to the sandy shore in order to lay their eggs, just as the land-crabs have to return to the sea. For the Natural History rule—with some explicable exceptions—is that animals go back to their old headquarters when they start a new generation. Then there are the genuine sea-snakes, no doubt descendants of land-snakes, which show a posterior flattening of the body from side to side, giving them a good grip of the water when they swim. At least some of them come to the shore to bring forth their young.

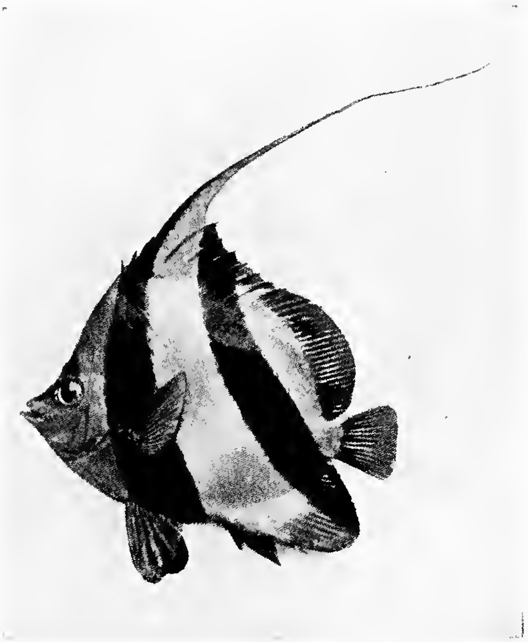
Fishes in the Open Sea

There are many Open-sea fishes like the so-called Flying Fishes, which skim along the waves when pursued by the Tunny, or may take advantage of a breeze to "sail" like an albatross. Mackerel and herring might be counted also as characteristically pelagic fishes. Among backboneless animals there are many

Photo: The Holloway Studio, Ltd.

AN ICEBERG

Icebergs are the detached sea-ends of coastal glaciers. Some are several miles in length and many are very high. As the submerged part gradually melts away they turn turtle. They are glittering white in the sun, often pearl-grey in the shade and rich blue in their clefts. "Their stupendous size, their exquisite architectural composition, more magnificent than the temples and pyramids of Egypt, more overpowering in solemnity than the Sphinx—make the most thoughtless think for a moment of the Power that controls the forces of nature" (W. S. Bruce, of the *Scotia*).



A CORAL FISH

One of the most beautiful of the inhabitants of the coral-reef, resplendent with blues and gold and green.

Reproduced by courtesy of Messrs. Andrew Melrose, Ltd., from "The Haunts of Life" by Professor J. Arthur Thomson.

A FLOATING BARNACLE

After the youthful free-swimming stage is over, the barnacle attaches itself to a piece of floating seaweed or the like. If growth makes it too heavy to be kept afloat by the support, it makes a buoy (shown on the stalk portion in the figure) to restore the balance.

Reproduced by courtesy of Messrs. Andrew Melrose, Ltd., from "The Haunts of Life" by Professor J. Arthur Thomson.

THE FLOOR OF THE DEEP SEA

Showing a dredge being dragged along, a long-legged crustacean (foreground), three strange abyssal fishes, and (extreme left) a graceful yard-high Umbellula, with a tassel of Polyps at the top and the base fixed in the ooze. (For the characteristics of deep-sea animals see text.)

that frequent the open waters—the beautiful sea-snails or sea-butterflies which whalebone whales are fond of, the argonaut cuttlefish which has the most beautiful cradle in the world (see figure facing p. 117), hundreds and hundreds of different kinds of crustaceans, one family of pelagic insects, various transparent worms, the exquisite Ctenophores, the strange Portuguese Man-of-War, the jellyfishes and the swimming-bells, and many Protozoa—often extraordinarily beautiful like the calcareous Globigerinids and the siliceous Radiolaria. Some are active swimmers, some are easy-going drifters, and one must remember that besides the animals that live always in the open waters there are many larvæ which only spend their youth there, afterwards returning to the more strenuous life of the shore. Among Open-sea animals there are endless adaptations that secure floatability, that save them from being broken by the waves, that help them to get their food, and that give the young ones a successful start; but let us take one instance. Ordinary ship-barnacles hatch out as minute free-swimming larvæ; after a while they fix themselves to floating logs or wooden ships, and the front of the head grows into a long flexible stalk, at the end of which there dangles the crustacean's main body. It is encased in five valves of lime, and six pairs of beautifully curled feet waft the food into the mouth. So far the common barnacle, but there is another species (*Lepas fascicularis*) which has a different history.

> It often fastens itself to a small piece of detached seaweed —it may be a feather or a wooden match. Its shell-valves are very lightly built, with little lime in them, and this is well suited for a creature that fixes itself to a light float. But in spite of its lightness of shell, the Floating Barnacle, as we may call it, often becomes, as it grows bigger, too heavy for its float, and begins to drag it below the surface. What, then, does the creature do—we wish we understood it better—but make a somewhat gelatinous, roundish buoy containing bubbles of gas. This is secreted at the lower end of the attaching stalk, just above the main body, and

the self-made buoy enables the barnacle to continue floating at the surface. This is a beautiful adaptation.[1]

Deep-sea Animals

No doubt the strangest haunt of life is the Deep Sea, by which is meant the floor of the very deep parts of the sea and the layers of dark water near the floor. It may be six miles below the surface; there is enormous pressure because of the immense weight of water—2½ tons on the square inch at 2,500 fathoms; it is very cold—a little on each side of the freezing-point of fresh water; it is absolutely dark apart from the fitful gleams of luminescent animals; it is calm, silent, monotonous, and plantless. But there is no "deep" too deep for animal life; indeed, in many places there is an abundant abyssal fauna. Some of the adaptations to the strange haunt are readily intelligible. The long stalks of sea-lilies and sea-pens lift the body out of the treacherous ooze; the long legs of some crabs and sea-spiders are suited for walking delicately; there is often an exquisite development of tactility well fitted for a world of darkness; the body is often porous and so thoroughly penetrated by water that the great pressure is not felt. Perhaps the big goggle eyes of some of the nightmare-like abyssal fishes may be suited for utilising the phosphorescent light. Some Deep-sea animals, whose seashore relatives liberate eggs, bring forth young ones viviparously—probably an adaptation that counteracts the risk of the passive eggs being smothered in the ooze.

As there are no plants in the abysses, the struggle for existence among the larger animals must be keen, and the teeth of many of the Deep-sea fishes declare their fiercely carnivorous habits. We can understand why the gape of some of these fishes is often so large in proportion to the body; they must make the most of a meal when they get a chance. The stomach is sometimes very elastic and the under surface of the body very

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[1] Thomson, *Haunts of Life*, 1921.

dilatable, so that what is swallowed may be large—even too large—for the size of the body. When a big Open-sea animal, like a whale, comes to grief and sinks to the bottom, with its flesh much compacted by the driving out of water from the muscle-fibres, it will be nibbled to bits by legions of crustaceans, such as some of the sea-slaters or Isopods, for it is not known that there is any rotting in the Deep Sea. But what counts for most in the way of nutrition is not the sinking down of big things, it is the rain of dead animalcules from the surface miles overhead. The circulation of matter is doubtless illustrated in the Deep Sea just as elsewhere: the fish eats the crustacean, and that the worm, and that the organic particles of the ooze; but it is possible that the vital processes are slowed down considerably in the conditions of great pressure, low temperature, and eternal night, so that the severity of the rationing is not so much felt as we might expect. The delicate bones and soft flesh of some of the abyssal fishes suggest that they are not capable of very energetic movements. And that would make the food-problem easier.

Can we make any sort of picture of a Deep-sea scene? Darkness like that of a moor at midnight with no light except from stars and will-o'-the-wisps. Beds of sea-pens with their bases in the ooze, swayed gently by their own life, like rocking lighthouses; many other long-stalked creatures, often supremely graceful, the sea-lilies for instance. Now and then among the fixed forms there come ruddy crustaceans, stealthily prowling, some with long limbs like stilts and with far-reaching feelers that probe into distant corners. Then there are cuttlefishes and true fishes, mostly swimming slowly, and often lit up all over like ocean liners at supper-time.

§ 8

Seashore Animals

In the Natural History sense the shore-area means the whole stretch of well-lighted, relatively shallow water, where seaweeds grow. As a haunt it is marked by notable diversity, much changefulness, great congestion, and a keen struggle for existence—struggle for foothold and for food, against furious storms, and the appetite of many enemies.

Almost every kind of animal is represented on the littoral area; there are even some seashore insects and spiders. Thus it seems fair to speak of seals as shore mammals, since they come on to dry land not only at the breeding season but for resting purposes at any time. It is plain that their emancipation from dry land is less thoroughgoing than that of whales, but yet their adaptations are many. The somewhat conical shape is suited for swift swimming; everything is done to reduce friction; the hind-legs are thrown backwards beside the short tail to form a propeller. The nostrils can be closed under water; the sensitive whisker hairs are of use in dark diving; the structure of the eye is adjusted to the gloom. The blubber makes the seal buoyant, it shuts in the animal heat, it is a store to fall back on when it is too stormy to fish. The teeth, with their tips tilted backwards, serve to grip the slippery booty. What a bundle of fitnesses!

The common Seal (*Phoca vitulina*) can swim at the rate of ten miles an hour, which is about half the dolphin's speed. The fore-limbs are kept close to the breast, except when turning or steering; the swimming is due to the very muscular posterior body, aided by the hind-legs—a powerful propeller that does not turn round! The movements on land are rather toilsome. Seals are quick of hearing and gather to unusual sounds, such as music. They have fine brains, affectionate dispositions, and a pleasant playfulness. In their conjugal relations they are at once polygamus and polyandrous. The pup can take to the water the day of its birth, but it needs long rests ashore and much mothering, which it certainly gets.

The Polar Bear of the Far North is a seashore animal, and often lies on the ice waiting for a seal's head to bob up. One of the Arctic Explorers has told us of a Polar Bear lifting the seal right out of the water with one stroke of the arm, and sending it crashing over the ice with its skull stove in. The walruses, also of the North, dig up shore bivalves with their huge tusks. Those archaic mammals, the dugong and the manatee, are also littoral, and it is interesting to hear of the manatee finding its way far inland to that naturalist's paradise, the Everglades of Florida, thus becoming practically a freshwater mammal.

Many birds frequent the shore, but in most cases for a season only. We think of gulls and terns and cormorants, of sandpipers and curlews and oyster-catchers—the last able to knock the limpets off the rocks with dexterous strokes of their bills. The seaweed-eating edible turtles can never go far from the shore, and there is a marine lizard (Amblyrhynchus) of the Galapagos Islands that swims out to sea and dives among the seaweed.

The seashore fishes are many—e.g. fatherlasher, sand-eel, cock-paidle, and stickleback. Very characteristic is the Gunnel or Butterfish (*Centronotus gunnellus*), which is incredibly difficult to catch because of its powers of insinuating itself between the stones and into crevices, and of slipping through your fingers when you have captured it at last. Many of the sea-squirts, which start life as Vertebrates and end as degenerate nondescripts are at home on the shore. And in the clean sand out a few yards there is often some kind of Balanoglossus—a most interesting connecting link (vulgarly supposed to be always "missing") between worms and Vertebrates.

Of littoral molluscs there seems at first no end—the toothsome vegetarian periwinkles, the limpets clinging to the rocks and "homing" from a short distance, the carnivorous "roaring buckies" or big whelks whose shells children hold to their ears like portable "whispering galleries," and the dog-whelks everywhere. Cockles and mussels, oysters and clams, scallops and razor-shells, are familiar bivalves of the shore-area, feeding daintily on microscopic organisms and organic particles which the gills waft into the mouth. The Octopuses lurking among the rocks on the lookout for crabs are the highest of Invertebrates, and are occasionally big enough to be formidable to man as Victor Hugo portrays in his immortal *Toilers of the Sea.*

Shore crustaceans are legion—crabs and lobsters, shrimps and prawns, Amphipods and Isopods, acorn-shells and water-fleas. What combinations of armour and weapons; what camouflaging and trickery; what fitnesses they show! A common accident is the bruising of a crab's leg by a dislodged stone; it will not mend, so it is sacrificed; and under the bandage, where the self-mutilation is effected, a new leg is formed in miniature. Then there is such a "living fossil" as the King Crab of North American coasts and the Moluccas, the last of an ancient race, a Rip Van Winkle among Arthropods, breathing by "gill-books" which no other animal in the world possesses. Its type has been living on since the Triassic—for millions of years; and it is fed to pigs!

There are also starfishes and brittle-stars, sea-urchins and sea-cucumbers, many of them practising the same reflex device as the crabs—a limb for a life: autotomy is followed by regeneration, as the technical phraseology quaintly puts it. Of the legions of worms, wandering and sedentary, segmented and unsegmented, no outsider can form a picture, but everyone knows the lob-worm or lug-worm which the fishermen dig for bait. It does on the flat beach what the earthworm does in the meadow: it keeps the soil circulating. Lower still are the corals and sea-anemones, the zoophytes and shore sponges, and the microscopic Foraminifera and Infusorians. Perhaps there is no haunt of life so interesting as the shore. It is so varied in different places, so diverse at the same place, so changeful, so stimulating, so full of danger. Given a diversified, changeful, difficult haunt, densely peopled by a representative set of animals, there must be a keen struggle for existence and a ceaseless sifting. Given a very stimulating environment, as the shore is *par excellence,* there will be opportunity to test all the variations which living creatures are ever venturing. It may be, indeed, that the stimulating character of the seashore has been, through the ages, *provocative* of those new departures which form the raw materials of evolution. The shore is a treasure-house of adaptations—all sorts of answers-back to the limitations and difficulties which meet the "urges" of "hunger" and "love." Most of the great stocks of animals have passed through the discipline of the shore-school, and even in man we can hear the echoes of the ancient tides.

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XXX

ELECTRIC AND LUMINOUS ORGANISMS

ELECTRIC AND LUMINOUS ORGANISMS

ENERGY, as we have seen in a previous chapter, is the power of doing work, or of changing the state of motion of a body. It takes many forms, such as heat, light, electricity, energy of movement, energy of position, and chemical energy. These are transformable into one another and they are transferable from one body to another body, but no energy is ever lost. The energy of the burning coal may drive a dynamo which generates electricity which lights a street, but

> however much energy may be transformed or transferred, when any quantity of one form disappears a precisely equal quantity simultaneously appears in some other form or forms. Just as with matter, you cannot create or destroy any quantity of energy, however small, and since energy is the great worker of the universe you cannot get something for nothing.

This is the general idea of "the conservation of energy," which must be borne in mind in thinking about those animals, like the Electric Eel, that can give an electric shock, and those animals and plants that can produce a brilliant light, like fire-flies and some bacteria. No living creature produces any new energy; all that can be done is to change one form of energy into another.

§ 1

Luminous Plants

It is well known that fishes hung up to dry are often brightly luminous in the dark. The same appearance is often seen on dead flesh, and it has been familiar since the time of Aristotle. But the discovery of the cause of the light is modern. It is due to some kind of bacterium, which is living very intensely on the fish or flesh, and is giving forth light as a by-product of its activity. The chemical energy of the bacteria is being changed into light energy. About thirty different kinds of luminous bacteria are known, one of the commonest being *Bacterium phosphoreum*. They occur in a great variety of situations, including wounds on the human body, and have often given rise to superstitious interpretations.

Apart from bacteria, there is light-production in some of the moulds and other fungi. Thus in the South of Europe there is a well-known luminous toadstool (*Agaricus olearius*) that grows at the foot of olive-trees, and there are many other cases. In some forms the light is produced only by the fine threads (mycelium) of the fungus; in others the whole of the disc of the toadstool shines. The luminosity of rotting wood, which interested Aristotle, is due to the spreading threads of a fungus, and some roots, e.g. those of the Common Tormentil (*Potentilla tormentilla*) of our hill-pastures, are likewise penetrated by shining filaments. The same explanation applies to the decaying leaves of beech and oak, which may sometimes be seen glimmering on the ground in the darkness. Small yellowish-white spots on the underside of the beech-leaves mark the headquarters of the microscopic threads of a luminous fungus. In decaying wood and leaves the light is due to fungoid threads, not to bacteria; but great care must be taken to make sure that the luminescence in any particular instance is due to the fungus and not to some associated bacteria. For, as a separate article makes clear, bacteria have a finger in many a pie. It is time to drop the word "phosphorescence" altogether in reference to living lights, for they have nothing to do with phosphorus.

In dim recesses among the rocks there lives the so-called "luminous moss," but its gleaming is merely the reflection of the sparse rays of daylight from reflecting surfaces of somewhat lens-like skin-cells. The lens-like structure is an adaptation to make the most of the little light that is going, for light is *everything* to a green plant. The shining appearance that suggests light-production is, so to speak, an incidental phenomenon, meaning no more than the shining of the cat's eyes in the dark. For these cat's eyes have, we feel assured, no power of *producing* light; they are merely light-*reflecting.* This is due to a strongly developed mirror-like layer (tapetum) at the back of the cat's eye, the significance of which is not to make the eye "shine in the dark," but to enable the cat to make the most of the little light there is available during its nocturnal hunting.

Among the other cases of *apparent* light-production we must refer to the beautiful sight that we often see in looking down into a shore-pool. The seaweeds show fascinating changing lights as they are gently swayed by the tide. Brown changes into blue, and blue into gold. This is a physical phenomenon, difficult to analyse, but it has nothing to do with light-production. Two kinds of phenomena are involved. There is a certain amount of iridescence due to the physical structure of the surface of the seaweed, just as in a peacock's feather. But there is also a "fluorescence," depending on deeper properties of the contents of the cells.

As to the moving lights or "will-o'-the-wisps" sometimes seen in marshy places, they are probably due to the combustion of marsh gas or of phosphene, but the question has not been satisfactorily answered. St. Elmo's fire, which sailors sometimes see at the mast-head, is caused by a brush-like discharge of electricity from a low cloud.

§ 2

Luminous Animals

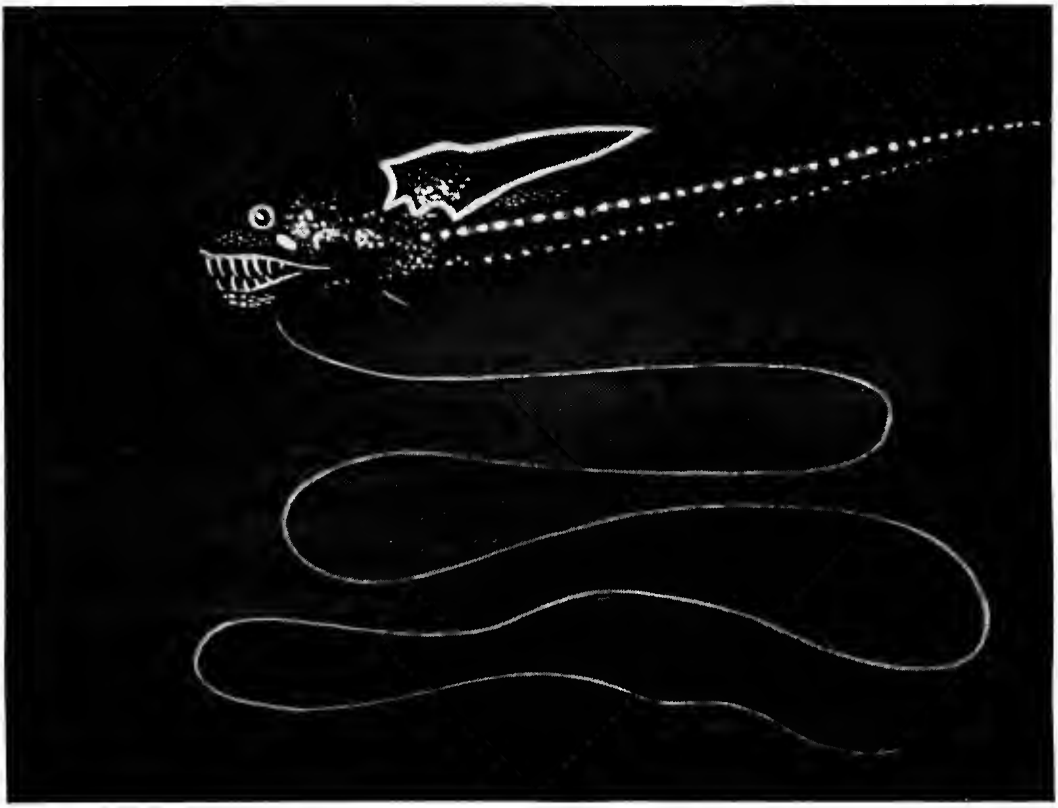
The production of light by animals is a phenomenon which occurs more widely than is generally realised. It is known in no fewer than thirty-six orders of animals, and there does not seem much rhyme or reason in its distribution. It is seen in various Infusorians like Noctiluca, the Night-light, which makes the sea sparkle in the short summer darkness; in numerous Stinging Animals, like the fixed Sea-Pens and the Portuguese Men-of-War of the open sea; in sundry marine worms; in starfishes and brittle-stars; in many crustaceans and insects; in some squids and in two or three molluscs; in compound Ascidians, like the Fire-flame (Pyrosoma), by whose light one can see to read; and in many fishes, especially from the deep sea. Animal luminescence does not occur above the level of fishes, for a "luminous" frog turned out to have dined well on fire-flies, and persistent reports of certain luminous birds, e.g. herons, are probably based on inexpert observation or on some fouling of the bird's feathers with luminous bacteria or fungi. There have been records of luminescence in a few freshwater animals, e.g. in the larvæ of one of the harlequin-flies, but it is usually maintained that "animal lights" occur only in the sea and on dry land.

What is the nature of this animal light? Robert Boyle proved in 1667 that air is necessary for the luminescence of decaying wood and dead fishes. This implies that what occurs is of the nature of an oxidation or combustion. In 1794 the not less ingenious Italian naturalist Spallanzani showed that when dried parts of luminous jelly-fishes are re-moistened they will emit light as before. This implies that what occurs is not in the strict sense *vital.* It is a chemical process. But it is possible to go further.

About 1887 Raphael Dubois, a French zoologist, made a very interesting experiment with a luminous bivalve, called Pholas, which bores holes in the seashore rocks. He made a hot-water and a cold-water extract of the luminous tissue of the mollusc, and let them stand till the light disappeared in both. He then mixed the two together, and there was luminescence again! This led him to the theory that a ferment-like substance,

A DEEP-SEA SCENE (mostly after Chun)

1. A deep-sea prawn with remarkably elongated feelers and legs. 2. A giant sea-pen, Anthoptilum, with its base embedded in the ooze. This is shown separately on page 1002. To the right of Anthoptilum is seen a graceful relative called Umbellula with the tuft of polyps on a long flexible stalk. 3. A small deep-sea fish (Melanocetus) with a luminous organ on the end of a stalk. 4. Young form of a deep-sea fish (Stylophthalmus) from the Indian Ocean, with the eyes on long stalks. 5. An abyssal fish with a prolonged snout region. 6. A beautiful sea-lily or crinoid, with fixed base, and ten feathery arms at the top of the long stalk. 7. Another deep-sea fish with numerous luminescent organs. 8. A small cuttlefish, *Lycoteuthis diadema*, about natural size, with regularly arranged luminous organs.



A REMARKABLE LUMINOUS FISH, *Lamprotoxu flagellibarba*, FROM DEEP WATER OFF THE SOUTH-WEST OF IRELAND. (After Holt and Byrne)

It is about seven inches long. The small spots and the looped band are luminous. Very remarkable is the long tactile barbel. Its coiling below the body is unnatural. It probably projects in front, several times longer than the fish, a feeler in the dark water.

destroyed by heating, and absent therefore in the hot-water extract, produces light when it operates on another substance which is oxidised. In the cold-water extract the light-producing substance had been used up by the ferment; in the hot-water extract the ferment had been destroyed, but the oxidisable material was still present. Therefore a mixture of the two extracts resulted in the production of light for a while.

The experiments of Professor Dubois have been confirmed and extended by Professor Newton Harvey, and the theory works well in regard to the three cases of animal luminescence that have been most studied, namely, the boring bivalve, a small marine crustacean called Cypridina, and those luminous beetles which are properly called fire-flies. The theory may be stated thus. Luminescence occurs in the presence of oxygen and water, and is due to the interaction of two different substances. One of these, the *luciferase,* acts like a ferment on the other, *luciferin,* and oxidises it or accelerates its oxidation, with the result that light is produced, as in some other rapid chemical processes.

Faraday's Contribution

The history of the scientific solution of a problem is rarely simple, and we know we are leaving out some important investigations and investigators when we say that the great steps in the still partial elucidation of the problem are:

(i) When Robert Boyle showed that luminescence was dependent on the presence of oxygen;

(ii) When Spallanzani showed that luminescence was independent of the life of the animal; and

(iii) When Raphael Dubois made it almost certain that in Pholas there is a co-operation of a ferment-like substance with a potentially luminous substance—a view confirmed by Professor Newton Harvey.

But, however short our history, we cannot omit reference to the experiments of Faraday, who was extraordinarily interested in the luminescence of glow-worms (in 1814!) and made many experiments. His genius was evident in his endeavour "to ascertain whether the luminous appearance depended on the life of the fly," in his observation that "no heat was sensible to the hands or to the underlip—the most delicate part of the body." His conclusions were (*a*) that there is a chemical substance in the glow-worm which has power to shine independently of the life of the insect; (*b*) that the luminous substance is probably a secretion of the insect; (*c*) that the shining depends on air; and (*d*) that the luminescence as a whole is controlled by the creature in the ordinary conditions of its manifestations.

§ 3

The Nature of Animal Light

A body that gives off light-rays because of its high temperature is said to be *incandescent.* But when the emission of light is due to some other cause we use the term *luminescent.* All animal light is "cold light," for not only is it produced apart from high temperature, but it is all light without any heat. Thus the luminescence of the fire-fly has been called "the cheapest form of light," for none of the energy is lost in the form of heat, and it would be great gain if man could learn the fire-fly's method. Moreover, the animal light is all *visible* light; it has no infra-red or ultra-violet rays. Yet it behaves in general like ordinary light—it affects a photographic plate; it can produce phosphorescence and fluorescence in various substances; it causes plant seedlings to bend towards it; and it stimulates the formation of chlorophyll.

The Fire-fly's Light Excels all Human Devices

It is interesting to quote a sentence from the paper in which Professor S. P. Langley and Mr. F. W. Very proved that the luminescence of the fire-fly is "the cheapest form of light," mean-

From Professor Doflein.

LUMINOUS DEEP-SEA ANIMALS FROM THE MID-ATLANTIC

The production of light by animals is a phenomenon which is not uncommon, especially in species from the deep sea. The illustration shows some striking examples: a prawn (*Acanthephyra*); a cuttle-fish (*Thaumatolampas*); a fish (*Gonostoma*) pursuing others.

ing by this phrase that in the transformation of energy which results in the insect's glow there is greater economy than in any other known transformation that results in light.

> Resuming, then, what we have said, we repeat that nature produces this cheapest light at about one four-hundredth part of the cost of the energy which is expended in the candle-flame, and at but an insignificant fraction of the cost of the electric light or the most economic light which has yet been devised [this was in 1890]; and that, finally, there seems to be no reason why we are forbidden to hope that we may yet discover a method (since such a one certainly exists and is in use on a small scale) of obtaining an enormously greater result than we now do from our present ordinary means of producing light.

Different Colours of Animal Light

A little must be said in regard to the different *colours* of "animal light," though we are unable to make any suggestion as to their significance, especially as they may be red, blue, and green in one and the same animal at different times. Green is illustrated by the glow-worm and some brittle-stars; blue by the Italian fire-fly; red by the Girdle of Venus and some Salps; and lilac by some Alcyonarian corals. In general it may be said that in marine luminescent animals the commonest colours are blue and light green. A purple light has been ascribed to the swollen proboscis of the Lantern-fly (Fulgora), but this insect is not really luminescent.

Different Modes of Light-Production

The animal light may be produced only in situ in certain cells where the luminous substance is produced, as in the Night-light of the sea or the glow-worm in its "dell of dew." Or there may be a luminous secretion that exudes over the surface of the body and spreads into the sea or forms a trail on the ground. This is seen very clearly in some small crustaceans (Copepods), where the light is not visible until there is actual exudation of the light-producing substance or substances.

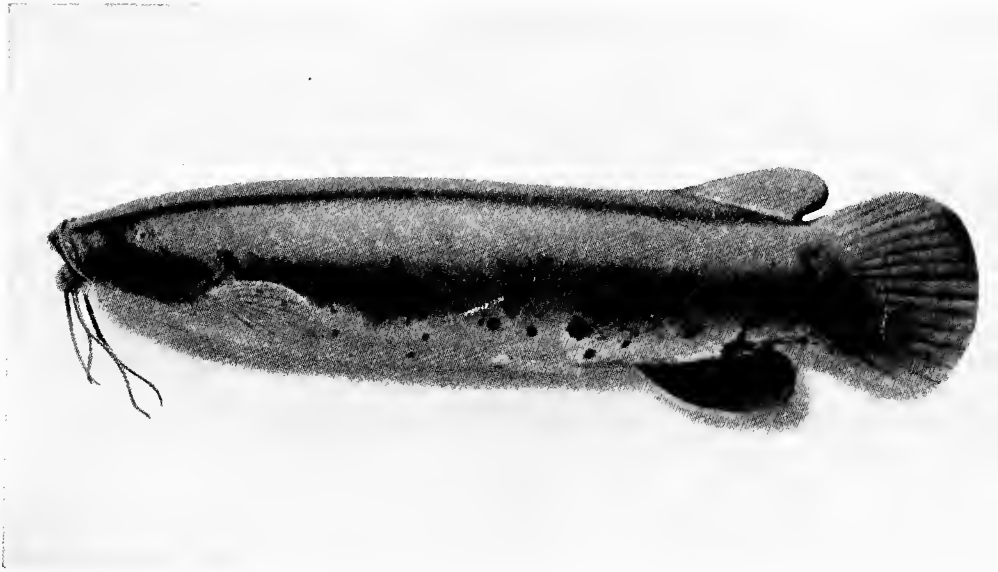
In many cases, however, as in some fishes, some cuttlefishes, and some higher crustaceans, the light streams out from elaborate luminous organs, and the remarkable thing is that these are often like eyes. In front of the light-producing cells there may be a lens, sometimes triple. Behind them there may be a reflector. Round the sides of the organ and behind the reflector there is often a dark envelope shutting off the light from the tissues of the animal itself. And then there is a stimulating and controlling nerve. Now this is all very suggestive of an eye, which has its lens, its reflector (we think of the cat's eye shining in the dark), and its darkly pigmented envelope which makes a camera. In the luminous organ, as Professor Newton Harvey neatly says, the important transformation of energy is *chemiphotic* (from chemical changes to light), while in the eye it is *photo-chemical* (from light to chemical processes). Of course the nerve of the luminous organ is of the stimulating or controlling sort, carrying a message out, while the nerve of the eye is sensory or afferent, carrying messages in to the brain. It seems important to emphasise the resemblance between an eye and a luminous organ, for in the eye there is a direct conversion of light energy into chemical processes, just as in the laboratory of the green leaf. And what is most remarkable in luminous living creatures is the direct conversion of chemical energy into light, and that without passing through heat, and quite apart from the application of heat.

When the Dredge Comes Up

The Marquis de Folin, who led one of the French deep-sea expeditions, describes the surprise and delight of the naturalists on board the exploring vessel when they first saw the dredge brought up in the darkness from a great abyss. There were many coral animals, shrub-like in form, which threw off

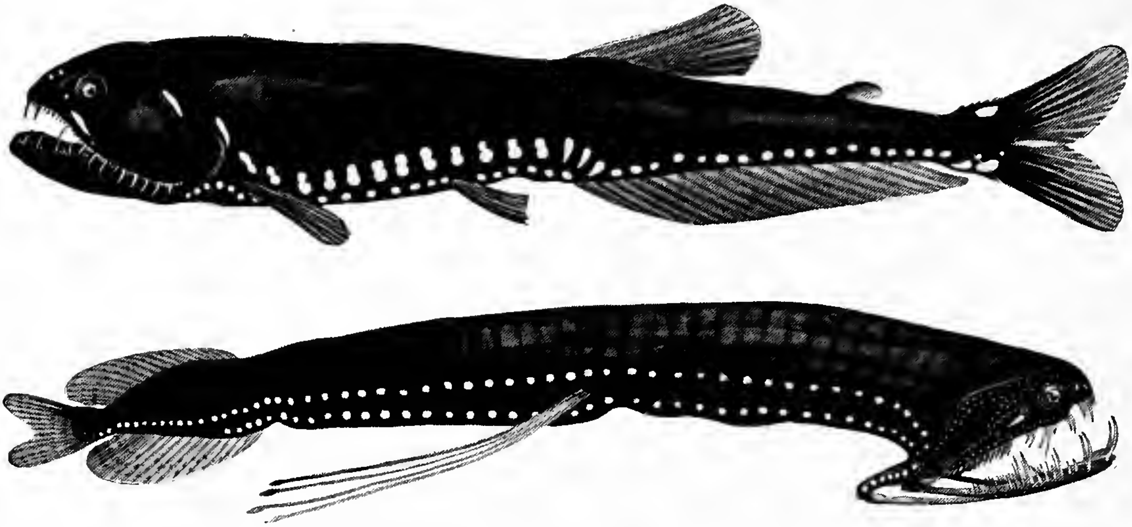
A VIEW IN A SURREY LANE, WITH THE HEDGE-BANKS LIT UP BY GLOW-WORMS THAT HAVE CLIMBED THE HERBAGE

In some favoured places they are specially abundant. The glow-worm (*Lampyris noctiluca*) belongs to the order of beetles, and the European fire-flies are closely allied.



THE ELECTRIC CAT-FISH

Its capacity for producing shocks is only slightly inferior to that of the Electric Eel. Its battery envelops the whole between the skin and the muscles, and is itself a transformation of the skin.



TWO DEEP-SEA FISHES (FROM THE PRINCE OF MONACO'S MEMOIRS)

The upper one, *Gonostoma polyphos*, is about 10 inches long, dense black, without scales, and with numerous luminous organs indicated by the white spots. The upper row of lateral luminous organs are green, blue, and violet; the lower row red and orange; those at the root of the tail red; and there are some violet ones along the ventral surface. The lower fish, *Photostomias guernei*, is smaller, though drawn to the same size. Its surface is velvety black and there are 1,500 luminous organs. The far-back hinging of the lower jaw gives the fish an extraordinary gape.

A FIRE-FLY

A beetle of tropical America with luminous patches on both upper and under sides. The upper patches are shown in white. The figure is twice the actual length. It would seem, in the case of some fire-flies, that flashes of light from the one sex to the other play some part in the mating.

> flashes of light beside which the twenty torches used for working by were pale. Some of these corals were carried into the laboratory, where the lights were put out. There was a moment of magic, the most marvellous spectacle that was given to man to admire. Every point of the chief branches and twigs of the coral Isis threw out brilliant jets of fire, now paling, now reviving again, to pass from violet to purple, from red to orange, from bluish to different tones of green, and sometimes to the white of over-heated iron. The pervading colour was greenish, the others appeared only in transient flashes, and melted into the green again. Minute by minute the glory lessened, as the animals died, and at the end of a quarter of an hour they were all like dead and withered branches. But while they were at their best one could read by their light the finest print of a newspaper at a distance of six yards.

In the corals the luminescence was diffuse, in other cases it was localised in organs. Thus one of the cuttlefishes had about twenty luminous spots, "like gleaming jewels, ultra-marine, ruby-red, sky-blue, and silvery."

The Illumination of the Sea

In Huxley's account of his voyage in the *Rattlesnake* there is a fine description of the illumination of the sea by the "pillars of fire" called Pyrosomes.

> The sky was clear but moonless, and the sea calm; and a more beautiful sight can hardly be imagined than that presented from the deck of the ship as she drifted, hour after hour, through this shoal of miniature pillars of fire gleaming out of the dark sea, with an ever-waning, ever-brightening, soft bluish light, as far as the eye could reach on every side.
>
> The Fire-Flames floated deep, and it was only with difficulty that some were procured for examination and placed in a bucketful of sea-water. The phosphorescence was intermittent, periods of darkness alternating with

> periods of brilliancy. The light commenced at one point, apparently on the surface of one of the members of the Fire-Flame colony, and gradually spread from this centre in all directions; then the whole was lighted up; it remained brilliant for a few seconds, and then gradually faded and died away, until the whole colony was dark again. Friction at any point induces the light at that point, and from thence the phosphorescence spreads over the whole, while the creature is quite freshly taken; afterwards, the illumination arising from the friction is only local.

§ 4

Possible Uses of Animal Lights

When a living creature simply exudes a luminous secretion, or glows as it oxidises certain complex substances in various parts of its body, it is quite possible that the luminescence is not as such of any importance in the everyday life of the creature. It may be no more than the by-play of something more vital, a side-track in the metabolism of the body. Thus no one feels bound to search for a use of the luminescence of certain bacteria or of the *eggs* of fire-flies. But the case is quite different when an elaborate luminous organ has been evolved. Then there *must* be a use. But most of the suggestions in the field are highly speculative.

(1) In some cases the luminescence may possibly serve to scare away intruders, or, if it is intermittent, to distract predatory animals. Perhaps a sea-pen suddenly illumined may warn off intruders. (2) In some cases the light may be a lure attracting booty in the darkness of deep waters, and it is striking that the luminous organ of an abyssal fish is sometimes pendent on a tentacle hanging down in front of the mouth. (3) In other cases the light may serve as a lantern, enabling deep-sea squids and fishes, for instance, to find their way about in the darkness. But this interpretation is only applicable when the hypothetical

lantern is hung in an appropriate place, which is far from being generally true. (4) In many cases the luminous organs have a very definite pattern, e.g. on the sides of the body of the fish. In the dark waters this pattern may facilitate the recognition of kin by kin. (5) In some cases the facts certainly suggest that the light is used as a sex-signal. It is noteworthy that the toad-fish, Porichthys, is luminous only during the breeding season. In the glow-worm, the female of the British species, *Lampyris noctiluca,* is wingless and creeps on grassy banks. She is more luminous than the male beetle, which flies about overhead. The intermittent luminous glow streams forth from two strata of cells, well-provided with air-tubes, near the posterior end of the body of the adult; but it is also seen in the larvæ and on the eggs.

The fire-flies are beetles related to our glow-worms, and the crowds of shining males dancing in the air in the summer twilight are familiar and beautful sights in warm countries. In the case of the Italian fire-fly, *Luciola italica,* the female is a small-eyed, weak-legged creature compared with the male, but she has wings and luminescence. She is very rarely seen except when she attracts round about her on the ground a brilliant circle of ardent suitors. It seems to the human spectator that flashes of light from the one sex to the other play some part in the mating. But there is no certainty. In the meadows around Bologna the female fire-fly may sometimes be seen in the evening among the grass. Numerous males fly about overhead. It looks as if the approach of a male served as the stimulus to the female to let her light shine forth. It looks as if he saw her signal—these things are difficult to prove—at any rate, he is soon beside her, circling round like a dancing elf. But one suitor is not enough. The female attracts a levée. Her suitors form a circle around her on the ground, and flashes pass to and fro. The luminous rhythm of the males is more rapid, with briefer flashes; while that of the female is more prolonged, but with longer intervals.

In a large Ceylonese glow-worm or fire-fly (*Lamprophorus tenebrosus*), the larvæ are luminous as well as the winged male and wingless female, and the colour of the light is emerald green. The female seems to signal to the male but a curious point is that the male often shuts off his light when approaching a "calling" female.

§ 5

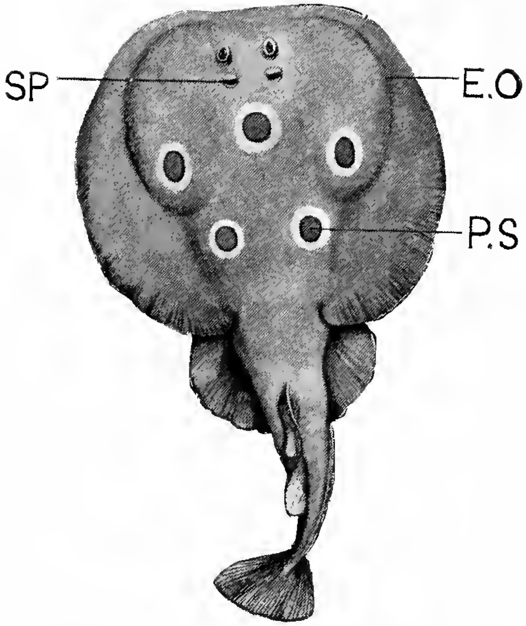
ANIMAL HEAT

If a thermometer is inserted into a beehive it shows a rise of temperature. Where is the heat coming from? The answer must be that the movements of the muscles of the hundreds of bees are producing heat which raises the temperature of the air in the hive. The chief source of animal heat is to be found in the activity of the muscles.

On a very cold day one sees cabmen beating their arms on their body in order to keep warm. They are quickening the circulation by exercise but they are also making the muscle-engines work rapidly, so that much heat is produced. The bee is a cold-blooded animal, i.e. of changeful temperature tending to approach that of the surroundings. The heat produced by the bees passes out into the air, and would be wasted in winter were not the hive a confined space. But the cabman is warm-blooded, i.e. of constant temperature, and in very cold weather he is able to adjust his body-temperature to the circumstances by increasing the internal production of heat and still more by lessening the loss from the skin. For the cold brings about a constriction of the blood-vessels in the skin, less heat is lost, and the man "looks cold." Conversely, on a very hot day a dog increases its loss of heat by putting out its tongue. Only in birds and mammals is there this power of regulating production and loss of heat, which is called "warm-bloodedness." The nerve-centre for its regulation is in the corpus striatum of the brain. It may

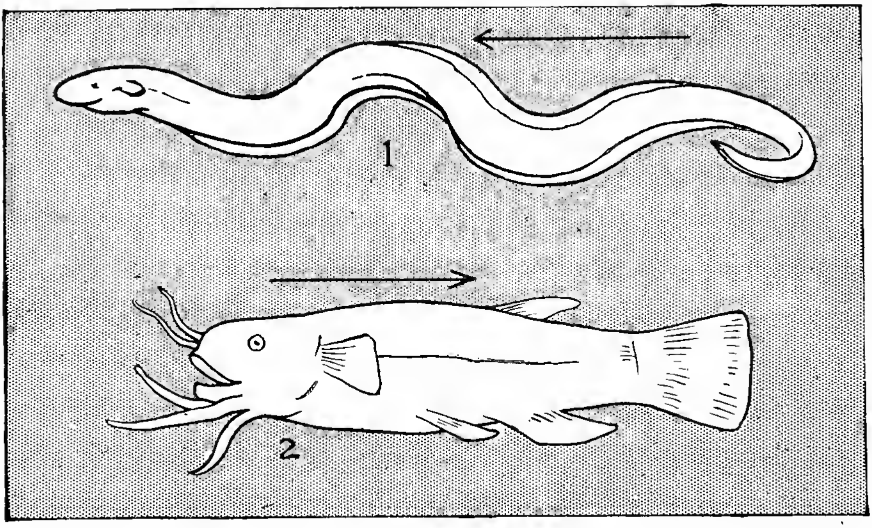
A MAGNIFICENT LUMINOUS SEA-PEN (ANTHOPTILUM), ABOUT A YARD HIGH, FROM DEEP WATER OFF JAPAN

The swollen base is embedded in the ooze, and the stem sways in the water as suggested in Fig. 2 of the illustration on page 994. The twist shown in the figure is not natural. Very striking are the hundreds of large polyps composing the colony: each is about an inch long.



