TRANSACTIONS

OF THE

ROYAL SOCIETY OF EDINBURGH.

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ROYAL SOCIETY

OF

EDINBURGH.

VOL. XXX.

EDINBURGH:
PUBLISHED BY ROBERT GRANT & SON, 107 PRINCES STREET,
AND WILLIAMS & NORGATE, 14 HENRIETTA STREET, COVENT GARDEN, LONDON.

MDCCCLXXXIII.

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PART I. (1880–81.)

TRANSACTIONS

OF THE

ROYAL SOCIETY OF EDINBURGH.

VOL. XXX. PART I.—FOR THE SESSION 1880–81.

CONTENTS.

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TRANSACTIONS.

I.—*The Law of Extensible Minors in Determinants.*

By Thomas Muir, M.A.

(Received 21st February 1881.)

§ 1. As a preliminary to the establishment of the law in question, it is necessary to state and exemplify another law to which I have elsewhere directed attention, viz.,

The Law of Complementaries.*

To every general theorem which takes the form of an identical relation between a number of the minors of a determinant or between the determinant itself and a number of its minors, there corresponds another theorem derivable from the former by merely substituting for every minor its cofactor in the determinant, and then multiplying any term by such a power of the determinant as will make the terms of the same degree.

For example, taking the well-known identity employed by Hermite,

$$\begin{vmatrix} |a_1b_2| & |a_2b_3| & |a_3b_4| \\ |a_1c_2| & |a_2c_3| & |a_3c_4| \\ |a_1d_2| & |a_2d_3| & |a_3d_4| \end{vmatrix} = \begin{vmatrix} a_1 & a_2 & a_3 & a_4 \\ b_1 & b_2 & b_3 & b_4 \\ c_1 & c_2 & c_3 & c_4 \\ d_1 & d_2 & d_3 & d_4 \end{vmatrix} a_2a_3 \quad . \quad . \quad . \quad . \quad (1)$$

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* I do not know who was the first discoverer of this law. It presented itself to me when correcting the proof of my paper on "General Theorems in Determinants" (Trans. Roy. Soc. Edin. 1879). But it must have been known to Professor Cayley before then, for in a note to a paper by Professor Tanner (Mess. of Math. 1878), he refers to it as a means by which Professor Tanner's corresponding law for Pfaffians might be established.

and substituting for each determinant its complementary minor in the determinant $|a_1b_2c_3d_4|$, we have

$$\begin{vmatrix} |c_3d_4| & |c_1d_4| & |c_1d_2| \\ |b_3d_4| & |b_1d_4| & |b_1d_2| \\ |b_3c_4| & |b_1c_4| & |b_1c_2| \end{vmatrix} = \begin{vmatrix} b_1 & b_3 & b_4 \\ c_1 & c_3 & c_4 \\ d_1 & d_3 & d_4 \end{vmatrix} \begin{vmatrix} b_1 & b_2 & b_4 \\ c_1 & c_2 & c_4 \\ d_1 & d_2 & d_4 \end{vmatrix} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

a special case of a theorem of SYLVESTER's in regard to compound determinants.

It is thus seen that in virtue of the Law of Complementaries the theorems of determinants range themselves in pairs, like pairs of theorems in geometry in virtue of such a law as that of Reciprocal Polars.

§ 2. We come now to

THE LAW OF EXTENSIBLE MINORS.

If any identical relation be established between a number of the minors of a determinant or between the determinant itself and a number of its minors, the determinants being denoted by means of their principal diagonals, then a new theorem is always obtainable by merely choosing a line of new letters with new suffixes and annexing it to the end of the diagonal of every determinant, including those of order 0, *occurring in the identity.*

The proof is dependent upon the Law of Complementaries, and upon the simple fact that every minor of a given determinant is also a minor of any determinant of which the given determinant itself is a minor. Let (A) be the established identity, and $|a_1b_2c_3 \ldots l_n|$ the determinant whose minors are involved in it. Then taking the complementary of (A) with respect to $|a_1b_2c_3 \ldots l_n|$ we have an identity, (B) say, likewise involving minors of $a_1b_2c_3 \ldots l_n|$. But these minors are also minors of $|a_1b_2c_3 \ldots l_nr_\alpha s_\beta \ldots z_\omega|$, and therefore it is allowable to take the complementary of (B) with respect to this extended determinant. Doing this we pass, not back to (A), but to a new theorem (A′) which is seen to be derivable from (A) by annexing to the end of the diagonal of every determinant in it the line of letters $r_\alpha s_\beta \ldots z_\omega$. The law is thus established.

The clause "including those of order 0" is necessitated by the last clause in the enunciation of the Law of Complementaries.

Taking as an example the simple identity

$$|a_1b_2c_3| = a_1|b_2c_3| - a_2|b_1c_3| + a_3|b_1c_2 \, ,$$

and using only one new letter d and one new suffix 4, we change

$$|a_1b_2c_3|,\quad a_1,\quad |b_2c_3|,\quad a_2,\quad |b_1c_3|,\quad a_3,\quad |b_1c_2|,$$

into

$$|a_1b_2c_3d_4|,\quad |a_1d_4|,\quad b_2c_3d_4|,\quad |a_2d_4|,\quad |b_1c_3d_4|,\quad |a_3d_4|,\quad |b_1c_2d_4|,$$

and noting that without further change the two sides would not be of the same degree, we annex the factor d_4 to the left hand side, thus, as it were, extending the process of elevation of order to an imaginary determinant of order 0. The result is the identity

$$d_4\,|a_1b_2c_3d_4| = |a_1d_4|\;|b_2c_3d_4| - |a_2d_4|\;|b_1c_3d_4| + |a_3d_4|\;|b_1c_2d_4| \qquad . \quad . \quad (3)$$

This is verified by observing that

$$d_4\,|a_1b_2c_3d_4| = \begin{vmatrix} a_1 & a_2 & a_3 & a_4 & a_4 \\ b_1 & b_2 & b_3 & b_4 & 0 \\ c_1 & c_2 & c_3 & c_4 & 0 \\ d_1 & d_2 & d_3 & d_4 & 0 \\ 0 & 0 & 0 & 0 & d_4 \end{vmatrix} = \begin{vmatrix} a_1 & a_2 & a_3 & a_4 & a_4 \\ b_1 & b_2 & b_3 & b_4 & 0 \\ c_1 & c_2 & c_3 & c_4 & 0 \\ d_1 & d_2 & d_3 & d_4 & 0 \\ d_1 & d_2 & d_3 & d_4 & d_4 \end{vmatrix}$$

and then expressing the last determinant in terms of products of complementary minors, one factor of each product being formed from the first and last line.

Taking the identity numbered (1) above and choosing the extension e_5, we have

$$\begin{vmatrix} |a_1b_2e_5| & |a_2b_3e_5| & |a_3b_4e_5| \\ |a_1c_2e_5| & |a_2c_3e_5| & |a_3c_4e_5| \\ |a_1d_2e_5| & |a_2d_3e_5| & |a_3d_4e_5| \end{vmatrix} = |a_1b_2c_3d_4e_5|\;|a_2e_5|\;|a_3e_5| \qquad .. \quad .. \quad . \quad (4)$$

The corresponding extensional of (2) is

$$\begin{vmatrix} |c_3d_4e_5| & |c_1d_4e_5| & |c_1d_2e_5| \\ |b_3d_4e_5| & |b_1d_4e_5| & |b_1d_2e_5| \\ |b_3c_4e_5| & |b_1c_4e_5| & |b_1c_2e_5| \end{vmatrix} = |b_1c_3d_4e_5|\;|b_1c_2d_4e_5|\,e_5 \qquad . \quad . \quad . \quad . \quad (5)$$

The identities (1) and (2) however admit each of two forms of Extensional, according as we look upon the letters in the right hand members as being mere elements, or as being determinants of order 1. Thus from (1) we have

$$e_5^3\begin{vmatrix} |a_1b_2e_5| & |a_2b_3e_5| & |a_3b_4e_5| \\ |a_1c_2e_5| & |a_2c_3e_5| & |a_3c_4e_5| \\ |a_1d_2e_5| & |a_2d_3e_5| & |a_3d_4e_5| \end{vmatrix} = \begin{vmatrix} |a_1e_5| & |a_2e_5| & |a_3e_5| & |a_4e_5| \\ |b_1e_5| & |b_2e_5| & |b_3e_5| & |b_4e_5| \\ |c_1e_5| & |c_2e_5| & |c_3e_5| & |c_4e_5| \\ |d_1e_5| & |d_2e_5| & |d_3e_5| & |d_4e_5| \end{vmatrix}|a_2e_5|\;|a_3e_5|\,. \qquad . \quad (6)$$

and from (2)

$$e_5^3\begin{vmatrix} |c_3d_4e_5| & |c_1d_4e_5| & |c_1d_2e_5| \\ |b_3d_4e_5| & |b_1d_4e_5| & |b_1d_2e_5| \\ |b_3c_4e_5| & |b_1c_4e_5| & |b_1c_2e_5| \end{vmatrix} = \begin{vmatrix} |b_1e_5| & |b_3e_5| & |b_4e_5| \\ |c_1e_5| & |c_3e_5| & |c_4e_5| \\ |d_1e_5| & |d_3e_5| & |d_4e_5| \end{vmatrix} \times \begin{vmatrix} |b_1e_5| & |b_2e_5| & |b_4e_5| \\ |c_1e_5| & |c_2e_5| & |c_4e_5| \\ |d_1e_5| & |d_2e_5| & |d_4e_5| \end{vmatrix} . \qquad (7)$$

In corroboration of these, we observe that from (4) and (6) we deduce

$$\begin{vmatrix} |a_1e_5| & |a_2e_5| & |a_3e_5| & |a_4e_5| \\ |b_1e_5| & |b_2e_5| & |b_3e_5| & |b_4e_5| \\ |c_1e_5| & |c_2e_5| & |c_3e_5| & |c_4e_5| \\ |d_1e_5| & |d_2e_5| & |d_3e_5| & |d_4e_5 \end{vmatrix} = |a_1b_2c_3d_4e_5|\, e_5^3 \quad . \quad . \quad . \quad . \quad . \qquad (8)$$

which is the extensional of the manifest identity

$$\begin{vmatrix} a_1 & a_2 & a_3 & a_4 \\ b_1 & b_2 & b_3 & b_4 \\ c_1 & c_2 & c_3 & c_4 \\ d_1 & d_2 & d_3 & d_4 \end{vmatrix} = |a_1b_2c_3d_4| .$$

§ 3. Thus in theory of determinants every general theorem in the form of an identity has its complementary and its extensional. The exact relation between the two latter is seen from the proof which has been given above, and may be formulated as follows :—*If the Complementary of* (A) *with respect to a certain determinant be* (B), *its Complementary with respect to a determinant of higher order is the Extensional of* (B). Consequently, if, as sometimes happens, the Complementary of (A) with respect to a certain determinant be (A) itself, its Complementary with respect to a determinant of higher order is its Extensional.