A SMALL ELECTRIC RAY, *Torpedo ocellata*, FROM THE MEDITERRANEAN, SHOWING THE DORSAL SURFACE

The position of the large Electric Organ (*E.O.*) is between the brain and the front of the large pectoral fin. Behind the eyes are seen two breathing holes or spiracles (*S.P.*), by which water passes to the gills. The gill-clefts by which the water passes out are on the ventral surface. There are curious pigment spots (*P.S.*), like eyes, on the dorsal surface.



TWO ELECTRIC FISHES

1. The Electric Eel: Gymnotus. The shocks pass, as the arrow indicates, from the tail towards the head. About four-fifths of its length is tail; on each side of this there lies a huge electric organ. The strength of the electric shock is sometimes sufficient to stun a man or to kill the fish's prey.

2. The Electric Catfish: Malopterurus. The shocks pass, as the arrow indicates, from the head towards the tail.

be noted that shivering is an irregular kind of contraction brought about by commands coming from the nervous system to the muscles, ordering the production of more heat.

All living involves oxidations or combustions, and some of the animal heat is due to the chemical processes which go on ceaselessly thoughout the body. But these account for only a small fraction of the total amount. In the main the animal heat comes from the muscles, and it is important to notice that they produce heat even when the body is at rest. This happens, for instance, when we are asleep, when there are not many muscles actually working except those of the heart and those concerned in breathing movements. The amount of heat produced during sleep is not so great as during waking hours, and everyone knows how cold a sleeper becomes in winter if he has not enough of blankets, how dangerous it is to fall asleep in the snow, and how animals take precautions of many kinds to secure comfortable resting-places.

In the contraction of a muscle there are two chapters. The first is on the whole a physical change; each fibre becomes shorter and broader, as if some spring had been released. No oxygen is used up, no carbonic acid is given off, nor any heat, but a substance called lactic acid is split off from the muscle substance. The potential energy or tension of the resting muscle is converted by contraction into the work done, and the splitting off of lactic acid is somehow concerned with the transformation. But to restore the potential energy, so that the muscle fibre can go on contracting, the lactic acid has to be put back in its original place. This restoration process requires energy, and that is supplied by the oxidation of blood-sugar and perhaps some fat. Much oxygen is used up, carbon dioxide is given off, and heat is evolved. Thus we come to *the main source of the production of animal heat.* But it must be noted again that heat is produced in a resting warm-blooded animal by the slight contractions which keep up what is called the reflex tone of the muscles. Moreover, if part of the tension of the contracting muscle is not converted to external work, part of the energy will be degraded into heat.

§ 6

ANIMAL ELECTRICITY

Electric Animals

Electrical changes are known to occur in connection with the activity of various parts of animals, e.g. muscles, nerves, the retina of the eye, and glands. Similarly, when the carnivorous plant known as Venus' Fly-trap shuts its leaf on an insect, there is an electrical change comparable to that which occurs when we contract a muscle—a fine instance of the unity of vital processes. Electrical changes have also been observed in connection with the movements of the Sensitive Plant, the rotation of the living matter inside the cells of the stonewort Nitella, and even in the ordinary upbuilding of carbon compounds that occurs in the green leaf of any plant. It looks as if electrical changes were associated with active vital processes in general, and this should be kept in mind when we pass to special cases where this transformation of energy becomes, so to speak, dominant and of high value in itself, as when the Electric Eel gives a shock.

The Electric Ray

The Electric Ray (*Torpedo marmorata*) of the Mediterranean is a smooth-skinned relative of the skate, and may be a yard long by two feet broad. It has two large electric organs between the front of the head and the gills, extending through the thickness of the body, and somewhat like flat kidneys in shape. Each consists of thousands (it may be half a million) of transparent perpendicular prisms, or "electric plates," separated by partitions. Each prism is due to the transformation of a muscle-fibre and its nerve-endings. When the fish is excited the dorsal end of each plate is electrically positive to the ventral end, and a succession of shocks passes from the under to the upper surface of the head. If the fish is grasped a very distinct and, indeed, painful current passes up the arm, and this is enough to benumb or even kill animals that come into close quarters with the Torpedo. Repeated discharges weaken the strength of the shocks. It is interesting to find that ordinary skate have two small electric organs about half-way up the tail. They are probably organs in process of evolution.

The Electric Eel

In shallow parts of the Orinoco, Amazons, and associated rivers, and in the marshes near by, there lives the well-known Electric Eel (*Gymnotus electricus*), which is able to stun a beast of burden. The fish may attain a length of 8 feet and a weight of 50 pounds. About four-fifths of the length is tail, and on each side of this there lies a huge electric organ, consisting of transformed muscular tissue supplied by numerous nerves from the spinal cord. The anterior and posterior ends of the longitudinally disposed muscle columns become oppositely electrified, and the current passes from the tail to the head. When the Electric Eel bends its body so that the head and the tail touch different parts of the same fish, a very strong shock is given. Repeated discharges, which may be reflex or voluntary, weaken the strength of the shocks, but the strongest are sufficient to kill the prey. Other electric organs have been found in the big-brained Mormyrs (Mormyridæ) of the Nile. The organ is situated on each side of the tail region, and is derived as usual from transformed muscular tissue. The shock is feeble.

The Electric Cat-fish

Quite different from all the other electric fishes is the Electric Cat-fish (*Malopterurus electricus*), found in rivers of Tropical Africa and in the Lower Nile. It is a sluggish, light-avoiding creature, sometimes a yard long, able to give shocks powerful enough to kill other fishes. The electrical apparatus is unique in being formed of modified skin-glands, which form a greasy mantle all round the fish between the skin and the muscles. It is controlled by a single nerve-fibre arising from one huge ganglion-cell on each side at the front end of the spinal cord. The (electromotive) force of the shock in this fish amounts to 450 volts, which is very high. The shock given by a Malopterurus or a Gymnotus to a man who steps on it with his naked foot is enough to knock him down.

There are said to be about fifty different kinds of fishes that give electric shocks, but only a few of these have been carefully studied. In the cases that have been investigated, with the exception of the Electric Cat-fish, the electric organ consists of transformed muscle and the associated nerve-endings. It is important to emphasise the fact that an ordinary muscular contraction is associated with an electric change, and that the same is observed in glandular activity. What is ordinarily a trivial accompaniment of an important change becomes in the electric organ the main issue. The electric organ discharges electricity, not as a current, but in a number of short shocks (lasting in Torpedo a small fraction of a second), and it is interesting to notice that strychnine, which throws the muscles of an animal into convulsions by acting on the nervous system, causes the Electric Ray to give off shock after shock in rapid succession until the creature is exhausted.

Biological Conclusion

There remains much that is puzzling in regard to the production of light and electricity by animals. In many cases it is impossible to suggest what use there may be in the luminescence. In many cases an electric organ also baffles us by its apparent uselessness. The general idea that emerges is this, that a merely accessory by-play or by-product may persist for a long time in the wake of some process or result of vital significance; but that the by-play or by-product may be seized upon, accentuated, and exaggerated when the conditions of life give it vital significance and survival value.

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XXXI

NATURAL HISTORY

V. The Lower Vertebrates

NATURAL HISTORY

V. THE LOWER VERTEBRATES

THE genealogical tree of animals splits at the top into the two great branches of Birds and Mammals, both of which may be traced back to an origin among extinct Reptiles. Separate articles have dealt with Birds and Mammals; it is now necessary to turn to the Lower Vertebrates, and a very interesting series they are. As they afford fine illustrations of progress, it will be convenient to begin with the most primitive types and work upwards.

The Essential Characters of Vertebrates

As far back as Aristotle (384-322 B.C.) there was a recognition of the distinction between Backboned animals (Vertebrates) and Backboneless animals (Invertebrates). It was seen that Mammals, Birds, Reptiles, Amphibians, and Fishes have a good deal in common, such as backbone and red blood, and stand by themselves as contrasted with molluscs, spiders, insects, worms, sea-urchins, corals, sponges, and unicellulars, which make up the sub-kingdom of the Backboneless.

Now this old contrast lasts to-day, but there are three changes in the modern outlook. In the first place, we know more clearly what are the deep differences—the most significant differences—between the Vertebrates and the Invertebrates. (*a*) Many Invertebrates, like a lobster or an insect, have a well-developed nerve-cord, but this lies on the *ventral* surface of the body, and is connected anteriorly, by a ring round the gullet, with a dorsal brain in the head. In Vertebrates, however, the whole of the central nervous system lies along the *dorsal* middle line, forming the brain and the spinal cord. (*b*) Underneath the spinal cord of the Vertebrate there runs a supporting skeletal rod, the (endodermic) notochord, which is pinched off from the dorsal middle line of the embryonic food-canal. It is the supporting axis of the body in a pioneer Vertebrate like a lancelot or a lamprey, but in most fishes and in all higher forms it is replaced by something better than itself—the (mesodermic) backbone. The notochord does not become the backbone; it is rather like a preliminary scaffolding—a provisional support—which is replaced in most cases by a more permanent structure of different embryonic origin. This is what is called *the substitution of organs.* The backbone with its numerous vertebræ is the substitute of the old-fashioned notochord.

But it is a fine example of the past living on in the present that the embryos of the higher Vertebrates always have a notochord, though it is represented after embryonic life by vestigial traces only. As regards the notochord, even man has to climb up his own genealogical tree. (*c*) The anterior region of the food-canal in fishes and tadpoles shows slits, bordered by gills, through which flows the water that is used in breathing. In Reptiles, Birds, and Mammals these gill-slits are not used for breathing, and are not of any use at all except that the first becomes the Eustachian tube, leading from the ear-passage to the back of the mouth. But these gill-slits, never represented in Invertebrates, constitute an important Vertebrate character. The recent discovery of minute traces of gills in the embryonic gill-slits of two or three Birds and Reptiles shows us again how the past lives on in the present. (*d*) Another deep difference is that the eye of the Vertebrate has its beginning as an outgrowth from the brain, whereas the eye of the Invertebrate is an ingrowth from the skin. (*e*) Many an Invertebrate has a well-developed heart, but it is *dorsal;* whereas the Vertebrate's heart is *ventral.* Thus we see that to put an Invertebrate into the Vertebrate position we must *invert* it, bringing the nerve-cord to the dorsal surface and the heart to the ventral surface. This has suggested the hypothesis that Vertebrates may have evolved from Invertebrates which took to swimming on their backs—not such a wild theory as it may seem at first sight. In any case the theory indicates the second change in the modern outlook—that we inquire into the pedigree of Vertebrates.

There is no certainty, but there is probably most to be said for the hypothesis that the primitive Vertebrates were scions of a ringed worm (Annelid) stock. The third change that has come about is the recognition that Fishes are not by any means the lowest Vertebrates. Below the level of Fishes, there are the jawless lampreys and hags, and the extinct, likewise jawless, Hypostomes. Below these come the lancelets; simpler still the sea-squirts; and lowest of all are numerous worm-like forms called Enteropneusts which almost seem to bind the Vertebrates to the Invertebrates. Let us briefly consider these lowest rungs on the ladder of Vertebrate evolution.

§ 1

The Pioneers

The Enteropneusts (their name means "gut-breathers") are certainly old-fashioned animals, and they are widely distributed in many parts of the world. They usually eat their way through sandy mud off the coasts. Probably they represent a side-track on the main line of Vertebrate ascent, for they are either Vertebrate-like worms or worm-like Vertebrates. Thus they have got numerous gill-slits opening from the pharynx to the dorsal surface of the body, and another remarkable feature is that the body-cavity develops in a manner closely similar to that seen in lancelets. The size varies from about an inch to several feet; the colours are bright; there is usually a peculiar odour like that of iodoform; the food consists of microscopic organisms and organic particles in the sand or mud; the sexes are separate. The body shows a burrowing proboscis in front of the mouth, a firm collar behind the mouth, a region with gill-slits, and a coiled posterior portion. In the proboscis there is a little supporting rod like a notochord, and there is a nerve strand both on the mid-dorsal and on the mid-ventral line. One of the common genera is called Balanoglossus, and besides Enteropneusts in the strict sense there are some other remarkable annectent types, notably the strange Cephalodiscus, discovered by the *Challenger* expedition. They show the falsity of the frequent anti-evolutionist suggestion, that connecting links are always "missing." The forms we have just spoken of may not be on the direct line, but that they are transitional is evident.

The Sea-Squirts

The second rung of the ladder is represented by Tunicates, Ascidians, or sea-squirts, many of which are like double-mouthed leather water-bottles. Nothing could be less like a Vertebrate than a typical sea-squirt, and yet it begins its life as a free-swimming larva, like a miniature tadpole, with a brain and spinal cord, a distinct notochord, two gill-slits, a ventral heart, and a brain-eye. The larva is an undoubted Vertebrate, but in most cases it fastens itself by its head to seaweed, stone, or shell, and becomes a nondescript. With great rapidity there sets in a progress of degeneration: the Tunicate stumbles at the threshold of vertebrate life. It begins well, but it does not fulfil the promise of its youth. In a few cases, e.g. Appendicularia, the larval characters are retained throughout life, exceptions that prove the rule. Many Tunicates form colonies and some of these are free-swimming, like the tubular Pyrosome or Fire-flame, which is sometimes 2–3 feet long and splendidly luminescent. On a line of their own are the glassy Salps of the Open Sea, which sometimes form long chains.

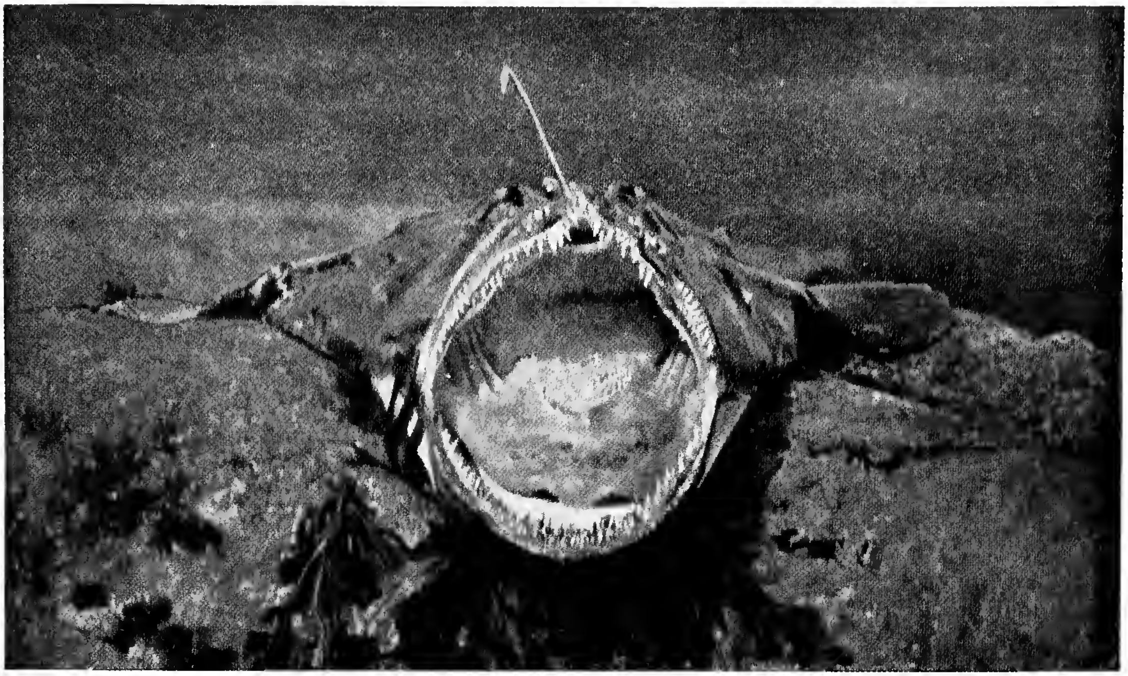

Photo: E. Step, F. L. S.

A FULL VIEW OF THE ANGLER'S TRAP

The Angler is not well-adapted for swimming, but it can lie almost concealed owing to its colour harmonising with the seaweeds. With its well-armed jaws open, and its "bait" above them, dangling in the current, it waits patiently for any passing fish to come within range. A touch is sufficient to make the lower jaw close with a snap. The backward-bent teeth, being hinged at their bases, make the entrance of the prey easy and exit impossible.

THE PROTEUS, OR OLM

This queer inhabitant of dark, subterranean waters was first discovered in the Adelsberg Cave, near Trieste. It is a blind newt, about ten inches in length, of a transparent fleshy-whiteness, and with persistent coral-red gills. Exposure to light causes the skin to develop pigment.

Photo: W. S. Berridge.

THE TUATERA

The Tuatera of New Zealand might aptly be termed "a living fossil," for it is the sole representative of an ancient group of reptiles which flourished in the age of the New Red Sandstone. It is, besides, notable for a rudimentary third or cyclopean eye situated deep down in the tissues of the brain. It lays its eggs (about ten in number) in the sand, and they are remarkable in requiring over a year to hatch out.

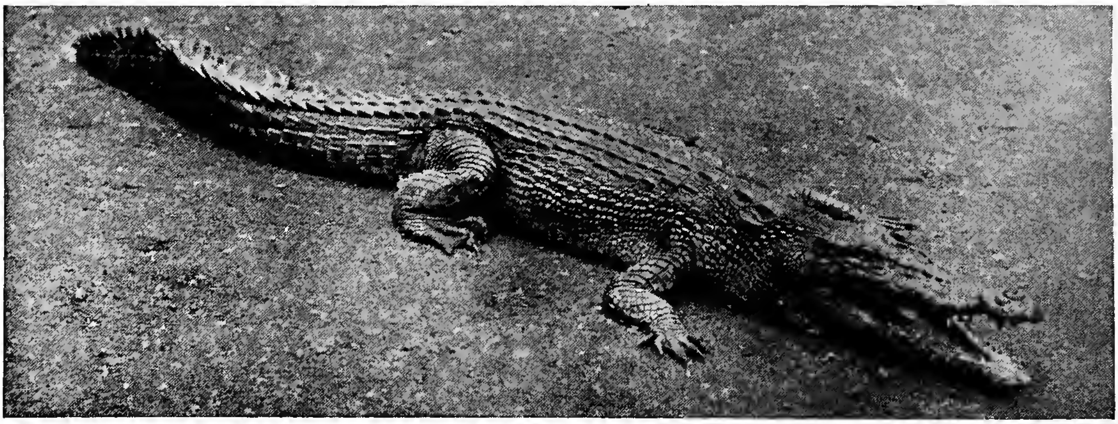

Photo: W. S. Berridge.

INDIAN CROCODILE

These reptiles (which sometimes reach a length of 18 feet) often lurk in river shallows near fords or bathing-places awaiting an opportunity to seize and drag below the surface a human or four-footed victim. In addition to the terrible jaws and teeth the tail is a powerful weapon, while the strong defensive armour can often turn even a bullet.

The Lancelets

Another class of Primitive Vertebrates is constituted by the Lancelets, such as Amphioxus. They are spindle shaped marine animals, about two inches long, translucent, fond of lying in fine sand with the mouth protruding, and surrounded by a wreath of ciliated cirri by means of which microscopic organisms and particles are wafted in. Now and then the lancelets rise out of the sand and swim about. They are archaic creatures and have had time to establish themselves in most seas. They have so many negative characters—no skull, no jaws, no limbs, no brain, no eye, no heart, and so forth, that one begins to wonder what they have. But they are genuine Vertebrates—with a spinal cord, a notochord, and gill-clefts; and they have several features in common with Tunicates, to which they present no superficial resemblance.

The Round-Mouths

Before we reach the level of Fishes there is the small class of Cyclostomes or Round-Mouths, represented by the lampreys and hags. If the word fish is to mean anything, it cannot include these forms, for they are jawless, limbless, and scaleless, and they have peculiar gill-purses and an unpaired nostril. They are antiquities and seem to be related to a very remarkable fossil called Palæospondylus, which occurs in the Old Red Sandstone of Caithness—a little animal about the size of a tadpole, but a most interesting relic of early vertebrate life. Still more ancient are the extinct Hypostomes, also jawless, which make their appearance in the Silurian, e.g. Pterichthys and Pteraspis. They are the oldest known Vertebrates, and it is a fact to be carefully considered that the vertebrate stock had more than begun in Silurian times, many scores of millions of years ago!

Lampreys are eel-like slippery animals, with gristly skeleton, simple skull, horny teeth, and seven pairs of gill-pockets. The smaller kinds live in fresh water; the yard-long *Petromyzon* *marinus* spends most of its life in the sea, but ascends the rivers to spawn, dying thereafter. The young forms are called "nine-eyes," though practically blind, and they remain larval for two or three years. Lampreys eat worms and other small fry, and even dead animals, but they sometimes fasten themselves aggressively to fishes, rasping holes in the skin, and sucking the flesh and juices. The Glutinous Hag (*Myxine glutinosa*) is a strange flesh-coloured, eel-like creature, about a foot in length, which lives in rather deep parts of the sea. It is a bundle of peculiarities. Thus the eye is arrested on its way out from the brain; under provocation the skin secretes so much slime that the old naturalists spoke of the hag "turning water into glue"; it seems to be first a male and then a female. Hags devour the bait and even the fish from the fisherman's lines, and three or four are sometimes found *inside* a hooked fish.

They are sometimes very troublesome by clogging the lines with slime and by biting off the bait. Of the Californian hag, Bdellostoma, a Chinese fisherman said with exasperation "Evely hook—one Sliklostome," having learned the scientific name of the creature from the students of the Hopkins Laboratory at Monterey.

§ 2

Fishes

The first Vertebrate animals to attain great success were the fishes, and they are as well adapted to the water as birds to the air. It is useful to distinguish three sub-classes: (1) the Gristly fishes with ventral mouth, like shark and skate; (2) the mostly Bony fishes, like cod and salmon, herring and eel, with terminal mouth; and (3) the small group of double-breathers or Dipnoi, which are half-way to Amphibians, having evolved a lung. These have all got their extinct predecessors, and there are some "living fossils" of great interest, like the Polypterus of African rivers and the Bony Pike (Lepidosteus) of North America with its splendid suit of chain armour.

In the great majority of fishes the body is torpedo-like, with stream-lines well suited for rapid swimming. The method of swimming is a kind of sculling; the posterior part of the body consists almost wholly of muscle and jerks off a mass of water on each side alternately. In a few cases, like the skates, where the tail has become a weapon, the paired fore-fins are used in swimming; in ordinary fishes they are balancing organs. Of course there are peculiar shapes, adapted to peculiar conditions: the skates are flattened from above downwards and lie on their ventral surface on the floor of the sea; the bony flat-fish, like plaice and sole, undergo in early life a flattening from side to side. They rest and swim on their right side or left side; pigment disappears from the down-turned unillumined side, which glistens with a silvery deposit of the waste-product guanin; the eye on the down-turned side travels round the corner to join its fellow on the upturned side, be that right or left. Then there are inflated globe-fishes adapted for floating on the surface of the sea; cylindrical eels adapted for insinuating themselves through crevices or burrowing in the mud; flying-fishes able to volplane over the waves; and the quaint sea-horses, with prehensile tails, suited for a leisurely playful life among the seaweed.

Similarly there are endless adaptations to different ways of feeding—the sharks intensely carnivorous, with great strength of jaw and an abundant succession of formidable teeth; the angler or fishing frog with its fishing-rod and dangling "bait," and an enormous gape, bordered by backward-bent teeth, which, being hinged at their bases, make the entrance of the booty easy and the exit impossible; the mackerel depending mainly on minute open sea crustaceans; the carp to a great degree vegetarian. Most fishes are prolific, sometimes producing several millions of ova; but there are some cases where the evolution of parental (usually paternal) care has coincided with economised reproduction. Thus the stickleback makes his nest; the sea-horse shelters the developing ova in a skin pocket; and Kurtus, from New Guinea, carries a double bunch about on the top of his head. In the great majority of fishes the fertilisation is external, the male discharging the "milt" (seminal fluid) on the "spawn" (the liberated ova); but there is internal fertilisation in Gristly Fishes and in viviparous Bony Fishes, such as the Viviparous Blenny, where the eggs hatch out within the mother.

Many fishes have a much less definite limit of growth than is usual among animals—thus a haddock sometimes occurs a yard long—but it is very rare for a fish to show any hint of senescent changes in its tissues. The age is registered in the rings of growth in the scales and ear-ossicles. Finally, we may note that in the class of Fishes we have the beginnings of bone, of jaws, of paired limbs, of true teeth, of paired nostrils, and many other features. All fishes have gills, feathery outgrowths of the wall of the pharynx on which the blood is exposed over a large surface to the oxygenating action of the water. But a few of them, like the Bony Pike, use the hydrostatic swim-bladder as an auxiliary breathing organ, while in the three Mud-fishes or Dipnoi this structure certainly deserves the name of lung. In this respect, as well as in their multicellular skin-glands (those of fishes are almost invariably unicellular), their incipiently three-chambered heart, and the first appearance of a great posterior vein, resembling the inferior vena cava of higher vertebrates, the betwixt-and-between mud-fishes point the way to Amphibians.

§ 3

Amphibians

The modern frogs and toads, newts and salamanders, are not impressive. The Japanese Giant Salamander, Cryptobranchus, which lives like a hermit in the dark places of cool, clear, swiftly flowing brooks, may attain a length of 5 ft. 3 in., but that is quite prodigious for a modern Amphibian. The large American bull-frog (*Rana catesbiana*) that calls from the ponds in a hoarse

Photo: James's Press Agency.

SPOTTED TURTLES FIGHTING

Turtles of various species inhabit the seas of warm latitudes. They swim actively. They come ashore to lay and bury their soft-shelled eggs in the sand.

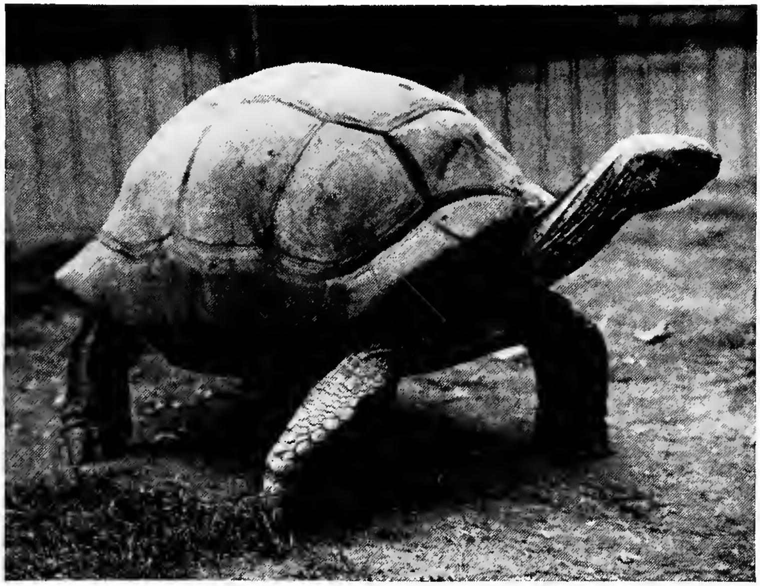

Photo: James's Press Agency.

ELEPHANTINE TORTOISE

These reptiles attain a large size and may live to a great age. They lead sluggish lives, their diet is vegetarian, and they move slowly about encased in the heavy armour into which the more vulnerable parts can be withdrawn at will.

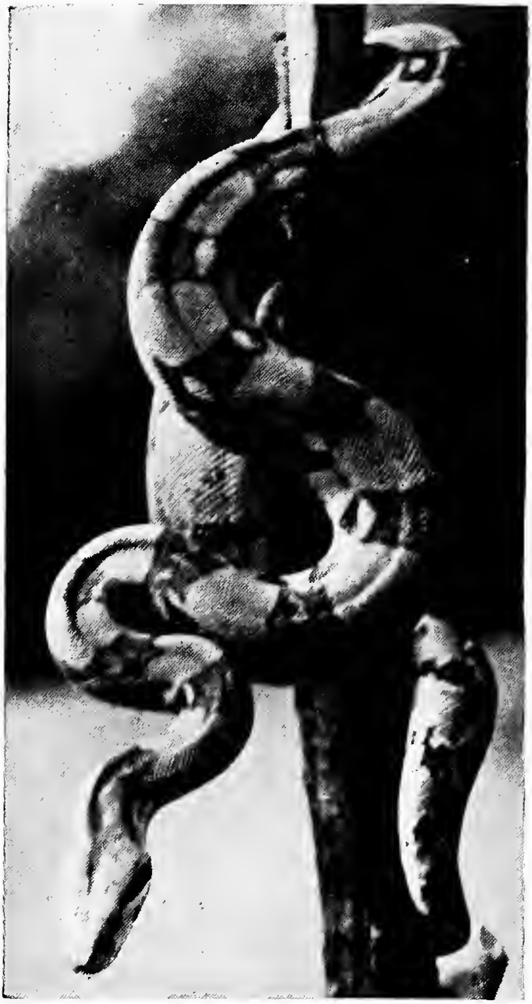

Photo: James's Press Agency.

PYTHON

These snakes grow to a very large size. They are not poisonous, but kill their prey by coiling their strong bodies round and round their victims.

bass voice "brwoom" (some observers hear it as "more rum") is only 7 inches long, or 10 if the hind-legs are stretched out. The fact is that most living Amphibians are pigmies, and we have to go back to the extinct Carboniferous forms to find the giants of this class. The Amphibians seem to have begun in the Devonian epoch (the first terrestial footprint has this date), but their Golden Age was in the Carboniferous. Since then they have gradually declined—gentle, unarmoured, weaponless creatures with a poor development of brains. Yet we must look to the ancestors of our Amphibians for many new acquisitions—fingers and toes for the first time, genuine ventral lungs, open communications between the nostrils and the mouth, a three-chambered heart, and a mobile muscular tongue. With few exceptions the young stages of Amphibians breathe by gills, and these are sometimes retained throughout life, as in the Proteus of the Dalmation caves. But all adult Amphibians have lungs except a few abnormal newts. And the skin is also capable of cutaneous respiration, as our frogs illustrate in their winter's rest. The greatest interest of Amphibians is that they were the first Vertebrates to colonise the dry land, and that most of them recapitulate in their individual life-history to-day some of the steps in that great adventure.

Reptiles

Lizards, snakes, tortoises, crocodilians, and the archaic Sphenodon of New Zealand—another "living fossil"—represent the reptiles of to-day, and they had their extinct predecessors. But besides the latter, which are continued on in their modern descendants, there were many ancient stocks that have entirely ceased to be. Thus the flying dragons or Pterodactyls have had no successors, and the same is probably true of Ichthyosaurs and Plesiosaurs. The blood of some of the Dinosaurs may still be flowing, so to speak, in birds and mammals, which evolved from that progressive and heterogeneous stock; but there are other reptilian branches on the genealogical tree which bear no leaves to-day. It was probably in the Carboniferous epoch that Reptiles evolved from their Amphibian ancestry; in the Permian they were the dominant Vertebrates.

The New Zealand Tuatera (Sphenodon) belongs to an order by itself, of which it is the sole survivor. It was in it first of all that the pineal body—an upgrowth from the roof of the tween-brain (optic thalami)—was recognised as having distinct traces of an eye, e.g. complex retina. This rare animal, 1–2 feet long, is preserved in some small islands off the New Zealand coast, surviving as best it can in virtue of its "cryptozoic" or elusive habits. It lives in a burrow, feeds on insects, worms, and other small creatures, and comes out at night. It sometimes shares its hole with a petrel. About ten eggs are laid in the warm sand, and they are remarkable in requiring over a year to hatch out. As in the case of other archaic types, the development of Sphenodon is of great zoological interest.

Crocodiles and alligators and the long-snouted gavials are strong, heavily armoured reptiles, at home in tropical rivers, clumsy and stiff-necked on land, feeding on fishes and small mammals, growing very slowly and without obvious limit, and attaining a great longevity. They often lie in wait for their victims at the water's edge, and drown them, being themselves able to breathe while the mouth is full of water. For they shunt the opening of the windpipe forward to embrace the posterior nostrils, situated at the end of the bony tunnel at the very back of the mouth. When the crocodile raises its nostrils above the surface of water during the drowning operation, the air can pass continuously to the lungs, and no water can go down the wrong way. The crocodilians have a four-chambered heart as in birds and mammals, but they remain cold-blooded. They are the only Vertebrates other than mammals to have teeth in sockets, and if one be broken there is another and another ready to replace the loss. In other words there are many sets of teeth. The eggs are like those of geese and are buried in the soil to be hatched by the heat of the sun, sometimes abetted by decaying vegetation. In some cases the mother digs up the hatching eggs when she hears the young ones piping from within. The Indian crocodile may reach a length of 18 feet, and the gavial may be 2 feet longer.

Tortoises and Turtles

Tortoises are among the most perfectly armoured of animals, surpassed only by the armadillos. They are boxed in by an arched carapace above and a flat shield below, and they can partially retract their head, tail, and limbs. They are almost invulnerable. They tend to be slow in growth and slow in movement; they have a very tough constitution and can endure prolonged fasting. The tissues are famous for their tenacity of local life; thus the turtle's heart will beat for two or three days after the rest of the animal has been made into soup.

The Lacertilians or lizards form a very heterogeneous order. They are usually active in their movements, but fond of basking in the sun; many of them are resplendent in their colouring, while others harmonise to perfection with their immediate surroundings; most of them are able to surrender the tail when seized by an enemy and to regrow it at leisure. Most lay eggs, but a few, like the British brown lizard, are viviparous. The only poisonous lizard is the Mexican Heloderma; the Chamæleons are adapted for arboreal life and are famous for their colour-changes; the Phrynosome or "Horned Toad" of Texas and Arizona is full of curiosities, e.g. in having an eyelid hæmorrhage when much excited; the little Dracos of the Far East swoop from tree to tree on collapsible parachutes of skin extended on much elongated ribs; the snake-like slow-worms and Amphisbænas are suited for burrowing in the earth. Perhaps there is no order of Vertebrates so diversified as the lizards.

The most highly specialised of the Reptiles are the snakes or serpents (Ophidia). Apart from rudiments of a hip-girdle and the vanishing points of hind-legs in pythons, boas, and a few others, snakes are thoroughly limbless, and there is no hint of shoulder-girdle or breastbone. They row on the ground with the ribs, which are attached to the ventral scales; and they may jerk themselves forward by a rapid straightening of their sinuous curves. Yet they swim and climb and burrow. The mouth is very expansible and suited for booty large in proportion to the size of the head; the bifid tongue is a sensitive organ of touch; a pair of salivary glands may be transformed into poison glands; the poison fangs are teeth folded to make a groove or a canal for the venom; the internal organs of the body are adjusted to the great elongation; the outermost layer of the epidermis covering the horny scales and taking their imprint, is peeled off and turned inside out from the head to the tail as a coherent "slough"; most are oviparous, but the adder and some others have developed viviparity.

Such, then, is a survey of the Lower Vertebrates: the worm-like Enteropneusts, the Sea-Squirts, the Lancelets, the Round-Mouths, the Fishes, the Amphibians, and the Reptiles. From among the last there arose the Higher, Warm-blooded Vertebrates—the Birds and the Mammals.

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XXXII

THE EINSTEIN THEORY

THE EINSTEIN THEORY

Are Things What they Appear?

LET us see what some of the startling ideas of Einstein are which have upset many of our fixed notions about things. We have been taught that parallel lines never meet, that the shortest distance between two points is represented by a straight line. According to the Einstein theory what we think are straight lines are "really" curved lines. We shall understand this point better later on. Meanwhile, suppose you draw a straight line on a sheet of paper. To you, looking only at the paper, the point of the pencil will have travelled in a straight line of, suppose, a foot long in a second. To an observer in the sun it will have moved through space, not only with the motion of your hand, but through the vast curve of the earth's spin round its axis, and the still vaster curve of its rotation round the sun. Where you see a short straight line he will see a curve some forty miles in length. Which is right? Both. The distance, as well as the straightness or curvature, described by a moving point is *relative*—they depend on the observer.

Motion and direction are *relative*—they depend on the observer. A body alone in empty space cannot be said, with any meaning, to be in motion; for motion implies that it is getting nearer to, or farther from, some other point. Again, if there are two such bodies which start moving side by side, but at different speeds, an observer on the swifter body will see the other apparently *receding* from him. To an outside observer it will appear to be following in his wake. Which is right? Both. Motion and direction are relative—they depend on the observer.

If you were sitting in a railway carriage with the window blinds drawn, the train running smoothly on a straight track with unchanging velocity, you would find it impossible to tell by any mechanical means whether the train was moving or not. You cannot detect in such circumstances any motion without reference to some outside object. Further, you may have noticed that if you look through the carriage window at a passing train on an adjoining line you are unable to tell whether that train or your own is in motion. In this way we are often puzzled to say whether some train is moving with us, or against us, or standing still. All motion is relative.

All this is preliminary—we shall see the bearing on Einstein's argument later.

Space also is a matter of relativity. What would become of space if you took everything out of it? It would have no meaning; we cannot form any idea of empty space. There is no such thing as absolute space. If the whole of our visible universe were compressed into the size of an orange, we should be quite unaware of any change. Our measures, reduced in proportion, would still, for example, show the sun to be ninety-three million miles away. Size is *relative*—it depends on the observer.

It is our measuring rods which create space for us, it is by *measures* we determine the position of material bodies in space; we can only measure the distance from a body at a certain point of space to a body at some different point.

And so with Time. Has it any reality? "What would become of time if nothing ever happened." Time is merely a local affair. As the measuring rod creates space, so it is clocks which create time. We cannot form any idea of absolute time or of absolute space. As we shall see, we make a wrong supposition if we suppose

> that an interval of time and an interval of space between two given phenomena are always the same for every ob-

> server, whatsoever and whatever the conditions of observation may be.

We cannot measure time itself—we can only measure it by the motion of something over a space, as a clock hand or a planet. But, as we have seen, motion and space are not real existences but *relative.* They depend on the observer, and so does time.

> If some malicious spirit were to amuse itself by making all the phenomena of the universe a thousand times slower we should not, when we awake, have any means of detecting the change. Yet every hour recorded by our watches would be a thousand times longer than hours had previously been. Men would have lived a thousand times as long, yet they would be unaware of the fact.

We shall see in a moment that Time and Space, according to Einstein's theory, are to be regarded as mere properties which we ascribe to objects.

One more point: "the dimensions of an object, its shape, the apparent *Space* occupied by it, depend upon its velocity"; the size and shape of any body depend upon the rate and direction of its movement.

One of the most revolutionary things about the Einstein theory has to do with Newton's Law of Gravity.

A New View of Gravity

Einstein thinks that gravity is not, as Newton held, a force, but a property of space. That all the effects of gravity may exist where there is no attraction is best shown by his own striking illustration. Imagine a chamber, like that of the projectile in Jules Verne's story, alone and motionless in empty space. A passenger therein will have no weight—his feet will not press downward on the floor. If he throws a ball into the air it will rise to the roof and remain there—there is no force of attraction to bring it down again. A weight hanging on a spring-balance will not stretch the spring. Now suppose that the chamber begins to move with a velocity which is continually increasing at the same rate as that of a body falling on the earth. The floor will press upward against the passenger's feet; it will catch up the ball, which will appear to be falling; the balance, drawn upwards against the inertia of the weight, will measure its amount precisely. There is no possible experiment which the passenger can make which will show him whether the projectile is moving with an accelerated motion or whether it is at rest, as we imagine we are, on the surface of an attracting body. This last, indeed, is what he will imagine. But he may be under a complete illusion—and so may we.

This is Einstein's "Theory of Equivalence." It shows that gravitation may have more than one explanation. And this leads us to his own explanation, which is an altogether new one.

Newton thought the apple fell because the earth exerts upon it an attractive force. Einstein considers that it falls because, wherever there is matter, space itself is curved, just as the space we see in a very slightly concave mirror, where there are no straight lines at all, and where, if any body is in motion, it must move along a curve. Suppose a man in a closed room discovers that a marble placed anywhere against a wall rolls towards a hassock in the centre of the room, it will appear to him that the hassock is attracting it. Yet the fact may be that the floor is slightly concave, like a very shallow basin, and the hassock has no connection whatsoever with the motion of the marble. Just in the same way the earth may have no direct connection with the falling of the apple, though it seems to us to be the cause of it. We are asked to believe that space is curved, that all things moving through it move in curves—all things including light. Einstein's theory asserts that the actual reality which underlies all the manifestations we experience in the physical universe is a blend of time, space, and matter. This trinity is comprised in *one* actual reality. All bodies move through space-time; and they move in the straightest possible tracks; motion is merely simultaneous change of position in space and time. Einstein's theory explains gravitation as distortion of the world of space-time due to the presence of material objects. He does not explain how or why a body can distort space-time; the theory explains gravity, not as a force of nature, but as a property of space-time.

> On Einstein's view of gravitation, the earth moves in an elliptical path around the sun, not because a force is acting on it, but because the world of space-time is so disturbed by the presence of the sun that the path of least time through space is the elliptical path observed. There is therefore no need to introduce any idea of "force" of gravitation.

The more matter is present, the more space is curved. And so it happens that the light from a star just behind the sun will come bending round it, like a train round a railway curve, and fall upon our eyes or cameras—that is, when the sun's glare is shut out during an eclipse—and we can see or photograph the star. It will appear to be shifted from its true position—how far shifted, Einstein has worked out. At the last eclipse the stars appeared where he had predicted.

§ 1

The Curvature of Space

One of the great difficulties of Einstein's theory is, of course, the assumption that space is curved, so that "straight lines" in this curved space are not the straight lines that Euclid talks about. But we can see how this may be possible if we first consider the matter in a simple form.

Let us imagine intelligent creatures who exist in only two dimensions, i.e. they have length and breadth, but no thickness—a sort of very intelligent flat-fish. Suppose they exist on a plane—like the surface of this sheet of paper. Then the geometry they construct will be like Euclid's. They will find, for instance, that a space cannot be enclosed by two straight lines. You must have at least three straight lines (a triangle) to enclose a space. And they will see that a straight line can go on for ever and ever. Also it will be quite easy for them to draw any number of lines parallel to one another. But now suppose that these little flat creatures are transported to the surface of a sphere. What sort of geometry will they now construct?

Now, first of all, we must remember that, by hypothesis, they have no notion of a third dimension. They cannot go inside or outside their sphere. They have no notion that any space exists except the actual surface of their sphere. What will they call a straight line? They will say that a straight line is the shortest distance between two points. Well, let us take any two points on the surface of the sphere and join them by the shortest line, *keeping to the surface of the sphere.* This line will be, from our three-dimensional point of view, an arc of a circle. And *no* parallel "straight" lines can be drawn to it by the creatures on the sphere. Further, let us select two points at opposite ends of a diameter of the sphere. Through these two points an infinite number of half circles can be drawn, all of the same length and all shorter than any other kinds of curves uniting these two points. That is to say, from the point of view of the flat inhabitants, an infinite number of different "straight lines" pass through these two points. And any two of these straight lines enclose a space—just as any two lines of longitude on the earth, running from the North to the South Poles, enclose a space. Now these properties of the straight line contradict the axioms of Euclid. The geometry developed by these creatures will *not* be Euclid's geometry.

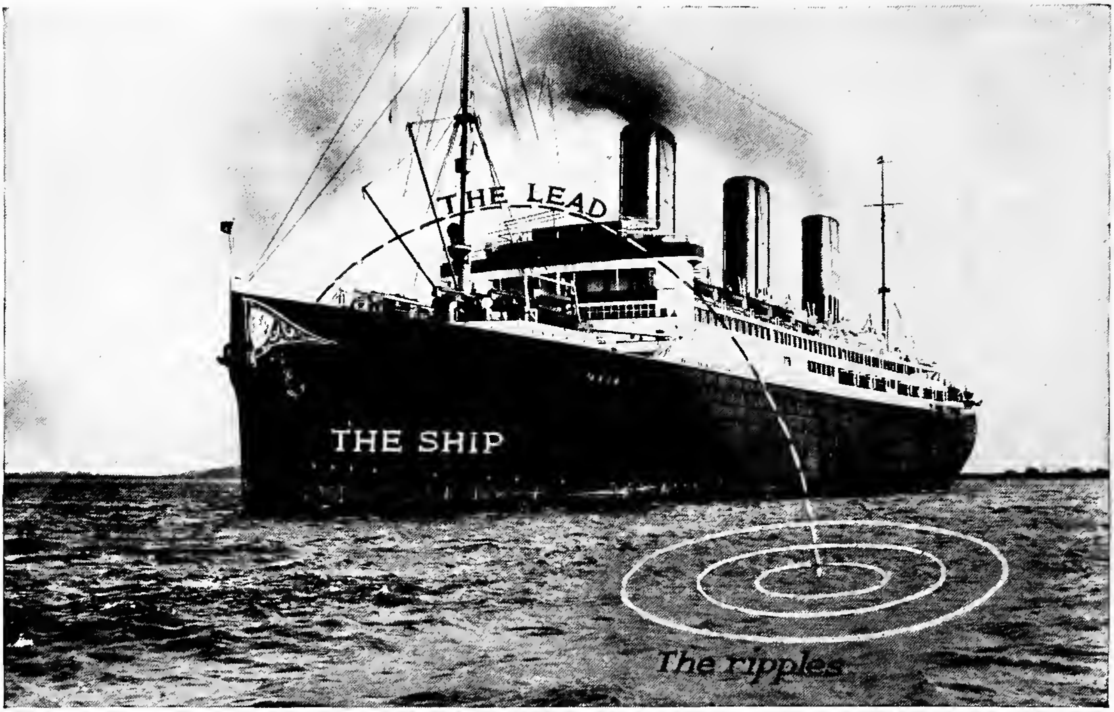
If they are very expert geometricians they will say that their space must be curved—as we know it is. And they will be able to measure *how much* their space is curved by making measurements on the figures they can draw. Now what Einstein asks us to do is to imagine something similar about our own

THE CURVE OF THE STAR-RAY SHOWS THAT SPACE IS CURVED IN PRESENCE OF MATTER (THE SUN). UPON THIS FACT EINSTEIN'S THEORY OF GRAVITY IS FOUNDED

A certain curvature would be expected on the electro-magnetic theory of light, but the curvature predicted by Einstein's theory was double that which the older theories predicted. Einstein's value for the deflection was handsomely confirmed by observation. This experimental result is justly regarded as a crucial verification of Einstein's theory.

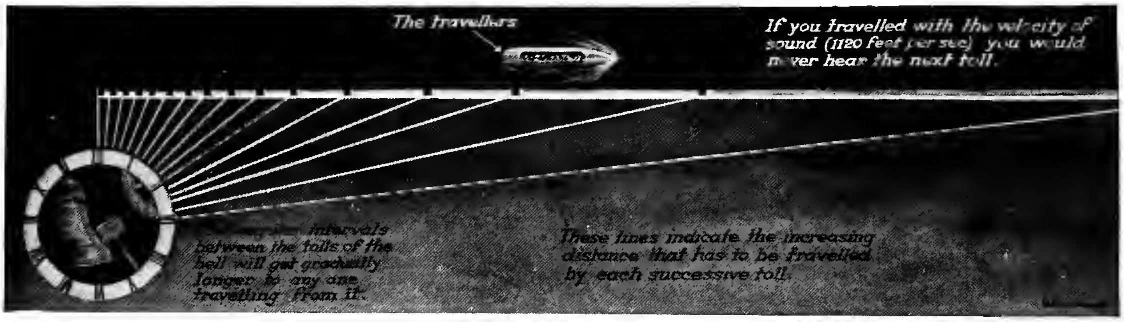
THE APPARATUS OF THE FAMOUS MICHELSON-MORLEY EXPERIMENT REFERRED TO IN THE TEXT

This was devised in the manner shown above in order to test the velocity (if any) of the earth relative to the sea of ether. A number of mirrors were arranged on a solid table floating on a circular bath of mercury. A lamp threw a ray of light, which was divided by partial reflection at a thinly silvered surface into two parts, running at right angles to one another. It was hoped that by revealing a difference of speed the motion through the ether could be determined. But to the experimenters' surprise no difference was discernible. The experiment was tried through numerous angles, but the motion through the ether was *nil.* (See diagram on following page. The text makes the connection between these two diagrams clear.)

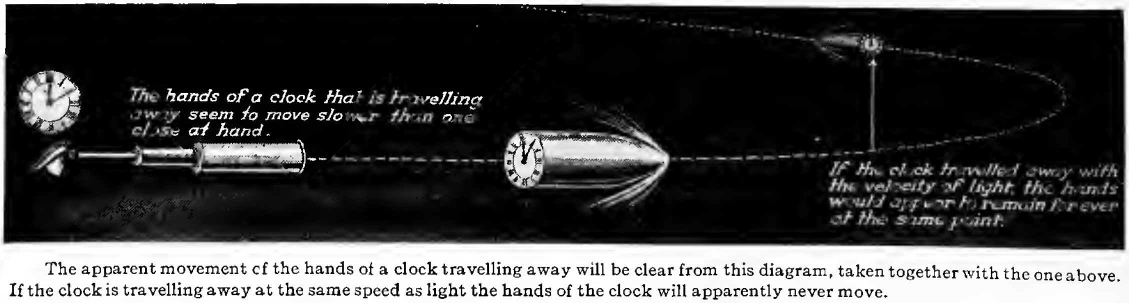


A SHIP AT SEA DETERMINING ITS MOTION. (A COMPARISON WITH THE FAMOUS MICHELSON-MORLEY EXPERIMENT CONCERNING THE ETHER)

Newton said that the motion of bodies in a given space is the same among themselves whether at rest or moving forward, and quoted as example the people and things in a ship. No experiment on board the ship itself discloses the vessel's velocity through the sea. "The matter stands differently," writes Mr. J. H. Jeans, "to one who is free to experiment with both the ship and the sea. Let a sailor drop his lead into the sea, a circular ripple will spread out; but every sailor knows that the point at which his line enters the water will not remain at the centre of this circle. The velocity with which the point of entry advances from the centre of the circle will give the velocity of the ship throughout the sea. If our earth is ploughing its way through a sea of ether, an experiment conceived on similar lines ought to reveal the velocity of the earth through the ether." (See diagram on preceding page.)



This diagram will make it clear that a traveller moving with a greater speed than that of a sound-wave will never hear the toll of the bell—the sound is not moving fast enough to catch him up. This will make it easier to understand the same principle applied in the following diagram to the case of light.



The apparent movement of the hands of a clock travelling away will be clear from this diagram, taken together with the one above. If the clock is travelling away at the same speed as light the hands of the clock will apparently never move.

space. Actual measurements of our space show that its geometry is not Euclidean. We can, therefore, as if by an analogy, talk about the *curvature* of our space.

Now there is another important analogy between our space and the surface of the sphere. What happens to a "straight line" on the sphere when it is produced? It goes all round the sphere and comes back to the point it started from. It cannot, that is to say, go on for ever and ever. The curvature of the surface bends it round. The space these creatures live in is a finite *space*—it does not go on for ever and ever. At the same time it is *unbounded*—there are no barriers. The flat creatures can wander about in their space as long as they like without ever meeting an obstacle to their further progress. Nevertheless, although unbounded, their space is not infinite. Einstein says that the same distinction holds good of our space. Our space, he says, is finite; the ray of light from a star would go on until it went all round the universe and came back to its starting-point. But our space is also unbounded. We could wander about in it for ever; we should never come to a notice saying "Thus far, and no farther." But when we had wandered far enough, going quite "straight" as it would appear to us, we should come back to our starting-point.

§ 2

Such are some of the revolutionary ideas imported by Einstein's theory. Let us now discuss this theory a little more closely.

The Theory of Relativity

Einstein's Theory of Relativity is probably the most profound and far-reaching application of mathematics to the phenomena of the material universe that the world has ever known. Yet in spite of the very abstruse nature of the theory it is no paradox to say that its object is to give us a simpler, a less sophisticated, view of the universe. We are sometimes apt to forget that the human consciousness is a very complicated and highly developed thing. Our minds represent a development that has extended through hundreds of thousands of years. It is very likely that some of the ideas which seem to us simplest are really complicated abstractions; the race has built up certain ideas because it found it useful to build them up in that way. We now take those ideas for granted, but that does not alter the fact that they are elaborate and, in a way, artificial constructions. It often requires as much, or greater, insight to analyse our ideas into their primitive constituents, as to build up still more complicated ideas on the basis of them.

Now the chief characteristic of Einstein's theory is that it takes us behind our present ideas about space, time, and matter, to the primitive reality out of which we have built up those ideas. We can see the nature of the theory most clearly if we begin at the end. Imagine some entirely fresh, inexperienced intelligence to be suddenly put in a field in our world on a summer day. This intelligence has at first a general awareness of the field, and everything in it, as a whole. We will suppose that this intelligence is essentially a human intelligence, and that after a little it begins to discriminate. It begins to distinguish parts of the field from other parts of the field. What sort of discrimination will this be? The intelligence will be aware of itself and of the field. We suppose the intelligence has a body; this will give it, as it were, a centre to work from. It will begin to distinguish between *here* and *there*. Suppose the intelligence has been watching a wasp on a flower. The wasp and the flower make just one indivisible whole for it. The whole thing—wasp and flower—is *there*. Presently the wasp detaches itself from the flower and settles on the hand of the intelligence. Part of the object that was *there* is now *here*. And if the wasp now stings the hand of the intelligence this event will occur *after* the wasp had formed one object with the flower. Here and there, before and after, introduce the notions of space and time. And if the intelligence agreed that the same wasp appeared on his hand as was on the flower, he would obtain the idea of objects that persisted in space and time—that were the same at different parts of space and at different points of time. He would thus begin to form the notion of matter.

The Fourth Dimension

Now we do not profess that this is an accurate account of how much an intelligence would split up the primitive reality into space, time, and matter, nor do we say that this is the actual path that has been pursued by the intelligence which culminates in man. We have introduced this illustration to give the reader some preliminary inkling of what is meant when we say that Einstein's theory has combined space, time, and matter into one unity. If the main idea is once grasped, however imperfectly, the way to understanding the broad outlines of the theory is made easy, although the details can only be followed by skilled mathematicians. The theory asserts that the actual reality which underlies all the manifestations we experience is neither spatial nor temporal nor material, but a blend of all three. It is we who have split up the original unity into the three entirely different things we call space, time, and matter, and we have performed this feat either because it was a very useful way of dealing with reality, or because our minds could not function in any other way. Let us consider first the division into space and time, and let us ask ourselves what this division really means. Let us take a solid body having length, breadth, and thickness—say a cube. What is implied in the existence of a cube? This problem is discussed in Mr. H. G. Wells' excellent story *The Time Machine,* written years before Einstein's theory was thought of. The Time Traveller asks:

"Can an instantaneous cube exist?"

"Don't follow you," said Filby.

"Can a cube that does not last for any time at all, have a real existence?"

Filby became pensive.

"Clearly," the Time Traveller proceeded,

> any real body must have extension in four directions: it must have Length, Breadth, Thickness, and—Duration. . . . There are really four dimensions, three which we call the three planes of Space and a fourth, Time. There is, however, a tendency to draw an unreal distinction between the former three dimensions and the latter, because it happens that our consciousness moves intermittently in one direction along the latter from the beginning to the end of our lives.

The matter could not be put more clearly, and it is scientifically quite accurate. As the Time Traveller says a little later, "there is no difference between Time and any of the three dimensions of Space except that our consciousness moves along it." Einstein's theory states that, from the point of view of science, there is no essential distinction between time and the three "dimensions" (Length, Breadth, Thickness) of Space. Science is not concerned with our feelings about the difference. *Before* and *after* appears to us as a much more fundamental difference than *before* or *behind, above* or *below, right* or *left.* But Einstein has proved that time enters into physical phenomena in the same way as the directions in space. That is what is meant by saying that the world is four-dimensional. Everything which happens, happens some*where* at some *time.* Two events are separated from one another not only by their position in space but by their position in time. Now all this is fairly elementary; we have seen that some people, like Mr. Wells, had a pretty clear idea of it before Einstein's theory appeared. But Einstein takes us a big step further. He asked a question which nobody had asked till then. Is the space and time interval which separates two events the same for everybody?

Let us see what this question means. Suppose you are running a race—one hundred yards—and suppose all the spectators have absolutely perfect watches. Suppose the judge declares that you have run exactly one hundred yards in exactly eleven seconds. That is to say, that between the event when you left the starting-line and the event when you breasted the tape at the other end, there is a space interval of 100 yards and a time interval of 11 seconds. Will all the spectators agree upon that? Common sense says they will, and common sense is quite right. But now suppose that at the instant you began to run, an aviator flying at 100 miles per hour flew above you, and suppose he watched your sprint from start to finish. We also suppose he has absolutely perfect measuring instruments with him, so that he can measure the length of the course you are running and the time you take. Will he agree with the stationary spectators? Common sense says that he will, but here Einstein, using mathematical proofs which would be out of place in this article, says that he will not. He will not agree, firstly, that you ran exactly one hundred yards nor, secondly, that you took exactly eleven seconds to do it. He will disagree with the judge both in his space and time measurements. Now this conclusion shocks us at first; but why should it? We have already seen that the *reality* of the world is an inextricable blend of space and time. We sort this blend out into space and time to suit ourselves. But why should we say that everybody always sorts it out in the same way? We know that different people can have different opinions about exactly the same thing. A political speaker may appear to one man to be a wise statesman talking to intelligent and patriotic citizens. Another spectator of exactly the same event may see a cunning rogue talking to a lot of fools. We explain this difference by saying that the two men have had different upbringings, different experiences, and so on. But can we be quite sure that no change of circumstances makes two observers of the same *reality* split it up differently into its space and time factors? As a matter of fact Einstein has shown that they will not split up the reality in the same way if their *motions* are different. But the difference of motion necessary to make the change appreciable is enormous.

We have said that our aviator, if he had perfect instruments, would disagree with the judge. But in truth, his instruments would have to be a million times more perfect than the best instruments we can make before there would be any likelihood of him and the judge quarrelling. No velocities that we can reach on earth would make the faintest observable difference to our space and time measurements, for we are not able to travel at several thousands of miles per second. That is why we have always supposed these measurements to be exactly the same. They *are,* for all practical purposes. But as a scientific fact they are not. Things which happen at the same time for an observer at rest do not happen at the same time for an observer in motion. But unless the observer in motion is moving at hundreds or thousands of miles per second, the best earthly instruments would show no difference. The actual mathematics of the problem show that the aviator would find the hundred yards rather shorter than one hundred yards, and the eleven seconds rather less than eleven seconds. But the difference, as we have said, is impossible of detection with our instruments. Even if the aviator were moving at 67,000 miles per hour, which is the earth's velocity round the sun, the judge's watch would seem to lose only 1/2300 second per day. And a one-foot rule would appear shorter by only one seventeen millionth of an inch.

But the difference mounts up rapidly as the speed increases. At 161,000 miles per *second,* for instance, a velocity which is in the neighbourhood of the velocity of light, the watch would lose twelve hours per day, and the foot-rule would become six inches long. At the velocity of light itself, the watch would not seem to be going at all, and the foot-rule would have shrunk to nothing. The velocity of light, therefore, is a theoretical absolute limit. No greater velocity is possible.

Doubtless these results seem fantastic at first sight. "A second is a second," you might say, "and a foot is a foot." But you have already been predisposed to believe that space and time themselves are not ultimate realities; the actual reality is a kind of union of the two. Now the apparent paradox of Einstein's theory is removed when we discover that there *is* a certain combination of space and time measurements on which everyone agrees, whatever their state of motion. They split up this combination differently, yes; but they agree on the combination.

§ 3

The Test of Experiment

The theory that we have been expounding is necessitated by the very extraordinary *experimental* fact that all observers, however fast they may be moving, *find the same value for the velocity of light.* The most careful test of this statement that has been made is the famous Michelson-Morley experiment. We can see what this extraordinary result means if we think of a bird flying from one end of a train to the other. If the train is at rest the bird takes a certain time for the journey. If the train is moving towards the bird it takes a shorter time; if the train is moving away from the bird, the bird takes a longer time. Here everything is as it should be. But Michelson and Morley found that if a ray of light, instead of the bird, is the flying thing, it takes exactly the same time in all three cases! How can that be? Here Einstein's theory gives a complete explanation. We are measuring the distance flown and the time taken from the train. But our measurements of distance and time vary, as we have seen, with our motion—and to exactly the extent required to produce complete compensation, so that in each case the measured velocity of light will be exactly the same. And this remains true however fast the train may be going. We must always remember that Einstein's theory, however strange it may appear at first, rests on experiment. It is no unsupported flight of the mathematical fancy. To those who will not accept the theory we may fairly say—"Well, how do *you* explain the experiments?"

Turning Time Backward

In order to free our minds from preconceived ideas of Time and Space, let us take an illustration from the scientific romance *Lumen,* by the celebrated French astronomer Flammarion. It relates how the soul of a man, on his death in 1864, flew with the speed of thought to one of the stars in the Constellation Capella, situated at a distance from the earth which light takes 72 years to travel, so that he found the inhabitants watching, with their supernatural telescopic eyes, the events of the French Revolution, *of which the light-rays were just reaching them.* The man's soul, flying further with a speed *greater* than that of light, *so that he overtook the light-rays that had long left the earth,* saw events occurring backwards, like a cinema film driven the wrong way.

> When I recognised the field of Waterloo, I saw at first a number of dead bodies stretched upon the ground. Beyond them I saw Napoleon arriving *backwards* holding his horse by the bridle. Then I saw the dead soldiers come suddenly to life and spring to their feet. The horses came to life again at the same time and their riders sprang into the saddle. As soon as two or three thousand men were thus resuscitated, they gradually reformed their ranks. The two armies began to fight with fury. In the centre of the French army I perceived the Emperor, surrounded by his soldiers. The Imperial Guard had come to life again! At the end of the day not a single man was killed or even wounded—not a uniform was torn. Two hundred thousand corpses, come to life, marched off the field in perfect order. And the result of this strange battle was not to vanquish Napoleon, but on the contrary to restore him to the throne!

§ 4

The Einstein theory does not stop here. It goes on to prophesy that a mass of matter, a pound weight, for instance, increases in mass as it travels faster. Here, again, the increase in mass is not appreciable at ordinary speeds. Even at 67,000 miles per hour a pound mass only increases by one two hundred millionth of a pound. But at 161,000 miles per second its mass is doubled—it increases by one pound. And at the speed of light its mass is infinitely great. So that here, again, we see that the velocity of light is an ultimate velocity. Now we actually have samples of bodies moving with enormous velocities. The cathode rays, for example, and some of the particles shot out by radium, have velocities very much greater than we are in the habit of dealing with. The increase of mass of these particles due to their velocities can be calculated, and here again the experimental facts confirm Einstein's theory. If we lived in a world where velocities in the neighbourhood of the velocity of light were common we should have known all about Einstein's theory long ago; we should find nothing paradoxical in it; it would seem quite commonplace.

Space and Time Blended Together

So far we have been describing what is called the special Theory of Relativity, which was published by Einstein in 1905, when he was 27 years of age. Since then, as all the world knows, he has taken an immense step forward. He has greatly extended his theory so as to include gravitation, and, as one consequence, he has shown that space, or rather, the space-time unity we have spoken about, does not obey Euclid's geometry. But although this Generalised Theory of Relativity is probably the profoundest single achievement of the human mind, it is not impossible to get an idea of its essentials on the basis of what we have already said. We have seen that it is not sufficient to think of space and time as existing separately. In reality they are blended together.

Now the further question arises, does matter exist independently of space and time? We must make our question more precise. Are we to conceive space and time as forming a sort of framework within which matter exists and in which it wanders about quite independently? Has matter no actual *influence* on space and time? To answer this question rightly we must get rid of certain philosophical assumptions. We all make these assumptions, whether we know it or not, and even if we have never read a line of philosophy. The assumptions belong to those complicated ideas built up by the race to which we referred at the beginning of this article. Now when Einstein asks this question he is asking it about a space and time that we can *measure* by rigid measuring rods and clocks. He makes the whole subject experimental. We must remember this in what follows.

Firstly, it will make the subject clearer if we go back to Newton. Newton said, in his first law of motion, that a moving body acted on by no forces moves in a straight line and always with the same speed. Well, now, how did he know? Where are we to find a body acted on by no forces? Certainly not on the earth, for the earth is a large rotating mass, and every body on it is acted on by the earth's attraction, and also by the centrifugal force set up by its rotation. The fact is that Newton's law is not an experimental law. It sounds so reasonable, and was accepted by the scientific world for centuries, simply because it appeals to our unconscious assumptions about the nature of space. We always assume, in fact, that Euclid's geometry holds good of actual space.

But now see what happens as a consequence of this. If we look up into the sky and watch the planets we find that they are not moving in straight lines. Why? "Because they are acted on by forces," says Newton. The natural, unconstrained motion of a body, he says, is a straight line. Consequently, if we find that it is not moving in a straight line, it is necessary to suppose that it is not unconstrained—some force must be deflecting it. So that we first of all start with a motion that nobody has ever observed and call that the natural motion, and then all the motions we do observe require the invention of forces to explain them. It is needless to say that we are not now trying to underrate Newton's wonderful achievement; we are simply preparing the way for another point of view. The other point of view is this: the actual motions of the planets are their natural motions; we require no "forces" to explain them; they move in the way they do, not because they are pulled continually out of their natural path, but simply because that *is* their natural path. But, you say, they do not move in straight lines! Einstein's answer is: No, but motion in a straight line is only natural in a Euclidean space; it must be that our space is not Euclidean!

The Great Prediction

We have, then, these two points of view. Newton says that space is Euclidean, and that the natural motion is a straight line. The planets move in this Euclidean space, and the fact that they do not move in straight lines is explained by saying that there is a force, "gravitation," pulling them towards the sun. Einstein says that space is not Euclidean, and that no "forces" are required to explain the motion of the planets; their motion is the natural one in the sort of space they exist in. How are we to decide between these points of view? There is a test. If Einstein is right and the movements of the planets are due only to the sort of space they move in, then this space must affect everything alike. A ray of light, for instance, must behave just as a material body would do in moving through this space. It *cannot* do otherwise. Now part of the theory is that matter actually influences the space in its neighbourhood; it distorts it, as it were, from the Euclidean form. Near a great body like the sun space is considerably distorted. A ray of light passing near the sun and, consequently, moving through this distorted space, should deviate quite appreciably from the straight line. Einstein's theory predicts the amount of deflection, and, as we all know, a great expedition was sent out from England to test the theory by photographing the stars whose light passed near the sun when the sun was eclipsed. And the result confirmed Einstein. This verification of Einstein's theory is a very striking one, for the result obtained could not have been predicted from any other theory.

But this is not all. The motion of Mercury, the planet nearest the sun, presents peculiarities which cannot be accounted for by Newton's Law of Gravitation. Great mathematicians had worried over this problem for generations, but no satisfactory explanation had ever been found. But the distorted space of Einstein's theory was found to supply a perfect explanation. This, again is a very striking confirmation of the theory. We must be content with this brief sketch of the theory; the details are too difficult for popular exposition.

Einstein's theory shows us that there is something in the nature of an ultimate entity in the universe, but it is impossible to say anything very intelligible about it. But a certain aspect of this entity has been picked out by the mind as being what we call *matter*. The mind, having done this, also partitions out a space and time in which this matter exists. It is not too much to say that the whole material universe has, in this sense, been created by the mind itself.

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XXXIII

THE BIOLOGY OF THE SEASONS

THE BIOLOGY OF THE SEASONS

The Rhythm of Life

MEN and animals depend on green plants, and these depend on the sun. But according to the earth's seasonal relation to the sun we get varying amounts of heat and light. Thus the ratio of heat-supply in summer to that in winter is as 63 : 37. To the varying income of heat and light living creatures have had to adjust themselves, except in haunts like the Deep Sea, where there are practically no seasons. So the Biology of the Seasons has for its central task an inquiry into the ways in which the life of plants and animals is adapted to the external periodicities of Spring and Summer, Autumn and Winter. But the problem is complicated by the fact that within living creatures themselves there are constitutional rhythms or periodicities. Everyone knows that after hard work he must rest and sleep and feed. A great expenditure of energy must be followed by a period of income. The essential processes of life, summed up in the word METABOLISM, consist of constructive, upbuilding, winding-up chemical activities (ANABOLISM), and of disruptive, down-breaking, running-down chemical activities (KATABOLISM), and there must be an alternation or see-saw between the two. Vital activity implies a two-fold process of waste and repair, discharge and restitution, activity and recuperation. Now the one predominates and again the other. Now there is storing and again there is work; now there is growing and again there is reproduction. As it is said in Ecclesiastes iii:

> To every thing a season . . . a time to break down, and a time to build up . . . a time to cast away stones, and a time to gather stones together; a time to embrace, and a time to refrain from embracing; a time to get, and a time to lose; a time to keep, and a time to cast away.

There can be no doubt that deep-sea animals, living in monotonous uniformity—eternal night and eternal winter—have their internal rhythms, their see-saw between work and rest, their alternation of reproducing and vegetating. All living creatures are inherently predisposed to be rhythmic; their operations are regularly discontinuous. But the point is that the internal oscillations have become adjusted to the external periodicities. We should have to sleep though there were no night, as in the Far North in summer, but we sleep better because of the night, which shuts off from our nervous system many of the messengers that are always rattling the knocker during the day. The central idea is that *Life is rhythmic, and that it is punctuated by the seasons and by other external periodicities such as the tides.*

Ripple-marks of Growth

Everyone has looked with pleasure at the well-sawn stem of a big tree, and counted the rings which register its age. We pause to think for a moment of one of the Big Trees or Sequoias of California, which showed 2,425 rings, and had therefore begun its existence 525 years before the Christian Era! (See p. 709.) But how is it possible to distinguish the annual increments of growth? Why do not the rings of wood simply coalesce? The reason is that the structure of the wood developed in summer is very different from that developed in autumn, and the alternation makes the lines of growth stand out clearly.

In the same way we can read summer and winter in the concentric lines on the scales of a salmon and many another fish; and this can be corroborated by making a section of the otoliths, or ear-stones. All through organic nature there are what may be called the ripple-marks of growth—the parallel lines on the scallop's shell, on the tortoise's scale, the rings on the rattlesnake's rattle, and the zones within the spine of the sea-urchin. There is a widespread self-registering of periodicities and pauses.

The correlation between internal rhythms and external periodicities is sometimes very direct. Since photo-synthesis depends on the sunlight, green plants must be intensely active during the day and relatively restful at night. Similarly many plant-cells, such as simple Algæ, feed during the day and divide at night. In other cases the correlation is more indirect and more subtle. Thus it is with striking regularity in October and November, when the moon is in her last quarter and the day before, that swarms of Palolo-worms occur in the coral-reefs of Samoa.

> Myriads of these worms crawl out tail foremost from the crevices they inhabit, and agitate themselves so violently that while the head end remains in the rock the posterior ends drop off and make the water "like vermicelli soup." These headless worm-bodies are laden with egg-cells and sperm-cells, and these are shed in countless millions in the water, so that fertilisation is quite secure. The swarming begins shortly before sunrise, and is mostly over in half an hour.[1]

There is much that is very interesting in this Palolo story. The swarming takes place so punctually that the natives are prepared for it, distinguishing the smaller October swarm from the larger one in November. The worms are eaten either alive or baked, and are esteemed a great delicacy. The land-crabs also come down to the beach to get their share of the abundant jetsam. There is some subtle stimulus connected with the moonlight and the sunrise. There is also the very profuse sowing of the seed. But perhaps the most extraordinary thing is the evasion of the death-penalty which reproduction often involves to animals.

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[1] Thomson, *The Wonder of Life,* 1914, p. 71

For the heads of the Palolo-worms remain in the fissures of the coral-reefs, and grow new bodies at their leisure.

In some cases the external periodicity takes so strong a grip of the constitution that the animal exhibits the correlated change even when the stimulus is not operative. This is well illustrated by the little green Planarian worm Convoluta, which is common on the flat sandy beach of some parts of Brittany. When the tide is out the worms come up in crowds and form green patches on the sand. When the tide returns, just as the first wave reaches them, they retire into shelter. But Bohn has demonstrated that in a quiet aquarium, away from all tidal influence, the worms exhibit for some time the normal rhythms, ascending and descending, keeping time with the tides. The external periodicity has gripped their constitution for a time.

I. THE BIOLOGY OF SPRING

Spring is a time of renascence, when a fresh start is made after a period of rest. The seeds have been lying dormant in the earth; processes of fermentation have been going on within, preparing the compact legacy of stored food; bacteria begin to work at the bursting envelopes; moisture seeps in; the seedlings emerge, and exhibit delicate movements in shoot and root. (See the article on Botany.)

The buds which have rested through the winter, well wrapped up in tough bud-scales, begin to burst. That is to say, the warmth of the spring sunshine has activated the living matter; the cells are dividing into intricate orderliness; the watery sap is ascending from the roots, or, it may be, from places where it has been stored within the stem. Like the seeds, the buds were formed in the abundance of the previous summer; like the seeds, the buds are adapted to contain much within a small and well-protected surface. The young leaves in the leaf-buds are often twisted in a close spiral, and when the shoot grows they show

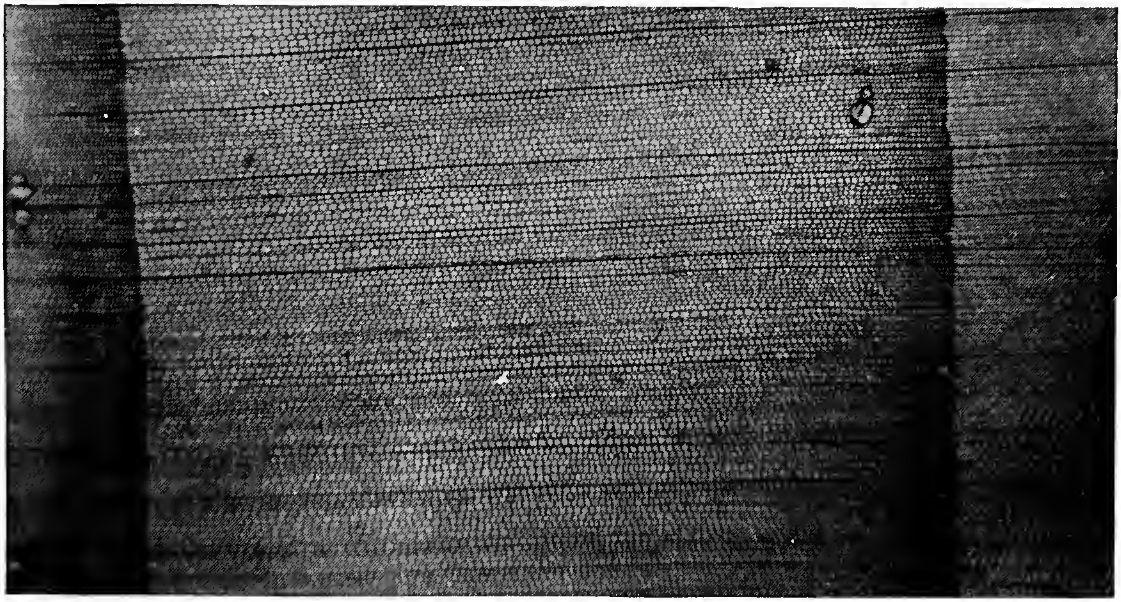

Photo: J. J. Ward.

ANNUAL RINGS OF GROWTH IN PINE-WOOD

In spring, when the growth is energetic, the wood-elements are larger than those formed during the slower growth later in the year. The early wood is important in the ascent of water; the late wood is important in giving the stem rigidity. The appearance of the two kinds of wood—dark lines and lighter zones in the photograph—makes it possible to compute the age of the tree. But there is sometimes a midsummer ring, and some tropical trees show no rings at all.

Photo: John J. Ward.

ONE OF THE EARLIEST FLOWERS OF SPRING

Male and female catkins of the "Palm" or "Pussie" Willow. The branch on the left bears female flowers, and that on the right male flowers. The male and female catkins grow apart on distinct trees. The flowers are reduced to the essentials, the stamens in the male, the carpels in the female, rising from the axil of a bract. There are no petals or sepals. Yet the flowers are almost always pollinated by insects, though those of their relatives are pollinated by the wind. There are still wind-pollinated willows in Greenland, but this is just a straw which shows how the evolutionary wind has blown. Insects, such as hive-bees and honey-bees, are attracted to the catkins by the sweet scent and the nectar.

the same spiral loosened and drawn out. In the one case the spiral means close-packing, in the other case it obviates too much overlapping of leaf by leaf. In the flower-buds the parts of the flower are all lying in miniature, and when the spring comes with a rush the flowers are ready. Brehm speaks of the sudden transformation on the Asiatic steppes.

> From the apparently sterile earth herbaceous and bulbous growths shoot up; buds are unpacked, flowers unfold, and the steppe arrays itself in indescribable splendour. Boundless tracts are gorgeous with tulips, yellow, dark red, white, white and red. It is true that they rise singly in twos and threes, but they are spread over the whole steppe-land.[1]

The sudden reappearance of flowers, so that the desert quickly becomes a garden, is more intelligible when it is clearly understood that the flower-buds were made in the previous summer's sunshine, and that there are stores of nutrition within the plant, especially when there is anything like a bulb or a corm or a rootstock, as there is so often in the flowers of the spring.

Many of the early flowers are somewhat primitive, as we may see in the willow-catkins; many tend to be bud-like as if some slight check had occurred in the opening of the blossom; and perhaps we should expect something of the primitive and the bud-like in the first flowers of the year. We have just spoken of the resplendent tulips of the steppes, and everyone is familiar with the fine blue of such early flowers as hyacinth and iris, but on the whole the spring flowers tend to be light in colour, e.g. white and yellow, like snowdrop and celandine. This probably means that in the scantier sunshine the average spring flower has not the intensity of vital processes that sets in later in the year, when the colours certainly deepen. It may also be associated with the fact that not a few of the spring flowers are wind-pollinated, and that variations in the direction of bright colour

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[1] Brehm's *North Pole to Equator,* 1896, p. 95.

are not so likely to take grip in flowers that blossom at a time when insects are not much in evidence.

Animals Reawaken

There is a spring reawakening or renascence among animals as well as among plants. One of the most familiar sights is the queen humble-bee making for the willow-catkins to refresh herself after a winter's fast and to collect pollen and nectar for provisioning the cradles which she will soon fashion in her nest in the mossy bank. She has been resting in a sort of lethargy all through the winter, one of the few survivors, perhaps the only survivor, of last year's large family. Of the scores, or even hundreds, that then crowded the nest, only the young queens survive.

Many insects pass the winter, not in the adult state, but as cocoons or pupæ. In sheltered recesses they have lain like mummies well protected by enswathing wrappings. They entered into their quiescent state as larvæ, e.g. caterpillars; they underwent at least a part of their great change or metamorphosis into a new style of bodily architecture; they reawaken in spring as winged adults, e.g. butterflies.

Similarly, there is a reawakening of the snails, which have been lying sealed up in their shells in the heart of an old wall; and of the frogs, which have been dormant in a snug hole of the bank near the pond—mouth shut, nose shut, eyes shut, breathing through their skins and with their hearts beating feebly. The vigour of the males' croaking and the rapidity with which the females proceed to deposit masses of spawn in the pool cannot be said to suggest any impairment of energies through the winter months. Then there is the interesting reawakening of winter-sleepers, such as hedgehog and dormouse, marmot and bat.

Spring is emphatically a time for young things—of seedlings, buds, and young blossoms, of tadpoles, nestlings, and young lambs. There is a striking multiplication of minute organisms in the waters of pond and lake, of estuary and sea. It is interesting to find in freshwater basins that there is often, as the result of the dying away of plants in autumn and winter, a production of chemical substances called "auxetics," which later on promote the multiplication of cells, and, towards spring, an increasing quantity of certain other substances called "augmentors," which give more "power to the elbow" of the first. Thus out of death come the stimulants of the awakening of pond-life and lake-life in spring. A single Infusorian may be the ancestor of a million by the end of a week—of more if the spring is genial. As we have noted in another article, the water-fleas eat the infusorians, and fishes eat the water-fleas; and so the world goes round and on.

One of the interests of spring is the repeopling of the fresh waters which seemed so empty through the winter. The female gnat or mosquito spends the winter in hiding and makes in spring a floating raft of two or three hundred somewhat cigar-shaped eggs. From these there emerge larvæ which hang head-downwards from the surface film, or sink to the bottom of the pool and jerk themselves up again by vigorous strokes of their tail. They feed and grow and moult, and eventually turn into pupæ of very different appearance, which rest head-upwards at the surface and do not eat at all. In three or four days the husk of the pupa splits and a winged gnat emerges, not without risk and difficulty. Many biological notes are struck. There are the adaptations of the gnat larvæ to living in the water and yet breathing dry air. There is the accumulation of reserves for a very vigorous short aerial life, mainly devoted to reproduction. There is the prolific multiplication and the prodigious infantile mortality; and in spite of the latter there are clouds of survivors—fine food for some of the migrant birds returning to the North. And there is the interlinking with human life, for the mosquito which carries the malaria organism and infects man with it is just a species of gnat. The pouring of a little paraffin on the pool makes a surface film which the mosquito larvæ cannot grip, and so it is drowned—with consequent reduction of malaria. Then there are the small fishes that devour the mosquito larvæ—wheels within wheels.

The gnat's life-history occupies about a month, and there is a succession of generations through the summer. When this is contrasted with the long life of the May-fly, which may be sub-aquatic for three or four years, though aerial for only two or three days, or it may be only one, there emerges another biological idea—that a portion of the life-history may be long drawn out in one type and telescoped down in another, all in adaptation to different conditions of life.

When we turn to the familiar development of the frog, which occupies about three months, we find a clear illustration of another biological idea—that of recapitulation. The individual tends to climb up its own genealogical tree. When it wriggles out from the protective sphere of jelly, the newly-hatched larva is little more than a very primitive vertebrate—limbless and gill-less, with eyes which have not yet reached the surface on their out-growing from the brain. When it is about a month old, the tadpole has a two-chambered heart, just as fishes have, and a very fish-like circulation. It is true that its gills are not like those of ordinary fishes, being "ectodermic" in origin, but they have their counterparts in the external gills of some old-fashioned fishes like the African Dipnoan, Protopterus. When it is about two months old and has got its limbs free, the tadpole begins to breathe with lungs as well as gills, just like the mud-fishes or Dipnoi. The individual development recapitulates in abbreviated form the evolution of the race, and yet from the very first the larval frog is an amphibian, not a fish. There is, for instance, no suggestion of scales.

Some of the butterflies and moths that have wintered as adults emerge and pair in the spring, and thus arise the early caterpillars which are often a source of considerable anxiety to the gardener. The contrast between the worm-like caterpillar and the winged butterfly is very striking—had we not become familiarised. A worm-like body, mouth-parts suited for biting, very diminutive antennæ, simple eyes, three pairs of jointed, clawed legs, and five pairs of unjointed, unclawed, posterior appendages—everything as different as possible from the butterfly. The crawling caterpillar is a voracious eater, the flying butterfly sips nectar daintily or sometimes fasts altogether. It is an antithesis—the antithesis between a nutritive and a reproductive phase. The stores of nutritive material accumulated by the caterpillar make the butterfly possible. There can be little doubt that changes involved in the evolution of climates made it profitable for the higher insects to have a long larval period interpolated between the egg and the adult. In the larval period reserves are accumulated, and at the end of the period, after full size has been attained, the great change or metamorphosis is initiated, completing itself in a quiescent pupa phase well suited for surviving the winter. But it is not easy to understand how the development which expressed certain hereditary qualities in building up a caterpillar should be able to recommence on a new plan and express other hereditary qualities which make up the butterfly.

The Story of Lampreys

In the Severn and other southern rivers the sea-lampreys come up in the spring, and the spawning is over by the end of June. It is later further north. These lampreys are big creatures, as long as one's arm and as thick as one's wrist, very lithe and slippery. If the word "fish" is to mean anything, it cannot be applied to lampreys, for they are jawless, limbless, and scaleless, and they have an unpaired nostril and peculiar gill-pouches, very different from the gills of ordinary fishes. They are representatives of primitive backboned animals, far below the level of true fishes, for there is a big anatomical gulf between animals without jaws and those that have them—between Cyclostomes and Gnathostomes, if we use the zoological language. Like most archaic animals, lampreys are extraordinarily interesting.