By the two laws the theorems of determinants are knit together in a way which is interesting theoretically, and which at the same time has the practical advantage of making the remembrance of the whole body of theorems a very simple matter.

II.—*On some Transformations connecting General Determinants with Continuants.* By THOMAS MUIR, M.A.

(Read 21st February 1881.)

§ 1. It is well known that by a simple transformation of a determinant we may cause a zero to take the place of any one of the elements. The theorems of HERMITE [*] and HORNER,[†] for example, for depressing the order of a determinant may each of them be viewed as the result of repeated transformations of this kind, the operation being continued until all the elements of a row or column except one are replaced by zeros.

With these facts in view, it occurred to me about a year ago to test the possibility of transforming a general determinant so as to have zeros in every one of the positions held by them in SYLVESTER's continued-fraction determinant, viz., everywhere except in the principal diagonal and the two bordering minor diagonals. The transformations to which I was then led form the subject of the present short paper.

§ 2. Beginning with the determinant of the fourth order $|a_1b_2c_3d_4|$ we have as the result of a first transformation

$$|a_1b_2c_3d_4| = \begin{vmatrix} |a_1d_2| & |a_2d_3| & a_3 & a_4 \\ |b_1d_2| & |b_2d_3| & b_3 & b_4 \\ |c_1d_2| & |c_2d_3| & c_3 & c_4 \\ 0 & 0 & d_3 & d_4 \end{vmatrix} \div d_2d_3 \, ,$$

and multiplying each element of the first column here by $|c_2d_3|$ and diminishing the result by $|c_1d_2|$ times the corresponding element of the second column, we have

$$|a_1b_2c_3d_4| = \begin{vmatrix} d_2|a_1c_2d_3| & |a_2d_3| & a_3 & a_4 \\ d_2|b_1c_2d_3| & |b_2d_3| & b_3 & b_4 \\ 0 & |c_2d_3| & c_3 & c_4 \\ 0 & 0 & d_3 & d_4 \end{vmatrix} \div d_2d_3|c_2d_3| \, ,$$

where on one side of the principal diagonal the resulting determinant is of

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[*] Liouville's Journal, xiv. p. 26.

[†] Quart. Journ. of Math., viii. pp. 157–162.

the form desired. Operating in an exactly similar way on the other side, we at once obtain the kind of result which was hoped for, viz.,

$$(1)\qquad |a_1b_2c_3d_4| = \begin{vmatrix} |a_1c_2d_3| & |a_2d_3| & 0 & 0 \\ |b_1c_2d_3| & |b_2d_3| & |a_2b_3| & 0 \\ 0 & |c_2d_3| & |a_2c_3| & |a_2b_3c_4| \\ 0 & 0 & |a_2d_3| & |a_2b_3d_4| \end{vmatrix} \div |a_2b_3|\ |a_2d_3|\ |c_2d_3|,$$

the non-zero elements making their appearance as determinants in virtue of the well-known theorem

$$\begin{vmatrix} |x_\alpha z_\beta| & |x_\beta z_\gamma| \\ |y_\alpha z_\beta| & |y_\beta z_\gamma| \end{vmatrix} = z_\beta |x_\alpha y_\beta z_\gamma|.$$

For the case of the determinant of the fifth order the corresponding identity is

$$(1')\qquad |a_1b_2c_3d_4e_5| = \frac{\begin{vmatrix} |a_1c_2d_3e_4| & |a_2d_3e_4| & 0 & 0 & 0 \\ |b_1c_2d_3e_4| & |b_2d_3e_4| & |a_2b_3e_4| & 0 & 0 \\ 0 & |c_2d_3e_4| & |a_2c_3e_4| & |a_2b_3c_4| & 0 \\ 0 & 0 & |a_2d_3e_4| & |a_2b_3d_4| & |a_2b_3c_4d_5| \\ 0 & 0 & 0 & |a_2b_3c_4| & |a_2b_3c_4e_5| \end{vmatrix}}{|a_2b_3c_4|\ |a_2b_3e_4|\ |a_2d_3e_4|\ |c_2d_3e_4|}$$

the general law of formation of the right-hand member being contained in the following rule:—To obtain the first part, viz., the continuant, take the original determinant $|a_1b_2c_3 \ldots z_n|$; from the first column delete the elements which in a continuant are zeros, and replace them by zeros, writing all the deleted letters in order alongside each of the remaining elements of the column; treat the other columns in the same way; affix such suffixes to these added letters that the suffixes of the first column may be 1, 2, 3, . . . , $n-1$, of the last column 2, 3, 4, . . . , n, and of each of the intervening columns 2, 3, 4, . . . , $n-1$; enclose each set of suffixed letters in determinant brackets. To obtain the second part, viz., the divisor, take the product of all the elements of the continuant which border its principal diagonal, excepting those in the first and last columns, and rejecting duplicates.

§ 3. Let us now return to our first determinant $|a_1b_2c_3d_4|$. Multiplying each element of the fourth column by m_3 and diminishing the result by m_4 times the corresponding element of the third column, and treating the third and second columns in a similar manner, we have

$$|a_1b_2c_3d_4| = \begin{vmatrix} a_1 & |m_1a_2| & |m_2a_3| & |m_3a_4| \\ b_1 & |m_1b_2| & |m_2b_3| & |m_3b_4| \\ c_1 & |m_1c_2| & |m_2c_3| & |m_3c_4| \\ d_1 & |m_1d_2| & |m_2d_3| & |m_3d_4| \end{vmatrix} \div m_3m_2m_1\,,$$

and subjecting this new determinant to the set of operations to which $|a_1b_2c_3d_4|$ itself was subjected in § 2, we finally obtain

$$|a_1b_2c_3d_4| = \frac{\begin{vmatrix} |a_1c_2d_3| & |m_1a_2d_3| & 0 & 0 \\ |b_1c_2d_3| & |m_1b_2d_3| & |m_1a_2b_3| & 0 \\ 0 & |m_1c_2d_3| & |m_1a_2c_3| & |m_1a_2b_3c_4| \\ 0 & 0 & |m_1a_2d_3| & |m_1a_2b_3d_4| \end{vmatrix}}{|m_1a_2b_3|\;|m_1a_2d_3|\;|m_1c_2d_3|} \quad . \quad . \quad . \quad (2.)$$

A comparison of this with (1) brings out the fact that the right-hand member there is not altered if we change the elements of the last three columns, and the factors of the divisor, all into determinants of the third order by inserting an m_1 in each.

§ 4. Making use now of the Law of Complementaries we return to (1), and substitute for each determinant its complementary minor in $|a_1b_2c_3d_4|$. This gives us the new identity

$$|a_1b_4|\;|b_1c_4|\;|c_1d_4| = \begin{vmatrix} b_4 & |b_1c_4| & 0 & 0 \\ a_4 & |a_1c_4| & |c_1d_4| & 0 \\ 0 & |a_1b_4| & |b_1d_4| & d_1 \\ 0 & 0 & |b_1c_4| & c_1 \end{vmatrix} \quad . \quad . \quad . \quad . \quad (3)$$

a relation connecting only the elements

$$\begin{matrix} a_1b_1c_1d_1 \\ a_4b_4c_4d_4\,, \end{matrix}$$

so that as there are six pairs of these lines, we can at once write six identities like (3), and thence find by the Law of Complementaries six identities like (1).

The corresponding relation for two rows of *five* elements is

$$|a_1b_5|\ |b_1c_5|\ |c_1d_5|\ |d_1c_5| = \begin{vmatrix} b_5 & |b_1c_5| & 0 & 0 & 0 \\ a_5 & |a_1c_5| & |c_1d_5| & 0 & 0 \\ 0 & |a_1b_5| & |b_1d_5| & |d_1e_5| & 0 \\ 0 & 0 & |b_1c_5| & |c_1e_5| & e_1 \\ 0 & 0 & 0 & |c_1d_5| & d_1 \end{vmatrix} \quad . \quad . \quad . \quad (3')$$

and from this and (3) the general theorem is apparent.

Again, taking the complementary of (2) with respect to $|m_1a_2b_3c_4d_5|$, and, for the sake of comparison with (3), changing the suffixes 4, 5 into 1, 4 respectively, we have

$$m_4\ a_1b_4\ \ |b_1c_4|\ |c_1d_4| = \begin{vmatrix} |m_1b_4| & |b_1c_4| & 0 & 0 \\ |m_1a_4| & |a_1c_4| & |c_1d_4| & 0 \\ 0 & |a_1b_4| & |b_1d_4| & d_4 \\ 0 & 0 & |b_1c_4| & c_4 \end{vmatrix} \quad . \quad . \quad (4)$$

where the right-hand member differs from that of (3) only in the first and last columns.

§ 5. By taking the complementary of (3) with respect to $|a_1b_2c_3d_4|$ we should of course return to (1); by taking the complementary, however, with respect to $|a_1b_2c_3d_4e_5|$ (or $|a_1b_2c_3d_4e_5f_6 \ldots|$) we obtain a new result, viz.,

$$|a_1b_2c_3d_4e_5| = \frac{\begin{vmatrix} a_1c_2d_3e_5| & a_2d_3e_5| & 0 & 0 \\ |b_1c_2d_3e_5| & |b_2d_3e_5| & |a_2b_3c_5| & 0 \\ 0 & |c_2d_3c_5| & |a_2c_3c_5| & |a_2b_3c_4e_5| \\ 0 & 0 & |a_2d_3e_5| & |a_2b_3d_4e_5| \end{vmatrix}}{|a_2b_3e_5|\ |a_2d_3c_5|\ |c_2d_3e_5|} \quad . \quad . \quad (5)$$

which it is interesting to compare with both (1) and (1′).

§ 6. If in (2) we write b, c, d, e for a, b, c, d respectively, a for m, and 2, 3, 4, 5 for 1, 2, 3, 4 respectively, the left-hand member of (2) will be a principal minor of the left-hand member of (1′) and the first determinant on the right-hand of

(2) will be the corresponding minor of the first determinant on the right-hand of (1′); and from the two identities we shall have by division

$$\frac{|a_1b_2c_3d_4e_5|\;|c_2d_3c_4|}{|b_2c_3d_4e_5|}=\frac{\begin{vmatrix} |a_1c_2d_3c_4| & |a_2d_3e_4| & 0 & 0 & 0 \\ |b_1c_2d_3c_4| & |b_2d_3e_4| & |a_2b_3e_4| & 0 & 0 \\ 0 & |c_2d_3e_4| & |a_2c_3e_4| & |a_2b_3c_4| & 0 \\ 0 & 0 & |a_2d_3e_4| & |a_2b_3d_4| & |a_2b_3c_4d_5| \\ 0 & 0 & 0 & |a_2b_3e_4| & |a_2b_3c_4c_5| \end{vmatrix}}{\begin{vmatrix} |b_2d_3e_4| & |a_2b_3e_4| & 0 & 0 \\ |c_2d_3c_4| & |a_2c_3e_4| & |a_2b_3c_4| & 0 \\ 0 & |a_2d_3c_4| & |a_2b_3d_4| & |a_2b_3c_4d_5| \\ 0 & 0 & |a_2b_3c_4| & |a_2b_3c_4e_5| \end{vmatrix}}.$$

Changing the numerator and denominator on the right hand in accordance with the theorem of which

$$\begin{vmatrix} a & d & 0 \\ f & b & e \\ 0 & g & c \end{vmatrix}=\begin{vmatrix} a & -df & 0 \\ -1 & b & -cg \\ 0 & -1 & c \end{vmatrix}$$

is an example, we have by SYLVESTER'S fundamental theorem regarding the application of continuants*

$$\frac{|a_1b_2c_3d_4e_5|\;|c_2d_3e_4|}{|b_2c_3d_4c_5|}=|a_1c_2d_3c_4|-\cfrac{|a_2d_3c_4|\;|b_1c_2d_3c_4|}{|b_2d_3c_4|-\cfrac{|a_2b_3e_4|\;|c_2d_3c_4|}{|a_2c_3e_4|-\cfrac{|a_2b_3e_4|\;|a_2d_3e_4|}{|a_2b_3d_4|-\cfrac{|a_2b_3c_4d_5|\;|a_2b_3e_4|}{|a_2b_3c_4e_5|}}}} \quad . \quad . \quad . \quad . \qquad (6)$$

The corresponding identity for determinants of the next lower order is

$$\frac{|a_1b_2c_3d_4|\;|c_2d_3|}{|b_2c_3d_4|}=|a_1c_2d_3|-\cfrac{|a_2d_3|\;|b_1c_2d_3|}{|b_2d_3|-\cfrac{|a_2b_3|\;|c_2d_3|}{|a_2c_3|-\cfrac{|a_2b_3c_4|\;|a_2d_3|}{|a_2b_3d_4|}}} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (6')$$

The general theorem is readily formulated by attending to the rule given in § 2 for forming the continuant in (1) and (1′).

§ 7. If in (4) we write b, c, d, e for a, b, c, d respectively, a for m, and 5, 1

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* Phil. Mag., 4th ser., vol. v. pp. 446–456.

for 1, 4 respectively, and then proceed with (3′) and (4), as we have just done with (1′) and (2), we find

$$\frac{|a_1b_5|}{a_1} = |a_1c_5| - \cfrac{|c_1d_5|\;|a_1b_5|}{|b_1d_5| - \cfrac{|d_1e_5|\;|b_1c_5|}{|c_1c_5| - \cfrac{e_1|c_1d_5|}{d_1}}} \quad . \quad . \quad . \quad (7)$$

This is the complementary of (6), and might so have been obtained. As it is easily verified, we can therefore readily have by means of it a verification of the more important theorem with which it is related.

§ 8. In the continuants of §§ 2–5 the zeros were introduced by operating only with rows upon rows, or with columns upon columns. If now, however, we introduce those on the one side of the principal diagonal by operating with rows upon rows, and those on the other side by operating with columns upon columns, we obtain a result quite distinct in character, and not less interesting, viz., we have

$$|a_1b_2c_3d_4f_5| = \frac{\begin{vmatrix} y_1 & x_1 & 0 & 0 & 0 \\ z_1 & y_2 & x_2 & 0 & 0 \\ 0 & z_2 & y_3 & x_3 & 0 \\ 0 & 0 & z_3 & y_4 & x_4 \\ 0 & 0 & 0 & z_4 & y_5 \end{vmatrix}}{a_2\;|a_2b_3|\;|a_2b_3c_4|\;b_1\;|b_1c_2|\;|b_1c_2d_3|} \quad . \quad . \quad . \quad . \quad (8)$$

where

$x_1 = a_2$, $\qquad z_1 = b_1$,

$x_2 = |a_2b_3|$, $\qquad z_2 = |b_1c_2|$,

$x_3 = b_1\;|a_2b_3c_4|$, $\qquad z_3 = a_2\;|b_1c_2d_3|$,

$x_4 = |b_1c_2|\;|a_2b_3c_4d_5|$, $\qquad z_4 = |a_2b_3|\;|b_1c_2d_3f_4|$,

and

$y_1 = a_1$,

$y_2 = b_2$,

$y_3 = a_2|b_1c_3| - a_3|b_1c_2|$,

$y_4 = |a_2b_3|\;|b_1c_2d_4| - |a_2b_4|\;|b_1c_2d_3|$,

$y_5 = |a_2b_3c_4|\;|b_1c_2d_3f_5| - |a_2b_3c_5|\;|b_1c_2d_3f_4|$.

The process of transformation is not given, because to do so would unnecessarily lengthen the paper; the reader, however, will find it worthy of attention, one or two little-known identities turning up in the course of it.

The corresponding expression for $|a_1b_2c_3d_4|$ is got by merely deleting the last row and column of the numerator, and the last two factors of the denominator.

The theorem related to (8), as (2), or rather that form of (2) used in § 6, is related to (1′), is

$$|b_2c_3d_4f_5| = \frac{\begin{vmatrix} y_2 & x_2 & 0 & 0 \\ z_2 & y_3 & x_3 & 0 \\ 0 & z_3 & y_4 & x_4 \\ 0 & 0 & z_4 & y_5 \end{vmatrix}}{a_2\ |a_2b_3|\ |a_2b_3c_4|\ b_1\ |b_1c_2|\ |b_1c_2d_3|} \quad . \quad . \quad . \quad . \qquad (9)$$

where $x_2, y_2, z_2, \ldots$ have the same signification as before. This may be obtained after the manner of (8), but (8) having been proved, (9) at once follows as the result of differentiation with respect to a_1.

From (8) and (9), by division, there comes

$$\frac{|a_1b_2c_3d_4f_5|}{|b_2c_3d_4f_5|} = y_1 - \cfrac{x_1z_1}{y_2 - \cfrac{x_2z_2}{y_3 - \cfrac{x_3z_3}{y_4 - \cfrac{x_4z_4}{y_5}}}} \quad . \quad . \quad . \quad . \qquad (10)$$

an identity more notable than those of like kind previously given.

§ 9. The result of taking the complementary of (8) is peculiar, the left-hand member remaining unchanged. We thus obtain still another expression for $|a_1b_2c_3d_4f_5|$, which would not readily have been lit upon otherwise, viz.,

$$|a_1b_2c_3d_4f_5| = \frac{\begin{vmatrix} \eta_1 & \xi_1 & 0 & 0 & 0 \\ \zeta_1 & \eta_2 & \xi_2 & 0 & 0 \\ 0 & \zeta_2 & \eta_3 & \xi_3 & 0 \\ 0 & 0 & \zeta_3 & \eta_4 & \xi_4 \\ 0 & 0 & 0 & \zeta_4 & \eta_5 \end{vmatrix}}{|d_1f_5|\ |a_4f_5|\ |c_1d_4f_5|\ |a_3d_4f_5|\ |a_2c_3d_4f_5|\ |b_1c_3d_4f_5|} \quad . \quad . \qquad (11)$$

where

$\xi_1=|b_1c_3d_4f_5|$, $\qquad \zeta_1=|a_2c_3d_4f_5|$,
$\xi_2=|c_1d_4f_5|\ |a_1b_2c_3d_4f_5|$, $\qquad \zeta_2=|a_3d_4f_5|$,
$\xi_3=|a_2c_3d_4f_5|\ |d_1f_5|$, $\qquad \zeta_3=|b_1c_3d_4f_5|\ |a_4f_5|$,
$\xi_4=|a_3d_4f_5|\ f_1$, $\qquad \zeta_4=|c_1d_4f_5|\ a_5$,

and

$\eta_1=|b_2c_3d_4f_5|$,
$\eta_2=|a_1c_3d_4f_5|$,
$\eta_3=|b_1c_3d_4f_5|\ |b_2d_4f_5|-|b_1c_2d_4f_5|\ |a_3d_4f_5|$,
$\eta_4=|c_1d_4f_5|\ |a_3f_5|-|c_1d_3f_5|\ |a_4f_5|$,
$\eta_5=|d_1f_5|a_4-|d_1f_4|a_5$.

Taking the complementary of (9) we have

$$a_1 = \frac{\begin{vmatrix} \eta_2 & \xi_2 & 0 & 0 \\ \zeta_2 & \eta_3 & \xi_3 & 0 \\ 0 & \zeta_3 & \eta_4 & \xi_4 \\ 0 & 0 & \zeta_4 & \eta_5 \end{vmatrix}}{|d_1 f_5|\ |a_4 f_5|\ |c_1 d_4 f_5|\ |a_3 d_4 f_5|\ |a_2 c_3 d_4 f_5|\ |b_1 c_3 d_4 f_5|} \quad . \quad . \quad . \quad (12)$$

and thus again, by division, there comes

$$\frac{|a_1 b_2 c_3 d_4 f_5|}{a_1} = \eta_1 - \cfrac{\xi_1\zeta_1}{\eta_2 - \cfrac{\xi_2\zeta_2}{\eta_3 - \cfrac{\xi_3\zeta_3}{\eta_4 - \cfrac{\xi_4\zeta_4}{\eta_5}}}} \quad . \quad . \quad . \quad (13)$$

—the complementary of (10).

If the values of the ξ's and ζ's be compared, it will be seen that there is something abnormal in the second line. This is not due to an error; the factor $|a_1 b_2 c_3 d_4 f_5|$ must appear in one of the two elements ξ_2, ζ_2, and may appear in either, but not in both.