The parents usually choose a briskly flowing stretch of the river, and they clear a nesting site by removing the stones in their suctorial mouths. If a stone is too heavy for one, the pair will tackle it! The stones are piled in a sort of breakwater on the up-side of the chosen spot and in a dam on the down-side, so that the eggs are less likely to be washed down-stream. In the shelter of the stone nest the eggs are laid, and the development is rapid; a rather interesting point, for the larval period is long-drawn-out. The young ones hatch out in about a fortnight, and in a month or so, when only half an inch long, they leave the nest and seek quietly flowing water. They wallow in the sand or mud, and feed on other water-babies. They grow out into what country boys call "niners," often confused with young eels, with which, of course, they have nothing whatever to do. An interesting detail, significant in its adaptiveness, is that the skin of the young lamprey secretes a digestive juice, making short work of the bacteria which abound in rather stagnant water. The name "niners," or "nine-eyes," is rather difficult to explain, for the larvæ are blind. There are eight gill-openings, however, and there is the place where the eye will eventually emerge, so these make nine—the "nine-eyes" of rustic Natural History!

After three or four years of rather monotonous youth, the niners begin to grow up. They undergo a remarkable structural change, putting off their juvenile characters, such as their horseshoe shaped mouth, and putting on adult characters, such as clearly exposed eyes. The change usually takes place in the autumn.

There are species of lamprey that remain in fresh water, but the large species we have been studying (*Petromyzon marinus*) spends a considerable part of its life in the sea. After two or three years (the number is uncertain) spent in the sea in

FIG. I.—HORSE-CHESTNUT BEGINNING TO BURST ITS BUD-SCALES ON MARCH 25

These bud-scales have protected the bud since it was formed—during the previous summer. They are waterproof and bad conductors. They are burst because of the pressure of the growth in the young leaves within.

FIG. 2.—SIXTH DAY. THE LAST PAIR OF BUD-SCALES GIVE WAY

As the bud elongates it is interesting to see that there is a gradual transition between the bud-scales and the leaves. For the scales are leaf-bases specialised for protective function.

FIG. 3.—TENTH DAY, THE FIRST PAIR OF LEAVES ARE ALMOST READY TO OPEN OUT THEIR LEAFLETS

The leaves arise opposite one another and each is palmate, that is to say, the leaflets spread out like the fingers from the palm of the hand.

FIG. 4.—THE BRANCH SHOWN IN FIG. I IS HERE SEEN AS IT APPEARED ON MAY 3

The palmate leaves are in their resting position, suffering a little from the drought. The beautiful white candelabra-like inflorescence has also appeared.

FIG. 5.—ON JULY 17 THREE FRUITS HAVE BEGUN TO FORM AT THE BASE OF THE FLOWERING BRANCH

The seeds have a bitter taste, but they are rich in starch. They are given in Turkey to broken-winded horses, and reduced to powder they serve as soap.

Photo: J. J. Ward.

FIG. 6.—BY SEPTEMBER 17 THE FRUITS HAD GROWN LARGE, WITH PRICKLY COATS

active predatory life—gripping fishes and rasping holes in their skin with a very effective toothed piston—the big Marine Lampreys return to the rivers to make their stone nests and spawn. It is a remarkable fact that they die after spawning, as eels seem to do. We have found the strong muscular body floating spent in the shallows of the river. As in the case of the delicate May-flies, so with these big lusty lampreys, the giving rise to new lives means the end of the old.

The Eel-Fare

It is in spring that the young eels or "elvers" come up the rivers from the sea in countless crowds. They are about 2½ inches in length, and like a very stout knitting needle in girth. They hug the banks but move persistently up-stream as long as the daylight lasts. When the sun goes down behind the hills they snuggle under stones and lie quiet till dawn. Their persistent migration illustrates in part an instinctive impulse, which does not work except in the light, and in part a "tropism," for the elvers automatically adjust their bodies so that the pressure of the stream plays equally on each side. The story of the eel has been referred to already in the article on THE HAUNTS OF LIFE; it must suffice to say that the elvers are already a year and a half old, that they spent their previous juvenile period as transparent knife-blade-like creatures (Leptocephali) near the surface of the Open Sea, that they go up-stream to quiet reaches and to ponds, and that the successful survivors return to the sea as big eels in 5-8 years.

The Return of the Birds

One of the pleasantest changes in spring is the return of the migratory birds which have been wintering in the south—birds like swallow and swift, cuckoo and nightingale (see article BIRDS). In many cases the adult males arrive first, and sometimes, as in the case of warblers, they choose a "territory" before their mates appear on the scene. The immature youngsters are the last to come. There is often great punctuality in the arrival of these summer visitors, as the puffins on the cliffs well illustrate; and another striking feature is that a bird, e.g. swift or swallow, may return to its precise nesting-place of the previous year. The silence of winter is soon broken; the country is full of singing birds.

II. THE BIOLOGY OF SUMMER

Summer is the time of maximum output and income of energy, when the fires of life not only burn brightest but begin to be banked up for another year. For it is characteristic of living creatures that they are able to accumulate energy acceleratively, that they are able to store.

Intense Activities of Summer

The most important activity of summer is the quietest of all—the manufacture of sugar and starch and still more valuable materials in the green leaves. The result is the accumulation of a great wealth of food—in a wheat field, for instance. Some of this goes to account of growth, e.g. in forming the buds for the next year; some of it is stored in root and stem and seed; some of the sugar is drafted into the flower to overflow as nectar and to fill the fruit with succulence; and no small part of it is immediately devoured by animals, passing into a fresh incarnation.

Summer is distinctly a flowering time, as spring of leafing; and as the days grow warmer and brighter the floral colours grow in intensity. There was more than a grain of truth in the old meteorologist's suggestion that the annual succession of colours in flowers corresponds on the whole to that of the rainbow.

If industry means the transformation of matter and energy from one form to some other form, then green plants are very industrious, and the same is true of the bees which are visiting the flowers and transforming the nectar of the blossoms into the honey of the honeycomb. As is indicated in the article on BOTANY, it is very interesting to inquire into the ways in which insects are attracted to the blossoms, whether by brightly coloured flags that catch the eye, or by fragrance appealing to the sense of smell, or by a recollection of a previous feast of nectar. It is important to notice, as Aristotle observed two thousand years ago, that

> a bee, on every expedition, does not pass from one kind of plant to another, but confines itself to a single kind—for instance, to violets—and does not change until it has first returned to the hive.

There are, indeed, exceptions, but what Aristotle noted is generally true, and the habit makes it more certain that the fertilising pollen will be scattered in an appropriate way, and not at random. Many biological notes are sounded, e.g. the value of the cross-fertilisation made possible by the most important linkage in the world (see article on INTER-RELATIONS), and the neat adaptation of insect to flower and of flower to insect. They fit like hand and glove.

Industries of Animals

The twofold business of animal life is caring for self and caring for others, and both may involve great industry. That is to say, things are made or moved, captured and stored, or changed from one form to another. When we think of an ant-hill, a piece of honeycomb, a bird's nest, a badger's burrow, we must admit that animals are often very industrious. Consider the business of *hunting*—the otter hunts alone, the wolves in winter hunt in packs; the sparrow-hawk hunts by day and the barn-owl by night; some big spiders pounce on their prey, most make snares and webs; the grub of the tiger-beetle makes a trap and the larval ant-lion a pitfall; the stoat pursues the rabbit with all its speed but the cat stalks the mouse with a hardly perceptible approach. As to *fishing,* the pelicans work in companies, the heron fishes alone; the dipper walks about and even uses its wings under water, and the osprey catches the trout in its talons. As to *shepherding,* several species of ants treat green-flies, or Aphides, as if they were cows, and even look after the young. As to *farming,* the Agricultural Ant of Texas weeds small circular patches, leaving only the needle-grass, the seeds of which are much esteemed. Both true ants and "white ants" (see the article on THE INSECT WORLD) grow certain Fungi, from which they obtain an important part of their food. The main use of the leaves which the Leaf-Cutting Ants collect seems to be to form, after they have been chewed, a medium on which the prized Fungus will grow. When the queen Leaf-Cutter founds a new colony she brings with her a minute pill of the Fungus, which forms the starting-point of a fresh growth. As to *storing,* we think of the squirrel's caches of nuts, the ants' granary, the hive-bees' honey, the digger-wasps' paralysed caterpillars. Then there is the making of shelters and nests and burrows. A climax along one line is the great termitary exceeding a man's height, built of salivated earth and often with internal furnishings of chewed wood. A climax on another line is the hanging paper house of the wasp, with one story suspended from another, and all surrounded by wind-proof and water-proof walls. There is no doubt as to animal industries.

Birds' Nests

Without trespassing on the article on BIRDS, we may emphasise what is important biologically in connection with nest-making. It is in great part an instinctive activity, but intelligent adjustment to peculiar conditions and materials is often detected. The kind of nest is often very specific; thus the blackbird and the thrush, which are first cousins, build very different nests. There is an inclined plane from no nest at all, as in guillemots, to elaborate nests like those of weaver-birds and the wren. The evolution of nests is to be linked up with the facts that it is always dangerous to lay eggs on the ground; that the development of embryo and nestling alike often demands a temperature which cannot be attained without the use of non-conducting material round about; that it is important that the parent bird be made comfortable during the long patience of brooding; that it makes the business of feeding the young easier; and that it is often essential that the eggs and the nestlings should be hidden from hungry eyes, and the young birds sheltered from the glare of the sun and from the danger of tumbling out. Finally, we find in the study of birds' nests many an eloquent reminder that in the struggle for existence the evolution of parental care may pay just as well as the evolution of sharp beak and strong talons. Professor MacGillivray counted 2,379 feathers in the beautiful nest of the Long-Tailed Tit.

Parental Care

The parental care so marked in birds is widespread through the whole kingdom of animals, and it is, on the whole, most characteristic of summer. Let us select three or four pictures.

> We sit down among the heather, and as we peer into the jungle round about we often see a mother spider moving swiftly and skilfully with a tiny silken bag on her breast. This is a "cocoon" containing eggs, and after a while young spiders. The mother seems to clutch it underneath her body with the help of the bases of her legs; but it is sometimes bound to her by silken threads. She looks as if she thought a lot of it, though we do not suppose that she thinks as *we* count thinking. But she resists if you try to take it away; and if you pull it off and place it at a little distance she seeks for it carefully—by scent, it seems, for she is very short-sighted. It is her family that she is carrying about till the young ones come out and run hither and thither of themselves, just like miniatures of their mother. Other spiders make silken nests on the heather, or in crevices among stones

> and bark; others hide their beautiful cocoons—white, pink, or greenish—in shelters made of bramble-leaves bound together with silk; the water-spider rears her family in a diving-bell of silk on the floor of a pool; the trap-door spider sinks a long shaft in the ground.[1]

In early summer the male Three-Spined Stickleback, conspicuous in red and green, makes a barrel-shaped nest in a shore pool or in a freshwater pond. Pieces of seaweed or of freshwater plants are glued together with sticky threads from the kidneys, and a cavity is made in the middle. A female is induced to enter the nest, where she lays a few eggs. When she has gone, another and another does the same, for the stickleback is polygamous. Over the nest the male then mounts guard, driving away other sticklebacks and much larger fishes. He is extremely pugnacious. When the young ones hatch out, the nest is partly picked to pieces, but the male still takes solicitous charge of the family. If a youngster strays, it is retrieved by the father fish and carried home in his mouth.

Wasps play an important part in the economy of nature by keeping down the numbers of injurious insects. Many of them kill not only for themselves but for their larvæ. Among the Digger-Wasps, some of which make tunnels in dry banks by the roadside, the mother places paralysed caterpillars and the like beside her laid eggs, so that there is fresh meat for the grubs when these hatch out. By that time the mother-wasps have died for they never see the reward of their labours. It is probable that the habit was established when the tenure of the parent's life was longer. In some other predatory wasps, such as the African Fury-Wasps, the mother brings freshly stung insects day by day to her offspring—there is sometimes only one—so that there is more of a personal touch here. In a third set of predatory wasps, the mother kills the insect right away, chews it into a mince, and gives this to her offspring, receiving in return

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[1] Thomson, *Nature all the Year Round,* 1920, p. 45.

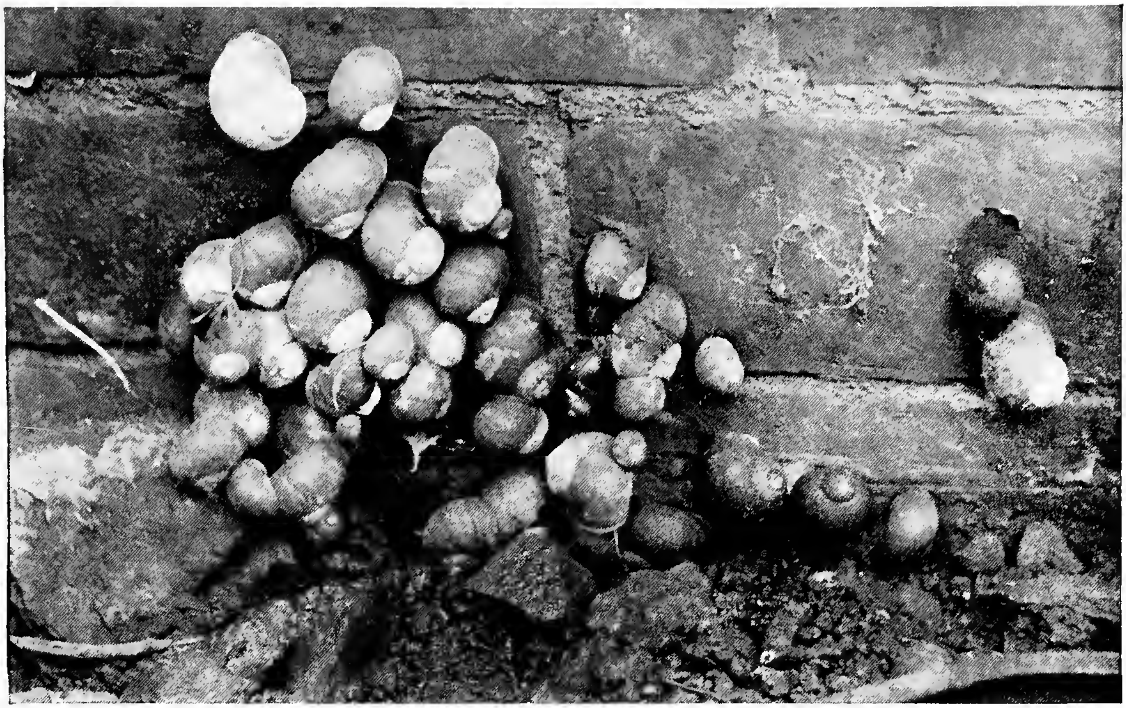

Photo: J. J. Ward.

SNAILS "LAID UP" FOR THE WINTER ON A SHELTERED WALL

The mouth of the shell is closed by a non-conducting lid of hardened slime and lime (the epiphragm), through which an interchange of gases takes place. The life of the snail sinks to a minimum.

Reproduced by permission from "The Wonders of Instinct," by J. H. Fabre.

INSECTS AT REST

Bees and wasps "asleep," fastened stiffly to the stem by the clinching of their mandibles.

Photo: J. J. Ward.

TWO ANTS SHEPHERDING GREEN-FLIES OR APHIDES, WHICH THEY USE AS "COWS," LICKING UP THE "HONEY-DEW" WHICH IS SECRETED

The ants sometime take the aphides underground in autumn, and they may even look after the eggs which the aphides lay. The linkage approaches domestication.

Photo: J. J. Ward.

HUNTING SPIDER (*Dolomedes mirabilis*) CARRYING A SILKEN EGG-COCOON

The cocoon of a spider is very different from the cocoon which some caterpillars spin around themselves when the time comes for metamorphosis. Both are silken, but the spider's cocoon is made by the mother as a bag to contain the eggs and, by and by, the young spiders. It is a portable cradle or nest. Many spiders hide it in some suitable corner; others carry it about below the body.

a drop of overflowing juice from the grub's mouth—an elixir that seems greatly appreciated.

The salient biological fact in summer is, we think, the extraordinary activity at various levels—vegetative, instinctive, and intelligent. The activity is swayed by the twin impulses of Hunger and Love. There is eager endeavour after individual well-being, and there is not less careful effort which secures the welfare of the young. The intensity of life sometimes goes too far, as the worker-bee illustrates in its very short life and in the demonstrated fact that a certain number of its brain-cells are always becoming over-fatigued and going out of gear. Another illustration of the tendency to overdo things may be found in the "summer-sleep" or æstivation of some animals in warm countries. Thus the tenrec (Centetes) of Madagascar—an earthworm-eating Insectivore—relapses in summer into a state hardly distinguishable from hibernation. We may notice in passing that there are many peculiar features in this type: thus, some of its dorsal hairs have turned into spines, and as the animal cannot roll itself up, like its distant relative the hedgehog, it dashes them with some force into the skin of an assailant; and, again, it has been reckoned as the most prolific of mammals, for it is reported to have had twenty-one young ones in a litter. But this is by the way. The keynote of summer is activity!

III. THE BIOLOGY OF AUTUMN

Autumn Fruits

Although autumn is the time when the tide of the year turns, a dominant biological impression is that of the abundance of life. We get that impression in the orchard and in hedgerow alike when we observe the abundance of fruits. Leafing in spring, flowering in summer, fruiting in autumn, resting in winter, such is the plant's normal life-story. A fruit consists of the full-grown seed-box or seed-boxes, often with accessories in the form of any parts of the flower or flower-stalk that may persist after the pollination. When the insect visitors have done their work and the possible seeds or ovules have become real seeds with a developing egg-cell within, the nectaries are closed, and the surplus sugar may be drafted into the fruit, as in stone-fruits and berries. But there are, of course, many kinds of fruits—pods, capsules, nutlets, nuts—which are not succulent. What are the chief uses of fruits to the plants that bear them?

The essential part of the answer to this simple question is that the use of the fruit is *racial, not individual.* They protect the seeds and they may help to scatter them, e.g. when they dry and break, like the withering leaves they are, or when with their dead roughnesses they adhere to passing animals. In other cases the succulence and fine colours attract hungry birds and fruit-eating mammals. At first glance it does not seem clear why being eaten should be of great service, but the point is that the seeds inside the fruit are often left undigested and are sown far and wide by the creatures that devoured the fruits. Seeds are rich in proteins; fruits have little of these valuable nitrogenous carbon compounds. They may have sugar, but sugar is simple compared with proteins, and is non-nitrogenous. Supposing the seeds are not eaten, it requires 1½ lb. of grapes, 2 lb. of strawberries, 2½ lb. of apples, and 4 lb. of pears to furnish as much protein as there is in a hen's egg or a small handful of peas. The significance of this is that what is spent in the fruit is lost, but what is stored in the seed is legacy.

The Scattering of Seeds

When man is harvesting, nature is scattering seeds. On a genial autumn day the pods of the gorse may be heard bursting; many capsules crack less violently, sometimes helped by seed-eating birds; rough-coated fruits (which may be practically equivalent to seeds) adhere to furry animals like rabbits and fall off by and by; others, like dandelion-down and thistledown, are wafted about singly by the wind, and the plumose nutlets of the Clematis or Traveller's Joy are entangled in long lines, which float off with a beautiful wavy motion, "like silver serpents in the air." Some birds digest the seeds they eat, but many fruit-eating birds pass out the seeds undigested and none the worse for their sojourn in the food-canal. Other seeds, as is noted in the article on INTER-RELATIONS, are distributed in the clodlets which accumulate on birds' feet and are washed off far away. There are many other methods of seed-scattering: thus the peanut pokes its pod into the earth, and the beautiful Ivy-leaved Toadflax on the wall pushes its box-fruit into a cranny, both behaving almost like animals, though the whole process may be explained in terms of automatic "tropisms."

The seed-scattering in autumn impresses us with the abundance of life, but the other side of the picture is the abundance of death—the chances against the germination of the seed are so enormous. Tennyson wrote with reference to nature's prodigality: "Of fifty seeds, she often brings but one to bear"; and he afterwards thought that he should have written "myriad" instead of "fifty." Darwin noted that the common Spotted Orchis may have 30 seed-boxes, each with 6,200 seeds. If we allow 400 bad seeds to each box there would be 174,000 seeds from one plant. These would cover an acre; the grandchildren would cover the Island of Anglesey; the great-grandchildren the whole land-surface of the globe. Such things do not happen, the chances against the success of the seeds are so great, as we are told in the immortal parable. There is enormous mortality and apparent wastage, but part of the elimination is *discriminate,* and this winnowing, singling, sifting, which we call Natural Selection, is one of the secrets of progress.

Withering Leaves

All through the summer the green leaves have been the seat of intense activity, but this wanes in autumn, and they wither.

They have begun to suffer from the wear and tear of living; the furnishings of the cell laboratories are becoming worn. Moreover, it is well that the leaves should die, reducing the exposed surface from which water is given off, for as the soil gets colder it becomes more difficult for the roots to keep up the supply.

But before the leaves fall off they surrender all their useful material to the plant that bore them. There is a passage of sugar, green-pigment, and more complex materials—even living matter itself—into the stem and root. There is almost nothing left in the withered leaf but ashes—and beauty. When the chlorophyll recedes it leaves yellow grains behind it, and the tree is crowned with gold. Often there appear special waste-pigments, such as anthocyan (also occurring in flowers and fruits) which give the leaves of bramble, vine, and Virginia Creeper their autumnal splendour. In various ways a weak line is established at the base of the leaf where it joins the twig. To the inside of this a corky partition grows across, which helps in the actual separation and forms a protective scar. The windy day comes and the leaves fall in thousands—to enrich the earth as they enriched the tree.

The Work of Earth-worms

It is in autumn that we see most of the work of earth-worms, dragging leaves into their burrows and thereby making vegetable mould, covering the surface with their castings of fine earth ground to powder in their gizzards. With their burrowing, bruising, and burying they have made most of the fertile soil of the world. This has been dealt with fully elsewhere (see p. 644).

Flights of Gossamer

Almost at any time of year there may be a shower of gossamer, but the characteristic time is in autumn—naturally enough, for the biological significance of the occurrence is as a spreading out of small spiders from a crowded area, and the

Photo: J. J. Ward.

THE EXPLOSION OF THE BROOM PODS

The seed-pods of the Broom ripen in August, and change from green to black. In the heat of the sun they burst open with a crackle. The two valves twist into a spiral and the seeds are jerked out to a distance of several feet. This is very effective, but there is no vitality in it. The explosion is due to the unequal shrinking of two layers of woody cells in the wall of the pod. It is a mechanical mode of seed-scattering.

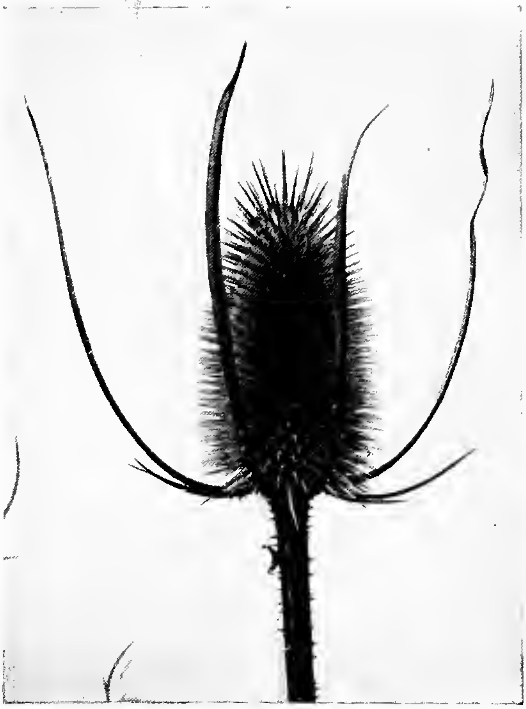

Photo: J. J. Ward.

FRUITING HEAD OF THE WILD TEASEL (*Dipsacus sylvestris*), WHICH JERKS OUT THE FRUITS MECHANICALLY, BY THE UNEQUAL SHRINKAGE OF THE SPRINGY BRACTS

The hard recurved bracts of the cultivated Fuller's Teasel (*Dipsacus fullonum*) are used for raising a nap on woollen cloth.

WINTER

The trees are leafless and the above-water parts of the aquatic plants have died away, leaving in most cases only the roots which are fixed in the mud.

(*See next photograph.*)

crowding is greatest after the abundance of summer. What happens is certainly remarkable.

Certain small spiders, especially when they are young, mount, on a breezy morning, on posts and paling, or on the top of tall herbs. They stand with their head to the wind and allow threads of silk—often four—to float out from their spinnerets. The multiple jets of liquid silk harden instantaneously on exposure to the air, and the wind begins to tug them. Then the small spider lets itself go from its perch, and, usually turning upside down, allows itself to be carried on the wings of the wind, supported by the silken floats. Reference has been made to this in another article, and it is enough to say that when thousands of spiders make their aerial journeys on a suitable morning, and eventually sink to earth, the threads may cover great stretches of links and meadow, field and hedgerow, and there is a "shower of gossamer." The wingless aeronauts or balloonists may be borne for many miles—sometimes far out to sea—and except in the last case, they are often successful in their passive migration.

Preparations for Winter

There is much in the biology of autumn that may be summed up in the idea of preparing for the hard times of winter. There is much storing on the part of plants; there is much on the part of animals, both inside their bodies and outside. The bud gets its hard, sometimes varnished, protective scales; the animal may get a thicker coat of fur. In the fall of the leaf there is a particularly striking example of a widespread tendency to sacrifice the more vulnerable parts and entrench. The birds we call "summer visitors" make their way southwards to more hospitable shores, and there are other movements besides true migration which may take place in autumn. A true migration is a seasonal mass movement from a crowded breeding-place to a place for recuperation —typically the winter-quarters, whence there is normally a return of the survivors the following year. Of course, there are exceptional cases, like the migration of the freshwater eels to the Deep Sea, where they seem to die after spawning; but in ordinary cases the migration is a periodic mass movement with a return journey.

The Story of the Lemmings

It seems warrantable to distinguish from true migration such mass movements as lemmings sometimes illustrate in the autumn. Brehm tells us how a warm summer increases their numbers past computing and past supporting.

> Scarcity of food begins to be felt, and their comfortable life comes to an end in panic. Their fearless bold demeanour gives place to a general uneasiness, and soon a mad anxiety for the future takes possession of them. Then they assemble together and begin to migrate. The same impulse animates many simultaneously, and from them it spreads to others; the swarms become armies; they arrange themselves in ranks and a living stream flows like running water from the heights to the low grounds. All hurry on in a definite direction, but this often changes according to locality and circumstances. Gradually long trains are formed in which lemming follows lemming so closely that the head of one seems to rest on the back of the one in front of it; and the continuous tread of the light little creatures hollows out paths deep enough to be visible from a long distance in the mossy carpet of the tundra. The longer the march lasts the greater becomes the haste of the wandering lemmings. Eagerly they fall upon the plants on and about their path, and devour whatever is edible; but their huge numbers impoverish even a fresh district in a few hours, and though a few may pick up a little food nothing is left for those behind; the hunger increases every minute, and the speed of the march quickens in proportion; every obstacle seems surmountable, every danger trifling, and thousands rush on to death. If men come in their way they run between their legs; they face ravens and other strong birds of prey defiantly; they gnaw

> through haystacks, climb over mountains and rocks, swim across rivers, and even across broad lakes, arms of the sea, and fjords. A hostile company follows in their wake: wolves and foxes, gluttons, martens and weasels, the ravenous dogs of the Lapps and Samoyedes, eagles, buzzards, and snowy owls, ravens and hoodie crows fatten on the innumerable victims which they capture without trouble from the moving army; gulls and fishes feast on those which swim across the water. Diseases and epidemics are not awanting, and probably destroy more of the lemmings than all their enemies put together. Thousands of carcases lie rotting on the wayside, thousands are carried away by the waves.[1]

In some cases the remnant of the army reaches the sea, and this also the lemmings seek to cross, obedient to the instinctive command engrained in their dull-witted smooth brains to go straight on at all costs. The waves of the North Sea or the Baltic sweep over them, and the march of the lemmings is ended, and their population problem solved.

IV. THE BIOLOGY OF WINTER

Winter is the low-tide of the year. Fundamentally because the reduced income of heat slows the chemical processes which living involves, and because the reduced income of light checks the manufacturing activity of the green leaves. But there are other reasons. The low temperature makes it imperative that many of the delicate structures of plants and animals should be shed or absorbed, else the whole creature will be fatally injured; the hardness of the frost-bound earth makes it necessary that many animals should lie low; in the scarcity and the storms and the short days there are reasons enough for the migration of birds to the south. Behind all this there is the physiological need for rest after toil.

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[1] Brehm's *North Pole to Equator.*

Winter Whiteness

Perhaps the most interesting aspect of the Biology of Winter is the variety of solutions that different creatures offer when face to face with the same problem—the cold, the scarcity, and the storms. A neat solution is to be found in the change to whiteness which occurs in ptarmigan and mountain hare, in the Hudson's Bay lemming and the Arctic fox, and in the common brown stoat which becomes the pure white ermine. The blanching is usually brought about by growing a new unpigmented suit, though there is sometimes a removal of the pigment from individual hairs. In the new-grown white hair or feather, and in a hair that has turned white, the place of the pigment is taken by gas vacuoles, from the surfaces of which the light is so perfectly reflected that the hair or feather appears white—just like foam or snow. Many northern creatures, such as polar bear, white whale, Iceland falcon, and snowy owl, are more or less white all the year round. In these cases the whiteness is permanent, in the other cases it is periodic. In all cases, no doubt, a constitutional predisposition to the suppression of pigment has been established, but it is probable that the low temperature is the immediate condition of the non-appearance of the pigment. We must keep in mind the case of the wan newt called Proteus, from the Dalmatian Caves, which is always pigmentless in the darkness, but rapidly develops pigment when kept in the light. Similarly, the stoat sometimes remains a stoat, e.g. in the South of England, or, somewhat mysteriously, in individual cases. We do not know enough as yet to say how far the whiteness of the winter suit expresses an engrained racial periodicity not to form hair-pigment in the fall of the year, and how far the whiteness means that the cold has directly and individually affected the chemical routine of the body and the circulation in the skin. We await more facts.

When we almost tread upon the white ptarmigan among the snow on the high hills, we are inclined to lay considerable emphasis on the protective value of the whiteness, which gives the bird a garment of invisibility. We should be slow to reject this interpretation, but suspicion rises in our mind when we see how conspicuous the mountain hare often is when there is no background of snow. We are also aware that the stoat has almost no enemies from which it may escape by turning into a white ermine, and if it be said that the elusive carnivore is enabled to slink on its prey—say a ptarmigan or a grouse—among the snow, it may be replied that the ermine is conspicuousness itself when the surroundings are not white. In short, there must be some deeper significance in the periodic whiteness of ptarmigan and ermine, and in the permanent whiteness of snowy owl and polar bear. The answer to the biological riddle is that for a warm-blooded animal in very cold surroundings the most economical dress is white, for it loses least of the precious animal heat. It is physiologically the fittest dress because it conserves the warmth of the body which enables the chemical processes to go on quickly and smoothly. In very hot surroundings a white dress is again the best, for it absorbs less than other colours would of the external heat.

Lying Low

Another way of meeting the winter is to sink into lethargy, lying low and saying nothing. When there is no income, the only chance is to have no expenditure—or almost none. Thus the snail closes the mouth of its shell with a lid of hardened lime and slime, and, seeking the recesses of an old wall, lies inert through the cold months, not without some loss of weight and some degeneration in its tissues. When the outside temperature is near the freezing-point the heart of the garden snail may beat only four times a minute instead of the forty times observed in summer. It is hardly a *modus vivendi* (a way of living) that this snail has adopted, but it is a way of not dying; and that is always something. The same kind of lethargy is to be seen in the chrysalids of moths and butterflies, which often remain hidden away during the winter months, in many ways like the seeds of plants. But it must be remembered that *in both cases* changes may be going on—especially as the severity of winter begins to yield before the approach of spring.

The full-grown frog feeds on insects and grubs, on earthworms and slugs; but these are not readily available in the winter. So the frog snuggles into a hole in the bank, or up a disused drain-pipe, or even into the mud (though this is rare), and sinks into a winter torpor, which must not be confused with the true hibernation restricted to a few mammals. Similarly there are tortoises and terrapins that bury themselves in the dry ground or in the wet mud, and lie quiet all the winter through. In some kinds of tortoises the winter torpor does not set in if they are kept in artificially heated quarters, and it is interesting to learn that this disturbance of the natural rhythm sometimes upsets the constitution in rather subtle ways. Another instance of lethargy may be found in the limbless lizards, or slow-worms, which coil up together—sometimes a dozen of them—in a mossy bank; and a great tangle of adders is sometimes found in the recesses of a cairn or haystack. In cold-blooded animals, such as reptiles, amphibians, and fishes, the temperature of the body tends to approximate to that of their immediate surroundings; hence the advantage of a confined space or blanketed nook, which is a little warmer than the open. The body may become stiff without fatal results, but if the heart should be actually frozen there is no recovery. We cannot help wondering that survival is so frequent, especially in cases where the normal life is intensely active. It is not so difficult to understand survival when an insect spends the winter in a well-wrapped-up quiescent pupa state; but we have to bear in mind cases like the full-grown queen wasp or hornet in the crevice of an old tree, or the full-grown queen humble-bee in a hole in a mossy bank.

Photos: S. Leonard Bastin.

SUMMER

The trees are in full leaf and the water plants show shoots and leaves rising out of the water.

Photo: J. J. Ward.

THE BLADDERWORT OR UTRICULARIA

A submerged aquatic plant which traps tiny water animals, such as crustaceans, in its "bladders," which appear to be transformed parts of leaves. The Bladderwort has no roots. Beautiful yellow flowers, which appear but once in several years, rise above the water. The terminal buds, heavy with reserves, sink to the bottom in autumn, and rise again, lightened of their stores, in spring—starting new Bladderworts.

Winter Sleep

In the article on MAMMALS there is some discussion of true hibernation, as seen in hedgehog and marmot, dormouse and bat. A brief reference must therefore suffice. A few mammals, such as those just mentioned, have some imperfection in their warm-bloodedness, that is in the power (confined to birds and mammals) of adjusting the production of heat and the loss of heat so that the temperature of the body remains constant. The hibernators are those mammals that cannot balance their books as regards heat; when the cold weather sets in they give up a hopeless struggle, in obedience to an engrained constitutional rhythm; they betake themselves instinctively to some snug corner or well-curtained recess. The temperature of this restricted space is higher than that of the open world, so that the relapse of the winter-sleeper into a sort of reptilian cold-bloodedness is not fatal. If they hibernated in the open it would be the end of them, but in a recess they do well.

Condensation into Small Bulk

In plants like tulips and hyacinths, we see another way of meeting the winter—the whole body of the plant is condensed into more compact and less vulnerable form. In the same way the shedding of leaves is like a relinquishing of outposts when hard pressed. A bud is a shoot in winter-quarters. A very interesting case is that of the rootless Bladderwort of the loch, that captures water-fleas in tiny traps on its floating stem. In autumn the terminal buds, heavily laden with reserves, drop off and sink to the warmer water at the bottom; whence, lightened, they float up again in spring and start new plants. This is to be compared to the not very familiar well-protected external buds ("hibernacula") of colonies of small aquatic animals called Polyzoa, which persist throughout the winter when the rest of the colony dies. Similarly, the freshwater sponge in the river or lake rots away in the autumn, but does not wholly die.

Certain clusters of cells called gemmules appear in the moribund body, each well compacted together, and encased in beautiful capstan-like spicules of flint which fit closely into one another. These start new sponges in the spring. Although they are not very well known, there are many illustrations of this method of meeting the winter by condensation and encystation.

Another solution, already referred to in connection with autumn, is laying up stores. The squirrel with its stores of nuts is the instinctive counterpart of the intelligent housewife; the hamster with its stores of grass and grain is the instinctive counterpart of the intelligent farmer. It must be recognised that the storing habit in hive-bees is an essential condition of the persistence of the community throughout the winter. It is interesting to know of the Mediterranean ant, *Aphænogaster sardoa,* which lives in holes in the ground, but does not store.

> Huddling together is their form of sociality. They form living balls, ant interlocked with ant by the mandibles and tarsal joints, and they hold the eggs, larvæ, and pupæ in the middle. It is almost like a diagram of a primitive society and certainly matriarchal! A ball consists of three hundred to a thousand individuals; males have not been found; and the investigator saw only one queen. In winter the ball is very stiff and is slow to relax when it is unearthed. In summer, however, the ball is naturally more plastic, it is always being unmade and remade.[1]

Now the point is, that this simple case, where the whole communal life is summed up in huddling together, is the beginning of the ant-hill, in which abundant storing has made more elaborate social life possible.

Migration

Neatest of all the solutions is the circumventing of the winter, illustrated by the migratory birds, which literally "know no winter in their year." Enough has been said of this in the

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[1] Thomson, *The Wonder of Life,* 1914, p. 331.

article on Birds, but a reference is necessary here to complete our survey. It has become engrained in the constitution of the great majority of our North Temperate birds to pass in autumn from their nesting-place—always in the colder part of their migratory range—to a resting-place in warmer southern lands. The neatest way of meeting the winter is to evade it altogether, and that this is *relative* is plain enough from the fact that many a curlew finds it sufficient to descend from the inhospitable moorland to the fields by the shore, and that many a lapwing finds it enough to pass from Aberdeenshire to Ireland. It must also be noted that various birds that nest in the farther North, such as fieldfare, redwing, snow bunting, great northern diver, and little auk, find Britain very congenial in winter, and are our "winter visitors."

Reduction of Numbers

On a different tack altogether is the solution of the winter problem which is suggested by the empty wasps' nest. There has been a drastic reduction of the population, so that only the young queens are left to survive the winter, which they pass in solitude and lethargy in the shelter of some partly broken tree stem. Towards the end of the autumn there is a grim tragedy in the wasps' nest, for the wasp-grubs that are left in their cells are devoured. But this wholesale infanticide is only anticipating the death which the cold weather would soon bring about, and it may be that the gorging helps the young queens to pass the winter months in their cupboardless hiding-places. The same kind of solution is exhibited elsewhere, as in the case of the humble-bees, for of the large summer community only the young queens live on through the winter.

Elimination

Such cases naturally lead us to the conspicuous fact in the Biology of Winter that it is a time of sifting—the time of severest elimination. Winter is indeed an opportunity for rest and recuperation, but it is also an opportunity for winnowing. The rest and sleep of winter are often the necessary conditions of the vigour of another spring, but in a deeper way it is through the sifting, winnowing, pruning, or elimination of ages of winters that there has been spring after spring of progressive evolution.

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XXXIV

WHAT SCIENCE MEANS FOR MAN

BY SIR OLIVER LODGE

WHAT SCIENCE MEANS FOR MAN

LIFE, MIND, AND MATTER

By Sir Oliver Lodge

THERE are three things partly within and partly beyond human reach—Truth, Goodness, and Beauty. All are necessary for completeness, and a Being in whom they all reach perfection would be what we call Divine. But with our limited capacities few of us can do more than aim at one of them; though, if we are able to retain the open mind, we may hope that by faithful effort in one direction something of the two others may be "added unto us."

The Aim of Science

The direct aim of Science is Truth, and the temptation of its devotees is to concentrate too narrowly on this one aim and lose sight of the wealth of existence which gives all the meaning and value to bare fact; thus gaining but a purblind view of the universe, in spite of a large accumulation of knowledge which is accurate as far as it goes, but so incomplete as regards the totality of things as to be liable to mislead.

But such narrow students of science are not Philosophers. They may pose as such occasionally, and be loud in the negation of everything outside their own range, but true philosophy must take a wider view, it must open its eyes in every direction, and seek to comprehend the length and breadth and depth and height, and to interpret something of the great Reality which passeth knowledge.

Only so can the man of science escape the narrowness of specialisation; he must keep his mind open to the Universe in every direction, if he is to perceive something of the fullness of existence. But to Truth he must be faithful. That is his peculiar quest, and no slackness in making sure of his facts can be permitted to the scientific man. Narrowness of range is a pity, but it is pardonable; blasphemy against the spirit of Truth can never be forgiven.

The particular aspect of the Universe which most impresses the man of science, at any one epoch, is liable to vary. Existence is so multifarious and bewildering in its scope and variety that not only has humanity to make distinctions and contemplate things seriatim, but investigators must divide themselves into groups, and each group attend specially to its own department.

In this way Science has become split up into a number of sections, and the workers in one section are often ignorant of what the others are doing. A wide philosophy under these circumstances is impossible. It is only by getting out of our groove, from time to time, and attempting a survey, that we can assist the philosophers, who perhaps have never entered a groove at all. They seem to us to be too thinly supplied with facts, whereas we are apt to be overburdened with a lop-sided load of them. Hence Philosophers and Scientific men often fail to understand each other and sometimes quarrel.

§ 1

Outlook on the World

Looking round, then, on existence, with eyes clouded a little by special study but as widely open as we can get them, what do we see?

An unbounded universe of space, containing spherical masses of matter, some hot and glowing, some dark and cool, distributed, not at random, but obedient to law and order, with motions that can be formulated and positions that can be more or less predicted. Examining Matter more closely, with the help of instruments of precision, we find it consists of atoms of known size and behaviour, and we find also that these ultimate atoms of matter are not really ultimate but are composed of something else, something that we call electricity. And this electricity also exists in little specks, which appear to imitate the larger masses in their regular motions, and which display a region of beautiful law and order in the very interior of the atom. Then when we come to investigate the intermediate region of apparently empty space we find that it is not empty, but contains a something that welds all the separate fragments of matter into a cosmic whole, and also that it carries vibrations and transmits force from one to another. And all this study of matter and ether, with its extraordinary ramifications, belongs to the science of Physics, or, as it used to be called, Natural Philosophy.

The laws of motion of the particles and masses of matter are so elaborate that they require for their elucidation and study an abstract science of form and number which we call Mathematics. With its aid a vast theoretical structure can be built upon a comparatively small basis of actual experience. The process is a wonderful example of brain-power, but it is risky; mistakes and oversights may readily be made; and accordingly every deduction must be brought to the test of experiment and observation, and rigorously verified. The two fundamental branches of mathematics relate to Number and Form; that is to say, Arithmetic and Geometry. Algebra is an auxiliary art or method of dealing with problems which otherwise would be too difficult.

Further, we can study the grouping of the atoms together, the patterns they make when they combine into molecules, and the complicated properties characteristic of the substances which their groupings form. So men have built up that great branch of Natural Philosophy which is known as the science of Chemistry.