§ 10. In (10) we have a continued fraction found as an expression for the quotient of a determinant by a differential coefficient of it with respect to one of the elements. This was obtained from the two distinct theorems, (8) and (9), by division, &c. Owing, however, to a peculiarity of (8), we do not need the assistance of (9) to obtain such a result. Taking, instead, the identity corresponding to (8) for the case of the determinant $|a_1 b_2 c_3 d_4|$, we have from it and (8), by division,

$$\frac{|a_1 b_2 c_3 d_4 f_5|\ |a_2 b_3 c_4|\ |b_1 c_2 d_3|}{|a_1 b_2 c_3 d_4|} = \begin{vmatrix} y_1 & x_1 & 0 & 0 & 0 \\ z_1 & y_2 & x_2 & 0 & 0 \\ 0 & z_2 & y_3 & x_3 & 0 \\ 0 & 0 & z_3 & y_4 & x_4 \\ 0 & 0 & 0 & z_4 & y_5 \end{vmatrix} : \begin{vmatrix} y_1 & x_1 & 0 & 0 \\ z_1 & y_2 & x_2 & 0 \\ 0 & z_2 & y_3 & x_3 \\ 0 & 0 & z_3 & y_4 \end{vmatrix}$$

and, continuants being unaltered in substance by having the order of the elements in their diagonals reversed, there thus results

$$\frac{|a_1 b_2 c_3 d_4 f_5|\ |a_2 b_3 c_4|\ |b_1 c_2 d_3|}{|a_1 b_2 c_3 d_4|} = y_5 - \cfrac{x_4 z_4}{y_4 - \cfrac{x_3 z_3}{y_3 - \cfrac{x_2 z_2}{y_2 - \cfrac{x_1 z_1}{y_1}}}} \quad . \quad . \quad . \quad . \quad (14)$$

There is evidently no theorem corresponding to (6) or (7), as this corresponds to (10), the continuants employed in finding the former having a symmetry with respect to *both* diagonals.

Note on Mr MUIR'S *Transformation of a Determinant into a Continuant.*

By Professor CHRYSTAL.

(Read 21st February 1881.)

I. The following way of arriving at some of Mr MUIR'S elegant theorems may be of some interest:—

Consider the system of equations,

$$\left.\begin{array}{l}(11)x_1+(12)x_2+\ \ldots\ +(1n)x_n=0\,,\\(21)x_1+(22)x_2+\ \ldots\ +(2n)x_n=0\,,\\\ldots\ldots\ldots\ldots\ldots\ldots\\(n1)x_1+(n2)x_2+\ \ldots\ +(nn)x_n=1\,,\end{array}\right\}\quad .\quad .\quad .\quad .\quad .\quad (1),$$

the left hand sides being zero in all but the last. Let Δ be the determinant of this system.

From the first $n-1$ of these equations we can eliminate all the variables but x_1 and x_2 in one way; and all but x_{r-1}, x_r, and x_{r+1} in $n-1$ ways; also from all the n equations (*i.e.*, from any $n-1$ of them, the last being always included) all the variables but x_{n-1} and x_n in $n-1$ ways. We thus get

$$\left.\begin{array}{ll}E_1x_1+F_1x_2 & =0\\D_2x_1+E_2x_2+F_2x_3 & =0\\\ldots\ldots & \\D_rx_{r-1}+E_rx_r+F_rx_{r+1} & =0\\\ldots\ldots\ldots & \\D_nx_{n-1}+E_nx_n=F_n & \end{array}\right\}\quad .\quad .\quad .\quad .\quad (2).$$

Where the determinants D, E, F are derived from Δ as follows, by omitting

In	Columns.	Rows.	
E_1	2d	n^{th}	
F_1	1st	n^{th}	
D_r	r^{th} and $\overline{r-1}\|^{th}$	s^{th} and n^{th}	s is any number common to these three except n
E_r	$\overline{r-1}\|^{th}$ and $\overline{r+1}\|^{th}$	s^{th} and n^{th}	
F_r	r^{th} and $\overline{r-1}\|^{th}$	s^{th} and n^{th}	
D_n	n^{th}	t^{th}	t is any number common to these three except n
E_n	$\overline{n-1}\|^{th}$	t^{th}	
F_n	n^{th} and $\overline{n-1}\|^{th}$	t^{th} and n^{th}	

Solving now the second set of equations, we get

$$x_1 \begin{vmatrix} E_1 & F_1 & & & & \\ D_2 & E_2 & F_2 & & & \\ & D_3 & E_3 & F_3 & & \\ & & \ddots & & & \\ & & & D_{n-1} & E_{n-1} & F_{n-1} \\ & & & & D_n & E_n \end{vmatrix} = \begin{vmatrix} 0 & F_1 & & & \\ 0 & E_2 & F_2 & & \\ 0 & D_3 & E_3 & F_3 & \\ \hline & & & & \\ F_n & 0 & 0 & 0 & \dots \end{vmatrix}$$

$$= (-1)^n F_1 F_2 \dots F_{n-1} F_n ;$$

but from the first set

$$x_1 \Delta = (-1)^n F_1 .$$

Hence

$$\Delta = \frac{\begin{pmatrix} F_1 & F_2 & F_3 \dots & F_n \\ E_1 & E_2 & \dots & E_n \\ D_2 & D_3 & \dots & D_n \end{pmatrix}}{F_2 \ F_3 \dots F_{n-1} \ F_n} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3) ;$$

where it is to be noticed that every row of the continuant except the first contains an index susceptible of $n-1$ different values.

By giving these indices the proper values, we get, as particular cases, Mr MUIR's formulæ (1), (1′) and (5).

By solving for x_n, we get at once a result like that of Mr MUIR in § 6.

II. The above may be generalised as follows :—

Noticing that every one of the equations in set (2), except the first, is susceptible of $n-1$ different forms, and multiplying each of these by one of the arbitrary quantities $m_{r1}\ m_{r2} \dots m_{r\,n-1}$, we get, by addition, in each case a new equation. Hence (writing also for uniformity's sake $e_1\, f_1$ for E_1 and F_1), we get the new set

$$\left.\begin{array}{r} e_1 x_1 + f_1 x_2 \qquad\qquad\qquad = 0 \\ \dots \qquad\qquad\qquad\qquad \\ d_r x_{r-1} + e_r x_r + f_r x_{r+1} = 0 \\ \dots \qquad\quad \\ d_n x_{n-1} + e_n x_n = f_n \end{array}\right\} \quad . \quad . \quad . \quad . \quad . \quad (4).$$

Whence, as before,

$$\Delta = \frac{\begin{pmatrix} f & f_2 \dots & f_{n-1} \\ e & e_2 & e \\ d_1 & d_2 & d_n \end{pmatrix}}{f_2 f_3 \dots f_n \ f_n} \quad . \quad . \quad . \quad . \quad (5) ;$$

where $e_1\, f_1$ are the same as $E_1\, F_1$; but $d_r\, e_r\, f_r$ now omit only the n^{th} row, and have each an additional first column m_r , $m_r \dots m_{r\,n-}$.

It is to be observed that in each of the rows of the continuant we have a *different* set of $n-1$ arbitrary quantities. The identity (5) is therefore one of considerable generality. It gives Mr MUIR's identity (2) as a particular case.

III.—*Report on Fossil Fishes collected by the Geological Survey of Scotland in Eskdale and Liddesdale.* Part I.—*Ganoidei.* By Ramsay H. Traquair, M.D., F.R.S., Keeper of the Natural History Collection in the Museum of Science and Art, Edinburgh. (Plates I.–VI.)

(Read 19th July 1880.)

INTRODUCTION.

I am indebted to the kindness of Professor Ramsay, Director-General, and of Professor Geikie, Director of the Scottish Branch of the Geological Survey of Great Britain, for the privilege of examining and describing a remarkable collection of fossil fish-remains from the Lower Carboniferous rocks (Calciferous Sandstone Series) of Eskdale and Liddesdale. Most of the specimens were collected by Mr Arthur Macconochie, one of the collectors attached to the Scottish Geological Survey; and Mr Walter Park of Brooklyn Cottage, Langholm, has also willingly co-operated in the search, so far as the district of Eskdale is concerned. I have myself also had the pleasure of twice visiting Eskdale, along with Mr Macconochie and Mr B. N. Peach, and on these occasions I obtained a few specimens for my own collection.

This collection is of the greatest possible interest, both from a geological and from a zoological point of view—both as opening up to us an almost entirely new Scottish Carboniferous fish-fauna, as well as from the purely zoological interest attaching to the structural peculiarities of many of the new forms themselves. My own business with these fossils is, of course, entirely as a zoologist.

The fish-remains which have occurred in these strata are referable to the orders of Ganoidei, Dipnoi, and Selachii, of which only the first will be considered in this instalment of the report, while a second part will be devoted to the enumeration and description of those belonging to the two remaining Orders.

The following is a list of the genera and species of Ganoids which have occurred, an asterisk being prefixed to the names of those species which are here described as new :—

		Eskdale.	Liddesdale.
	ACANTHODIDÆ.		
1	*Acanthodes*, sp.	+	
	RHIZODONTIDÆ.		
2	*Strepsodus sauroides*, Binney, sp.	+	+
3	*Archichthys Portlockii*, Ag.	?	+
	SAURODIPTERIDÆ.		
4	*Megalichthys*, sp.	+	+
	CŒLACANTHIDÆ.		
5	*Cœlacanthus lepturus*, Ag.		+
6	* *Huxleyi*, Traq.	+	
	PALÆONISCIDÆ.		
7	**Elonichthys serratus*, Traq.	+	
8	* *pulcherrimus*, Traq.	+	
9	*Rhadinichthys Geikiei*, Traq.	+	
10	* *delicatulus*	+	
11	* *Macconochii*, Traq.	+	
12	* *tuberculatus*, Traq.	+	
13	* *angustulus*, Traq.	+	
14	* *fusiformis*, Traq.	+	
15	**Cycloptychius concentricus*, Traq.	+	
16	**Phanerosteon mirabile*, Traq.	+	
17	**Holurus Parki*, Traq.	+	
18	* *fulcratus*, Traq.	+	
19	**Canobius Ramsayi*, Traq.	+	
20	* *elegantulus*, Traq.	+	
21	* *pulchellus*, Traq.	+	
22	* *politus*, Traq.	+	
	PLATYSOMIDÆ.		
23	*Eurynotus crenatus*, Ag.		+
24	* *? aprion*, Traq.		+
25	*Wardichthys? cyclosoma*, Traq.	+	+
26	**Cheirodopsis Geikiei*, Traq.	+	
27	**Platysomus superbus*, Traq.	+	
	TARRASIIDÆ.		
28	**Tarrasius problematicus*, Traq.	+	

Concerning the above list, there are three things which principally strike the attention,—

1. The occurrence of a large number of forms perfectly new to science. I have endeavoured most strenuously to avoid all undue multiplication of genera and species; indeed, I may have erred in the opposite direction; yet out of twenty-eight species of Ganoids occurring in these beds, at least twenty must be described as previously unknown. Of fourteen genera, five are new, namely, *Phanerosteon, Holurus, Canobius, Cheirodopsis,* and *Tarrasius,* while the last named genus is altogether so peculiar that I can find no place for it in any known family. Some amount of change in our notions of the definition and limits of the family Palæoniscidæ will also be necessary, if the genera *Holurus, Phanerosteon,* and *Canobius* are to remain where I have placed them.

2. The absence or paucity of forms characteristic of rocks of similar age on the northern side of the southern uplands of Scotland. There are no remains which can with certainty be referred to the genus *Rhizodus,* which in central Scotland occurs abundantly from the bottom of the cement-stone group upward through the Carboniferous Limestone series. The well-known *Eurynotus crenatus* of Mid-Lothian and Fifeshire is represented only by a few scales and bones from Liddisdale. And as regards the Palæoniscidæ, all are new save one, which I refer, not without doubt, to *Rhadinichthys Geikiei,* a species described by myself in 1877 from the Wardie shales of Colinton, near Edinburgh. Even the characteristic Cement-stone and Edge-coal type of the genus *Elonichthys,* that of *Elonichthys Robisoni,* is represented only by one rare species, *Elonichthys serratus,* and that also new.

3. The passing down into the Calciferous Sandstone Series of genera, hitherto known as characteristic of the Coal Measures or Upper Carboniferous series of rocks, although most of these have, it is true, occurred sparingly in the Carboniferous Limestone series. *Strepsodus, Cœlacanthus,* and *Platysomus* are best known to us as Coal Measure genera; and although fragmentary remains of them have been found also in rocks of the Scottish Carboniferous Limestone series, their appearance in the subjacent Calciferous Sandstones is now observed for the first time, while *Cycloptychius* has not hitherto occurred in any horizon below the Millstone Grit.

DESCRIPTION OF GENERA AND SPECIES.

Order GANOIDEI.

Suborder ACANTHODEI.

Family ACANTHODIDÆ.

Genus *Acanthodes*, Agassiz, 1833.

(Agassiz, Poissons Fossiles, vol. ii. p. 19.)

Several imperfect specimens of Acanthodes have occurred in the Eskdale beds, but in the present unsatisfactory state of our knowledge of the British Carboniferous members of this genus, it may be safer to leave them for the present undetermined as to species. It is to be hoped that ere long the accumulation of more material, from various, horizons and localities, will render practicable a satisfactory revision of the Acanthodidæ of the Carboniferous formation generally. Meanwhile, the want of sufficiently definite characters for the species already named renders the determination of specimens, especially when in a fragmentary condition, a matter of extreme doubt and uncertainty.

Suborder CROSSOPTERYGII.

Family RHIZODONTIDÆ.

Genus *Strepsodus* (Huxley), Young, 1866.

A tooth undistinguishable from those of *Strepsodus sauroides*, Binney sp., has occurred at Tweeden Burn in Liddisdale, and another at Glencartholm in Eskdale. To *Strepsodus* may also be referred some large thin cycloidal scales from Glencartholm, one of which measures 1¾ inch in diameter.

Strepsodus is of rare occurrence below the horizon of the Millstone Grit, and the present specimens occur lower down in the series than any which have hitherto been found. The remains of *Strepsodus sauroides* constitute, as is well known, abundant and characteristic fossils in the bituminous shales and cannel coals of the True Coal Measures both in England and Scotland.

Genus *Archichthys*, Hancock and Atthey, 1871.

Archichthys Portlockii, Ag. sp.

Holoptychius Portlockii, Agassiz, Poissons Fossiles, vol. i. pt. xxxvi.—name only.
„ „ Portlock, Geol. Rep. p. 464, pl. xiii. figs. 5–11.

M'Coy, in his "British Palæozoic Fossils," p. 613, states that he is quite certain "that the *Holoptychius Portlockii* (Ag.) of the fish beds at Cultra Holywood, near Belfast, and Draperstown, &c., are identical in all characters, both of the teeth and scales, with the *Holoptychius Hibberti (Rhizodus)* of the Burdiehouse and Gilmerton beds." However, in his list of synonyms of

Rhizodus Hibberti (ib. p. 612), he has given *Holoptychius Portlockii* with an appended query.

But an examination of the originals of Col. Portlock's figures from Maghera, Derry, now in the Museum of Practical Geology, Jermyn Street, reveals the unquestionable fact that they are not specifically identical with *Rhizodus Hibberti, nor even generically,* if the usual ideas as to the definition of *Rhizodus* are to be retained. The teeth are rounded or oval in transverse section, and devoid of the cutting edges characteristic of *Rhizodus;* the folds of the base are proportionally large and coarse, and the surface is covered with close and minute yet sharp vertical striæ, which fade away towards the apex as well as along the anterior aspect of the tooth. Now these are precisely the main external characters of the teeth from the Coal Measures first named by Messrs Hancock and Atthey *Archichthys sulcidens,*[*] and accordingly I have already (Proc. Roy. Soc. Edin. ix. 1878, p. 657) proposed to transfer "*Portlockii*" to the last named genus.

From Tweeden Burn, Liddisdale, there are two teeth which I cannot distinguish in essential characters from those of *Archichthys Portlockii* of the Irish Lower Carboniferous rocks. Of these the larger is broken, both at base and apex, but when entire would I think have measured 1$\frac{3}{8}$ inches in height. The transverse section is rounded; the base displays remains of coarse plications; the greater part of the surface as shown in the specimen is smooth, but the posterior aspect is strongly marked with the characteristic delicate striation. The other is half an inch in height by $\frac{3}{16}$ inch in long diameter at the base, which also shows remains of coarse plications; the transverse section is rounded, and the characteristic striæ extend over a proportionally larger extent of the surface than in the larger specimen. In fact, this smaller tooth is nearly the exact counterpart of one from Maghera in the Jermyn Street collection.

Associated with these teeth are numerous thin rounded scales, which probably belonged to the same fish, and which also, though smaller in size, closely resemble those of *Archichthys Portlockii* from Maghera. All of these have the outer surface attached to the matrix, and concealed, the inferior surface alone being exposed. But one scale from Tarras Water, Eskdale, shows some patches of the outer surface, and this is covered with minute granules arranged in closely set lines radiating from the centre. This scale I am also inclined to refer to *Archichthys Portlockii.*

I have as yet seen no evidence that any of the Rhizodont scales from either Liddesdale or Eskdale belong to *Rhizodus,* and undoubtedly no tooth referable to that genus has occurred.

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[*] "Note on an undescribed Fossil Fish from the Newsham Coal-shale near Newcastle-on-Tyne."—Nat. Hist. Trans. Northumb. and Durham, vol. iv. 1871, pp. 199–201.

Family SAURODIPTERIDÆ.

Genus *Megalichthys*, Agassiz.

(Agassiz, Poissons Fossiles, vol. ii. part 2, p. 89.)

Fragmentary remains, consisting both of scales and head plates, referable to the genus *Megalichthys*, have occurred both at Tweeden Burn and near Glencartholm. They are far too imperfect to justify any specific determination.

Family CŒLACANTHIDÆ.

Genus *Cœlacanthus*, Agassiz, 1843.

(Agassiz, Poissons Fossiles, vol. ii. pt. 2, p. 170; Huxley, Dec. Geol. Survey xii. 1866, p. 8.)

Cœlacanthus lepturus, Agassiz.

A few scales which I cannot distinguish from those of the common *Cœlacanthus lepturus* of the Coal Measures (Huxley, *op. cit.* pl. ii. figs. 3 and 4, pl. iii. fig. 1a), occur upon a bit of shale from Tweeden Burn, along with scales of *Eurynotus* and *Megalichthys*.

Cœlacanthus Huxleyi, sp. nov. Traquair.

Pl. I. figs. 1–4.

Among the specimens from Glencartholm, Eskdale, are five of a *Cœlacanthus*, which seems undoubtedly different from any hitherto described member of the genus. They are hardly so perfect as most of the smaller fishes from these rocks, and it will therefore be advisable to notice each of the specimens in succession.

No. 1 (fig. 2) is the most perfect as regards figure, but its details are considerably obscured by a thin and utterly irremovable layer of matrix which adheres to its surface. It shows a small fish $1\frac{1}{2}$ inch in length, and $\frac{1}{2}$ inch in depth at the first dorsal fin. The head, concerning whose structure nothing more can be said, save that it displays the general contour of that of a *Cœlacanthus*, is contained nearly four times in the total, the terminal appendage, or secondary caudal fin, being however absent. Both dorsal fins, as well as the principal caudal, are tolerably plainly exhibited, all showing the form and structure characteristic of the genus, but of the other fins there are no certain traces; and as to scales, only the merest "shadows," as it were, can be distinguished. The internal skeleton is also dimly visible, and from the crowded appearance of the vetebral spines it seems possible that the short stumpy contour of the fish is to some extent due to *post-mortem* shortening up. Interesting as this little specimen is, it is hardly possible to found much upon it beyond the generic diagnosis.

No. 2 is the posterior part of a fish $1\frac{1}{8}$ inch in length, being cut off just in front of the posterior dorsal fin, of which feeble traces are present. Behind this, the caudal vertebral apophyses, interspinous bones, and fin-rays are shown in a good state of preservation. Eighteen rays may be counted in the upper part of the caudal fin; not so many are seen in the lower part, but they are evidently not all preserved. No scales are shown.

No. 3 is a portion of a fish, deficient in all the fins save some traces of the anterior dorsal and of the ventral, and in all probability belonging originally to a specimen of about the same size as No. 2. The scales are pretty well shown, and these seem proportionally larger than in *Cœlacanthus lepturus;* they are ornamented with delicate ridges, which are proportionally *fewer* and *wider apart* than in the last named species, although they follow the same general arrangement in converging towards the middle line of the scale. The head is considerably crushed; two bones are, however, very distinctly seen, and demand special attention. One of these is the right operculum dislocated from its place, and thrust away to a position close above the cranial shield. It has the usual trigonal shape of the operculum of Cœlacanthus, but what is undoubtedly its *external surface* is *quite smooth,* and devoid of the close-ridged ornament found in *Cœlacanthus lepturus.* The other bone (fig. 3) is that which in *Cœlacanthus lepturus* has been determined by Messrs Hancock and Atthey as the largely developed angular element of the mandible, and this, instead of the fine close thread-like striation of the same bone in that species, is marked on its outer surface only by *four slightly oblique, comparatively coarse, and distant prominent ridges.*

No. 4 (fig. 1) is a very pretty specimen, showing as it does the vertebral apophyses and the remains of the ossified air-bladder with great distinctness. It is 3 inches in length, of which the head occupies $\frac{3}{4}$ inch. The bones of the *cranial roof* display the same *smoothness on their outer surfaces* as the operculum in No. 3, and some coarse ridges are seen on a fragment of the angular element of the mandible. Beneath the lower jaw is seen the impression of the internal surface of a jugular plate of a narrow form, its length being $\frac{1}{2}$ an inch, and its breadth hardly more than $\frac{1}{12}$. In the body twenty-four neural spines, bifurcated proximally, may be counted as far as the commencement of the hæmal spines; the bones of the caudal region are somewhat disturbed. Below the abdominal part of the vertebral axis the air-bladder is indicated by a black shining film; the scales agree in character with those of No. 3. The first dorsal, the principal caudal, and some remains of both ventrals, as well as of the pelvic bones, are exhibited, but do not call for special remark.