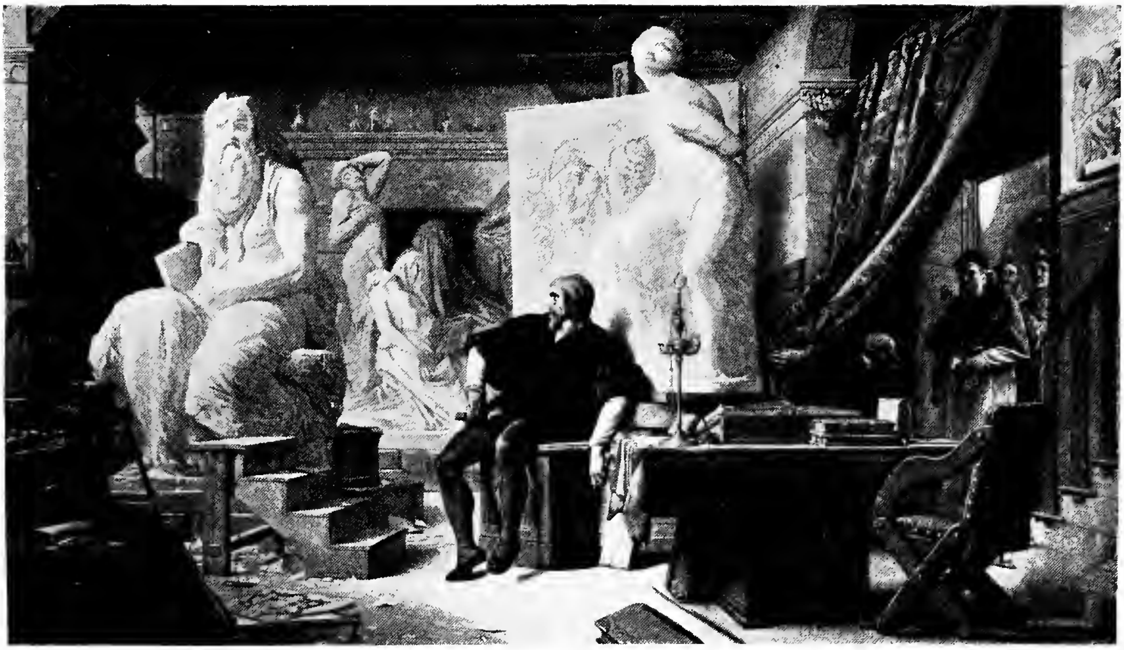
Certain collocations of these complicated molecules give expression to a new emergence of Reality, for they are able to form the physical basis of living creatures or organisms. These are the seat of chemical and physical processes, but we cannot deal adequately with living creatures, e.g. in their behaviour and development, by means of chemical and physical formulæ and concepts alone.

It appears that they are controlled and utilised by something that we call Life; or else, as some desire or prefer to express it, the complexity of their molecular structure enables them to simulate such a control. Thus arises the science of Biology. Under the influence of life the available energy of the world, which all arrives from the sun, is guided and directed so as to produce structures such as would never be produced by unaided Physics and Chemistry (for instance, sea shells, honeycombs, leaves, and birds' nests), though all that goes on is wholly obedient to the laws of ether and matter. But those laws are supplemented by the activity of something that we call life; and the result is a world of plants and animals, flowers and birds, an extraordinary world of beauty and animation and instinct, and something surely akin to joy.

Evolution of Mind

A further development makes this manifest, for life gradually evolves into mind; and through Mind we know at first hand, and from our own experience, that joy and sorrow, pain and grief, love and hate, aye, and thought and design, will and desire, feeling and aspiration, hope and faith, are realities certainly existent in the totality of things, however they can be accounted for. So comes into being the science of Psychology, and other developments, up to those gropings of the spirit of man that we call, on their practical side, Religion, and in their theoretical aspect, Theology.

These may be regarded as the major sciences, but there are many minor ones having to do with special portions of the Universe: like Geology and Geography and Meteorology, all related to the earth; others to do with man, like History and

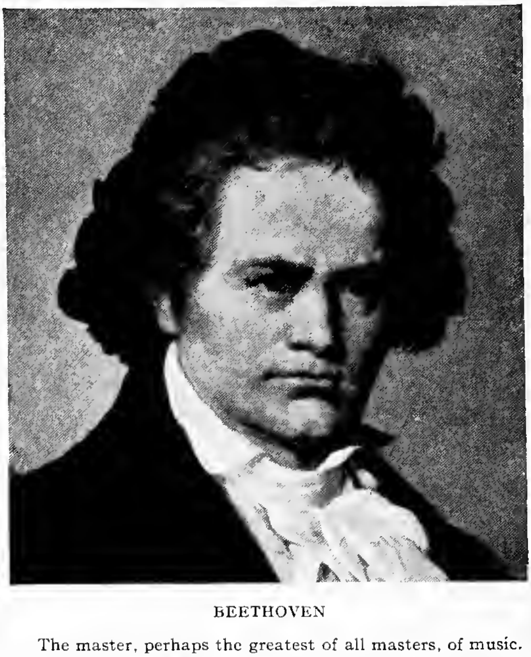


MICHAEL ANGELO IN HIS STUDIO

"We still feel the force of Michael Angelo, wearing the four crowns of architecture, sculpture, painting, and poetry."—EMERSON.

JOHN KEATS

Beauty is truth, truth beauty—that is all
Ye know on earth, and all ye need to know.
—KEATS.



BEETHOVEN

The master, perhaps the greatest of all masters, of music. Beethoven said, "Music is the mediator between the spiritual and the sensual life."

Sociology and Anthropology and Archæology. And, of course, Biology has many branches, such as Physiology—the mode of working of the animal or vegetable organism and Anatomy, its structure; also Zoology and Botany, dealing with the classification and habits of living things. Then, again, others have to do with practical applications, like Engineering and Medicine and Agriculture. The abstract science of number and form called Mathematics we have already referred to; and the separate branch of physics called Astronomy must be mentioned.

§ 2

Does, then, Science cover the whole of existence? By no means. There is the region of Art and Literature, and the whole realm of the good and the beautiful, which lie outside its scope. As human beings we have the right of entry; as men of science we must ask permission to enter. If we ignore all this realm, we suffer, and our philosophy is little better than dry bones—a skeleton which others may clothe with flesh and wake to life. (Readers who desire a more eloquent exposition of the relation between science and the rest of existence should read the *Introduction to Science* in the Home University Library, by Prof. J. Arthur Thomson.)

The human spirit is more at home in Poetry and Literature and Art than it is in the gropings and cautious investigations of Science. It is able to leap to conclusions by intuition. It likes to disport itself with full and untrammelled imagination. It is privileged to enjoy, and so far as may be to produce, beauty, in music, in painting, in architecture, in poetry. And its achievements in these directions—Sonatas, Parthenons, and Divine Comedies—are of supreme interest to humanity, and rank among the highest creations of man. For in this region it is not discovery that is arrived at, but veritable creation—the production of some work of art that would not otherwise come into existence, and before which the man of science can only bow his head. Men like Shakespeare, Dante, Michael Angelo, Beethoven, love and perceive the principles of Goodness, Truth, and Beauty, all three; and have thus caught some glimpse of the Unchangeable Reality.

There is no antagonism between poetry and science. There should be no antagonism between religion and science. There are many ways of arriving at Truth, the scientific path is but one.

Beauty and Truth

We have said that the conscientious pursuit of Truth may perhaps lead us to some apprehension of Goodness and Beauty, too. So it may be that the reverent pursuit of Beauty will lead us intuitively into the realm of Truth—as Keats more concisely said. And what the earnest following of the Good may do for man has been shown by the achievements and inspiration of the saints; the full meaning of which we are as yet hardly competent to judge. The mind of man is enriched from many diverse channels; the feet of man are guided up the ascent by many diverse paths. The aims are different, the goal may be one. All roads lead to Rome, and all avenues conscientiously explored lead in the direction of the Truth. For the Truth is larger than what any man deems possible, and no one man or group of men has any monopoly over that divine fragrance. Hidden and rare and yet dazzling and splendid, she emerges from her enwrappings, more beautiful than ever we had imagined and grander than anything we had conceived.

§ 3

RELATION BETWEEN LIFE, MIND, AND MATTER

Life, Mind, and Will

These things being so, how can we acquiesce in the materialism of science, or justify the scientific man in excluding from his attention so many aspects of the universe and attending to the laws of forces and the motion of matter? The answer is, because that is his proper business, and because the whole of nature is obedient to these fundamental laws, no matter what other laws it may be also obedient to. Exclusion from attention is perfectly legitimate if it assists the business in hand, and has no sort of connection with a materialistic philosophy which affirms some things and denies others. Thus Laplace, when catechised by Napoleon as to the place of God in his mathematical System of the World, was right in replying that he did not need that hypothesis, because he was working out his theory in accordance with the laws of matter and force alone. And a splendid achievement it was! Not complete as a philosophy of existence—certainly not. Nor was Newton's still greater, because earlier and more fundamental, theory complete philosophically; and, indeed, he felt this so strongly that he diverges and ends his book with a reasoned assertion of his profound faith in a Divine Being. Nevertheless, he had reduced the heavens to law and order on purely mathematical lines; and he went further and uttered the pregnant aspiration, which since his time has been so extensively fulfilled, that all the rest of physics—everything depending on the motion of the atoms and of the electrons, and upon all the intricacies of molecular constitution and movement—might be similarly dealt with: "WOULD THAT THE REST OF THE PHENOMENA OF NATURE COULD BE DEDUCED BY A LIKE KIND OF REASONING FROM MECHANICAL PRINCIPLES!" Yet he was a Theist of the most profound conviction. Whether Laplace was, or was not, I do not know; but it does not matter: his achievement was not in philosophy or theology, but in mathematical science. And he made the famous supposition that, given certain data and sufficiently superhuman mathematical skill—so that the path of every atom could be followed, its past orbit ascertained, and its future orbit predicted —all the phenomena of nature past and future could be calculated out and would inevitably follow.

So they would if the universe were solely mechanical, and if there were not the element of life, mind, and will, in addition.

The introduction of self-will or free-will shatters the completeness of every purely mechanical scheme. Predictions can only hold good in the absence of a disturbing cause; and the predictions of Laplace's Calculator would be valid only in the region of inanimate matter, and perhaps in the regions animated by the lower forms of life.

How early spontaneous activity occurs, in the ascending grade of existence, is a matter for discussion; but in my view the path of a common fly, as it sports with others round a pendant from the ceiling, is not likely to be deducible from any physical data on purely mechanical principles. And, if that is so, it means that an incalculable element introduces itself very low down in the scale of animal life, even though physical or mechanical principles alone dominate the vegetable kingdom; which some may doubt.

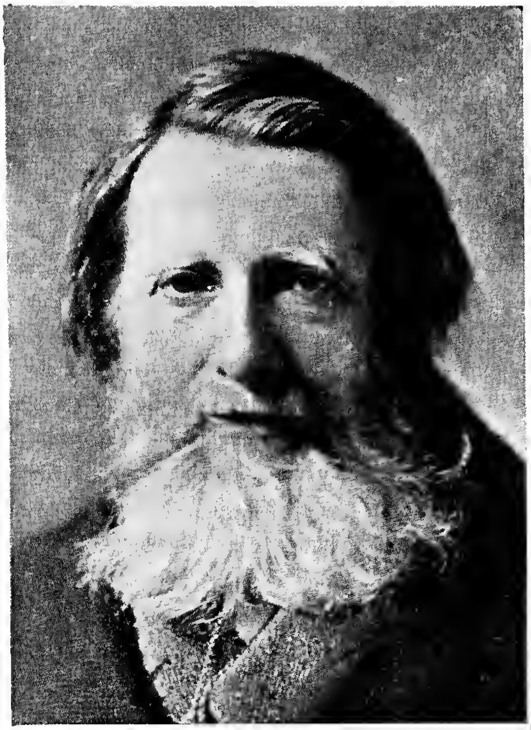
Life does not break any of the laws of chemistry and physics. It employs them all. But it supplements them. It directs energy into new channels. It cuts through an isthmus and unites two oceans. It builds a viaduct and unites two countries. It plants a forest, or floods a desert, and alters a climate. It can divert rivers, and tunnel through mountains; it has developed the manifold structure of civilisation. And, lower down in the scale, it collects wax and builds a honeycomb; it consumes corn and produces a feather—a marvellous structure when closely examined; it lives on a cabbage leaf and develops the beauty of a butterfly's wing.

So also, and *par excellence,* the spirit of man rises superior to bodily and material trammels, and disports itself in the region of intellect and imagination and poesy. Things beyond experience become food for its contemplation, and it feels itself akin to the infinite and the eternal.

§ 4

Nature of Life

What, then, do we know about this organising principle that we call "life"? Exceedingly little.



JOHN RUSKIN

"We cannot fathom the mystery of a single flower. Nor is it intended that we should, but that the pursuit of science should constantly be stayed by the love of beauty, and accuracy of knowledge by tenderness of emotion."—*Modern Painters*.

GOETHE

He pursued a lonely road,
His eyes on Nature's plan;
Neither made man too much a God,
Nor God too much a man.
—MATTHEW ARNOLD.

Photos: Rischgitz Collection.

J. M. W. TURNER, R.A.

"It is as the master of the science of *Aspects*, that . . . Turner must eventually be named always with Bacon, the master of the science of *Essence*."—RUSKIN.

DANTE

'The first awakener of entranced Europe . . . the congregator of those great spirits who presided over the resurrection of learning."—SHELLEY.

The living organism was shown by Pasteur to be responsible for a good many processes which up to this time had been regarded as merely chemical. Chemical they still are, but guided in fashion; much as similar chemical changes may be guided and contrived by the skill of a chemist in his laboratory. Unconsciously, through the agency of microscopic forms of life, fermentation and digestive operations are carried on, agriculture is aided or rendered possible, and diseases are both produced and combated.

One must not dogmatise on what has been and probably is a controversial subject, but the possibility that "life" may be a real and basal form of existence, and therefore persistent, is a likelihood to be borne in mind. The idea may at least serve as a clue to investigation, and some day may bear fruit; at present it is no better than a working hypothesis. It is one that on the whole commends itself to me; for I conceive that though we only know of life as a function of terrestrial matter, yet it presumably has another aspect, too. And I say this because I see it arriving and leaving—animating matter for a time and then quitting it—just as I see dew appearing and disappearing on a plate. Apart from a solid surface, dew cannot exist, as such; and to a savage it might seem to spring into and to go out of existence—to be an exudation from the solid, and dependent wholly upon it. But we happen to know more about dew than that; we know that it has a permanent and continuous existence, in an imperceptible, intangible, supersensual form, though its visible manifestation in the form of mist or dew is temporary and evanescent. Perhaps it is permissible to trace in that elementary phenomenon some superficial analogy to an incarnation.

So, also, when we come to the higher manifestation of life that we call mind and will. These things are not energy, but they utilise energy, and direct it into prearranged channels. They aim and fire, as it were. They discriminate between friend and foe, they attend to things far beyond the scope of material force; they have ulterior motives, and are influenced by anticipation of the future. The blind energy of an explosive is liberated, and neither increased nor diminished; but its manner of application, and therefore the result attained, can be a subject of consideration and can be preordained.

The Essence of Mind

Matter possesses energy, in the form of persistent motion, and it is propelled by force; but neither matter nor energy is endowed with the power of automatic guidance and control. Energy has no directing factor, it has no element or ingredient of direction, it possesses magnitude only. In that respect energy is like matter. It is also conserved like matter; and it is amenable to directing influences, which are applied to it indirectly through the agency of material force.

To change the course of a fragment of matter, a force must act upon it. Matter itself has no spontaneity, it is entirely inert. Inorganic matter is impelled solely by pressure from behind; to everything in front it is perfectly blind; it is not influenced by the future; nor does it follow a preconceived course, nor seek a predetermined end.

An organism animated by mind is in a totally different case. The intangible influences of hunger, of a call, of perception of something ahead, are then the dominant feature. An intelligent animal which is being pushed is in an ignominious position and resents it; when led, or when voluntarily obeying a call, it is in its rightful attitude.

The essence of mind is design and purpose. There are some who deny that there is any design or purpose in the universe at all. But that cannot possibly be maintained when humanity itself possesses these attributes. Is it not more reasonable to say that just as we are conscious of the power of guidance, in ourselves, so guidance and intelligent control must be an element running through the universe, and may be incorporated even in material things?

Matter the Vehicle of Mind

Matter is the instrument and vehicle of mind; incarnation is the mode by which mind interacts with the present familiar scheme of things; and thereby the element of guidance is supplied. It can, in fact, be embodied in an intelligent arrangement of inert inorganic matter. Even a mountain path is a concrete expression of something human; it is able to guide, and it has direction; it is a manifestation of intelligence, it leads to a destination, though itself inert.

Direction is not a function of energy. The energy of sound from an organ is supplied by the bellows, which may be worked by a mechanical engine; but the melody and harmony, the sequence and coexistence of notes, are determined by the dominating mind of the musician; not necessarily by that of the executant, for the composer's mind may be expressed to some extent even by a pianola. The music may be said to be incarnate in the roll of paper which is ready to be passed through the instrument. So also can the conception of any artist receive material embodiment in his work, and if the picture or a beautiful building is destroyed it can be made to rise again from the ashes, provided the painter or the architect still lives. In other words, his thought can receive a fresh embodiment; and a perception of beautiful form shall hereafter, in a kindred spirit, arouse similar ideas.

There is thus a truth in materialism, but it is not a truth readily to be apprehended and formulated. Matter may become imbued with life, and full of vital association; something of the personality of a departed owner seems to cling sometimes about an old garment—its curves and folds can suggest him vividly to our recollection. The tattered colours of a regiment are sometimes thought worthy to be hung in a church. They are a symbol truly, but *they may be something more.* I have reason to believe that a trace of individuality can cling about terrestrial objects in a vague and almost imperceptible fashion, yet to a degree sufficient to enable those traces to be detected by persons with suitable faculties.

There is a deep truth in materialism; and it is the foundation of the material parts of worship—sacraments and the like. It is possible to exaggerate their efficacy, but it is also possible to ignore it too completely. The whole universe is metrical, everything is a question of degree. A property like radio-activity or magnetism, discovered conspicuously in one form of matter, turns out to be possessed by matter of many kinds, though to very varying extent.

So it would appear to be with the power possessed by matter to incarnate and display mind.

Grades of Incarnation

There are grades of incarnation: the most thorough kind is that illustrated by our bodies; in them we are incarnate, but probably not even in that case is the incarnation complete. It is quite credible that our whole and entire personality is never terrestrially manifest. This, indeed, is part of the doctrine of "the subliminal self."

There are grades of incarnation. Some of the personality of an Old Master is locked up in a painting; and whoever wilfully destroys a great picture is guilty of something akin to murder, namely, the premature and violent separation of soul and body. Some of the soul of a musician can be occluded in a piece of manuscript, to be deciphered thereafter by a perceptive mind.

Matter is the vehicle of mind, but it is dominated and transcended by it. A painting is held together by the cohesive forces among the molecules of its pigments, and if those forces rebelled or turned repulsive the picture would be disintegrated and destroyed; yet those forces did not make the picture. A cathedral is held together by inorganic forces, and it was built in obedience to them, but they do not explain it. It may owe its existence and design to the thought of someone who never touched a stone, or even of someone who was dead before it was begun. In its symbolism it represents One who was executed many centuries ago. Death and Time are far from dominant.

Are we so sure that when we truly attribute a sunset, or the moonlight rippling on a lake, to the chemical and physical action of material forces—to the vibrations of matter and ether as we know them—we have exhausted the whole truth of things? Many a thinker, brooding over the phenomena of Nature, has felt that they represent the thoughts of a dominating unknown Mind partially incarnate in it all.

XXXV

ETHNOLOGY

ETHNOLOGY

THERE are sound reasons for regarding the existing races of mankind as varieties of one species, *Homo sapiens,* just as the numerous breeds of pigeons are offshoots from the ancestral stock of the rock-dove. One reason is that, so far as is known, the members of the different races are fertile with one another, giving rise to fertile crosses, such as mulattos. Another reason is that the embarrassingly numerous races grade into one another. And a third reason may be found in the extreme improbability that such a happy new departure as "the modern man type" (*Homo sapiens*) would arise more than once in evolution. It is likely that some tentative types, like Neanderthal Man, antecedent to "the modern man type," became extinct or were absorbed; it is likely that *Homo sapiens* arose from a stock which he shared with the Neanderthal, the Heidelberg, and the Pithecanthropus races.

One Species with Many Races

The number of different races of man is very large, but the phenomenon is familiar at lower levels. A group of living creatures belonging to a species becomes in some way isolated; variations or mutations may occur in the families, and they are often numerous; selection or sifting sets in and the variants which are fittest in relation to the particular conditions of life become dominant over their neighbours; inbreeding occurs, and the new characters become firmly established, while analogous recessive characters with a disadvantageous bias are sifted out; *a race is* *established.* Thus, if the original colour of man was brown, a dark-coloured race or a white race may have arisen over and over again in different parts of the earth. It must be understood also that a removal of isolation barriers, e.g. by a migration or an invasion, would tend to bring about a mingling of races, and as a result, new permutations and combinations. Inbreeding promotes stability and uniformity; outbreeding promotes variability, unless the divergence of the parents is too pronounced. One is apt to underestimate the possibilities of novelties. Prof. E. G. Conklin writes:

> The principles of Mendelian inheritance show that for every pair of contrasting characters in the two parents, as for example straight or curly hair, brown or blue eyes, there are two types of grandchildren showing these characters; when there are five such pairs of contrasting characters in the parents, there may be $(2)^5$ or 32 types of grandchildren showing various combinations of these five characters; when there are ten pairs of contrasting characters, there may be $(2)^{10}$ or 1,024 types of grandchildren. Between different races there are many more than ten unit differences, and thus with a relatively small number of mutant characters an enormous number of different combinations of the characters is possible in the offspring. Subsequent inbreeding of such a mixed race leads to the separation or segregation of particular types, having certain of these combinations, from other types having other combinations.

As with domestic animals and cultivated plants, so with human races; mutations or variations arise (as to the conditions determining the origin of the distinctly new, there is little certainty); there is sifting by selection and stabilising by inbreeding; there is mingling with fresh blood and a fresh shuffling of the hereditary cards; there emerges a new set of novelties; there is sifting and inbreeding again. In outline, that is how race-forming has come about.

THE RED "INDIAN"

The American "Indians" in former times occupied a vast extent of territory. Yet they present a remarkable uniformity in regard to their physical characters, though linguistically and in culture they differ widely.

"Story-books" and the early Colonists from England have familiarized the world with the North American Indian, or "Red-skin," but his relatives of South America are no less interesting, although in many ways less picturesque.

§ 1

The Primary Groups of Mankind

More for convenience than with conviction, ethnologists are accustomed to recognise three primary groups of human races—the black, the yellow, and the white. Each group has numerous subdivisions or races, each race may have its sub-race, each sub-race its breeds, each breed its stocks.

1. The group of Black or Negroid races is typically characterised by darkly pigmented skin, frizzly hair, a broad flat nose, thick lips, prominent eyes, large teeth, a narrow hip-girdle, and long heads (dolichocephaly). But there is great variety within the group, which includes African negroes, South African bushmen, various Pygmy races, together with such divergent types as the Melanesians and the Australian blackfellows (who have not frizzly hair).

2. The group of Yellow or Mongolian races is typically characterised by yellowish skin, black straight hair, broad face with prominent cheek-bones, small nose, sunken narrow eyes, moderately sized teeth, and diverse types of skull. Here come in Chinese, Japanese, Tibetans, Siamese, Burmese; Malays, Brown Polynesians, Maoris, Esquimaux, and Red Indians; and most divergent of all, the Lapps and Finns, the Magyars and Turks.

3. The group of White or Caucasian races is typically characterised by soft and straight hair, well-developed beard, retreating cheek bones, narrow and prominent nose, small teeth, and broad hip-girdle. But the group includes along with the fair-haired and white-skinned peoples of northern Europe, the dark-haired and often dark-complexioned southerners. Thus in Europe we may distinguish the tall and blond *Nordics,* the stocky dark *Alpines,* and the small dark *Mediterraneans,* while in Asia there are the Indo-Aryan and other types. It hardly requires to be said, for the heterogeneity of our enumeration is so evident, that these three primary groups—Negroid,

Mongolian, and Caucasian—do not mean very much scientifically; yet everyone will admit that a Persian is nearer to a Britisher than a Hottentot is, and we think we understand what an Arab is after, while a Chinaman remains a sphinx.

A Change of Outlook

A generation ago it was thought possible to distinguish three "primary races"—a phrase we have not used—black, yellow, and white; and it was commonly thought that these represented a very ancient trifurcation of the human species. But there are good reasons for suspecting that this view—which we might call "the Shem, Ham, and Japheth" view—is all too simple. No doubt the contrasts are striking and real.

> We are all familiar [Sir Arthur Keith writes] with the features of that racial human type which clusters round the heart of Africa; we recognise the negro at a glance by his black, shining, hairless skin, his crisp hair, his flattened nose, his widely opened dark eyes, his heavily moulded lips, his gleaming teeth and strong jaws. He has a carriage and proportion of body of his own; he has his peculiar quality of voice and action of brain. He is, even to the unpractised eye, clearly different from the Mongolian native of north-eastern Asia; the skin, the hair, the eyes, the quality of brain and voice, the carriage of the body and proportion of limb to body serve to pick out the Mongol as a sharply differentiated human type. Different from either of them is the native of central Europe—the Aryan or Caucasian type of man; we know him by the paleness of his skin and by his facial features—particularly his narrow, prominent nose and thin lips. We are so accustomed to the prominence of the Caucasian nose that only a Mongol or Negro can appreciate its singularity in our Aryanised world.

Now if the distinctive features are so well-marked as this great authority indicates, why should we hesitate to accept them as indicative of a fundamental trifurcation of the human species? The answer is interesting.

§ 2

Hormones and Ethnology

At many points in this OUTLINE OF SCIENCE reference has been made to the ductless glands of internal secretion which manufacture "hormones" and "chalones"—potent chemical messengers discharged into the blood. The pituitary body, "about the size of a ripe cherry, attached to the base of the brain, and cradled in the floor of the skull," makes a secretion that regulates growth. An abnormal enlargement brings about "acromegaly," which profoundly alters the character of face and body, hands and feet; or the youth may become an unhealthy giant; or the limbs may grow disproportionately long, and the sex system fail to develop properly—the result being sometimes eunuchoid obesity.

> We are justified [Sir Arthur Keith says] in regarding the pituitary gland as one of the principal pinions in the machinery which regulates the growth of the human body and is directly concerned in determining stature, cast of features, texture of skin, and character of hair—all of them marks of race. When we compare the chief racial types of humanity—Negro, the Mongol, and the Caucasian or European—we can recognise in the last-named a greater predominance of the pituitary than in the other two. The sharp and pronounced nasalization of the face, the tendency to strong eyebrow ridges, the prominent chin, the tendency to bulk of body and height of stature in the majority of Europeans are best explained, so far as the present state of our knowledge goes, in terms of pituitary function.

Before this view can be accepted in its entirety, there must be very precise comparisons of the pituitary body in different races, for Science begins with measurement. But the idea is plainly a shrewd one. It does not mean that the European is an acromegalic in disguise; it means that variations in the development of the ductless glands may account for some of the changes that are rung on human characters. There is some evidence that some of the extinct giant Vertebrates had relatively large pituitary bodies. Variations in the development and activity of these regulating organs may have played an important part, not only in the evolution of human races, but in the evolution of Vertebrate types.

We must not follow this fascinating line of thought much further, but it may be noted that the hormones from the reproductive organs have a profound influence on many characters of the body; that the supra-renal secretions affect pigmentation and hair; that the thyroid glands, set astride the windpipe just behind "Adam's apple," influence skin and hair, skull and skeleton; that two kinds of dwarfs are due to a defect in their growth regulating function; that the abnormal children, significantly called "Mongolian idiots," are not reversions to hypothetical Mongolians supposed to have once lived in Europe, but are the outcome of disordered thyroid functioning. Given a susceptible structure, variations in the internal secretions may account for many features which have been over-exalted as deep racial differences. On the other hand, we must not minimise these racial differences because Sir Arthur Keith gives us a clue which makes them more intelligible. The difference between male and female is a very profound one, and none the less far reaching because it may turn out to be fundamentally a difference in the rate and rhythm of metabolism, or because the actualisation of some of the secondary sex characters depends on the liberating stimulus supplied at appropriate times by hormones from the reproductive organs.

It is a luminous idea, however, that racial differences in skull and skin, in hair and colour, may be correlated with hereditary variations in the ductless glands; and we see the likeli-

Photo: E. N. A.

A MAORI

The Maoris are commonly regarded as a practically pure Polynesian race. But this is by no means true. In their passage to New Zealand they interbred with several other distinct races, traces of which are indubitably present in the skull.

Photo: H. J. Shepstone.

ZULU

An irregular line drawn across Africa from the southern end of Italian Somaliland in the east to Calabar in the west divides the true negroes from the Bantu, which occupy the area south of this line. The Bantu are represented by innumerable tribes and races, of whom the Zulus are the most warlike and the most powerful.

Photo: Bourne & Shepherd, India.

HINDU

The Hindu represents but one of a number of very distinct races in India, and is properly restricted to the Indo-Gangetic region of India.

Photo: H. J. Shepstone.

ARAB

The Arabs occupy Arabia, part of Mesopotamia, the shores of the Red Sea, the eastern coast of the Persian Gulf, and the North of Africa. The pure type is long-headed, has an elongated face, an aquiline nose, and a slim figure. The most typical specimens of this race are found in South Arabia, the mountaineers of Hadramaut and Yemen, and among the Bedouins.

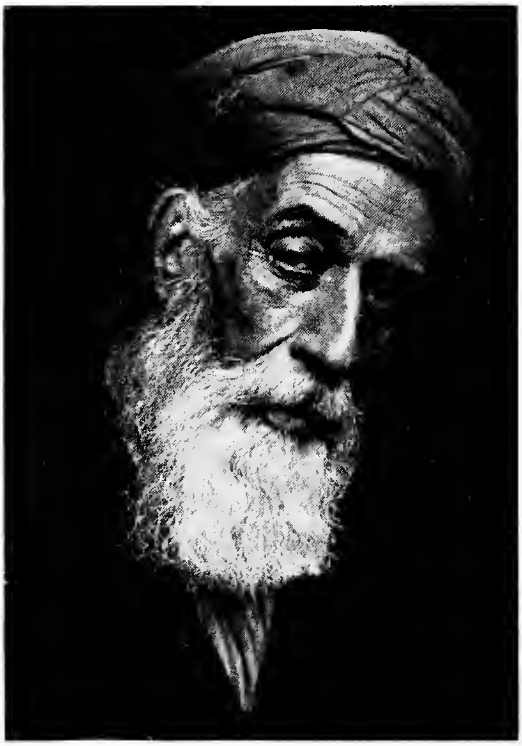


Photo: H. J. Shepstone.

JEW

Physically the Jews present two different types—and blends thereof. One approximates to the Arab race, as in this photograph, the other to the Assyriod, in which the nose has the characteristic shape commonly designated "Jewish."

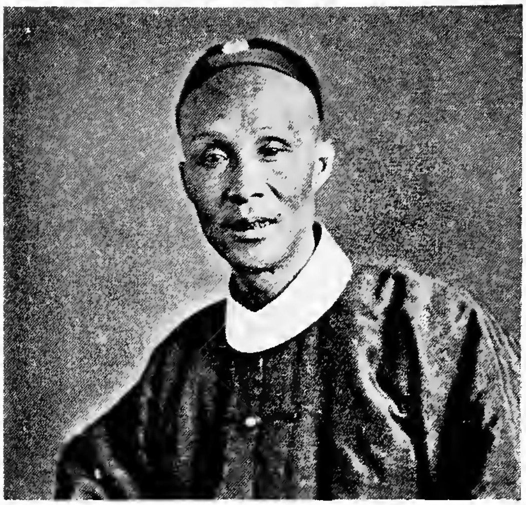


Photo: E. N. A.

A CANTONESE GENTLEMAN

The Chinese people have sprung from many intermixtures. Today there is a marked difference between the Northern and the Southern Chinese. Those of Central China have retained more of the original characters of the race. The Southern Chinese belong, very largely, to the Southern Mongolian race, and are short, round-headed people.

Photo: E. N. A.

A TYPICAL ESKIMO

hood that the same types, e.g. Pygmies, may have arisen repeatedly on different lines of evolution, and in widely separated parts of the world. Modern science has transformed the old "Ham, Shem, and Japheth" doctrine.

§ 3

The Making of Races

Ethnology studies races rather than nationalities; and by a race is meant a sub-species or a variety—a group of individuals with many features in common, and with a community of ancestry within itself greater than that between it and another race. But the difficulty is to find pure races in modern times—after so many centuries of intermingling. A race may consist of clans, and a clan of tribes, and a tribe of communities, and a community of families—all these words implying different degrees of kinship. But the idea of kinship is not necessarily implied in the word nation or nationality, which is a political conception, a social integrate with a geographical home, and some measure of psychical unity. A unified nationality may include several distinct races, but in some cases, such as the Swedes, race and nation are almost convertible terms. It is plain, however, that kinship groupings, with which ethnology deals, must be distinguished from political and social groupings.

The making of numerous races depends, first of all, on man's migratory tendencies, and the question rises why mankind has spread over all the earth. Even in prehistoric times man has gone practically everywhere. There were Morioris in New Zealand before the Maoris; the American Indians were preceded by the "Mound Builders"; there has always been some one before Columbus; and the question is why man is "the most wide-ranging of all mammals." The answer must be found in his big brain—always restless, ever adventurous, able to adapt life to circumstances and to force Nature into service. But we must look for spurs to adventure in the ever recurrent pressure of increased population, and in the frequent changes of climatic and other environmental conditions. Man is not a very prolific organism, but parental care is strong and effective, and a little one soon becomes a thousand, and a small band a great nation. The pressure of increasing population may be checked by infanticide, or by a very high death rate; perhaps the keener spur was an environmental change, such as the setting in of aridity, which made "trekking" imperative. As Ellsworth Huntington and others have shown, climatic changes and diversities have had a profound effect on human evolution: they prompt migration, they insist on initiative, they sift and winnow, and perhaps they stimulate variability. The old view that in a new climate men acquired new "modifications," which were entailed as racial characters, is not readily tenable. In the new country new germinal variations crop up, and there is an elimination of the relatively less fit variants. It is indirect rather than direct adaptation that we see in the establishment of races.

Wandering is prompted by the adventurous spirit, by pressure of increasing population, and by climatic changes. Adaptive varieties arise. But we cannot leave out of account the conflict of races, which has gone on through the ages almost without ceasing. Diffusion and spreading may mean at first nothing more than Man versus Nature, but sooner or later they involve Man versus Man. Over and over again a "superior" race has ousted an "inferior"; over and over again the victory in the long run has been with the conquered. It would be preposterous within brief limits to try to estimate the relative importance of the various forms of the human struggle for existence, but it is idle to deny that the conflict of races has been one of the sieves of mankind.

Diffusions, migrations, raids, conquests, colonisations bring about intermingling or hybridisation. In regard to the profitable limits of this, we know little. The union of races, having markedly different characteristics, is apt to be disappointing.

Hence the popular prejudice against the "half-breeds." Drs. East and Jones have put the case biologically:

> Through the operation of the laws of heredity such unions tend to break apart series of character complexes which through years of selection have proved to be compatible with each other, and with the persistence of the race under the environment to which it has been subjected. Because of the transmission of factors in linked groups, the low probability of obtaining a single recombination equal or superior to the average of the latter race does not warrant the production of multitudes of racial mediocrities, which such a mixture entails.

But there is another fact, which history seems to verify, that very good results follow the intermingling of peoples who are unlike but not *too* unlike. Thus Great Britain is inhabited by a very variable people whose blood includes contributions from many diverse Nordic Aryan stocks. Similarly the so-called Jewish race is made up of complex crosses. The moral is that in a strong nation the mingling of good stocks is promiseful.

Ethnology and Population

There is diversity of fertility in different races, and this has operated as a factor in evolution. There has always been a "yellow peril," or—of some other colour. As a matter of fact, the yellow races are not at present increasing very rapidly in numbers, for while their fecundity is high, so is their death-rate. Similarly in the United States the rate of increase of the blacks is not equal to that of the whites, for the death-rate among negroes is high. It is plain that differential fertility—greater increase in some races than in others—must lead to struggle in many forms, prompting wars, migrations, and colonisations, leading to social unrest and distress, and sometimes profoundly affecting the current moral sentiment. For it is very interesting to observe in contemporary evolution how economic conditions lead naturally to polygamy in one tribe and to polyandry in another, to exposure of female infants in one region and to their welcome in another.

But beyond the problem of differential fertility, there is that of the possible over-population of the globe. Every year some forty million persons die, but far more than that are born! It has been estimated that the human population is at present about 1,700,000,000, about a third of these being white. In most of the older civilised countries there has been for some years a decline in the birth-rate, but there is also a notable lowering of the death-rate. As civilisation develops the length of life will be increased and the health-rate will be heightened. The world will become too full, though prophetic statisticians differ considerably as to the date of the tight-fit.

> The population question [said Huxley] is the real riddle of the Sphinx, to which no political Œdipus has as yet found an answer. In view of the ravages of the terrible monster, over-multiplication, all other riddles sink into insignificance.

There are two suggestions, however, which must be considered. The first is that science is rapidly increasing man's mastery of the resources of Nature. In many a field he can reap a richer harvest every year, and at less cost. The limits of this are unknown. The second suggestion is increased birth-control in its most enlightened forms.

Must Races Decline?

There is no one answer to the difficult problem of the decline and fall of races. (1) Sometimes there may have been a hopeless contest with a relatively fitter civilisation, especially when that included entirely new weapons, appliances, diseases, and luxuries. It is not necessary that the contact of the old and new should involve a malevolent conflict. Even pacific unconformability may be fatal, as the modern story of some Central African tribes clearly shows. (2) Sometimes, perhaps, an aggressive and insurgent sub-race, or, more usually, a nationality, may outstep itself in militarism, may suffer too severely from an elimination of its best men, and may be overwhelmed by hordes of pushing and populous newly integrated peoples, naturally, and not altogether unjustly, called barbarians. Even Julius Cæsar complained that there was beginning to be a lack of *men*. (3) Sometimes, perhaps, the damning factor has been a slackening of morale, an insatiable love of luxury and ease, a slackening of the biological ideal of good stock and happy families, a relapse into the prosaic, the Epicurean, and the flabby. For lack of *vision,* as well as for lack of knowledge, the people perish. (4) Sometimes, we think, the fatal blow has come from "the hand of God"—a succession of arid seasons, which has happened often, a failure of agricultural and pastoral industry, a dismal turning of fruitful land into desert—and then came the desperate trekking, often, if not oftenest, a tragedy, though sometimes eventually a great success. Or it might be that "the hand of God" expressed itself in the introduction, in the normal course of events, of a new terror—such as a new parasite. So, according to some authorities, the introduction of the malaria-disseminating mosquito into Greece brought about the waning of that glory. And everyone knows how modern races allow themselves to be victimised by avoidable parasitic diseases, just as "the heathens," more excusably, submit to Hookworm and its horrors.

Yet it does not seem to be biologically necessary that a race should decline and die out. On the animal genealogical tree there are many branches that have been dead for millions of years. The fossil-bearing rocks—the great graveyards of the buried past—are full, not only of ancestors, but of *lost races.* Yet there are many very ancient races of animals that are going strong to-day; and there seems no reason why this should not hold true for human races also—provided that the survival value of health and vigour of body and mind is practically recognised.

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XXXVI

THE STORY OF DOMESTICATED ANIMALS

THE STORY OF DOMESTICATED ANIMALS

THE art of domesticating wild animals is one of immense antiquity, carrying us back to a period long before written records were possible. So far as the evidence goes it would seem that the dog was the first of man's conquests over Nature. And this was made towards the end of what we know as the Old Stone Age or Palæolithic period. Man was still a nomad and a hunter. But he had by this time developed the custom of burying his dead, and more than this, he would seem also by this time to have developed some vague notions, at least, of a future life; for when a man died his rude weapons, and his dog, were buried with him, as if to serve him in the land of shadows. It is to this custom that we owe our only evidence as to the period when the domestication of animals began. And since the dog only is found with these early interments we must conclude that it was man's first companion and servant. Puppies brought home, perhaps, to amuse the children laid the foundation of what was to prove an immense aid to the evolution of civilisation.

With the succeeding Neolithic stage of culture, wherein the surfaces of the stone axes and other weapons were beautifully polished, the nomadic habit gave place to settlements, and the arts of Peace—pottery-making, weaving, and agriculture, and the possession of flocks and herds. The wild oxen, sheep, goats, and pigs by which these ancient men were surrounded all seem to have been laid under tribute almost simultaneously to furnish, from animals bred in captivity, a permanent supply of meat, milk, skins, and beasts of burden.

Domestication during unnumbered thousands of years has done nothing to change these several animals in one respect, and this in the matter of the peculiarities of their flesh as food. For each has still its characteristic qualities and flavour. An ox, a sheep, and a pig, all reared in the same field and partaking of the same food, will yet, owing to the subtle and inherent differences in their nature, respond differently to their nurture. Yet in the matter of form, size, and rate of maturity these creatures, under man's control, have undergone the most striking transformation. So much so that the various races of many of our breeds of domestic animals differ more from one another than do many wild species. Our various breeds of cattle, sheep, and pigs, dogs and horses, are all witnesses of this fact. These are often cited as so many examples of the "breeder's art," as if the founder of any given breed had before him a definite conception, a power of visualising the ultimate development of the salient features, at any rate, of the breed he cherished. The breeder of the old English bull-dog could have had no conception of the bull-dog of to-day. It would have filled him with consternation, for the bull-dog, as we know it, would have been useless for the work which his ancestors had to perform. All that the breeder has been able to do is so to control the mating of his stock as to accentuate such variations from the normal as seemed to him, either from utilitarian or spectacular reasons, to be worth cultivating. In his own day he sees but little real change. Only after some scores or hundreds of generations is there any striking advance on the type accepted by the earlier breeders.