No. 5 is the somewhat distorted anterior part of a specimen which must have originally been of a larger size than any of the foregoing. It is chiefly remarkable for the clear and distinct manner in which the scale-markings are exhibited, and these consist of the same fine and comparatively distant ridges seen in the other specimens. Scarcely anything of the head remains, but a part of the anterior dorsal fin is present, its rays being, as usual, articulated towards their terminations.

Remarks.—As assuredly the above described *Cœlacanthus* cannot be identified with any Permian or Secondary species, and as the American Carboniferous species seem to be closely allied to *Cœlacanthus lepturus*, Ag., it is only necessary to compare it with the latter, and with *Cœlacanthus Phillipsii*, Ag., and *Cœlacanthus elongatus*, Huxley. Of these *Cœlacanthus Phillipsii* is founded upon a large tail from the Carboniferous rocks of Halifax, Yorkshire, and is well distinguished by its large rounded scales.* *Cœlacanthus elongatus*, from the Coal Measures of Ballyhedy, County Cork, Ireland, is described by Professor HUXLEY as having a more elongated head than the other species, and the impressions of the bones of the skull present "traces of a minutely granular or lineated sculpture."† *Cœlacanthus lepturus*, whose characters, external and internal, are best known to us, have the exposed surface of its scales extremely closely striated, while the external cranial bones are everywhere covered by a very well-marked ornamentation, consisting of close, fine, yet sharply defined wavy and tortuous ridges and granules, which we search for in vain on the skull of *Cœlacanthus Huxleyi*, where, on the other hand, the head bones are mostly smooth, or as in the case of the angular element of the mandible, marked only with a few comparatively coarse distant and prominent ridges.

I take the liberty of dedicating this species to Professor HUXLEY, to whose researches ichthyological science is so much indebted for a more correct insight into the definition and structure of the Cœlacanthidæ.

Suborder ACIPENSEROIDEI.

Family PALÆONISCIDÆ.

Genus *Elonichthys*, Giebel, 1848.

(Giebel, Fauna der Vorwelt, vol. i. pt. 3, p. 249; Traquair, Carboniferous Ganoids, p. 47; and Quar. Journ. Geol. Soc. London, vol. xxxiii. 1877, p. 553.)

Elonichthys serratus, sp. nov.

Pl. I. figs. 5–8.

Two specimens only of this interesting form are contained in the Survey Collection, and both are unfortunately not quite perfect. The larger (fig. 6) measures

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* Agassiz, Poissons Fossiles, vol. ii. pt. 2, p. 173.

† Huxley, Dec. Geol. Survey, vol. xii. p. 24.

3½ inches in length, but the extremities both of the head and of the upper lobe of the caudal fin being deficient, the total cannot have been less than 4 inches. The other (fig. 5), which wants the greater part of the head as well as of the caudal fin, represents a fish of slightly smaller dimensions, whose original length was probably 3½ inches.

The shape is fusiform, moderately deep between the head and dorsal fin, thence tapering gracefully towards the tail. Some remains of the cranial roof bones in the parietal region show a closely granulated external surface, while the facial bones and those of the shoulder girdle are ornamented with wavy sub-parallel ridges. The scales are somewhat small, and, as usual, diminish in size and increase in obliquity towards the tail. On the flank scales (fig. 7) the ornament consists in the first place of very delicate closely placed grooves or furrows, often interrupted and intercalated, their direction in the upper part of the area being more or less oblique from above downwards and backwards, while in the lower they become parallel with the inferior margin. Towards the posterior margin a number of coarser foldings or elevations of the surface make their appearance, and presently end in about half a dozen rather strongly marked marginal denticulations. It may be mentioned that the minute striation is much less obvious on the smaller than on the larger of the two specimens. Posteriorly (fig. 8), as the scales become smaller, the ridging and striation become less prominent, and reduced to a few longitudinal grooves and punctures, which finally disappear near the commencement of the caudal fin, while at the same time the denticulations of the posterior margin become also fewer in number, and likewise ultimately disappear. The variations in the form of the scales on different parts of the body are in accordance with what is found in *Elonichthys striolatus*, *Robisoni*, &c.

A considerable portion of the pectoral fin, the rays and their joints being however slightly dislocated, is preserved in the larger specimen, and affords sufficiently clear evidence that the principal rays of this fin were articulated up to their origins, the joints being rather longer than broad. A small ventral is shown in the other specimen. The dorsal fin is placed nearly opposite the interval between the ventrals and the anal; it is not of very large size, and is short-based, acuminate, high in front, and concavely excavated posteriorly; the anal, situated between the ventrals and the caudal, is similar in size and shape. Both of these fins have their rays divided by transverse articulations, for the most part rather distant, and their ganoid joints are marked by one or two longitudinal ridges and furrows, sometimes also a tendency to more minute striation is observable. Dichotomisation of the rays occurs towards their extremities. The caudal is deeply cleft; the lower lobe of moderate size; its rays, nearly quite smooth externally, are divided by distant articulations, which become, however, closer in the fringing rays of the upper lobe. Minute fulcra may be seen wherever the anterior margin of a fin is perfectly preserved.

Remarks.—The relative position, as well as the shape of the dorsal and anal fins, and the nature of the scale ornament, prove unmistakably that this little fish belongs to the group of species (*Elonichthys Robisoni, striolatus*, &c.), which is so characteristic of the Lower Carboniferous rocks of Scotland. Although the hitherto described species of this group are in many cases difficult to distinguish, yet, in all, the serration of the posterior margin of the flank scales is minute, in some (*Elonichthys tenuiserratus*, Traq.) excessively so; here, the comparatively coarse and prominent aspect of these serrations forms a tangible mark of distinction; the median fins are also proportionally smaller. So far as the present investigations go, the rare occurrence of representatives of the *Robisoni* group is certainly a remarkable feature in the palæontology of the Eskdale beds.

Position and Locality.—Near Glencartholm, Eskdale, in the Cement-stone group of the Calciferous Sandstone series.

Elonichthys pulcherrimus, sp. nov. Traquair.

Pl. I. figs. 9–12.

Of this there is only one specimen in which the posterior part of the ventral margin is unfortunately cut off by a joint, so that the anal and caudal fins are deficient, although the commencement of the caudal body-prolongation is preserved. The entire length exhibited is 4½ inches; when perfect the fish could not have measured less than 5½; its greatest depth at the arch of the back, just in front of the dorsal fin, is 1½ inch. The body is thus rather deeply fusiform, and the length of the head (1½ inch) is contained about five times in the estimated total. The cranial roof bones are covered with a small close tuberculation; the facial bones exhibit a ridged ornamentation. The lower margin of the maxilla is, however, tuberculated, and is set with strong, sharp, conical teeth of different sizes, large and small; one of the larger teeth measuring about $\frac{1}{16}$ inch in length. The dentary element of the mandible is ornamented with closely set ridges, mainly following the longitudinal direction of the bone, though also slightly divergent from back to front. The suspensorium is oblique and the gape wide, but the state of preservation of the specimen hardly allows of any further description of the bones of the head.

The scales are of moderate size, and over the whole body highly ornate. Their exposed area is covered with close, delicate, yet sharply defined ridges, which mostly proceed from before backwards and end in fine denticulations of the posterior margin. On the flank scales (fig. 10) these ridges tend to proceed obliquely downwards and backwards on the upper and posterior part of the area, while below this, on the antero-inferior part, their direction is more parallel with the inferior margin. Passing towards the caudal region (fig. 11), the ridges become less divisible into two sets, and are generally tolerably parallel with the upper and lower margins of the scale; they exhibit, moreover, a tendency to reticulation or anastomosis, till finally, on the small lozenge-shaped scales of the caudal body-prolongation the pattern assumes more of a punctured than of a striated aspect. The denticulation of the hind margin of the body-scales is persistent up to the tail pedicle. A few strong, broad, imbricating scales are seen in front of the dorsal fin, and the upper margin of the caudal body-prolongation is set with the usual median row of imbricating V scales, displaying a ridged ornamentation corresponding with that of the body scales.

The dorsal fin commences midway between the head and the probable origin of the caudal, and is triangular and acuminate in shape, with the posterior margin excavated. Not less than thirty rays are contained in it, these being rather delicate. dichotomising towards their extremities, and divided by transverse articulations, which are somewhat distant. Externally the rays are ganoid, and finely striated in the direction of their length (fig. 12); the anterior margin of the fin is set with fine fulcra. None of the other fins are preserved.

Remarks.—*Elonichthys pulcherrimus* evidently belongs to the same group of species as *Elonichthys Egertoni* of the British Coal Measures, and those originally described by GIEBEL (*Elonichthys Germari*, &c.), but it is so distinct in its short deep form and its beautiful scale ornamentation as to render detailed comparison unnecessary.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, near Glencartholm, Eskdale.

Genus *Rhadinichthys*, Traquair, 1877.

(Traquair, Quar. Journ. Geol. Soc. xxxiii. 1877, p. 558.)

Rhadinichthys Geikiei, Traquair.

Rhadinichthys Geikiei, Traquair, Proc. Roy. Soc. Edin. ix. 1877, p. 438.

Pl. I. figs. 13–18.

Description.—Length of a particularly fine and perfect specimen, 4¼ inches; less perfect examples, however, indicate that it often attained larger dimensions, and one in particular, judging from the size of the head, must have originally measured over 6 inches. The shape is elegantly fusiform and rather slender; the length of the head being rather greater than the depth of the body at the ventral fins, and contained about 4¼ times in the total.

The cranial roof bones are ornamented with closely set, well-defined elevated ridges, which, although wavy and sometimes contorted, mainly follow a longitudinal direction, especially on the parietal and frontal plates and the posterior part of the superethmoidal; they are often bifurcated, intercalated, and interrupted, and on the lateral parts of the cranial shield these interruptions often become so frequent as to cause the ornament to assume a somewhat tubercular character; in some specimens this condition invades even the more central parts. On the anterior part of the superethmoidal, which forms the usual projection over the mouth, the ridges are disposed transversely, or at right angles to those behind.