§ 1

Horses

Our domesticated horses, there is good reason to believe, are descended not merely from more than one originally wild species,

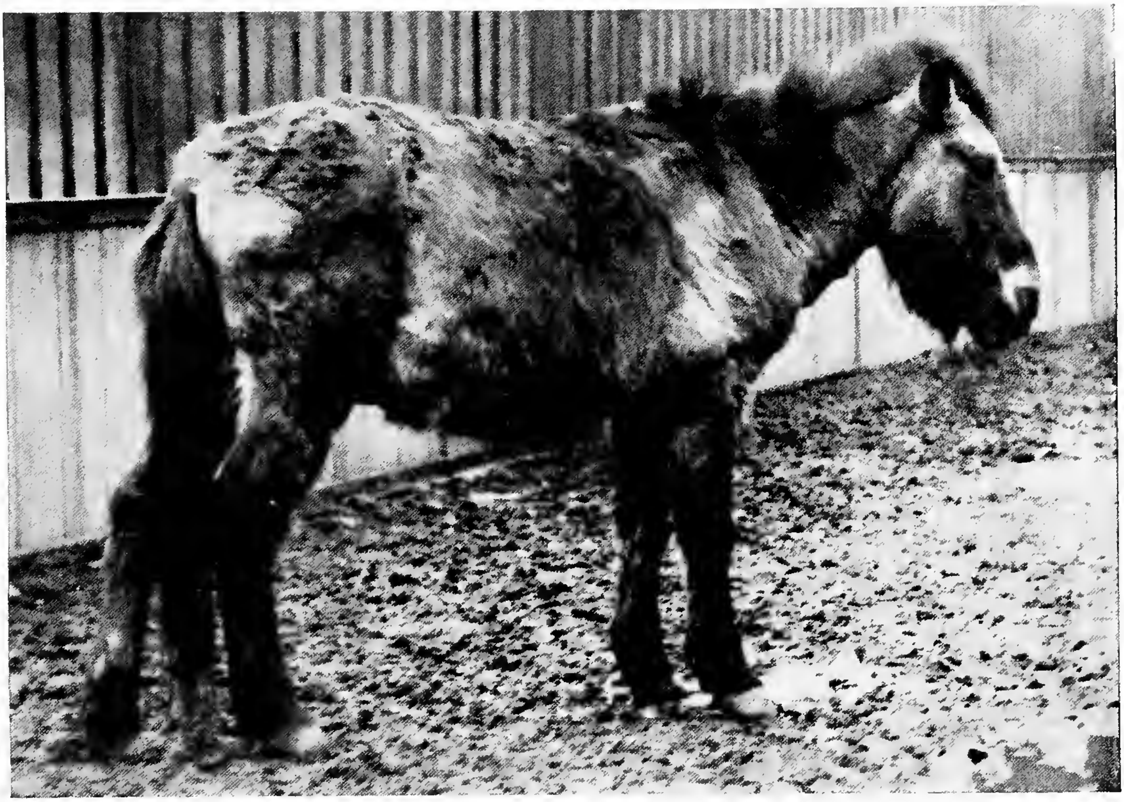


Photo. F. W. Bond.

MONGOLIAN WILD HORSE

The "Tarpan," from which the horses of Western Europe have been derived.

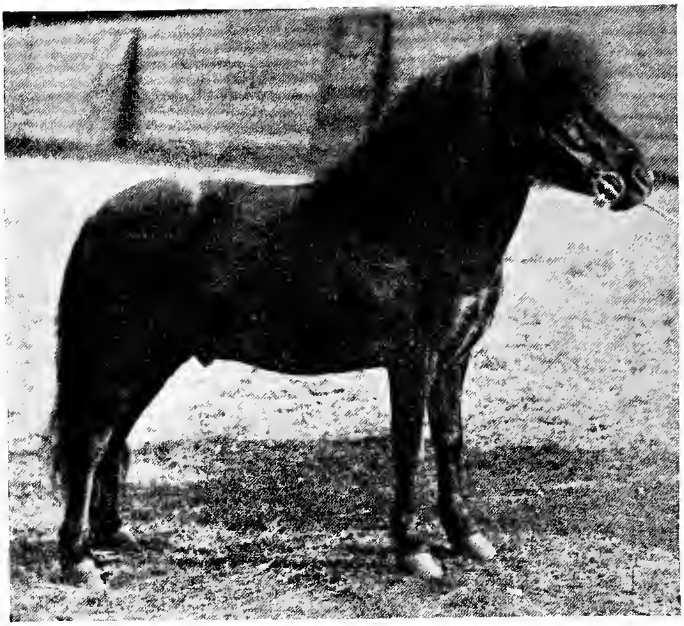


Photo: Charles Reid.

SHETLAND PONY

The smallest of our native horses. How, and when, it gained entry into the Shetlands is unknown.

Photo: W.A. Rouch.

ARAB STALLION

It was from Arab sires mated with native English mares that our "thoroughbred" was derived.

but from two distinct stocks. One of these, which flourished during Pliocene times, was a slender-limbed species, standing about 15 hands high, and having a broad forehead and tapering face, and certain peculiarities of the molar teeth. This type is represented by the Siwalik horse (*Equus sivalensis*). The Arab may be a descendant of this stock. The other dates from Pleistocene times, and is represented by a smaller, heavier, stout-limbed animal, surviving to-day in the Tarpan, or Mongolian wild horse (*Equus przevalskyi*). This view is supported by the striking likeness of the prehistoric carvings of horses of Stone Age man which have been found in the haunts of Cave Man in France and elsewhere. During prehistoric times, however, it was apparently represented by more than one species. The survivors to-day appear to be the Mongolian horse of the Gobi Desert, just referred to, and the "Celtic pony," represented by a race of small horses or ponies, ranging from Connemara, the Outer Hebrides, Iceland, and the Færoes, to Western Norway.

While it is generally held that, with the exception of the dog, man possessed no domesticated animals until Neolithic times, and that the horse was the last of his conquests, it must be remembered that engravings of horses' heads wearing a rope-like halter have been found, which were certainly the work of men of the Palæolithic period. Yet during these times—in favoured localities perhaps—the horse formed one of the staple articles of diet. This much is shown by the refuse heap discovered outside the celebrated cave, or rock-shelter, of Solutre. This could scarcely have accommodated more than half-a-dozen families, but the entrance was protected by two walls of horse-bones, one 150 ft. long and 10 ft. high, the other 40 ft. long and 5 ft. high, representing, it is estimated, the remains of some 100,000 horses. The man who engraved the horse's head with the bridle, an Aurignacian, also added his share of victims to this pile.

That the horse was domesticated in Neolithic times there is no room for doubt, though whether used as a riding animal or as a beast of burden is not known. It may be that it was first domesticated for the sake of its flesh and milk; then as a beast of burden--pack-horse—and still later as a draught animal. But though during all this time isolated peoples may have used horses for riding purposes, it is significant that the Ancient Egyptians and Assyrians, the Ancient Greeks and Romans, and the Ancient Britons used them to draw chariots, and not as riding animals.

British Breeds

This is not the place for a detailed description of our British breeds of horses. Suffice it to say that the oldest of these is represented by the Shetland, Welsh, New Forest, Dartmoor, Exmoor, and Connemara ponies. In the South of Scotland, a larger type, known as the Galloway, is found. From the larger types of these ponies the old pack-horses of the South of England were bred, and these were also largely used for riding. The magnificent carriage-horse known as the Cleveland bay hails from the North Riding of Yorkshire. Of its early history nothing is known, but it is believed to have been produced by crossing horses of foreign blood with the native stock of the district. Nearly akin to this is the Yorkshire coach-horse, an animal of rather more slender build. Unfortunately both these breeds are threatened with extinction.

Among the English heavy breeds perhaps the most famous is the Shire-horse, the Great Horse of Mediæval England. According to some this breed was derived from the chariot-horses of the Britons of Cæsar's time.

The slightly smaller Clydesdale represents the Shire-horse in Scotland. It is a comparatively recent breed dating back to the importation in 1715 of a Flemish stallion, which was crossed with native horses.

The Suffolk Punch is a famous and very distinct breed, and readily distinguished from either of the foregoing breeds, having a large head, short, arched neck, low and heavy shoulders, straight back, and short limbs. It is a very powerful animal, but suitable only for farmwork. As to its origin nothing certain is known, but it is believed to have been carried from Normandy centuries ago into the Eastern counties of England.

The Arab

As to the Arab: this type, as already mentioned, represents an older stock than that of the "cold-blooded" Western horses, since it is apparently descended from the Indian, Pliocene, Siwalik horse; and in consequence, it has been claimed, it should rank as a distinct species. But be this as it may, the part played by this animal in the history of the evolution of domesticated horses is one of profound importance. For it has been proved beyond cavil that there is hardly a breed of our Western horses which has not been immensely improved by an infusion of Arab blood.

During the time of the Crusaders, Arabs, Barbs, and Turks—the two latter being derivatives of the Arab—were from time to time introduced into England, and these importations were continued at intervals and aimlessly, up till the time of James I. From this time till Anne's reign—just 100 years—Arabs, Barbs, and Turks were imported in considerable numbers for the set purpose of improving our native race-horses. The sires of the earlier importations were mated with native English mares, and it was the progeny of these unions which laid the foundations of our "Thoroughbred" or "Race-horse"—a peculiarly English creation, though now scattered all over the world.

But more than this. Throughout all this time "thoroughbred" sires have been persistently used for the purpose of improving the qualities of ponies, carriage-horses, and riding-horses, as well as of the heavier breeds. It is for the preservation of this refining stock that we need our race-courses to-day.

The domestic Ass is a direct descendant of the North African Wild Ass (*Equus asinus africanus*), from which it differs but little in appearance and coloration, though some breeds are black and some white. The largest of all domesticated asses is that of Poitou, some specimens of which rival cart-horses in point of size. In Spain, as in the East, ass-breeding is carefully studied, and this has resulted in the development of a number of distinct types, finer in appearance and of greater utility than any found in England, where it is never used for riding purposes, save for children, or in farm-work. But with us, and indeed wherever it is met with, its milk is valued. In ancient times, in the East, herds of she-asses were kept solely for the sake of their milk.

The Mule is, properly, the product of the cross between the male ass and the mare. The product of the converse cross—between the stallion and the she-ass—is known as a "hinny." In the British Islands mules are as a rule very little used, but in Spain they are prized on account of their sure-footedness in mountainous country. They are largely employed in the Punjab frontier districts for military purposes, where mule batteries for hill-work are needed. (During the late war large numbers were also imported into this country to be used on the various fronts for military transport purposes.) In addition to their sure-footedness, mules, in proportion to their size, are stronger and more enduring than horses; like the ass, they will also thrive on poorer fodder and are less liable to disease, and they are further said to be longer lived. As is commonly the case with hybrids between very distinct species, neither mules nor hinnies are fertile, consequently no new breeds are possible.

§ 2

Cattle

It is worth remembering that the earliest known British domestic cattle, which date back to Neolithic times, are of an alien breed—the Celtic shorthorn (*Bos longifrons*). The origin of this breed is unknown, for it has nowhere been found—and its remains are scattered all over Europe—save as a domesticated

Photo: W. A. Rouch.

PERSIMMON (taken immediately after winning the Derby, 1896).

He also won the St. Leger in 1896, and the Ascot Gold Cup and the Eclipse Stakes in 1897. His sire was St. Simon, his dam Perdita. His owner was King Edward VII.

Photo: Charles Reid.

HIGHLAND COWS

The West Highland, like the Pembroke cattle, are indigenous to Great Britain, and of great antiquity.

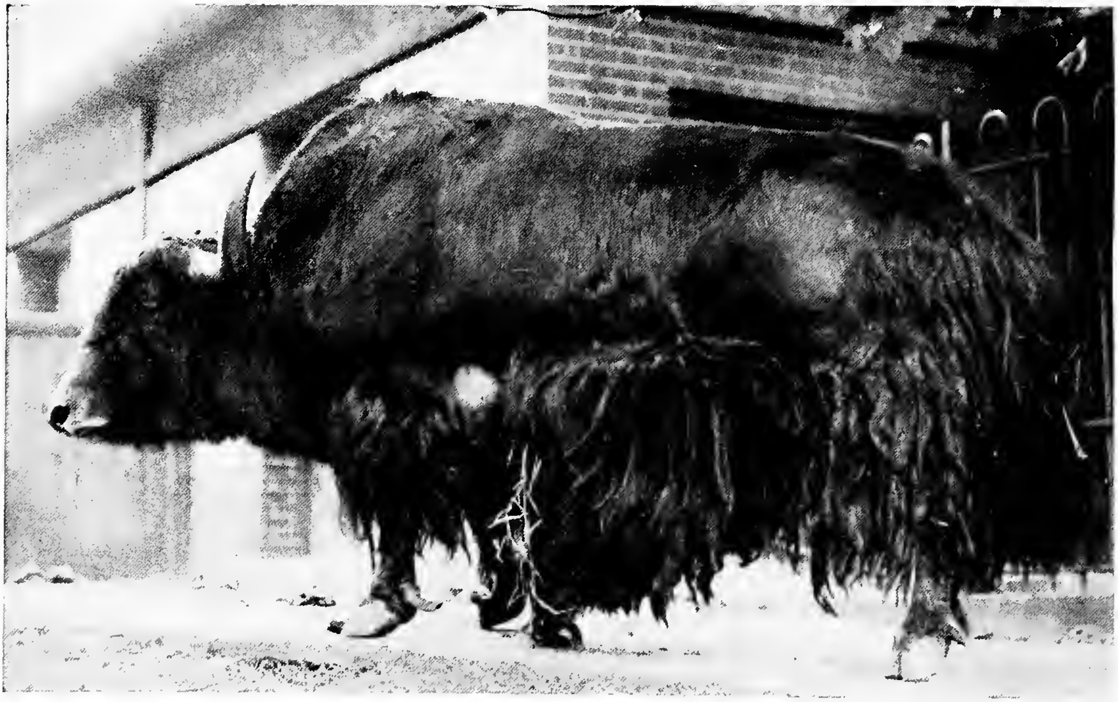


Photo: F. W. Bond.

A DOMESTICATED FORM OF THE WILD YAK, FOUND ONLY IN THE RUSPU PLATEAU

The wild animal is larger, and has longer horns.

animal. And it remained the only domesticated ox, so far as the British Islands are concerned, until the coming of the English, 500 years after the birth of Christ. These new settlers, it would seem, either brought with them a new breed, derived from the great wild ox, or Aurochs, of Europe (*Bos primigenius*), or they gathered to themselves herds from the wild Aurochs which they found in the vast woods which still covered the country. But be this as it may, it is from this stock that most of our native breeds of to-day are descended.

At one time it was firmly believed that the famous white "Park cattle," of which the best known are the Chillingham and Chartley herds, were the lineal descendants of the Aurochs. To-day they are held to be extremely ancient descendants of one of the many domesticated breeds which can be directly traced to this source. The black Pembroke cattle or "Welsh runts," the black or red Highland cattle or "Kyloes," and the "long-horned," are the most famous of the breeds which man has, so to speak, fashioned out of the original stock—the wild Aurochs.

Careful selection on the part of the old-time breeders has brought about the evolution of three distinct types of our British domesticated cattle—beef-producing, dairy cattle, and draught animals. Of the first-named type the Shetland would stand easily first but for its small size, since it attains to maturity earlier than any other of our British breeds of cattle, and as "beef" it is unsurpassed. This breed also furnishes some wonderful milkers. Kerry cows are famous, yielding, in proportion to their size, more milk than any other British breed. But most of our dairy cattle are represented by "Dairy shorthorns."

While the Celtic shorthorn and the Aurochs have furnished the stock from which our British breeds of cattle have been derived, on the Continent a number of very distinct breeds are found, which have been derived from the Indian humped cattle which, in turn, are descended from the wild Malayan Bantin (*Bos sondiacus*).

The large, dun-coloured Podolian and Hungarian cattle with enormous horns, and the similar cattle of northern Spain, are derived from humped cattle, and are used largely for draught purposes and agriculture. The Castilian and Andalusian bulls, and those of the Navarra breed, used in bull-fights, are apparently descended from the Aurochs.

The Indian humped cattle differ from the European cattle in the great fleshy hump on the withers, which may weigh as much as 40 or 50 lb., and is esteemed a great delicacy in India. Furthermore, they display an enormous dewlap, and the voice is a grunt rather than a low. Commonly the humped ox is known as a "Zebu," a word of unknown origin and never used in India. These animals, in India, commonly take the place of horses. Some breeds, like the Hissar cattle of the North-West Provinces, have enormous horns and drooping ears.

The native cattle of Africa are the humped races, though some, like the Uganda cattle and the famous Cape Trek-oxen, have lost the hump. In these, and the Nuer cattle of the Eastern Sudan, the horns often attain a huge size.

Very different from any of the wild oxen so far mentioned is the great Indian buffalo, or Arna, standing 6 ft. at the withers, and with enormous outstanding horns. Domesticated breeds of this animal are used by the natives throughout India, Ceylon, and the Malay States. The Todas, of the Nilgiri hills of Madras, keep enormous herds of these buffaloes for the sake of their milk and butter. In many parts of the plains they are mainly employed for agricultural operations, and as beasts of burden.

The last of the wild oxen which have been brought under the yoke of man is the Yak of Tibet, the nearest living relative of the Bison. It is used both as a beast of burden and as a riding animal, while it also furnishes food and clothing to the hardy natives. It has also been introduced into parts of Siberia: here as in Tibet, travel without its aid would be an impossibility.

§ 3

Sheep

They were great benefactors of mankind who first domesticated the sheep; but we can raise no monument to their memory, for we know no more than that they lived in Neolithic times. And the difficulty of any effort to-day to identify these benefactors is immensely increased by the fact that the gentle art of shepherding was acquired in two widely sundered regions. This much seems certain, since our existing flocks give proofs of a derivation from two very distinct stocks—the Moufflon of Europe (*Ovis musimon*) and the Asiatic Urial (*Ovis vignei*); and he would be a bold man who would venture to say whether the Europeans or the Asiatics were the first flockmasters.

But man has done more than domesticate the sheep. He has transformed it to a much greater extent than is the case with cattle or the horse. To-day we think of sheep in terms of wool—to us it is before all else a woolly animal. But this is not the case in the wild sheep, which appears to be as hairy as an antelope or a goat; but under the superficial hairy coat is an "under-fur" as in many other animals, like seals for example. During long ages of domestication this under-fur has been developed so that only the face and legs retain their original covering. Two other changes have resulted from domestication: the brain has greatly decreased in size as compared with wild sheep, and the tail has greatly increased in length, so much so that "docking" has become imperative in nearly all breeds. But some breeds of domesticated sheep have no wool, such, for example, as the African Long-legged sheep and the Abyssinian maned sheep.

By way of contrast we may take an example or two from among the "woolly" breeds wherein the wool has been enormously developed, as in the Merino and the Scottish black-faced in which the fleece reaches to the ground. But the wool of the last named is of more use for carpet-making than for cloth-making.

It is difficult to imagine to-day how the civilised world contrived to rub along without wool, but when and where man first conceived the desire to cultivate its growth we shall probably never know. It began, we may suppose, among people who used skins for clothing, and these would be people living where the winters were severe. This factor, the stimulus of cold, would of itself induce an increased development of the under-fur where, as in the sheep, it already existed. When the primitive herdsman discovered that such skins were warmer than the normal hairy skins, he would speedily set himself to breed only from such of his flocks as promised the woolliest coats.

A very remarkable kind of wool is that of the Bokharan or Astrakhan dumba sheep, the very young lambs of which furnish the much prized "fur" known as Astrakhan. It is a native of Bokhara and the Kirghiz steppes and of Persia.

Though most of our British breeds of sheep are now hornless, some, like the Norfolk, Dorset, and Scottish sheep, have really magnificent spiral horns. In the matter of these weapons, indeed, sheep have, under domestication, developed some very remarkable features. For some, like the St. Kilda sheep, have increased the number from one to as many as three pairs, while in the Wallachian sheep they take the form of extremely long spirals, looking like gigantic corkscrews.

The tail of the domesticated sheep, it has been pointed out, is always longer, sometimes considerably longer, than in wild sheep, and in some breeds it presents a further peculiarity in that it becomes loaded with fat till it may attain a weight of as much as 40 lb., as in the common sheep, which is kept also by the Arabs (who regard it, fried in slices, as a rare delicacy). In this animal the tail does not reach below the hocks, but it is of great breadth, measuring as much as a foot across. But in the Cape fat-tailed sheep it is much longer and may trail on the ground: it never, however, attains to the width seen in the Syrian sheep.

The opposite extreme, in this matter of tails, is found in a

Photo: British Museum (Natural History)

WALLACHIAN RAM

This remarkable breed is found only in Hungary and N.W. China.

Photo: British Museum (Natural History)

SOA (SOAY) EWE, ST. KILDA

This is a very small and primitive type: the rams stand only about 24 inches at the shoulder, and the ewes are still smaller

Photo: British Museum (Natural History).

FOUR-HORNED MANX LOAGHTAN RAM

Related to the Shetland breed. They are very small, and this is due to the fact that they are found only on the hill-tops where the soil is poor. On English pasture-lands they increase in size.

Photo: British Museum (Natural History)

UNICORN BARWAL RAM, NEPAL, INDIA

The apparently single horn is really formed of two distinct horns, which are artificially pressed together by the native breeders.

large, lop-eared sheep ranging from southern Siberia to the Kirghiz steppes, wherein the tail is reduced to a minute vestige, while an enormous accumulation of fat is developed on the hind-quarters, weighing from 30 to 40 lb. This fat, semi-fluid and butter-like, constitutes the great bulk of Russian tallow. The fat "rump" of sheep used by the Israelites in sacrifices seems to show that in Biblical times fat-rumped sheep were kept in Palestine. These sheep, by the way, are singularly coloured, the head, neck, and legs being black, and the rest of the body white. They are also hornless.

Our British sheep are commonly divided into Long-woolled, Down, and Mountain breeds. But this leaves out of account one of the most interesting, because the most primitive, of all. This is the little animal known by the uncouth name of Loaghtan—"mouse-coloured"—of the Isle of Man. This at any rate is the type. But very similar sheep are found throughout the Outer Hebrides and in Soay, in the St. Kilda group, the Shetlands, and north yet to the Færoes and Iceland. Three features distinguish the sheep of this type—small size, short tail, and brown coloration. Further, there is a tendency to increase the number of horns, of which there may be as many as three pairs.

For the most part sheep are kept for the sake of their wool, flesh, or milk, while the skin is used for parchment. But there is a tall, long-legged sheep known as the Hunia, which is used for carrying salt and borax over the Himalayan passes. Both sexes are horned, and in the male there may be four horns. Another Himalayan sheep, known as the Barwal sheep—a near relation of the Hunia, but shorter-legged—is used in the Punjab and other parts of India as a fighting sheep, being pitted in combat either with its fellows or with other animals. This is the fighting ram of India, and displays remarkable courage. The shock with which two rams meet is astounding, the sound of the impact of their heads being audible at a distance of two or three hundred yards.

Finally, because showing how amenable to domestication the sheep has proved, it must be mentioned that in some of the Orkneys, where no other provender exists, the little sheep of the Loaghtan type are fed upon fish which are dried upon the rocks for that purpose. By way of a change of diet they will make their way down to the sea at low tide for the purpose of feeding upon seaweed.

Goats

Let him who talks glibly of "separating the sheep from the goats" essay his hand at the attempt, and he will find that he has undertaken a task several sizes too large for him. At any rate the man of science has not yet succeeded in achieving this feat. The matter is not easy even when domesticated animals alone are concerned, but when a sharp line has to be drawn between wild sheep and wild goats the difficulties become insurmountable. But since we are concerned here only with the domesticated goat no useful purpose would be served by discussing the nature of these difficulties at length.

The earliest known domesticated goat, it is to be noted, is obviously derived from the existing wild goat (*Capra œgargus*) of the Mediterranean isles, Asia Minor, and Persia.

One of the most striking and most valuable of domesticated goats is the Kashmir or Tibetan shawl goat, which has developed a thick woolly under-fur, from which the famous Kashmir shawls are made. This animal is kept in enormous flocks in Ladak and Tibet. It is a long-horned, lop-eared animal, and varies in colour from white to black. No less valuable is the Angora goat of Asia Minor. This is a large animal, with long spiral horns, resembling those of the Markhor, and long, pendant ears—a foot long. But its value lies in its long, silky, white hair, which may reach almost to the ground and is used for the manufacture of a peculiar kind of cloth known as Mohair. Some authorities hold that this animal is a direct descendant of the wild Markhor. If this be so, then we have direct evidence of the derivation of domesticated goats from two distinct wild stocks.

The remarkable persistence to type which some breeds of domesticated animals display is strikingly illustrated by the Syrian and Theban goats, since both were cherished by the ancient Egyptians, who painted them in their frescoes and mummified their bodies. Thus, then, we can say of a certainty that these two breeds are many thousands of years old, yet in all this time they have hardly changed!

Under certain conditions the domesticated goat may become a really formidable animal, entirely changing the economic conditions of vast tracts of country. And this is owing to its preference for browsing on woody shrubs and seedling trees, rather than on grass like the sheep. As a consequence, even in the most deserted parts of Palestine, they have destroyed the forests; and similarly they have devastated the Island of St. Helena. In other parts of the world cattle and the camel have wrought like destruction, producing barren wastes where once flourished luxuriant forests.

§ 4

Pigs

Cattle, sheep, and pigs, wherever we wander about the country-side, are always so intimately associated that it is difficult to think of one without thinking of all three. And they have come to us thus linked together from the days of the Stone Age. One can hardly conceive it possible that the domestication of all three began simultaneously; indeed, the evidence, so far as it goes, seems to show that the pig was the last of the trio to give hostages to man. But it would seem that man lost no time in adding to his responsibilities as a stock-keeper, when once he had appreciated the advantages to be gained by the possession of flocks and herds. How much of this choice was due to "intuition," and how much to selection from a number of different animals kept for experiment, we shall never know. But he must have congratulated himself on his subjection of the pig, whose toothsomeness had long been known to him from the flesh of boars—and occasionally sucking-pigs—slain in the forests.

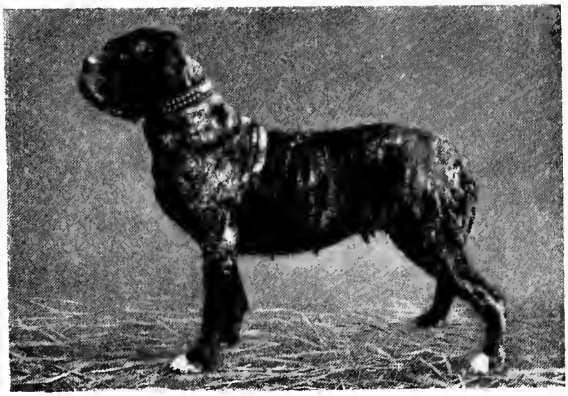
Our domesticated pigs have been derived from two distinct stocks. The wild boar is the ancestor of the Northern European breeds, while those of Southern Europe, Asia, and Africa have been derived from one of the Malayan pigs, possibly the "collared pig" (*Sus vittatus*).

It is surely not a matter for surprise that in the course of 10,000 years or so of idleness and domesticity, one should remark a considerable loss, both of litheness and intelligence, as compared with their wild relations. The boars display a considerable degeneration in regard to the size of their still formidable tusks; while both sexes have developed a great facility for putting on fat, and this at the expense of their hairy coats. All wild pigs, when young, have longitudinally striped coats. This is never the case with domesticated pigs, but these have no need of such "camouflage." Apart from the transformation due to fat, domesticated pigs have changed chiefly in the great increase in the size of the ears, and the very striking shortening of the face seen in breeds like the "Middle-white" Yorkshire and the Berkshire breeds. There is also a very remarkable breed of "solid-hoofed" pigs, in which the two front toes are enclosed in a single sheath. It now chiefly survives in America, where it is cherished under the belief that it is immune to swine fever, though there seems to be no very certain evidence that this is the case. Finally, all domesticated pigs seem to have developed a curious semicircular twist in the tail, for which no explanation has yet been offered.

§ 5

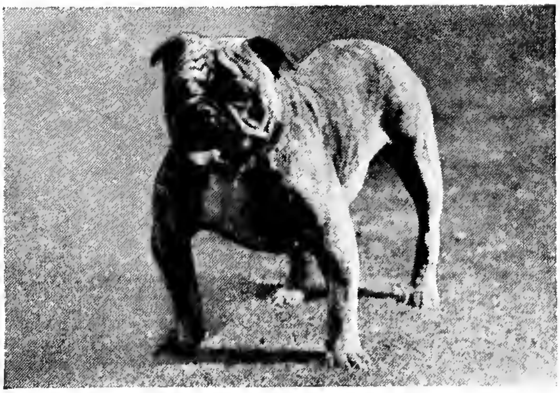
Dogs

Those ancient hunters, the Azilians, apparently despised art, but they laid the foundations of tremendous events—the domesti-



THE MASTIFF

The Mastiff is, perhaps, the oldest of our British breeds of dogs. Its ancestors were flourishing in England before the time of Julius Cæsar's invasion. But the Mastiff of the present-day show-bench has changed for the worse by the great shortening of his face.



THE BULLDOG

The Bulldog is an early descendant of the Mastiff. But since the days of "bull-baiting" he has undergone a drastic change of form, such as would have made him useless for the work performed by his ancestors.

THE SCOTS DEER-HOUND

The Scots Deer-hound is a very ancient breed, and its origin is obscure. Some authorities insist that it is an indirect descendant of the Irish Wolf-hound.

THE WIRE-HAIRED FOX-TERRIER

The Wire-haired Fox-terrier is a comparatively modern breed, since the evolution of the English terrier began only about 130 years ago. His ancestors, black and tan in colour, were very unlike the terrier of today—from the show-bench point of view. Then, as now, their real purpose was for "bolting" foxes. The terrier of today, whether wire-haired or smooth, is white with dark markings.

Photo: Sport and General.

THE BLOOD-HOUND

The Blood-hound is descended from the St. Hubert, a breed of great antiquity. The Blood-hound in modern times has undergone a great transformation in regard to the modelling of the head and face.

THE COCKER SPANIEL

The Cocker Spaniel is a very old breed. From it is derived the toy spaniel. It was originally bred for woodcock-shooting.

cation of animals. True, they got no further than the mastery of the dog to aid and abet them in their hunting; perchance because already their game was growing scarce, and more wary, from constant harassing. But this conquest over wild Nature was a great beginning, and there can be no doubt but that it had a profound influence over man's future destiny. For 7,000 years—unfortunately we cannot fix the precise date when the first dog pulled down the first deer at his master's bidding—the dog has been man's most intimate companion and servant.

That first "dog," we may be almost certain, was a wolf. Later, there is good evidence to show, the jackal was in like manner enlisted. From these two stocks our dogs of to-day are descended. Bearing this in mind we shall the more easily appreciate the almost infinite variety which confronts us in any survey of the breeds of dogs which the records of the past, and of the modern show-bench, have preserved to us.

In using the term "wolf," it should be remarked that it includes not only the European wolf, but also the Indian wolf (*Canis pallipes*) and the North American Coyote (*C. latrans*). When immigrants from the East settled down to form the earliest Swiss lake-dwellings during the Stone Age, they brought with them dogs derived from the Indian wolf, and these, no doubt, must have hastened the evolution of new types by crossing with the Azilian dogs derived from the European wolf.

The desire to raise a strain of dogs for some special purpose, or to satisfy the love of developing mere freakishness, has indeed borne fruitful results: inasmuch as we can now recognise no fewer than six distinct types—the Wolf-like group, Greyhound group, Spaniel group, Hound group, Mastiff group, and Terrier group. Among the Wolf group we have Eskimo dogs, Sheep-dogs, Collies, and the Pariah dogs of Eastern Europe, Asia, and Africa. Among the Greyhounds the English and Italian greyhound, Deerhound, Irish wolfhound, and the great Borzois. The Spaniels include giants like the

Newfoundland, and dwarfs like the useless little Pekinese and Japanese spaniels, as well as the Field and Water spaniels. Bloodhounds, Staghounds, Foxhounds, Otter-hounds, Dachshunds, Pointers, and the Dalmatian carriage hound represent the Hound group, wherein the power of scent is developed in a remarkable degree.

A long list of names such as this does not make very entertaining reading. But con it again and reflect that it stands for man's achievements in the manipulation of flesh and blood during some 7,000 years, and it at once assumes a new significance. Read it again, trying to visualise the appearance of these animals. Eskimo dogs, sheep-dogs, collies, and Pariah dogs. Eskimo dogs, trained to draw strange-looking fur-swathed people in sledges over the snow. Collies and sheep-dogs rounding up flocks of silly sheep with a skill surpassing that of man himself. Think of the bond of sympathy between the master and servant. Pariah dogs, outcasts, every man's hand against them, yet contriving to hold their own in spite of buffetings, in sun-scorched Eastern streets. Look at the lithe and graceful greyhound, kept for no other purpose than to course hares during the chill, short days of winter. His forbears, "prick-eared" but otherwise not very different, were cherished by the ancient Egyptians, embalmed when they died, and portrayed in vivid colours on monuments. To serve the ends of sport alone, man has created, so to speak, an almost bewildering number of breeds; and the behaviour of some of these demonstrates a high degree of canine intelligence, as for example in the case of the retriever and the pointer.

The St. Bernard, a near relation of the great Newfoundland, has been assigned another rôle. His part is to discover and succour the lost in deep snow-drifts on terrible mountain passes, whereat he has won fame imperishable.

There are few dogs which do not inspire affection; many crave it. But there are some which seem to repel us, like the bloodhound. True, man has made him what he is. Terrible to look at and terrible to encounter, man has raised him up to hunt down his fellowman. Hence the poor beast is shunned alike by innocent and guilty. But, as a product of man's capacity to guide, if not to control, the evolution of a given type, the bloodhound is really a remarkable animal.

Selection in Breeding

As a witness to the subtle and sub-conscious directness of the human mind the evidence furnished by the domesticated dog is valuable indeed. By careful selection of his breeding stock and shrewd matings, man has, so to speak, inveigled Nature to fashion for him just the kind of dog he wanted for a particular purpose. In make and shape and temperament he has contrived to attain very near to his ideal. And this is as true of the dogs which he has brought into being, as with a magician's wand, to please his fancy for freakishness, as well as of those desired to satisfy his needs. The bulldog of the show-bench—which is a modern innovation—well illustrates this point. His prototype, bred for the barbarous and singularly brutal sport of "bull-baiting," bore but a slight likeness to the animal known as a bulldog to-day. This poor creature, heavy-bodied, bow-legged, and "underhung," unable to walk a mile, and with defective breathing-passages and bad teeth, would have been absolutely useless in the bull-ring. His only merit to-day lies in his ugliness. It has taken something like a hundred years to bring this animal to its present state of "perfection," and the only useful purpose which can be urged for this expenditure of mental energy on the part of his "creators" is that it shows what can be done in the direction of evolving new types by persistently breeding from animals which promised to show exaggerations of certain salient features pleasing to the capricious fancy of the devotees of the breed. And what is true of the bulldog is true also of "lapdogs" like

Pekinese, pug-dogs, and the little woolly doormats known as Maltese terriers.

And now a word as to "Edible dogs"! To the Western mind this sounds a repulsive form of food. To-day the principal dog-eaters are the Chinese, who keep the "Chow-chow" for this purpose, and the natives of the Society Islands. The natives prefer dog to pork, and if we are to believe Captain Cook, between a South Sea dog and English lamb there is little to choose! The Eskimo have a fondness for foxes, which the Stone Age people also apparently regarded as a delicacy. Hence it seems that the taste for dog-flesh is a very ancient one.

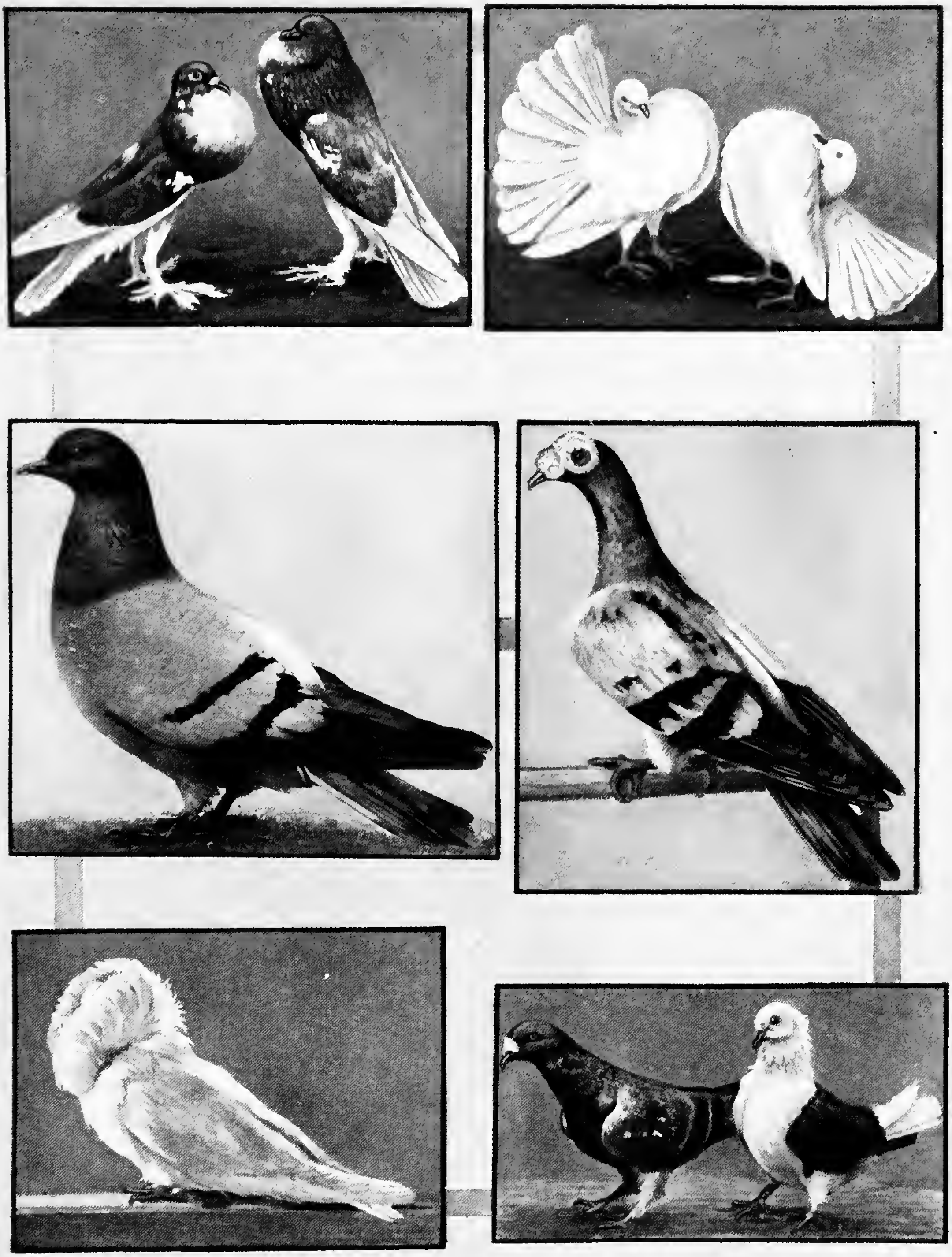
§ 6

Cats

Stone Age man boasted no "household": hence he had no cat. For the domesticated cat is before all things a "household" animal, living idly, and rendering no service for the shelter afforded, save catching an occasional mouse—for sport.

When civilisation had, so to speak, got into its stride, and man had an abiding resting-place, and started keeping "pets," the cat appeared. When its domestication actually began we do not know, but it had very definitely established itself with the ancient Egyptians of the XX Dynasty, that is to say about 1,000 B.C. So much so that it had come to be regarded as a sacred animal and was embalmed at death, as witness the mummied cats in the British Museum.

Cats are far more stereotyped creatures than dogs. That is to say, they are by nature prone to go on, generation after generation, with an almost machine-like precision in regard to their structural characteristics; and hence they offer no new features upon which the breeder might seize for the development of new types. This much is shown by the fact that after some 3,000 years of domestication we have still very few distinct breeds of cats. True, there are the tabby, and the tortoise-shell—



THE EVOLUTION OF DOMESTICATED PIGEONS

All the varied races of domesticated pigeons have been derived from the wild Rock-Dove or "Blue-rock," as a result of "selection" on the part of the fancier. That is to say, during long centuries, by seizing now upon this and now upon that exaggeration of some particular feature, or upon some chance variation, and mating with others showing a like departure from the normal, totally distinct races have been brought into being.

Reading from left to right: Pouters; Fan-Tails; Rock-Dove; Carrier; Jacobin; Antwerp and Turbit.

which are nearly always females—black cats, and white cats; long-haired cats, strangely coloured Siamese cats, and cats with "bob-tails." But they are all cast in the same mould, differing only superficially; and this even though descended from several distinct but closely related wild ancestors, of which the Egyptian wild cat may be taken as the type.

There is one point about our domesticated cats which is not only extremely interesting but also very puzzling, and this concerns the pattern of the coat, which presents two quite distinct types. In the one the head is longitudinally and the body transversely striped, after the fashion of the European wild cat and the Egyptian cat. In the other the body is marked by broad bands, roughly spiral, on the flanks. This type represents the true "tabby": the word having reference to the well-known pattern of "watered silk." Cats of all colours may be thus marked. Even when the two types are crossed the several members of the litter will present both types but no suspicion of blending—some will be striped and some will be "tabbies." No explanation of these very striking differences seems possible.

§ 7

Rabbits

We are dealing in these pages not so much with domesticated animals as with the domestication of animals, for this is an Outline of Science dealing with principles rather than with details. In considering domesticated rabbits, for example, it is a matter of no profit to know the names of all the numerous breeds of these animals—that information concerns the "fancier," and even he generally confines his attention to one or two breeds. Rather we are concerned with these questions. Firstly, why were rabbits and not hares domesticated? And secondly, how is it that the species *Lepus cuniculus*—the common wild rabbit—has come to be the ancestor of our tame rabbits rather than any one of a number of other species of wild rabbit? More than this:

one is tempted to ask how came there to be domesticated rabbits at all?

No definite answer can be given to these questions. But we may imagine that when once man discovered the many and great advantages that would follow from his ability to create a permanent supply of beef and mutton, by taming wild sheep and oxen, he began to experiment with all kinds of wild species; either because they promised to furnish him with the necessaries of life, or pleasure in the contemplation of beasts and birds kept as "pets." He probably experimented with both hares and rabbits, and found the latter were readily amenable to domestication, while hares were not.

There is no evidence to show that the domestication of the rabbit is of any very great antiquity. Yet some very remarkable breeds have been produced, such, indeed, as could never contrive to exist in a wild state, as for example the "lop-eared" rabbit. This, in bodily size, far exceeds the ancestral wild rabbit, from which it further differs in the enormous size of its ears, which may measure as much as 28 inches long and 6 inches wide! No wild rabbit could exist whose ears trailed along the ground with its every movement. The long, woolly-haired Angora is another striking transformation of the original wild rabbit, while in point of size the "Flemish giant" is equally remarkable—a full-grown buck sometimes weighing over fourteen pounds!

§ 8

Elephants, Camels, and Llamas

The domestication of the elephant, camel, and llama support the view already put forward here, that man's choice of domesticated animals has in no small degree been determined by force of circumstances. That is to say he brought into subjection the most adaptable of the wild animals nearest to his hand.

The Indian elephant alone, of the two existing species, has proved amenable to domestication. Even this but seldom breeds in captivity, so that the stock has continually to be replenished by wild-caught animals, which present a most surprising amenability to captivity.