The direction of the suspensorium is very oblique, and the gape consequently wide. The opercular bones are well developed, and of the usual shape in this genus, but their external markings are not distinctly preserved. The maxilla has its broad portion ornamented with fine ridges, which run parallel with its superior and posterior margins; its infra-orbital process is tuberculated, and the tubercles are continued backwards as a narrow band along the entire inferior or dentary margin of the bone. The beautifully tapering mandible is covered externally with fine ridges, which pass forward from the angle in a somewhat radiating manner, so that below they are pretty parallel with the inferior margin, while above they cut the superior one at low angles. In large specimens these ridges break up into a minute tuberculation along the superior margin of the jaw—a condition rarely met with in the smaller examples. The orbit is anteriorly placed, and furnished with the usual arrangement of suborbital and circumorbital plates.

The bones of the shoulder girdle are ornamented with well-defined subparallel ridges, which are arranged according to the common pattern, namely, somewhat concentrically, and more or less parallel with the margins of the bones.

The scales are of moderate size, with narrow covered area, rhomboidal in shape, and increasing in obliquity, and diminishing in size towards the tail. On the flanks they are tolerably equilateral, but along the belly between the pectoral fins and the posterior part of the base of the anal, they suddenly become very low and narrow, their height diminishing to from $\frac{1}{2}$ to $\frac{1}{3}$ of their length. This change of form usually occurs at the fourth or fifth scale downwards from the lateral line. A few large scales are seen in front of the dorsal anal, and lower lobe of the caudal fin, and on the body-prolongation in the upper lobe of the latter the usual modifications of shape occur.

As regards the scale-markings, their general plan may be described as follows:—Taking a scale from the anterior part of the flank (figs. 15, 16), a few delicate grooves are seen passing down along the anterior margin of the ganoid area, which then turn round at the anterior inferior angle so as to become parallel with the inferior margin. The rest of the area presents, according to the size of the specimen, from 4 to 7 longitudinal elevations or feeble ridges running across the scale with a slight downward obliquity, as well as a slight tendency to radiation, and ending on as many sharp denticulations of the hinder margin. Towards the back and belly (fig. 18) both sets of markings tend to become confounded into one set of delicate, more or less diagonal ridges and grooves, and towards the tail (fig. 17) these markings usually fade away; a few punctures and longitudinal furrows being in most cases all that is to be seen on the scales behind the dorsal and anal fins. In different individuals, however, very considerable differences are found as regards the strength and prominence of the scale-markings. In some the markings are very distinctly and sharply defined (fig. 15), and the scales continue to be highly ornate up to the caudal body-prolongation, while in others (fig. 16) even those on the front part of the body are comparatively smooth, the middle of the scale being marked with a few short grooves, and the oblique ridges becoming apparent only towards the posterior margin; a reference to the figures will, however, give a better idea of the variations in the general aspect of the scale sculpture than any amount of description.

The pectoral fin is rather small, its length being hardly more than half that of the head; the larger rays on the præaxial aspect are unarticulated till towards their terminations. The ventrals are small and delicate, and not well exhibited in any of the specimens. The dorsal fin commences only very slightly in front of the anal, the two fins being thus placed nearly opposite each other; they are very similar in shape and structure, being moderate in size, acuminate, concavely cut out behind, and composed of delicate rays, which dichotomise towards their extremities, are distantly articulated, and having their brilliantly ganoid joints marked usually by a single sharp longitudinal furrow, though even this is sometimes wanting save near the origin of the fin. Between the anal fin and the commencement of the lower lobe of the caudal is an interval fully equal to the length of the base of the former. The caudal is also moderate in size, deeply bifurcated, and with a well-developed body-prolongation along the upper lobe; its rays partake of the same general appearance as those of the dorsal and anal, though their articulations are a little closer, and their surfaces usually quite smooth. Delicate fulcra are observable in the anterior margins of all the fins.

Var. *elegantulus* (Pl. II. figs. 1–5).—Length 2½ to 2¾ inches, elegantly fusiform, general proportions as in the foregoing, but the cranial roof bones are ornamented with closely set rounded ridges, which are proportionately somewhat coarser, and more contorted in their arrangement; in one very perfect specimen, in which the head bones are beautifully exhibited, the maxilla is destitute of tuberculation along its inferior margin. The markings on the scale are faint, those on the sides and belly being nearly smooth; their posterior margins display a few denticulations—4 to 5 on the largest flank scales, diminishing to 2 or 3 in those further back. The most remarkable feature in this form is, however, the very small development of the low narrow ventral scales, which are so conspicuous in the preceding. Such scales are indeed distinguishable along the ventral margin between the pectoral and anal fins, but on the other hand, in the abdominal region as many as eight scales may be counted down from the lateral line without any prominent change in form taking place.

Remarks.—This is by far the most common fish in the Eskdale beds, and from the comparatively large number of specimens before me, has admitted of a very full description, nevertheless there are difficulties in the way of its satisfactory determination as a species.

In 1877, I described, under the name of *Rhadinichthys Geikiei,* a small fish from the Wardie Shales near Colinton, Mid-Lothian, from specimens, which unfortunately were mostly fragmentary or distorted, save one very small one, which I considered to be a young individual of the species. These specimens, so far as they go, show a fish of much the same proportions as the above described form from Eskdale; the markings on the head bones, where visible, are very similar; so is the scale ornament, though perhaps the ridges are a little finer, and the denticulations of the posterior margin rather more numerous in proportion to the size of the scale. None of the larger specimens show the ventral region, save one, in which a similar arrangement of low narrow scales exists, though not so conspicuously, and the absence of this feature in the smaller examples is paralleled by the condition found in those from Eskdale, which I have felt obliged to consider only as young forms, or at most as a variety (*elegantulus*). On the whole, after most careful comparison of every scrap from both localities, I cannot find any very tangible or decisive mark of specific distinction, and therefore, although I may possibly be hereafter proved to be in error, I do not feel justified in separating the common *Rhadinichthys* of Eskdale from *Rhadinichthys Geikiei.*

Again, it is possible to point out scales on the flanks of many Eskdale specimens of *Rhadinichthys Geikiei* which are indistinguishable from those of the Coal Measure *Rhadinichthys monensis,* Egerton. This isolated fact, however, cannot prove the identity of the two species unless corroborated by the discovery of more perfect examples of *Rhadinichthys monensis,* which is as yet only known from scattered scales, and very fragmentary specimens indeed. What I have seen of the latter certainly inclines me to believe in the distinctness of the two forms, and the similarity of certain scales is of constant occurrence in closely allied species of Palæoniscidæ.

Position and Locality.—Near Glencartholm, Eskdale, in the Cement-stone group of the Calciferous Sandstone series.

Rhadinichthys delicatulus, sp. nov.

Pl. II. figs. 6–9.

Description.—Length from 1½ to 3¼ inches; shape and general proportions as in the last described species.

The bones of the head and shoulder girdle are externally sculptured with delicate ridges, which, although they follow the same general pattern as in *Rhadinichthys Geikiei*, show less tendency to contortion and interruption, and, except along the dentary margin of the maxilla, are nowhere seen to break up into tubercles. The scales (figs 8, 9) are proportionately thinner, and those of the front part of the body have their upper and lower margins rather straighter and more parallel with the long axis of the body, but the same arrangement of low narrow scales is seen along the belly. The vertical grooves along the anterior margin of the sculptured area of the scales are almost lost, nearly the whole surface being covered with minute sharp ridges and furrows, which, with the exception of one or two which run parallel with, and close to, the inferior margin, are directed rather diagonally across the scale from before backwards, ending on fine denticulations of the hinder border; sometimes two of these ridges ending on one denticulation. Finally, this delicate ornament is in most cases continued back to the scales of the tail pedicle itself. The fins are similar in position, shape, aud structure to those of *Rhadinichthys Geikiei*, but, comparing specimens of the same size, their rays seem to be rather more delicate, and more distantly articulated. One specimen (fig 6), the largest of the series, shows the strange phenomenon of the upper lobe of the caudal fin being neatly cut off and laid across the lower one.

Remarks.—*Rhadinichthys delicatulus* so closely resembles the preceding species in structure and proportions, that I was for long in great doubt as to whether it were not better to treat it as a mere variety, or perhaps, seeing that the specimens are mostly of small size, as a young form. But so far as the collection goes, the differences between the scale-markings of the two forms are so constant that it is always easy to point out the specimens referable to the one and to the other. Moreover, small specimens, both from Colinton and Eskdale, which I believe to be referable to the young of *Rhadinichthys Geikiei*, have the scales always comparatively smooth, whereas in *Rhadinichthys delicatulus*, the smaller the specimen, the more decided appears the distinctive pattern of the scale-markings. On these grounds I have decided to consider *Rhadinichthys delicatulus* as a "good species," in the sense in which that term is usually employed.

Position and Locality.—Near Glencartholm, Eskdale, in the Cement-stone group of the Calciferous Sandstone series.

Rhadinichthys Macconochii, sp. nov. Traquair.

Pl. II. figs. 12–16.

Description.—Length from 3 to 3½ inches; shape elegantly fusiform, the dorsal and ventral lines being gently and evenly curved. The length of the head is contained a little more than four times on the total, and is equal to the depth of the body midway between the pectoral and ventral fins.

The cranial roof bones are ornamented with *a close, comparatively coarse, and frequently confluent tuberculation;* the orbit is, as usual, anteriorly placed, and the ethmoid forms a projection over the mouth. The suspensorium is very oblique, and the gape correspondingly extensive. The maxilla is of the usual form, its broad portion being ornamented with closely set ridges, which run parallel with its superior and posterior margins; the beautifully tapering mandible is marked externally with ridges which pass from behind forwards in a slightly radiating manner, but which are also so frequently interrupted as to cause the ornament to assume *nearly as much of a tuberculated as of a striated aspect.* The operculum is of moderate size, rather broader below than above; the interoperculum is rather large; both of these plates are ornamented with prominent and proportionally coarse rugæ, which run mostly parallel with the lines of growth.

The bones of the shoulder girdle present nothing peculiar in form and arrangement, and are sculptured externally with ridges similar to those on the opercular bones.

The scales are of medium size, rhomboidal, as usual diminishing in size dorsally, ventrally, and posteriorly; they are low and narrow on the belly from the throat to the anal fin, while those of the front part of the lateral line are proportionally higher than the others. The scales of the middle line of the back are small until just in front of the dorsal fin, where a few of comparatively large size and imbricating arrangement are found. In one specimen 45 oblique dorso-ventral bands of scales may be counted from the shoulder girdle to the commencement of the lower lobe of the caudal fin. The scale ornament is sharpest on the scales above the lateral line, where it consists first of a few sharp grooves parallel with the anterior margin, and tending below to turn round along the inferior one, the rest of the area being occupied by two or three slightly prominent ridges, passing somewhat obliquely across towards the posterior margin, before reaching which they usually stop short, a prominent feature in this species being *that on no part of the body do the scales appear to be denticulated posteriorly.* Towards the tail the vertical furrows become imperceptible, or reduced to a single one. Below the lateral line the scale ornament is for the most part less marked, though similar in character, but towards the tail pedicle little or no difference is seen above and below.