Of the two species of camel, one, the Arabian camel, has so long been extinct as a wild animal that we are unable to say with certainty whence the first of the domesticated stock was derived. Of the Bactrian or two-humped species it is said that a few wild animals are still to be found in the remote parts of Turkestan. Both species not only breed readily but they can be freely crossed. Among the Yourouks of Asia Minor the resultant hybrids, or "mules," are preferred to either of the pure breeds.

The western side and the southernmost parts of South America harbour some near relations of the camels of the Old World—the llama and the alpaca. These are domesticated breeds of wild species. Up to the time of the Spanish Conquest the Peruvians possessed neither horses, cattle, nor sheep. They were dependent on the llama alone for meat, milk, and clothing, and for beasts of burden, and this beast still continues to fulfil these several needs of their owners, even though domesticated animals, horses, cattle, and sheep, have been introduced from Europe. The alpaca is of little use as a transport animal, but it provides a most valuable "wool" for clothing.

§ 9

The Taming of the Birds

Turning now from mammals to birds we find that here also man has made some signal conquests, though it would seem that he did not try his hand at the subjection of the Fowls of the Air until he had evolved a comparatively stable mode of life. Migration, accompanied by flocks and herds, was not only easy but necessary. During these peregrinations, however, it would be impossible to transport feathered live-stock.

Probably the earliest of his experiments was made upon ducks and geese. The mallard then, as now, proved readily amenable to domestication, as also did the grey-lag goose. Of the two, however, the mallard has proved the more plastic. This is shown by the fact that it has given rise to a greater variety of "breeds," exhibiting a wider diversity of structure, size, and coloration than is the case with the goose.

The pigeon was a still later conquest. Our domesticated pigeons have all been derived from the rockdove, which, in the hands of the "fancier," has undergone some really extraordinary transformations, as may be seen on reference to the colour-plate facing page 1124.

Our domesticated "Game-birds" are represented by the common fowl, the guinea-fowl, the turkey, and the peacock. As with the pigeon, these are all relatively recent additions to man's possessions.

The common fowl is a descendant of the Indian jungle-fowl, *Gallus bankiva.* Like the blue-rock pigeon this bird has proved to be singularly prone to variation. The number of known breeds, past and present, is positively bewildering: almost every conceivable change in the matter of coloration and feathering has taken place, while the soft parts, represented by the comb and wattles, have in like manner assumed strange developments. To-day the trend of the breeder is to produce severely utilitarian breeds. His aim is to secure birds with prodigious egg-laying powers, or birds for the table. But there is one fact which has escaped him: his "table-birds" are growing steadily less and less weighty in regard to just that portion of their anatomy which it is most to be desired should on the contrary increase, to wit, the breast muscles. These are the muscles which sustain flight, and as for generations untold these muscles have ceased to be used, they are in consequence rapidly declining. No amount of "selection" can remedy this. The only possible hope of stemming this decline is to devise some means of making these birds use their wings.

It would be beyond the scope of these pages to pass in review the well-nigh innumerable species of birds which man has succeeded in domesticating more or less completely, for æsthetic reasons, as "cage" birds. But we may cite the Canary as an example, for this bird has now become so transformed that only an ornithological expert could identify it with its wild ancestor. Even its shape, in some breeds, has been changed.

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XXXVII

THE SCIENCE OF HEALTH

THE SCIENCE OF HEALTH

What is Health?

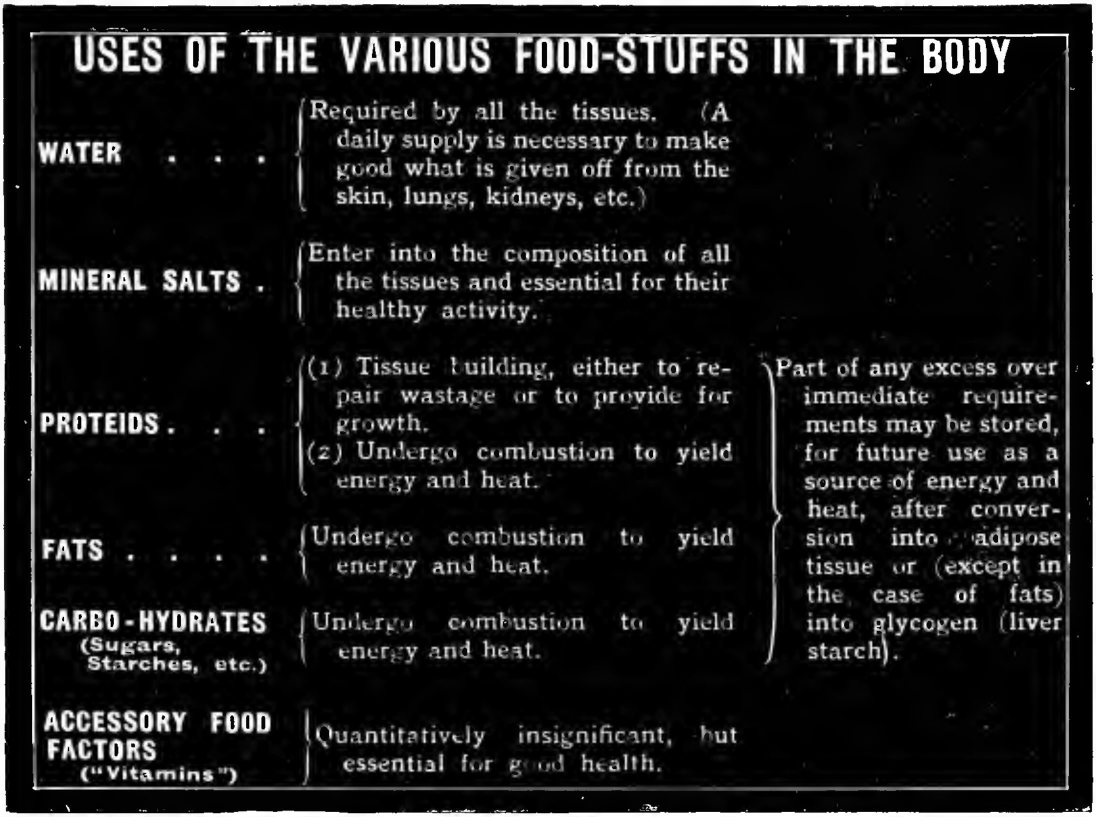
HEALTH is a word which means so much and means so many things that it is impossible to compress its wide and varied significance within the compass of any brief definition. It is an ancient word, too, and it has been changing and widening in its connotation ever since it was conceived and born, and it is changing and widening still. As its derivation suggests, it originally meant something like *wholeness,* and probably referred to freedom from obvious bodily wounds and injuries, and had little or no reference to the deeper and obscurer vital processes. It is true that Hippocrates, the "Father of Medicine," defined health physiologically as a condition in which "each humour is in due proportion of quantity and force, but especially properly commingled"; but physiology was very crude and empirical in those days, and Hippocrates did not know the difference between a vein and an artery, and could not distinguish between a nerve and a tendon, while Aristotle taught that the brain was a sponge to keep the blood cool, which is good metaphor but bad physiology. The work of Galen made it possible to have a clearer view of the physiology of health, and to-day, when physiology has become a great science, some very definite physiological ideas dominate the meaning of the term health, as used by doctors and scientific men. The body is now regarded as a chemical and physical system, and by health we mean mainly useful, efficient, and harmonious production of energy—a matter depending more upon general functional harmony and perfection than upon anatomical integrity.

Health as Working Capacity

The conception of health as working capacity, founded on chemical and physiological bases, becomes ever more definite and precise with the advance of chemistry and physiology and their sister sciences, for we find out more and more the factors which affect energy income and output. To-day we may put a little thermometer under a man's tongue, and if it read 102° F. we can say with certitude that the man is out of health, and that he is as incapable of full work as an overheated engine. Or we may listen to a man's heart and find that its valves leak, and we may justly conclude that it is as inefficient for work as a leaking pump. Or we may test a drop of a man's blood and decide that the man is in bad health, since he lacks oxygen to keep his furnaces going full blast. Or we may find a microbe in a man's veins and know that his energy must quickly fail. Or we may count a man's pulse and find it 140, and judge at once that he is out of health and unfit for work. On the other hand, we may find that a man's temperature is 98.4° F., that his heart is as sound as a bell, that his blood is pure, that he has no microbes in his veins, and that his pulse is 72 and of good quality, and even if the man have lost an arm or a leg or an eye, we can label him healthy, and can safely infer that he has normal health, i.e. normal capacity for work. In fact, all our accumulating knowledge of physiological processes makes for precision in our conception and measurement of health.

The Energy of Food

Regarded as a material system for the development and regulation of energy, a living animal organism is in many ways a mechanical marvel. Like other machines it requires fuel, and as in the case of other machines, its fuel is mostly carbon; but the carbon of food, not the carbon of coal or of oil. Now the carbon



USES OF THE VARIOUS FOOD-STUFFS IN THE BODY

WATER	Required by all the tissues. (A daily supply is necessary to make good what is given off from the skin, lungs, kidneys, etc.)	
MINERAL SALTS	Enter into the composition of all the tissues and essential for their healthy activity.	
PROTEIDS	(1) Tissue building, either to repair wastage or to provide for growth. (2) Undergo combustion to yield energy and heat.	Part of any excess over immediate requirements may be stored, for future use as a source of energy and heat, after conversion into adipose tissue or (except in the case of fats) into glycogen (liver starch).
FATS	Undergo combustion to yield energy and heat.	
CARBO-HYDRATES (Sugars, Starches, etc.)	Undergo combustion to yield energy and heat.	
ACCESSORY FOOD FACTORS ("Vitamins")	Quantitatively insignificant, but essential for good health.	

THE USE OF THE FOOD-STUFFS IN THE BODY

Food is a source of material for tissue-building and tissue-repair, and a source of energy and heat for the activities of the body. The diagram shows the uses of the various food-stuffs in the body.

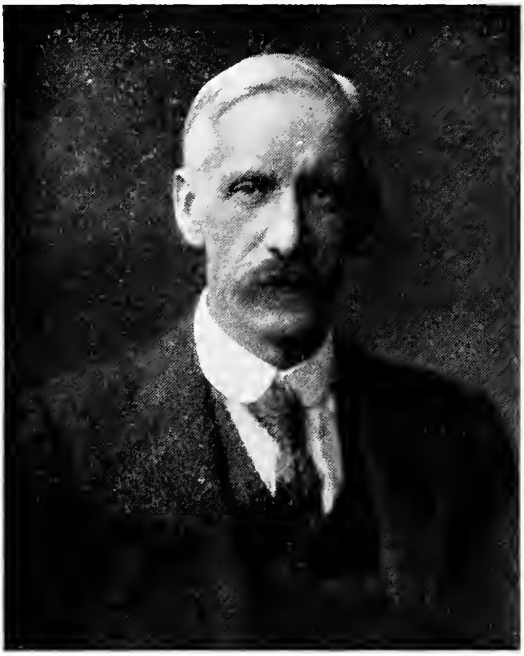
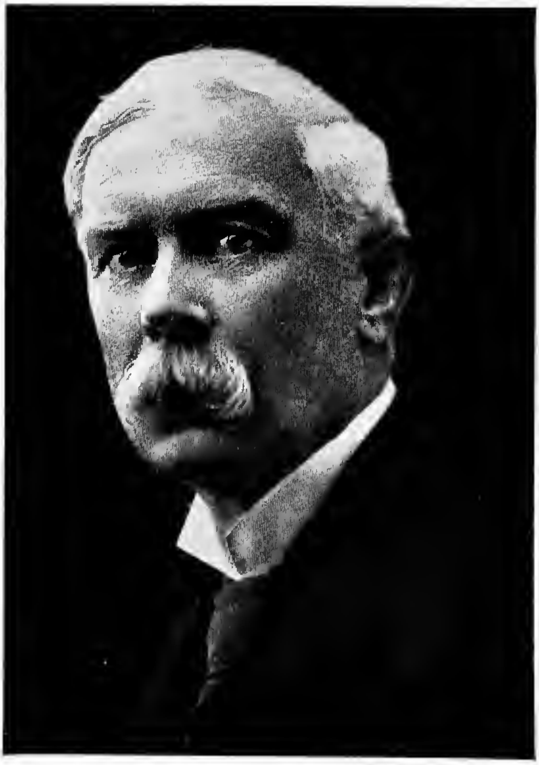


Photo: Palmer Clarke.

PROFESSOR F. GOWLAND HOPKINS, F.R.S.

Professor of Biochemistry in the University of Cambridge and a great authority in this new branch of science, from which great advances in biology and in medicine may be confidently expected. He has been a pioneer in the study of accessory food factors or "vitamins" and of the part they play in nutrition.



PROFESSOR J. ARTHUR THOMSON, M.A., LL.D

Regius Professor of Natural History in the University of Aberdeen. Editor of "The Outline of Science."

of food is the very same carbon which the red rays of the sun tear from the carbon dioxide of the atmosphere in the laboratory of the green-leaf (see BOTANY, page 604). The wrench of the sun sets the carbon vibrating with new energy, and when it is afterwards built into starch the energy is latent there, and is delivered to the animal which eats the starch (or fat or sugar or protein constructed out of the starch), and is manifested as actual animal energy as soon as the food is oxidised in the animal's tissues, just as coal gives off its energy (as heat) when it is oxidised in a furnace. (When another element combines with oxygen, as carbon in particular so readily does, we speak of it as being *oxidised:* the process is one of combustion, in which heat and energy are liberated.) If we put glowing carbon into a jar of oxygen it oxidises quickly and burns fiercely, while, if we put the carbon of our food in contact with the oxygen carried by our red blood corpuscles, it oxidises slowly and burns quietly, heating the body usually only to 98.4° F., and manifesting itself not only in heat but in chemical, mechanical, and electrical energy. But in each case the process is essentially a freeing of solar energy previously imparted to the carbon. Our bodies, therefore, are sun machines, worked by the red rays of a star 93 million miles away, radiated it may be a million years ago. When Gimbernat, for instance, consumed soup made of a mastodon's teeth, he put into his heartbeat the carbon of the food crushed by the monster's molars hundreds of thousands of years ago, and the carbon had probably been energised in some tree-fern by the tropical sunlight of that prehistoric era. Gimbernat really drank in his soup not only gelatin from monstrous molars, but also starch from prehistoric trees and the red light of a prehistoric sun. We are not all so prehistoric in our meals as that, but every man lives and moves by virtue of the red light of the sun which he consumes with his porridge, or potatoes, or beefsteak, or bread and butter. We cannot wink an eyelid without liberating the energy of these red rays from our culinary carbon.

Chemically speaking, foods are divisible into: carbohydrates, such as starch and sugar; fats, such as butter; and proteins, such as white of egg and meat. All such foods can be oxidised by burning, and their value as energy-producers can be estimated by the heat they give off during their combustion. We estimate heat in calories, a calorie being the amount of heat required to raise one gramme of water 1° C.; and we find on burning these three kinds of food in oxygen that one gramme of carbohydrate produces 4.1 calories of heat, one gramme of fat 9.3 calories, and one gramme of protein 4.1 calories. Heat is, of course, a form of energy, and is changeable into definite amounts of other forms of energy, such as muscular motion, and it is known that a calorie of heat is equivalent to the energy required to raise a weight of 425.5 grammes one metre. Thus it is quite easy to calculate how much heat and muscular energy should be given to the body by the slow oxidation in its tissues of certain amounts of food; and if we put a man in a special chamber called a calorimeter, where the amount of heat and of other forms of energy he expends can be measured, it will be found that he produces about as many calories of heat, and other forms of energy, as his food would produce if burned outside the body. Accordingly, if we know how much energy a man expends under various conditions, it is not difficult to calculate the food he requires: all living involves expenditure of energy, breathing and thinking as well as manual work or physical exercise. It is also easy enough from figures of food consumption to find out how many calories are contained in an average man's diet. Before the war the average Englishman consumed 3,422 calories of energy in his food; during the war, the Royal Society Food Committee came to the conclusion that the average man required 3,390 calories of energy, so that the average man would seem to have adapted his diet to his requirements very successfully. To keep the heart beating and the other organs working, and to maintain the temperature of the body, about 2,836 calories are required on the average, and any calories in excess of these requirements are available for muscular energy. Only about 20 per cent., however, of the calories available can be converted into actual muscular work; the rest is dissipated as heat. Twenty per cent. seems a small proportion of work; but it is a larger proportion than can be obtained from any steam-engine.

Proportions of Different Kinds of Food

In view of these facts it might seem that a man has only to swallow so many calories of energy in his food in order to get so many calories of work from his muscles; and we find men who are foolish enough to eat huge quantities of food in order to gain strength. But food must be carefully chosen; it must also be suited in quantity to the "boiler capacity" of the man and to his digestive, respiratory, and circulatory potentialities. We must not take foods indiscriminately; we must take certain proportions of carbohydrates, of fats, and of proteins, and the last is particularly necessary, providing not only fuel to work the body but also material to build it up and to repair its waste, for it must be noticed that the body-machine not only does work but also builds up and repairs itself. We must also take such forms of these food materials as the digestive organs can digest, and we must consider their digestive capacity. Further, we must consider the oxidising capacity of the blood, heart, and respiration, for the carbon of the food is of no value for work unless there be oxygen to burn it. A man who is to obtain much energy from large quantities of food must have all his organs strong and efficient, otherwise the food will be wasted. A man of powerful constitution may be able to digest and utilise perhaps 10,000 calories in twenty-four hours; but all men are not made that way, and it is perhaps just as well they are not.

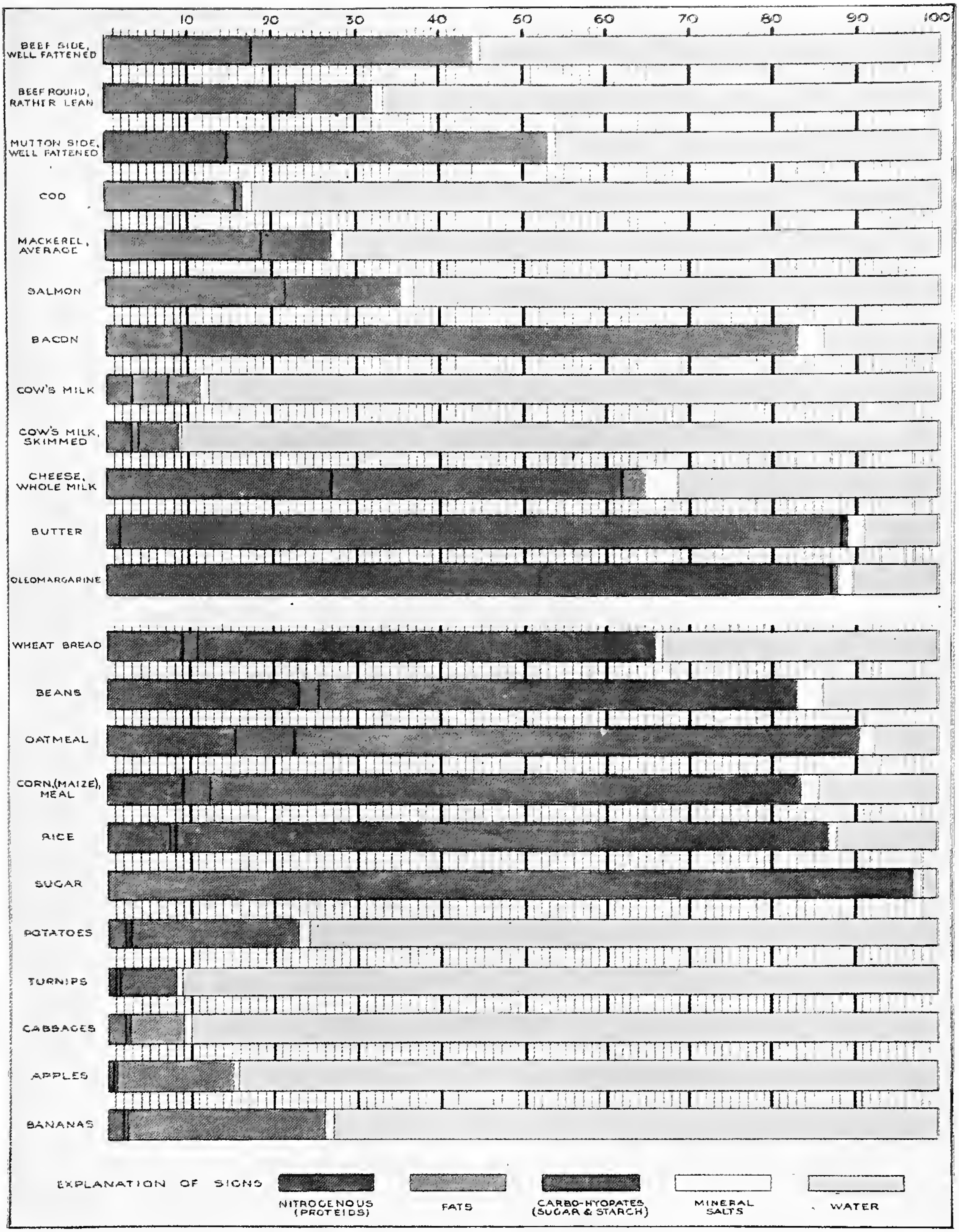
It is not necessary for a man to weigh out so many calories of food, and indeed it is always better for a man to weigh himself than to weigh his food. If he find his weight becoming unduly great, that is proof positive that he is eating more than he can turn or is turning into energy; while if he find he is losing weight and if there is no disease to account for the loss, that is proof presumptive that he is consuming his own tissues in the production of energy and could therefore utilise more food for the purpose if it were given him. Further, an observant man will soon discover, with a few scientific principles to guide him, what foods and what quantity of food result in the best output of energy. The trouble, of course, is that men are often careless or unobservant or self-indulgent. A very busy man neglects his dietary till suddenly he finds his bones sticking through his skin and his energy unequal to his daily work.

§ 1

The three classes of foods, as we have said, are carbohydrates, fats, and proteins. These are the foods proper, that is to say, the substances whose oxidation gives man his supply of energy; but besides these foodstuffs proper, man must add to his dietary certain other substances which are necessary for the complete digestion, assimilation, and utilisation of these main articles of diet. He must include in his menu a certain amount of the remarkable liquid—water; he must also make sure that his dietary contains certain salts such as common salt, and certain mysterious substances called "vitamins." But in ordinary dietaries there is always water added in some form or other, and in any properly varied dietary, containing milk, meat, bread, and vegetables, there are plenty of vitamins.

Importance of Vitamins

The "vitamins," or "accessory food factors," have introduced a new idea into the theory of dietetics which is independent of any question of calories. These substances are present in food-stuffs in such small amounts as to be valueless in themselves as sources of energy, but in some way not yet understood, they



THE COMPOSITION OF CERTAIN COMMON FOODS

This diagram will enable the reader to see at a glance what kinds of food are especially rich in proteids, in fats, and in carbohydrates respectively, and also which contain a large proportion of water and which are of a more solid nature, and how much mineral matter is present. Each band represents a hundred parts by weight of a particular food-stuff, and the percentages of the different ingredients may be read off from the scale which is marked along the top; a key to the colours is given at the bottom. A comparison with the diagram facing p. 1134, showing the uses to which these food ingredients are put in the body, will indicate what foods (i.e. those rich in proteids) are necessary for the building and repair of tissues, and which (i.e. those rich in fats or carbohydrates) are mainly useful as sources of body-heat and muscular energy. (Reference is also made in the text to the importance of accessory food factors or "vitamins," but these do not occur in measurable quantities.)

are essential to the health, growth, and even life of the body. They have not been isolated or chemically defined, but it is now becoming well-known what food-stuffs contain them, and what diets produce the disastrous results which mark their absence. They are all ultimately products of the plant world. Lack of one of these accessory food factors causes scurvy, a disease which was commoner in the days of sailing ships and of consequent long periods without fresh food. Lack of another causes the nervous disease known as beri-beri, which has a curious history. Some native races of India live largely on rice, and when machine-rolling began to replace more primitive methods beri-beri became rampant. It was then found that the machines husked the rice grains *too* efficiently, and that it was the lack of some ingredient in the husks—formerly eaten in large part—that caused the disease. Careful experiments in the feeding of pigeons confirmed the result, and when the knowledge was gained the remedy was simple. The third accessory food factor is an ingredient of animal fats, notably of cod-liver oil, and seems to play an important part in the physiology of growth and in the prevention of rickets. All these substances, as has been said, exist in sufficient quantity in a well-varied dietary, but wherever we get restriction in the nature of the diet—however ample the mere quantity of food—there is a danger of one or other being present in insufficient degree. During the siege of Kut there was scurvy among the British troops and beri-beri among the Indians, and even at home the question was an important one to those responsible for controlling and rationing the nation's food-supply. In the feeding of infants and invalids, in the rationing of exploring expeditions and of military forces on active service, and in the food-supplies of the poor, special attention requires to be paid to providing adequate vitamins: without these, no mere sufficiency of quantity, no mere numbers of calories, no mere increase of proteins, carbohydrates, or fats, as such, will be of any avail in the preservation of proper health.

Enjoying Food

The whole organic well-being of a man depends on his food, and no man can have that harmonious output of useful energy which we call health if he eat too much or too little food, or if his digestion be inefficient. Digestion, however, begins in a sense in the olfactory organ, and ends in that colloid solution which constitutes living protoplasm, and indigestion is very often not due to any deficiency of the digestive organs, but can be attacked and cured on quite other grounds. To digest food properly we must enjoy it (and the man who does not enjoy his food is unlikely to enjoy anything else), and to enjoy it thoroughly we must smell it and taste it. The smell and taste of food makes the "mouth water," and that is the beginning of digestion; but the smell and taste, as the Russian scientist Pavlov showed, also cause the stomach to "water." To eat food in the spirit of "dust to dust I commit" is to invite indigestion and ill-health, and many people suffer from ill-health simply because they have never learned to enjoy their food. The improvement in health, i.e. the increase of energy, that often follows more thorough mastication, is largely due to stimulation of the digestion through the senses of smell and taste. The digestive juices, stimulated by the sense of taste and smell, were called by Pavlov "psychic juices," and they undoubtedly play a big part in preliminary digestion. Another cause of indigestion is certainly the lack of fresh moving air in dining-rooms. Without fresh moving air we cannot have sufficient respiration and circulation, and without efficient respiration and circulation the processes of secretion and assimilation associated with digestion cannot function properly.

Muscular Development may be Exaggerated

The great majority of people have digestions quite capable of supplying them with all the energy they can pleasurably and profitably employ. There is no great advantage in the possession of large muscles and great muscular energy. So far as energy of that kind is concerned, a flea or grasshopper or ant or beetle can put man to shame. Perfect health is possible without unusual muscular development, muscular strength, or muscular endurance; and the various health systems that devote themselves to developing and strengthening muscles are usually a mistake from the point of view of energy. For at best big muscles can manifest mighty energy only for a few years, and the energy they use means unnecessary work for all the vital organs: it is waste of the wonderful potential energy of the carbon compounds. In bygone times muscular energy was of value in the struggle for existence. The man who could draw a stout bow, or swing a heavy battle-axe, or even carry a big load, had vital advantages over the man with weaker arms and legs; but even then muscular strength did not count for everything, for man managed to extirpate many animals ten times stronger than himself. Now, in these days of rifles and poison-gases and machinery, muscle plays a subordinate part in life. From the carbon of his food a man may obtain a few hundred calories of energy for his two arms; but the energy of coal now supplies every man with about as many arms as Briareus, and the energy of oil carries a man in his motor-car as far in one hour as his legs could carry him in ten. Muscular energy, beyond a certain point, is no longer "worth the candle," and a man may be all the healthier, in the fullest sense of the word "healthy," in that he requires and uses only a moderate amount of muscular energy. The chief advantage, indeed, of coal and machinery is that they liberate man's energy for higher tasks than hewing wood or carrying water. The average man does not now require to make his heart and other vital organs labour on behalf of his muscles; he can make his muscles labour on behalf of his vital organs, and especially on behalf of his brains. He can take muscular exercises to develop his breathing capacity, to strengthen the grip of his heart, to improve his circulation and to stimulate his digestion, and all for the sake of his intellectual and æsthetic life. Not only the idea of wholeness but also the idea of *values* enters into the modern conception of health, and a man who exercises all his energies harmoniously and in proportion to their spiritual and social value must be considered healthier than a man with the digestion of an ostrich, the strength of an ox, and the brains of a guinea-pig.

Exercise

For intellectual work little food is required over and above what is needed by the heart and lungs and for the maintenance of the body heat, and it is certain that most men, other than manual workers, eat more food than is necessary for the muscular and nervous energy they expend. It is equally certain that many men unnecessarily expend much more energy in muscular movement than is good for their mental constitution. Yet muscular exercise in moderation, after food in moderation, increases the sum-total of the energies. A normal man can dance, walk, swim, play golf or cricket, and take other forms of exercise, and by such exercises so increase his digestive, respiratory, and circulatory powers that even after the expenditure of muscular effort he has more energy available than before for higher purposes. Exercise, short of fatigue, is one of the best ways of facilitating the running of all the machinery of the body, and of adding to the general store of energy. Some men seem to be able to maintain mental energy without it, but even the strongest man will suffer in some degree in his mental and muscular efficiency if he do not exercise his muscular system, and so promote the activity of all his vital organs.

Happiness Correlated with Health

We have said that most men eat too much, or at least more than they require for the energy they expend; but it would be a mistake to carry asceticism too far. The food gives the body not only warmth and working power, it has also some subtle action on the character and temperament. A hungry man is an angry man, a well-fed man is often a warm-hearted man, and a fat man a contented man. Energy—even mental energy—is not everything, and it is sometimes wise to sacrifice a little efficiency for the sake of a little happiness. It is probably better to be happy and unhealthy than healthy and unhappy (though the choice may seldom have to be made), for happiness liberates and directs energy even if it does not create it. On these grounds, and only doubtfully on these grounds, can the use of alcoholic drinks be justified. It is well proved now that alcohol has very little food value, and that even in small doses it reduces energy and possibly shortens life, but if it gladden a sad heart it gives both heart and brain more driving power and makes life more worth living. Food may be the best fuel for the machine, but where life's wheels grate dry, happiness is a good oil.

§ 2

Respiration and Circulation

So much for the relationship between food, muscular exercise, and general health. But as we have already indicated, food and muscular exercise cannot be considered apart from respiration and circulation. If the food keep the heart and lungs going, no less do the heart and lungs give the food its driving power. We have already explained that the main source of the energy of the body is the energy liberated by the carbon on oxidation. The oxidation of the carbon is effected by the oxygen which is loosely combined with the colouring matter of the red blood corpuscles; the act of respiration brings oxygen to the blood, and removes from it the carbon dioxide which collects in it as a result of the combustion of the carbon in the tissues. Except for the oxygen and the oxidation, the energy ultimately traceable to the solar rays might remain latent in the carbon compounds for ever.

Who knows for how many hundred thousand years the solar energy had been imprisoned in the mastodon's tooth ere Gimbernat swallowed it in his soup, and oxidised it with the oxygen of his blood, and turned it into heat and motion?

The regulation of both circulation and respiration is automatic. When a man does hard muscular work, his breathing automatically quickens and deepens in order to provide oxygen and remove carbon dioxide, and the heart beats stronger and faster to carry oxygen to the tissues and carbon dioxide from them. During hard exercise, ten times as much oxygen may be consumed and ten times as much carbon dioxide discharged as during rest. Plainly, then, a man's muscular energy depends not only on the energy supplied to his muscles by his food but also on his respiratory and circulatory efficiency. A man may have a good digestion, but if his lungs or his heart are diseased or impaired in their action he will not have full energy. The three great systems must work in harmony, and the strongest member of the Triple Entente must accommodate itself to the capacity of the weakest. A man with a weak digestion must recognise the fact and must "cut his coat according to his cloth." The essence of health is harmonious energy, and lack of health is largely disharmony. The average man does not require a large income and output of energy, but he requires such efficient and harmonious working of his vital organs as will make mental and physical work, within reasonable limits, not only possible but pleasurable; and this happy consummation is within the average man's reach, if he eat, exercise, and breathe wisely. Food and exercise we have already discussed; let us now look for a moment at breathing.

The Breath of Life

In recent years a great deal has been written on the subject of breathing exercises. Breathing, however, is an automatic action which never ceases from birth to death, an action, too,

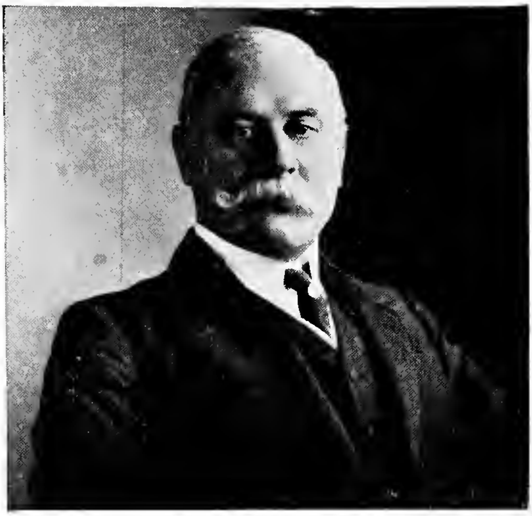


Photo: Bacon.

SIR FREDERICK TREVES, BART., G.C.V.O.

A famous exponent of the modern science of operative surgery.

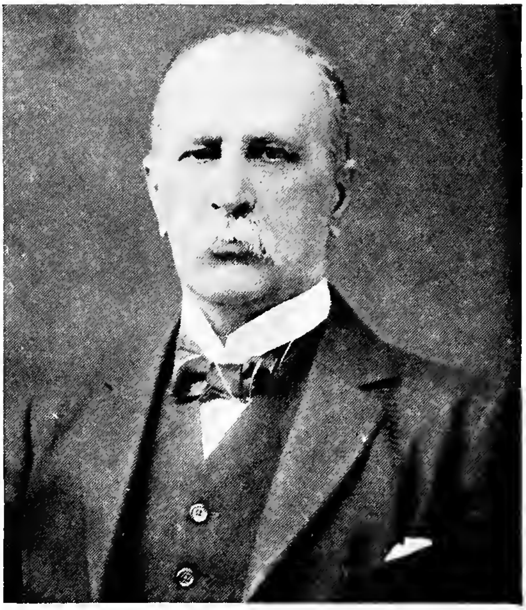
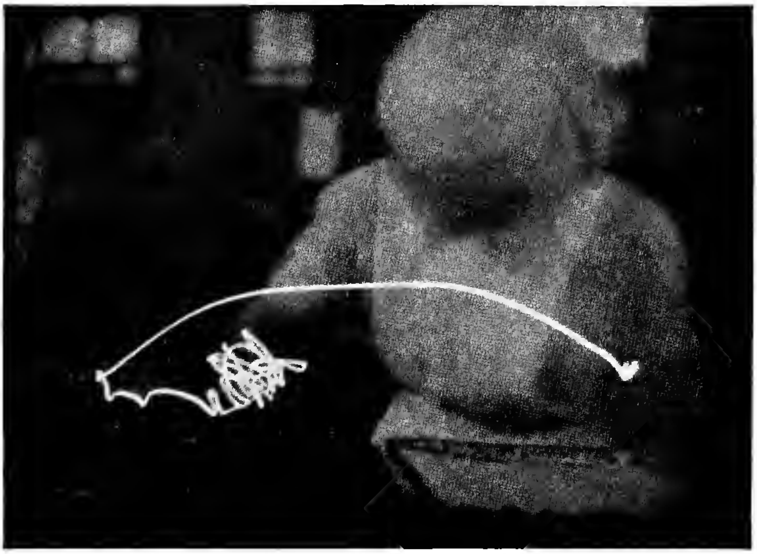


Photo: J. Russell & Sons.

THE LATE SIR WILLIAM OSLER, BART.

Until his death a few years ago he was Regius Professor of Medicine in the University of Oxford. He was remarkably successful in applying scientific methods of research to the art of healing.



From Report No. 14, Industrial Fatigue Research Board.

SCIENTIFIC MOTION STUDY—I

This photograph, taken in the dipping department of a sweet factory, shows the operation of covering a chocolate. The white line traces the movements of the instrument held by the worker. Even an experienced hand, such as the one shown, performs many unnecessary movements owing to want of training in systematic methods.

From Report No. 14, Industrial Fatigue Research Board.

SCIENTIFIC MOTION STUDY—2

The same operation is illustrated as in the previous photograph. The movements have been studied, analysed, and reduced to their simplest and least tiring form. By the application of methods of this kind to industrial processes, output can be increased, while the strain in the worker is at the same time reduced. (See page 1154.)

which is regulated by a series of nervous and chemical reflexes, and breathing exercises for a few minutes a day will have little effect on the total ultimate respiratory efficiency. The best breathing exercises are muscular exercises in the open air. Any exercise whatsoever that demands oxidation for muscular work will, as we have said, quicken and deepen the breathing, and the quickening and deepening will not, as in voluntary breathing exercises, stand by themselves; they will be an integral part of a general increase in vital activity. The chief desiderata are that the exercises should be qualified by the efficiency of the heart and lungs, and that they should be taken in the open air so that plenty of oxygen may be ready to hand. Only in this way can the average activity of oxidation and the average output of vital energy be increased, and to the ordinary man leading a sedentary life it is the average output of vital energy—the average output of mental energy—that matters.

The Body Temperature

There are other things, however, even more important than muscular exercises for the maintenance of respiratory activity at a height conducive to mental and physical energy, and these things are temperature and skin reflexes. As we have already pointed out, about 80 per cent. of the energy value of food is manifested as heat, and the heat normally maintains the body at a temperature of about 98.4° F. Since, then, any increase in muscular energy means proportionate increase in heat production, there must also be increased loss of heat from the body, else the temperature of the body will rise. For instance, 200 calories of an increase in output of muscular energy will mean an increase of 800 calories in heat production, and if this extra heat be not conducted or radiated or evaporated away the temperature of the body will rise. Briefly, there can be no increase of muscular energy without quicker production and loss of heat, and if loss of heat do not keep pace with production of heat the temperature of the body will rise, and fever with disastrous results will follow. Nature meets this situation by taking measures to accelerate and facilitate the loss of heat. The skin becomes flushed with warm blood, so that the heat can radiate away into the atmosphere, and the skin also becomes moistened with sweat, so that heat may be removed by evaporation. But it is plain that if the atmosphere be hot and damp and still, these measures will not be very efficacious, since both radiation and evaporation will be hindered, and in such a case Nature wisely refuses to allow an increase in the output of energy. She takes away a man's appetite and slows down his vital machinery. We know that in hot damp climates all men suffer from lack of energy, and that muscular work often means heat apoplexy.

The Climate under the Clothes

The commonest cause of ill-health, lack of appetite, lack of energy, lack of spirits, general tiredness, is nothing else than a damp, warm, still atmosphere, sometimes outside, sometimes inside, somtimes both outside and inside a man's clothes. In a warm, tropical climate the trouble is chiefly in the outside atmosphere; but many of those who do not live in the Tropics like damp, warm still air in their rooms, especially next their skin and under their clothes. It is the climate under the clothes that is of the chief importance to health, and there are thousands of people in England who keep under their clothes the climate of a tropical marsh—hot, damp, stagnant. They render it impossible for heat to escape, and Nature has to choose between giving them heat apoplexy and damping their furnaces. She chooses the less of the two evils and damps the damp man's furnaces, and he is ungrateful enough to complain of lack of appetite and lack of energy.

Luckily for themselves most men live in two climates at once. Their bodies, arms, and legs languish in the Tropics, while their face, neck, wrists, hands, ankles, and sometimes feet "carry on" in a temperate or cold climate. In fact, face, neck, wrists, hands, ankles, and feet act as radiators, and if it were not for these radiators most English men and women would be as limp in London as in Zanzibar. If a man were to wear an undervest and a shirt and a waistcoat and a coat and an overcoat over his whole body—face, hands, and neck—his energy would quickly flag. It is just his radiators that save him, and the open necked dresses that women have recently been wearing undoubtedly increase the energy of women by increasing their radiation. But such radiators are not enough; if a man wishes to enjoy energetic health he must burn energetically, and must permit free radiation from his *whole* body. We go to the hills and the seaside, and we at once feel invigorated, and say that the change of air has done us good. But there has been no change of air; it is just the same air as before, only it is air in motion with hill-breezes or sea-breezes, and it gets under our shirts, blows away the damp hot air there, and increases radiation. Without adequate radiation it is impossible for either the engines of the body or the engines of a motor-car to work efficiently. Moving air within our walls and within our garments is a prime condition of good working capacity.

The climate under the clothes is of importance not only from the point of view of loss of heat but also from the point of view of loss of water. Under normal conditions of heat and exercise the skin excretes about a pint of water every twenty-four hours, and during violent exercise, in great heat, quarts of water may be excreted. If the air under the clothes is saturated with moisture, not only is the cooling of the skin by evaporation hindered, with results we have already noted, but the excretion of water is retarded and the tissues are apt to get waterlogged. There are millions of sweat glands, with tubing altogether twenty or thirty miles long, and any interference with their free secretion reacts injuriously on the health. We have all experienced the tired feeling consequent on wearing an air-tight and waterproof coat. A man living in a room full of warm still air is bound to have a damp sub-tropical climate under his waistcoat, unless he have actual open-window ventilation; and the ventilation of a room is not satisfactory unless it remove not only the vitiated air within the walls, but also the damp and vitiated air under the garments. Thorough ventilation is the draught in the furnace of vitality.

In still other ways the climate under the shirt is of great importance in the production of energy. In nature and origin the skin and the brain are bound up together, and messages from the skin nerves play a great part in the initiation and regulation of impulses from the brain to the vital organs. A cold douche makes one gasp, a cool breeze restores a fainting man, stimulation of the skin excites breathing movements in a new-born infant, and messages from the skin to the brain are followed by messages from the brain that bring about contraction or relaxation of the vessels of the skin to suit the temperature of the air. But when we surround the skin with a layer of warm, damp, stagnant air we shut it off from the stimulus of moving air, and also from the stimuli of heat and cold, and no messages go from the skin to the brain urging it to quicken the respiration or increase the blood-pressure. And so the nerve-centres in the brain that control breathing and blood-pressure become lethargic, and the vital functions suffer in their efficiency. A man whose whole skin is open to the stimulation of moving air, of heat and cold, and perhaps of light, will have more physical and mental energy than a man who protects his skin from these natural and healthful stimuli.

Open Air and Light

The open-air treatment of tuberculosis is based on the physiological principles which have just been explained. The patients are encouraged to live night and day in moving air. The result is that oxidation is encouraged, and the energy of all the vital functions increased, not only as regards such functions as circulation and respiration but also as regards the secretory and excretory functions, and the chemical processes that play a part in resisting microbes and their poisons. What exact part the sun's rays themselves may play in the matter is uncertain, but recent research work suggests that it may be important, and that the chemical processes taking place in the blood are greatly affected by light. It is probable, therefore, that measures for abating the smoke nuisance in industrial centres are even more urgently required in the interests of health than had previously been supposed.

§ 3

Sleep

There remains still to mention the most mysterious and one of the most important of all the factors relating to vital energy. A man may live for weeks or months without food; but he cannot live many days without sleep. Without sleep his energy quickly fails, however much food he may take and however much oxygen may be at his disposal. Why sleep should be so essential it is difficult to understand. Theoretically speaking, so long as digestion, circulation, and respiration work, energy should be produced indefinitely, but in some way sleep is necessary for the continuance of vigour, especially as regards the brain and nervous system. The loss or partial loss of consciousness characteristic of sleep is probably due to a complex of causes—relaxation of certain blood-vessels, accumulation of waste products, some kind of fatigue blockage in the nerves of sensation—and during the period of sleep the vital organs work more feebly, and more oxygen is absorbed than expended. Sound deep sleep is essential if a man is to enjoy full vigour, and a great deal of lassitude and lack of energy is due to too late hours and too little sleep. Lucky men who can sleep as long as they wish should avail themselves of the gift, and not attempt to add to the length of their days by stealing a few hours from the night.

But in many cases short hours of sleep are quite compatible with sound health. Brain-workers, especially, seem able to maintain mental energy without many hours of sleep, and indeed, sleep requirements seem to vary to a large extent in various individuals. When actual insomnia occurs, physical and mental energy diminish; and every effort should be made to get at the cause underlying the condition, for insomnia is not so much a disease as a symptom. The cause may be indigestion, fever, physical or mental fatigue, or even surplus energy. When any obvious causes such as these are found, the first thing to do is to remove them. Sleeping draughts, at all times very dangerous and pernicious things, are quite out of place in such cases. What is the use of giving an opiate to a man whose brain has been disturbed all night by messages of remonstrance from an overladen stomach? If insomnia be due to undigested food, the right and reasonable way to avoid it is by going to bed with an empty stomach. If, again, as is sometimes the case, the brain is kept awake by a stomach requesting more food, a little food will be better than any soporific. If a man cannot sleep because he is not tired enough, the obvious remedy is to give him more work to do; and if he cannot sleep because he is too tired, the remedy of less work is obvious. Excitement, often quite pleasurable excitement, especially excited suspense, will often cause wakeful nights, and the cure, of course, is to avoid excitement, so far as possible, especially towards bedtime. People temperamentally excitable are particularly liable to insomnia, and in certain cases the only cure is the persistent cultivation of a calmer and more phlegmatic character. Excitement acts to a large extent by quickening the action of the heart, and thus preventing the reduction of the blood-flow to the brain, which is one of the essential preliminaries of sleep; and even apart from excitement, conditions of circulation sometimes cause excess of blood in the brain, and this can frequently be relieved by giving warm baths or hot drinks.

Much more troublesome, are cases of insomnia due to what is called "worry." Worry is some unpleasant or irritating thought that possesses or obsesses the mind, very often some pressing problem that insists on solution. To a certain extent worry is inevitable; life, for most people, is full of problems that require to be solved, and that require persistence and concentration for their solution. In the darkness and silence of the night these problems intrude and start trains of thought lying ready in the subconscious mind, and once these are started they turn the brain into a weary and sleepless Sisyphus. There is no remedy for such worry-insomnia except to keep the mind during the day as much as possible from worrying matters. It must be noticed, too, that insomnia itself is apt to become a worry. The sleepless man lies awake worrying about his insomnia, and his emotional concentration on the subject renders sleep quite impossible. Possibly more harm is done to a man's health by worry over insomnia than by insomnia itself, and if a sleepless man can lie quiet, keep his mind on pleasant topics, and take the whole matter philosophically he will suffer very much less from loss of sleep than if he tosses about and frets and laments.

We have talked of worry in relation to insomnia, but quite apart from insomnia, too persistent preoccupation with the dark side of life—with its anxieties and sorrows and problems—reduces health and energy. The energy which ought to go to the vital organs is in some way inhibited, and indigestion and other symptoms of organic disorder follow. It is a man's duty both to himself and to other people to look so far as possible at the bright side of things, and to cultivate the power of setting worries aside and of rising superior to at least the petty annoyances of daily life. To a great extent, avoidance of worry is a matter of the education of the will; but it is certain that a man living a healthy open-air life is more able to throw off cares and troubles than a man whose vitality has been reduced by unhealthy habits. Not only worry, in the usual sense of the term, but all unpleasant emotions have a pernicious effect on the health. Fear, hatred, envy, disappointment, all depress and disturb the vital functions. A man suffering from a grievous disappointment loses his appetite; and in India a man suspected of theft is given rice to chew, since if he be guilty fear will dry up his mouth and render him unable to swallow the dry rice.

And if it be true that worry and unpleasant emotions depress vitality, it is equally true that joyful emotions have the opposite effect.

A merry heart goes all the day,
Your sad tires in a mile-a,

is sound physiology, and equally sound physiology is expressed in the proverb "He that is of a merry heart hath a continual feast." It is not enough to resist depressing emotions: a man who is to make the most of himself must seek happy experiences. Health is necessary for happiness, but also happiness increases health.[1]

§ 4

We have stated that great energy alone does not constitute health, that the energy must be harmoniously co-ordinated to useful and, so far as possible, intellectual and spiritual ends. But the useful co-ordination of energy is the function of the nervous system, and in a sense the nervous system is the real man. There is a preparation in the Royal College of Surgeons which shows the whole nervous system of a man dissected out from his body, and if there were some way of supplying such a nervous system with food and oxygen we would have a conscious being that might be called a man; but take away the nervous system and the other organs and tissues would never be anything like a man. Thought, sensation, and the regulation and co-ordination of the muscular movements, voluntary or involuntary,

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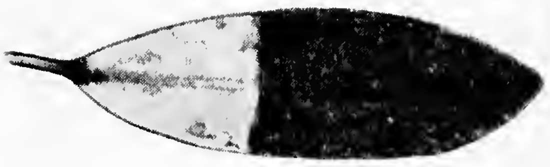
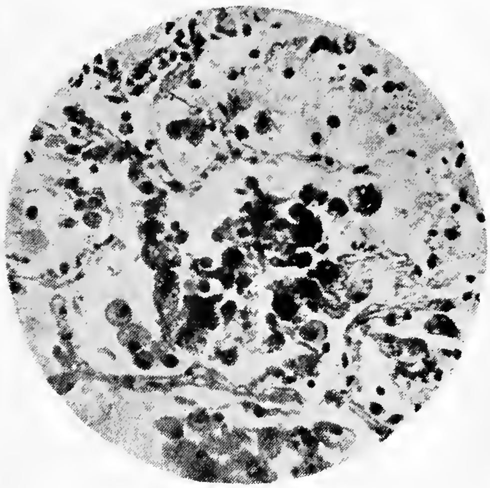
[1] See "The Cult of Joy, p. 359.



Photograph: J. B. Cohen, F.R.S. From Special Report No. 52, Medical Research Council.

PHOTOGRAPH OF A LEAF FROM A CITY TREE (LEEDS)

The photograph illustrates the extent of air-contamination by city smoke. The soot has been removed from half the leaf for purposes of comparison.



Microphotograph: after Watt, Irvine, and others, "Silicosis," Pretoria, 1916.

PHAGOCYTES OR WHITE BLOOD CELLS DEFEND THE BODY FROM INVADING MICROBES

The illustration shows phagocytes in the alveoli of the lung loaded with coal-dust. They are ingesting the foreign particles.

Photo: Russell, London.

SIR ALMROTH WRIGHT

An authority on questions of immunity and a pioneer in modern methods of treatment by vaccine therapy. His name is especially associated with the substances formed in the blood which were named by him "opsonins," and to which reference is made in the text.

Photo: Bennington.

ALBERT EINSTEIN

The creator of what may prove, in its implications, to be the most far-reaching scientific theory that the world has yet seen. Einstein was born in Germany in 1874. At 18 years of age he had already conceptions of his theory. At the age of 27 he reside in the brain, spinal cord, and nerves, including, of course, the wonderful nerve structures called the special senses. Without this nervous hierarchy not a single useful movement could be performed, and life itself would be impossible, for without exquisitely regulated and co-ordinated action the circulation and breathing could not go on. This wonderful system is to a certain extent, as we have already suggested, under the control of the will, and through it a man is able to have a good deal of influence indirectly on other organs not under will control (otherwise it would not be much use to write on the science of health), and again through the relationship of these to the nervous system he can influence the nervous system itself. Thus through the co-ordinating power of his nervous system a man can feed himself, feed his heart and lungs, and through them can feed his brain and nerves. Accordingly, though the nervous system stands pre-eminent above all other systems, guiding and ruling them, it is dependent on the health of the other systems, and its health can be promoted chiefly by the measures which we have already mentioned when talking of the digestive, respiratory, and circulatory systems. It is, however, particularly resistant to ill-health. So long as there are food and oxygen to be had, the nervous system will clutch them, and it is the last organ in the body to suffer from under-nutrition. It is essential that this should be so, for if the nervous system failed first, all the functions of the body would become chaotic and anarchical. When McSwiney starved himself, his mind remained active and clear almost to the very end. On the other hand, the nervous system, especially the intellectual faculties of the brain, is easily disordered by certain poisons circulating in the blood —such poisons as the toxins of fever, alcohol, opium, Indian hemp.

But the chief hygienic peculiarity of the nervous system depends on the peculiar function of the brain as the organ of thought. The health of the brain as an organ of thought depends not only on air and food but also on education. The brain feeds on books and on thoughts quite as much as on bread and butter. A single paragraph in a book may wind it up for days, and a few words on a telegraph form may unlock thousands of calories of energy. Its co-ordinating, its guiding, its initiative powers, its capacity for happiness, and its capacity for giving happiness can be multiplied a thousand-fold by education.

Mental Hygiene

There is, thus, a hygiene of the mind as well as a hygiene of the body. To achieve the ideal of "Mens sana in corpore sano," a healthy mind in a healthy body, it is necessary to apply the fruits of the knowledge gained not only in the realm of physiology but also in that of psychology (see THE SCIENCE OF THE MIND, p. 541). The mind, no less than the body, requires to be properly exercised and properly reposed, and it must be given intellectual and emotional "food" of a suitable kind. How important this is considered may be judged from the recent formation of a distinguished National Council of Mental Hygiene to promote the study of the subject and the dissemination of knowledge on the questions involved. In the particular field of industry, also, we have the young science of "Industrial Fatigue" —the word is used not in its ordinary sense of "weariness," but in the scientific sense of reduced efficiency. In this we find attention given, both from a physiological and a psychological point of view, to many problems of economy of effort, of monotony, of rhythm, of vocational selection, of spells of work and the introduction of rest pauses, of factory conditions, and the like: and as our knowledge on these points increases, so does our capacity to improve the well-being and happiness of the worker on the one hand and our industrial output on the other.

Nervous ill-health begins when a man's nervous system is so readily and so violently excited by stimuli that the nerve-power is wasted and exhausted; or when a man has such deficient nerve-power that his nerve-responses to stimuli are no longer easy and effective. In the first case we say the man is nervous or neurotic; he is always "on the jump," excitable, irritable, generally "nervy," and periods of exhaustion alternate with periods of excitement. In the second case the man is nervously weak or neurasthenic; he is always tired, he lacks interest in life, and initiative, and enthusiasm; the "grasshopper is a burden," and all the vital processes are depressed. Closely allied to these two conditions is hysteria.

Both neurotic and neurasthenic conditions are, to a certain extent, innate; the nervous system, more than any other system, is born, not made, and some men are born with over-excitable nervous systems and some with too little nerve vigour; but both conditions can be bettered to a very great extent both by the education of the will and by the hygienic measures which we have already detailed in dealing with the other systems. Under proper hygienic treatment, most neurotics can acquire steadier, more stable nerves, and most neurasthenics larger reserves of nerve energy.

In talking of health, whether of body or mind, it must always be recognised that there is no such thing as standard health—no such thing as absolute health. Different men are healthy in different ways and to different degrees, and it is necessary for each man to find out his own way of health and acquiesce in his own limitations. A 3 h.p. engine will not lift an aeroplane nor drive along a liner, but it will work usefully and harmoniously in a motor-bicycle, and one of the commonest causes of breakdown in health is the employment of 3 h.p. engines to do 300 h.p. work, either mental or physical. The test and proof of health, indeed, will be found not so much in the amount of work done as in its smooth facile efficiency, and in the happiness and pleasure found in its performance. Man is more than a working machine, and his work is to be judged not merely by its value in calories, but also by its emotional quality, and by the happiness it brings both to the worker and his fellow-beings.

§ 5

Bacteria—the Fruitful Source of Disease

Although we are dealing here with health of the body, and not with its diseases, it is perhaps not going beyond our subject to remark on the great advance in recent years in the Science of Medicine, and in our knowledge of the human body. The discoveries connected with the ductless glands, and the part they play in the regulation of the body, have been referred to elsewhere. As explained in the article on Biology, the ductless glands are organs which pour their secretions directly into the blood. Many of these secretions, or hormones, have an extraordinary power over the growth of the body, its rate of working and the co-operation of its parts. Many distressing conditions may result from the failure of one or other of the ductless glands to pour its proper secretions into the blood-stream: the whole chemistry of the body is deranged, but the trouble may often be remedied, as in the case of diseased thyroid, by the administration of secretions prepared from the glands of animals. Bacteria have also been dealt with in a previous chapter. The increasing mastery of the microbe—that fruitful source of disease—is one of the triumphs of modern medical science. These injurious microscopic organisms invade the human body, liberate poisons, and work incalculable havoc. By their activity they set up dangerous fevers, they also break down membranes and cause structural injuries of a serious kind. The science of bacteriology is young; while there remain still undiscovered many germs of particular diseases, hundreds of specific germs, unsuspected only a few years ago, have been discovered and their life-histories have been unveiled in the laboratory of the bacteriologist.

There is a long list of diseases which are caused by infections with micro-organisms, bacteria on the one hand and protozoa, or single-celled animals, on the other. Thus, tuberculosis, typhoid or enteric fever, diphtheria, tetanus or "lock-jaw," anthrax, cholera, bacillary dysentery, and cerebro-spinal or "spotted" fever are all caused by bacteria, each particular species causing its particular disease, while malaria, amœbic dysentery, and sleeping sickness are of protozoan origin. Other diseases remain which must certainly be ascribed to micro-organisms of some kind, but for which no cause has yet been identified with certainty: these include scarlet fever, measles, whooping-cough, and influenza. Probably the organisms in these cases are even more minute than those hitherto observed, and evidence is accumulating—as recently published researches show—that there are organisms capable of passing through the fine filters used by bacteriologists.

Luckily in the body we have two great counteractives to these organisms of disease: in the first place there are the phagocytes, wandering white cells in the blood which engulf and digest microbes; in the second place the body has the power of producing antidotes against the deadly poisons which the intruders liberate in their victim's blood. In various ways it is possible to increase the protective efficiency of both these natural defences of the body. In many cases it not only happens that a cure is effected, but that future attacks of the same disease are rendered either impossible or less serious.

A dirty pin-prick, for instance, may be the means of introducing into the body a host of deadly micro-organisms. In the blood their numbers quickly multiply, until where there were thousands there are millions. A series of changes takes place in the blood and blood-vessels. Soon there is a state of warfare in the body; a battle between the phagocytes or white cells (the word phagocyte means "eating cell") and the invading germs takes place.

> The white blood-cells squeeze through the vessel walls, and, in their thousands and millions, gather round the point of disturbance. Rapidly the jelly-like cell alters its shape,

> steadily surrounds one microbe after another, until its body contains ten, fifty, one hundred, or more. If the conditions are favourable to the white cells, the battle goes on until every microbe is absorbed by a cell, until the exudation, solid or liquid, is all reabsorbed, and until the circulation of the blood in the part again becomes normal.

The issue, however, may be very different. The numbers of the invading germs may be too great;

> then millions of white cells die in the struggle, their bodies perhaps breaking up and liberating small quantities of antitoxin. The micrococci (minute germs) too die in their millions; but their rate of increase is enormous, and they continue to advance. To meet them come millions more of the white cells, absorbing their enemies, digesting them, and producing the antidote to the poison of the microbes.

If the microbes continue to gain the upper hand and invade the larger vessels of the body, the battle continues there;

> if the microbe meets its antidote everywhere its warfare fails. If, however, the conditions are still unfavourable to the white cells the microbes, dying in millions, produce more millions to continue the invasion. The war goes on until every defence is broken down; then the slight inflammation of the pricked finger ends in a fatal blood-poisoning.[1]

We have said that the body has the power of producing antisubstances to the poisons introduced by micro-organisms. These substances are of various kinds: they include antitoxins, which are antidotes to the poisons of the disease; lysins and agglutinins, which help directly to destroy the invading germs; and the opsonins (a word meaning a sauce or seasoning) discovered by Sir Almroth Wright. These last seem to act indirectly by aiding the phagocytes, apparently making it easier for these white cells to take in and digest the particular organisms concerned.

[1] Sir Leslie Mackenzie, *Health and Disease.*

Artificial Immunity

One attack of certain diseases confers a passing or permanent immunity against another attack of the same kind, but although this fact is ancient knowledge, its inner meaning is as yet by no means fully understood. But acquired immunity—the immunity which one attack gives against a subsequent infection—has suggested a line of attack on infecting micro-organisms. The invading organisms produce a toxin, or a mixture of several toxins, and in response to this the body, as we have seen, produces an antitoxin—an antidote to the bacterial poison. But the process takes time, and the toxin always has a start and may even get control irrevocably. The question arises, therefore, as to whether the body cannot be made to produce its antitoxin beforehand: then the further question, cannot the antitoxin be made outside the body altogether and held in readiness to be injected as soon as the disease becomes manifest?

The earliest answer to the first of these questions dates from long before the era of modern scientific knowledge. Artificial infection from mild cases of smallpox was practised in the East centuries ago as a protection against possible attacks of a severer nature, and the custom was introduced into this country early in the eighteenth century. It has since been superseded, however, by Jenner's discovery of vaccination, a safer method in which the artificial infection is with calf-lymph containing the virus of cow-pox (possibly a mild form of the same disease). Vaccination and improved sanitation have together banished smallpox from this country as a serious plague.

The modern discovery and identification of the organisms that cause many diseases have led to a further modification in certain cases. In the protective inoculation against typhoid fever, for instance, it is dead bacteria—killed by heat sterilisation—which are used. This process implies the administration of a definitely limited amount of toxin: the organisms, not being alive, cannot multiply in the body or produce further quantities of the poison. Anti-typhoid inoculation has proved immensely valuable, especially in the case of troops on active service as was shown in the late war, although the immunity given in this case disappears after a few years.

There are, of course, obvious practical limitations to the protective inoculation of entire populations against numerous diseases, and wider possibilities are opened up by the discovery of means of producing antitoxins and the like outside the human body. It is not possible to manufacture these substances artificially, for their subtle chemistry still eludes our researches to a large extent, but they can be produced in the bodies of animals. The principle is the same as that already described except that it is an animal which is inoculated with the killed bacteria or the toxins of the disease. Horses are commonly employed because of their conveniently large size: gradually increasing doses are given so that the animal's health is not impaired, and when its blood is rich in anti-substances quantities are drawn off from time to time. The blood-serum is separated from the solids and subjected to various processes of purification and testing, and it is then made up for use on human patients who contract the disease. The diphtheria antitoxin is the best-known example of this kind. It is purely an antitoxin, an antidote to the poisons produced in the body by the bacteria, and does not kill the organisms themselves: these are dealt with by antiseptic treatment of the centre of infection in the throat. In the case of some other diseases, however, sera are used containing anti-substances which are effective not only against the toxins but also against the invading organisms.

Without going further into the question, it will suffice to say that there is an ever-increasing number of diseases which are yielding to protective or curative measures based on the principle of acquired immunity. One important point, however, must be made clear. Immunity is not general against all or a number of diseases, but is quite specific. Immunity against one disease does not involve immunity against others: each must be dealt with separately and each presents to science its own peculiar difficulties.

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XXXVIII

SCIENCE AND MODERN THOUGHT

By the Editor

SCIENCE AND MODERN THOUGHT

By the Editor

IT is not easy to define Science. It is a system of knowledge built up on a basis of observation and experiment, and compacted by reflection on the data thus supplied. Scientific knowledge is typically of such a kind that it can be verified by competent inquirers who repeat the observations and experiments, and make them the subject of careful independent reflection. Science is verifiable, communicable, impersonal, unemotional knowledge; but all the fields of science are not on the same level. Thus Newton's *Principia* may be called very perfect science, but its range of communicability is limited. It is probably easier to be impersonal in Astronomy than in Ethnology.

The Aim of Science

The establishment of a science depends on processes of selection and detachment, what might be called isolating certain aspects of things. Thus the geologist does not as such concern himself with the beauty of the scenery, nor the astronomer with the majesty of the star-strewn sky. Nor does the physiologist primarily concern himself with the subjective aspect of life, though here the abstraction of metabolism from mind is less easy. The aim of science is to work out descriptive formulæ—as short, as simple, as complete, and as consistent as can be devised. As Aristotle said: "Art" (we should say "Science") "begins when, from a great number of experiences, one general conception is formed which will embrace all similar cases." Science means unifying diversities and detecting uniformities. As Professor J. H. Poynting put it: In science "we explain an event not when we know 'why' it happened, but when we know 'how' it is like something else happening elsewhere—when in fact we can include it as a case described by some law already set forth." As Professor Karl Pearson has said:

> The law of gravitation is a brief description of *how* every particle of matter in the universe is altering its motion with reference to every other particle. It does not tell us *why* particles thus move; it does not tell us *why* the earth describes a certain curve round the sun. It simply resumes, in a few brief words, the relationships observed between a vast range of phenomena. It economises thought by stating in conceptual shorthand that routine of our perceptions which forms for us the universe of gravitating matter.

This view of science as essentially descriptive is well suggested by Kirchhoff's famous statement of the aim of mechanics—"to describe completely and in the simplest manner the motions that occur in nature." Many of the misunderstandings that have arisen in regard to "science and religion," "science and philosophy," and similar questions are due to a failure to recognise what Science aims at—the formulation of things as they are and as they have come to be. The primary aim of science is not to "explain," except in the sense of saying "This is a particular case of Law X," or of saying, "This is the outcome of that." It does not inquire into the "why" of things, the purpose or significance of the cosmos. That is not its métier.

The Scientific Mood

The scientific study of a subject implies a certain intellectual attitude or mood, which need not, however, be regarded as the only right of way. Thus the æsthetic or poetic or purely practical approach to a subject may be not less legitimate than that of the scientific investigator. The scientific mood, which reaches very diverse degrees of development, is marked by (1) a passion for facts (this includes a high standard of accuracy and a detachment from personal wishes); (2) a cautious thoroughness in coming to a conclusion (this implies a persistent scepticism and self-elimination in judgment); (3) a quality of clearness (which includes a dislike of obscurities, ambiguities, and loose ends); and (4) a less readily definable sense of the inter-relations of things, an insight which discerns that apparently isolated phenomena are integral parts of a system. When a body of knowledge is very young or very elusive, there is apt to be a penumbra of what Faraday called "doubtful knowledge." One must steer between uncritical easygoingness and expurgatorial intolerance.

The Methods of Science

In any scientific inquiry the first step is to get at the facts, and this requires precision, patience, impartiality, watchfulness against the illusions of the senses and the mind, and carefulness to keep inferences from mingling with observations. The second step is accurate registration of the data. In most cases science begins with measurement. As Lord Kelvin said, "Nearly all the grandest discoveries of science have been but the rewards of accurate measurement and patient, long-continued labour in the minute sifting of numerical results." There is a certain quality of character here, and it is very significant that Clerk Maxwell should have spoken in one sentence of "those aspirations after accuracy of measurement, and justice in action, which we reckon among our noblest attributes as men."

A third step is arranging the data in workable form—a simple illustration being a plotted-out curve which shows at a glance the general outcome of a multitude of measurements, e.g. the range of variability in a particular specific character in a plant or animal. The data may have to be expressed in their simplest terms, reduced perhaps to a common denominator with other sets of facts with which they have to be compared. There is the danger here of losing sight of something in the process of reduction. Thus, in reducing a fact of animal behaviour to a chain of reflex actions we may be losing sight of "mind"; or in reducing a physiological fact to a series of chemical and physical facts we may be losing sight of "life."

The fourth step is when a whole series of occurrences is seen to have a uniformity, which is called their law. A formula is found that fits—the finding being sometimes due to a flash of insight and sometimes the outcome of many tentatives. Newton's "passage from a falling apple to a falling moon" was a stupendous leap of the scientific imagination; the modern science of the atom is the outcome of the testing of many approximate formulations.

The Laws of Nature are man's descriptive formulæ of uniformities of sequence, which enable him to say, "If this, then that." These laws are not all of the same rank; they differ in precision and comprehensiveness; the meaning of their terms often changes with time. Science is not only human, it is often anthropomorphic. It may even reflect the social outlook of the age. Thus in Biology, one of the less exact sciences, provisional concepts, such as "the struggle for existence," are often borrowed from human affairs; and while illuminating suggestion often comes from this, there is no small risk of fallacy. Science is not so objective as is sometimes supposed; we can no more escape from anthropomorphism than from our shadow. Yet those who exaggerate the subjectivity of science and declare with a great philosopher of to-day that "scientific truth is the creation of the human mind, and not of outer nature," are missing what is characteristic of man's scientific formulation of the Order of Nature, that it must be verifiable by all normally constituted minds, and that it must form a reliable basis for prediction, if not also for control. The fact that the astronomer can predict the night of the comet's return, and the Mendelian the nature of the hybrid rabbit's litter, shows that our formulations approximate towards objective reality.

Scope of Science

There is much to be said for using the word science with a qualifying adjective—e.g. chemical and physical science, natural science, biological science, mental and moral science, social science, abstract science. For the various sciences differ greatly in their degree of precision. When we pass from chemistry and physics to the study of living creatures and their behaviour, to the study of human societies and their inter-relations, we find that accurate measurements and precise registration are more difficult, analysis is very imperfect, formulation is very provisional, test-experiments are hard to devise, and prediction is usually hazardous. The discovery of methods, concepts, and formulæ has advanced much further in regard to matter and energy than it has in dealing with the realm of organisms and the kingdom of man. An exact science is like a solar system, a young science is like a nebula, yet the student of, say, dreams may be as "scientific" as the student of rocks, provided he never allows assertion to outstrip evidence, and understands what he knows. Science includes all knowledge, communicable and verifiable, which is reached by methodical observation and experiment, and admits of concise, consistent, and connected formulation. But all science is not the same science.

A saving clause of some importance relates to the use of scientific symbols. The modern physicist assures us of the reality of the atom, but until a few years ago the atom was only a symbol—a working hypothesis approximating to reality. Many terms in common scientific usage remain in the symbolic stage. A chromosome is a visible something, but no one has seen a "gene" or "factor." Yet these genes are dealt with in modern theories of heredity as if they were seeds in a pod. They are indispensable. No one supposes that a carbon atom has four hands, but this symbol has been extraordinarily useful. Fanciful or arbitrary symbols never live long; they are retained only when they afford a convenient basis for prediction and control. The history of science shows in an eloquent way how provisional symbols are tested, and how some of them gradually attain to the dignity of realities—as the atom has done.

Classification of the Sciences

There are three great orders of facts: the domain of things, the realm of organisms, and the kingdom of man. Thus some have spoken of the cosmosphere, the biosphere, and the sociosphere. The fundamental sciences of chemistry and physics deal with matter and energy, especially in the physical universe. Biology has the life of organisms for its province. The young and yet, in a sense, very old science of sociology deals with human societies and folk-ways. Physics and chemistry are practically inseparable; biology and psychology often look like different aspects of the same elusive activity which we call life; sociology deals with groups of men where the whole is more than the sum of its parts. But there is much to be said for the recognition of five fundamental sciences, which may be arranged on this scheme:

SOCIOLOGY
PSYCHOLOGY
BIOLOGY
PHYSICS
CHEMISTRY

It will be seen that biology occupies a central position, resting in part on physics and chemistry, though with independent methods and concepts of its own, and supplying in turn a basis to psychology and sociology. Each main or general science has its subdivisions: thus, biology includes botany and zoology; a great part of astronomy must be ranked under physics, and much of mineralogy under chemistry. Then there are the combined sciences like geology and geography and anthropology, which use the methods and concepts of several sciences for their own particular purposes. Thus geography is like a circle intersecting four or five others for a particular end. Furthermore, there are "applied sciences" where departments of general science are focussed for practical purposes on particular sets of problems, e.g. those connected with the arts and crafts. Thus agricultural science and medical science, the science of engineering and the young science of education are, in great part, applied sciences, and are neither more nor less scientific on that account. As Huxley always insisted, applied science is nothing but the application of pure science to detailed practical problems.

But on a different line are the abstract sciences, which deal with necessary relations between abstract ideas or propositions, irrespective of the actual content. They are deductive rather than inductive; ideal, not experimental; dealing with methods, not with observations. They comprise mathematics in particular, also statistical methods, graphic methods, and logic. Some would include here that part of metaphysics which has for its business the criticism of categories, or a study of explanations as such.

So we reach an outline map of scientific knowledge:

Abstract Sciences.	General Sciences.	Some Special Sciences.	Some Combined Sciences.	Some Applied Sciences.
METAPHYSICS	SOCIOLOGY	Ethnology	Science of History	Economics
LOGIC	PSYCHOLOGY	Æsthetics	Anthropology	Education
STATISTICAL and GRAPHIC METHODS	BIOLOGY	Zoology Botany	History of the Biosphere	Medicine
	PHYSICS	Astronomy Meteorology	Geology and Geography	Engineering
MATHEMATICS	CHEMISTRY	Mineralogy	History of the Solar System	Metallurgy Agriculture

In considering such a map of the sciences it should be kept in mind that they differ not merely in their subject-matter, but in their aims and methods. The same subject may be tackled by several sciences. There is a chemistry and a physics of the human body as well as a biology thereof. The chick may be studied anatomically, physiologically, embryologically, psychologically, and even then we have not exhausted the totality of the chick. The sciences are parts of one endeavour to understand the order of nature and human life within it; they form a correlated body of knowledge; they work into each other's hands, and succeed best when they recognise mutual rights and limitations. The chemistry and physics of the beanstalk are indispensable, but when they are added up they do not give us the biology of the beanstalk, still less of Jack. It is begging many questions to insist that there is only one science of nature, which describes all things and changes in terms of ideal motions, expressible in mathematical formulæ. This is trying to give a false simplicity to the facts. Even the omniscient chemist cannot tell how the cat will jump. Professor Dolbear writes: "By explanation is meant the presentation of the mechanical antecedents for a phenomenon in so complete a way that no supplementary or unknown factors are necessary." But many biologists of to-day would agree that in dealing with distinctively vital behaviour, such as the cat's jump, it is *necessary* to invoke other than mechanical factors, such as the organism's power of enregistering and profiting by experience. There is a correlation, rather than a unity, of the sciences.

Limitations of Science

No one will be inclined to set limits to man's understanding, but it is useful to recognise that science as we know it is subject to certain limitations. (1) There is a self-imposed limitation in the fact that science applies its methods to abstracted aspects of things. We cannot intellectually separate a living creature from its surroundings any more than we can separate a whirlpool from the river, yet for biological purposes we continually think the fish away from the sea and the bird from the air. In analytical anatomy it is actually profitable to do so. Even in more exact sciences this limitation operates. In dynamics we treat the mass of a body as if we studied the body under the influence of gravitation only. But in actual observations and experiments we can never secure the entire absence of electrical, magnetic, and other energies. In other words, science works with "ideal systems"; it aims at practically convenient representations of certain aspects of facts, deliberately abstracted from other aspects.

(2) Science works with "counters" or concepts which are in various degrees far from being self-explanatory. What mysteries lie behind the terms "organism," "protoplasm," "heredity," "energy," "chemical affinity," "gravitation," "inertia," "matter"! It is admitted that the analysis of concepts proceeds apace and that the number of "irreducibles" grows less. But there are many "*x*'s" left.

(3) Another limitation has to do with causal sequence. One billiard ball strikes another—an impelling cause; a spark explodes the gunpowder—a releasing cause; the relaxed spring turns the cylinder of the gramophone, and there is music. But it is only in the first case that the cause *explains* the effect; in the other cases the effect is more or less given in advance. In the great majority of cases all that science does is to say: "If this, then that." Its causal explanations are usually very partial.

(4) Another limitation concerns origins, which remain mysteries. The biologist begins with the first organisms, but whence came they? The chemist begins with the elements, but what has been their history? There is always something before the beginning with which the scientific investigator starts and must start. So there are limitations implied in the partial view we have to take in prosecuting a scientific inquiry, in the radical

mysteriousness of the counters we use, in the difficulty of giving complete causal explanations except in the field of mechanics, and likewise in the obscurity of origins. If these necessary limitations were more clearly kept in mind the aim and scope of science would be less frequently misunderstood.

Moreover, besides all these limitations there are others of a different kind—imposed on us by the limits of our sense-organs, even when greatly helped by ingenious instruments, and by the narrow limits of exact data in regard to the past. Furthermore, it should be kept in mind that formulæ or laws which seemed for a time to fit well have often had to undergo readjustment with the increase of knowledge and the recognition of residual phenomena. So Kepler improves on Copernicus, and Newton on Kepler, and Einstein, some say, on Newton. Science may be compared to an asymptotic line, which is always approaching nearer and nearer to some curve but never reaching it except at infinite distance. Sometimes a single discovery may change the whole framework of a science. Thus Professor Soddy, speaking of radio-activity, says:

> It sounds incredible, but nevertheless it is true, that science up to the close of the nineteenth century had no suspicion even of the existence of the original sources of natural energy. . . . The vista which has been opened up by these new discoveries [of the radio-active properties of some substances] admittedly is without parallel in the whole history of science.

And sometimes it is a new idea, like that of organic evolution, which changes the whole outlook of a science and makes the world new.

Finally, according to well-warranted scientific belief there was once a time when all that happened upon the earth might have been formulated with apparent exhaustiveness in terms of matter and motion. But ages passed and living creatures emerged

—a new synthesis, requiring new formulæ. Ages passed and intelligent creatures commanded their course; a new aspect of reality required a new science. Ages passed and Man emerged —with self-consciousness, language, reasoning capacity, and a social heritage. As the world grew older, the biosphere emerged from the cosmosphere, and out of the biosphere there emerged the sociosphere. As long as its subject-matter continues evolving in the direction of new integrations, science must also evolve.

Science and Feeling

Our life is like a prism: its three sides are (1) DOING, (2) FEELING, and (3) KNOWING, corresponding to the old-fashioned HAND, HEART, and HEAD. Each is a doorway *out*—(1) to the world of action; (2) to the world of art, music, religious ritual, literature; and (3) to the world of externally registered thinking, from a stone circle to a nautical almanac, from a map to a census, from a calendar to a chemical balance. Men are happily of diverse moods: (1) Some have "a practical turn of mind," with a pathological extreme in "matter-of-factness" and "materialism," but are essentially men of action, who make things hum and get things done. (2) Some are "men of feeling," going out by the emotional doorway, with a pathological extreme in "sentimentalism," but essentially men of artistic insight, and sometimes, as poets and seers, the makers and shakers of this world of ours. (3) Some are predominantly men of intellect, who "elect to know, not do," who discover causes, uniformities, laws, and who try to think things out. The pathological extreme "botanises on his mother's grave," as Wordsworth put it, and gibes at "proud philosophy," but there is no doubt that the makers of new knowledge have transformed human life, giving it a new freedom and fulness.

Every intellectual combatant seeks more or less resolutely to gain an all-round or synoptic view of his experience, and this is his philosophy. Our present point is that this must be for most men in a large degree a matter of temperament, according as the practical, the emotional, or the scientific mood is dominant. To return to the old-fashioned Hand, Heart, and Head, these are not only doorways *out,* they are portals *in.* For life is like a dome, always with its concave and convex side, subjective as well as objective. Thus there is the inner world of appetencies and "urges," desires and ideals, which lead externally to action; the world of feelings and emotions which lead to art; and the world of intellectual experimentation which has its external expression in, let us say, the archives of science. All these are natural and necessary expressions of the developing human spirit, and it is in the deepest sense unphilosophical to pit one against the other, or to make antitheses between the different glimpses of reality which are to be obtained from each of the three great doorways of our being.

Truly, science as science is unemotional and impersonal, and its analytic, atomising, or anatomising methods are apt, in their matter-of-factness, to seem antagonistic to artistic unities and poetical interpretations. But here must be learned the lesson of patience and open-mindedness, and here the limitations of science must be borne in mind. The poetry of the man of feeling must not contradict the formulations of the man of science, but they are speaking different languages, and we may know by feeling some aspect of reality which eludes us in scientific analysis. Our delight in fine scenery is not less real than our knowledge of the geology. Both are pathways to reality.

When science makes minor mysteries disappear, greater mysteries stand confessed. For one object of delight whose emotional value science has inevitably lessened—as Newton damaged the rainbow for Keats—science gives back double. To the grand primary impressions of the world power, the immensities, the pervading order, and the universal flux, with which the man of feeling has been nurtured from of old, modern science has added thrilling impressions of manifoldness, intricacy, uniformity, inter-relatedness, and evolution. Science widens and clears the emotional window. There are great vistas to which science alone can lead, and they make for elevation of mind. The opposition between science and feeling is largely a misunderstanding. As one of our philosophers has remarked, science is in a true sense "one of the humanities."

Science and Religion

Science seeks to discover the laws of concrete being and becoming and to state these in the simplest possible terms. These terms are either the immediate data of experience or verifiably derived from these. Religion, on the other hand, implies a recognition—practical, emotional, and intellectual—of a higher order of reality than is reached in sense-experience. It sees an unseen universe, which throws light on the riddles of the observed world. Its language is not scientific language and the two cannot be spoken at once. The concepts of religion are transcendental, those of science are empirical. The aim of religion is interpretation, not description. Religious interpretation and scientific description must not be inconsistent, but they are incommensurable. This is not falling back on the impossible solution of having idea-tight compartments; what is meant is that while the *form* of a religious idea, of Creation, let us say, must be congruent with the established scientific system, scientific description and religious interpretation work in two quite different "universes of discourse."

Science and Philosophy

The philosophical outlook is synoptic; an all-round view. In other words, a philosophical system is the outcome of interpretative reflection on the whole data of our experience. Science and philosophy are complementary. To the scientific thinker philosophy is of service in helping him to recognise the limitations of his task and the assumptions with which he starts. It may save him from being easygoing in the criticism of his categories. On the other side, a modern philosophy must take account of all the far-reaching results of scientific inquiry. Thus an adequate interpretative system must have been receptive to all the influences of such conclusions as the principle of the conservation of energy, the doctrine of organic evolution, and the outstanding facts of heredity. Philosophy has of course no right to call the tune which it wishes science to play, but its task is to correlate the conclusions of science with those which may be reached in the course of practical, ethical, æsthetic, or religious experience. Philosophy begins where the experimental and observational sciences leave off, but it does not follow that philosophy in its edifice must use the building-stones just as science hands them over. It is here that philosophical criticism and all-roundness must come in. Thus the results of the modern study of heredity need not be accepted in a form so crude that the inevitable outcome is fatalism; the results of modern biochemistry need not be accepted in a form so partial that they confine us to a mechanistic view of the living creature; the results of the modern study of animal behaviour need not be accepted in a form so one sided that it practically rules "mind" out of court. These are merely examples of the opportunities which philosophy has for a criticism of scientific categories—a task for which the majority of scientific investigators is poorly equipped.

To take another illustration, the principle of the conservation of energy, formulated in reference to the transformations that go on in physical experiments, must not be allowed to foreclose discussion of the question whether "mind" and "body" (if these be recognised as admissible scientific or philosophical terms) can interact in a way that really counts. And the answer given to that question, or to some similar question more satisfactorily phrased, affects the general philosophical or metaphysical theory that one holds in regard to the world as a whole and man in particular.

Similarly, when philosophy takes over from the biologist the formula of organic evolution that the present is the child of the past and the parent of the future, it is bound to scrutinise the concept of evolution and to show that it is no easy one; and it is bound to make very clear the difference between accepting the *modal* formula (indicative of the general mode by which the present biosphere has come about) and accepting any particular statement of the factors in the age-long process. The general *fact* of evolution stands firmer than ever; but inquiry into the *factors* is still relatively young.

Science and Life

The primary purpose of science is understanding, but knowledge is power. As Bacon said:

> The end of our foundation [Salomon's House] is the knowledge of causes and the secret motions of things; and the enlarging of the bounds of human empire, to the effecting of all things possible.

The two aspects are hardly separable. All the sciences, including mathematics, sprang from concrete experience of practical problems, and the most theoretical investigations have made the biggest differences in man's everyday life to-day. Wireless telegraphy, the telephone, aeroplanes, radium, antiseptics, antitoxins, spectrum analysis, and X-rays were all discovered in the course of abstractly scientific researches. If the utilitarian criterion is pressed in a short-sighted way, then, as to results, it defeats itself. And apart from this consideration, itself utilitarian, it is profitable to return to Bacon's distinction between those results of science which are of direct practical utility (*fructifera*) and those which are light-giving (*lucifera*)—a distinction which led to the admirable deliverance:

> Just as the vision of light itself is something more excellent and beautiful than its manifold use, so without doubt

> the contemplation of things as they are, without superstition or imposture, without error or confusion, is in itself a nobler thing than a whole harvest of inventions.

The old discouragement expressed in the saying that increase of knowledge is increase of sorrow has been replaced by a more robust confidence in what science may achieve in the control of life. The modern outlook is expressed in Herbert Spencer's pithy sentence: "Science is for Life, not Life for Science," or in Comte's well-known saying: "Knowledge is Foresight and Foresight is Power."

Bacon had the idea clearly in mind when he wrote in *The Advancement of Learning:* "This is that which will indeed dignify and exalt knowledge if contemplation and action be more nearly and straitly conjoined and united together than they have been." And the passage ends by declaring that what is sought in science should be "a rich storehouse for the glory of the Creator and the relief of man's estate." But what is distinctively modern is the ideal of bringing the light of science to bear on man's problems all along the line, on health of mind as well as of body, on education as well as on agriculture, on ethical development as well as on the more economical exploitation and usage of natural resources, on eugenics as well as on eutopias. Just as many ills that the flesh is heir to are met no longer with folded hands, but by confident therapeutics, so over a wide range there is a promiseful application of all kinds of science to the amelioration of the conditions of human life. Great stores of wealth are awaiting the scientific "Open Sesame"; a great heightening of the standard of health will be attainable in a few generations if men of good-will take science as their torch. But wealth and health are the pre-conditions of true progress, which means a fuller embodiment of the true, the beautiful, and the good in lives which are increasingly a satisfaction in themselves.

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