The pectoral fin is scarcely more than half the length of the head; its principal rays are unarticulated till towards their terminations. The situation of the ventrals is indicated by a few stumps of rays at a point a little behind the middle point between the pectorals and the anal. The dorsal is situated far back, being nearly exactly opposite the anal; both of these fins are similar in appearance, being moderate in size, triangular, acuminate, and slightly cut out behind; their rays are of medium coarseness, smooth, dichotomising towards their extremities, and having their articulations somewhat distant. The caudal is well developed, heterocercal, deeply cleft, the rays similar in appearance to those of the dorsal and anal; in the lower lobe dichotomising towards their extremities, in the upper towards the middle. Traces of well developed fulcra are seen along the fin margins.

Remarks.—The position of the above described species in the genus *Rhadinichthys* is indicated by the structure of the pectoral fin, by the shape of the scales and the nature of their sculpture, and by its general form and proportions, although the dorsal fin is placed still further back than is usual in *Rhadinichthys*, its position being hardly if at all in advance of the anal. This latter character allies it to *Cycloptychius*, but the peculiar form of scale with the posterior inferior angle rounded off, and which constitutes one of the main diagnostic marks of the last named genus, is here absent. Its main specific characters—the tuberculation of the cranial shield, the peculiar sculpture of the mandible, and the non-denticulation of the posterior margins of the scales taken along with its size and proportions—are so exceedingly well marked, that it may at once be identified even from small fragments.

I have pleasure in naming this new species after Mr ARTHUR MACCONOCHIE, Fossil Collector to the Scottish Geological Survey, to whose industry in his department is due the discovery of the rich deposits of new fishes and crustacea in the Lower Carboniferous rocks of Eskdale and Liddisdale.

Position and Locality.—Near Glencartholm, Eskdale, in the Cement-stone group of the Calciferous Sandstone series.

Rhadinichthys tuberculatus, sp. nov. Traquair.

Pl. IV. figs. 1–3.

Description.—The length of the only entire specimen which has occurred, is 7 inches from the tip of the snout to the bifurcation of the caudal fin; the extremity of the upper lobe of the tail is not preserved, otherwise the total length of the fish would probably be, at least, 8½ inches. The length of the head is 2 inches, equalling the greatest depth of the body just in front of the ventral fins, and being contained little more than three times in the length of the specimen up to the bifurcation of the caudal, or more than four times in the estimated total. The depth of the tail pedicle is $\frac{3}{4}$ inch.

The head is much crushed, and its bones badly preserved, its structure is, however, clearly seen to be typically palæoniscoid, with very oblique suspensorium, anteriorly placed orbit, wide gape, and powerful jaws. The operculum seems somewhat long and narrow, the interoperculum square-shaped. No teeth are visible.

The bones of the head being almost everywhere seen only from their internal surfaces, their external ornamentation is but scantily exhibited. Evidences of a minutely tubercular sculpture, the tubercles being sometimes rounded, sometimes slightly elongated or confluent, are seen on the parietal and ethmoidal regions of the cranial roof as well as, in impression, on a small portion of the interoperculum. Towards the extremity of the mandible also, a patch of the outer surface of the bone is seen, but here the ornamentation consists of closely set delicate wavy ridges running in a longitudinal direction.

The bones of the shoulder girdle—supra-clavicular, clavicle, and infra-clavicular—are pretty well shown, the two latter from their internal aspects only. The outer surface of the supra-clavicular displays some traces of a longitudinal striated sculpture.

The scales are rather small for the size of the fish, especially at the tail, towards which region they rapidly diminish. In the flank scales (fig. 2) the covered area is narrow; the sculptured one presents a few fine ridges and grooves along the anterior margin, the rest of the space being covered with small closely set *tubercles*, sometimes rounded, sometimes elongated or confluent. Towards the tail (fig 3), and also towards the dorsal and ventrical margins, the tuberculations largely gives way to a ridged ornamentation; the ridges running parallel with the anterior and inferior margins, sometimes also with the superior, while the postero-central portion of the area is occupied by tubercles, tending to become confluent, with diagonal ridges which are a little coarser, and more wavy and irregular than the marginal ones already mentioned. Powerful longitudinally ridged V-scales protect the upper margin of the caudal body-prolongation, which is of great strength, and the acute lozenge-shaped scales which clothe its sides are of small size, arranged in many rows, and, so far as they are traceable, ornamented with sharp diagonal ridges.

On the attached surface of the body-scales, the vertical keel is rather delicate, yet very distinctly defined, as is also the socket for the reception of the articular spine of the scale next below; this spine, which is of moderate size, arising from the upper margin of the scale close behind the upper termination of the keel. As usual, spines and sockets disappear in the scales of the posterior part of the body. *No denticulations are observable on the posterior margins of any of the scales.*

The pectoral fin is $1\frac{1}{4}$ inch in length, and has its principal rays unarticulated for the greater part of their length. The origin of the ventral is situated $1\frac{5}{16}$ inch behind that of the pectoral; the fin itself is not in good preservation, its rays being much broken up, so that its shape and size are lost. The dorsal fin is situated nearly opposite the anal, arising opposite a point 4 inches back from the tip of the snout; this arises only a little behind the dorsal, and extends correspondingly farther back. Both of these fins are rather large, each measuring about an inch in length at the base and the same in height anteriorly, and the latter measurement would probably be somewhat greater were their larger rays preserved up to their extremities, which does not seem to be the case. They are also very similar in shape, being triangular and acuminate; their numerous and rather delicate rays have their transverse articulations somewhat distant, so that the joints are rather longer than broad; no sculpture is visible. The caudal is incompletely preserved, the extremities of both lobes being wanting, but enough is seen to show that it was powerfully developed, deeply cleft, and having a *body-prolongation of great strength* along the upper lobe; the rays are similar in character to those of the dorsal and anal. Well developed fulcra are seen in connection with the margins of the fins wherever these margins are preserved.

Remarks.—I have considered this strikingly new and beautiful Palæoniscid to be a *Rhadinichthys* on account of the structure of the pectoral, and the relative positions of the dorsal and anal fins, although the caudal body-prolongation is more powerfully developed than in the more typical members of the genus, such as *Rhadinichthys ornatissimus, Rhadinichthys carinatus*, &c., and although the epithet "slender fish" can hardly be applied to its proportions. Its large head, short, thick, fusiform body, peculiar ridged-tuberculate scale ornament, and non-denticulated scales, with other peculiarities which need not be recapitulated, form an assemblage of specific characters which collectively are so novel that no detailed comparison with any other species is necessary.

Position and Locality.—Near Glencartholm, Eskdale, in the Cement-stone group of the Calciferous Sandstone series.

Rhadinichthys (?) *angustulus*, sp. nov. Traquair.

Pl. II. figs. 10, 11.

Two specimens only of this interesting and somewhat doubtful form have occurred, one of which, the larger and less perfect, measures $2\frac{1}{4}$ inches in length, while the other more perfect example attains a length of only $1\frac{1}{2}$ inch. The length of the head is equal to about $\frac{1}{4}$ of the total; the greatest depth of the body is at the shoulder, and is contained about six times in the entire length of the fish, while it is not so much as twice the depth of the tail pedicle, the dorsal and ventral margins being nearly straight. The general contour is therefore peculiarly short and straight, and wanting in the usual more or less fusiform outline, while the tail pedicle is of great proportional depth.

All that can be said of the head is that it is typically palæoniscoid in structure, with oblique suspensorium, &c., and that some traces of a minute ridged ornament are seen on some of its delicate bones, *e.g.*, the mandible. The body-scales (fig. 11) are of moderate dimensions in proportion to the size of the fish, and are marked each with three or four delicate, yet sharply-defined and somewhat distant ridges, which run right across from before backwards, parallel with the superior and inferior margins; on the minute lozenge-shaped scales of the caudal body-prolongation these ridges, now excessively fine, are diagonal in position; the V-scales of the tail are proportionally largely developed.

The pectoral and ventral fins are small, the dorsal and anal nearly opposite, though the former arises a little in advance of the latter. The two last named fins resemble each other in their triangular-acuminate contour; the caudal is not completely preserved, but its appearance seems to indicate that it was bifurcated in the usual manner. The fins are preserved only in the smaller of the two specimens, and their rays are so excessively delicate that it is impossible to describe their articulations, but they are closely set, and appear to bifurcate towards their extremities.

Remarks.—On account of its general structure, so far as can be made out, along with the form and position of the fins, this strange little fish is referable, at least provisionally, to the genus *Rhadinichthys.* Its prominent specific characters are its large head, short straight body, deep tail pedicle, and the scale sculpture consisting of a few delicate, straight, non-bifurcating longitudinal ridges. The scale ornament of *Rhadinichthys Grossarti*, Traq.,* another very small species from the Coal Measures of Lanarkshire, also consists of straight ridges, but these are more or less oblique in their direction, besides being closer and more numerous, while the shape of the fish, with its narrow elongated tail pedicle, forms a character at once distinguishing it from the form before us.

Position and Locality.—Near Glencartholm, Eskdale, in the Cementstone group of the Calciferous Sandstone series.

Rhadinichthys (?) *fusiformis*, sp. nov. Traquair.

Pl. III. figs. 1–5.

Description.—Length of an entire specimen, 6½ inches; shape elegantly fusiform; length of the head equal to the greatest depth of the body between the shoulder and dorsal fin, and contained 4¾ times in the total, 3½ times up to the bifurcation of the caudal fin. The dorsal fin is placed far back, so as to be nearly opposite the anal; the caudal is very heterocercal and inequilobate,

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* Proc. Roy. Phys. Soc. Edin. vol. iv. pt. 3, 1878, pp. 237–245.

the length of the upper lobe, from a point opposite the commencement of the rays of the lower one, being $2\frac{3}{8}$ inches. These proportions are taken from a very perfect and undistorted specimen, whose entire length is $6\frac{1}{2}$ inches; none of the others are quite perfect or free from distortion, though the peculiar characters of the fish are such as to enable it to be easily recognised even from small fragments.

The head is typically palæoniscoid in structure, with oblique suspensorium, wide gape, ethmoidal prominence, and anteriorly placed orbit. The cranial roof bones are ornamented with closely set irregularly contorted rugæ, frequently interrupted, so as at times to pass into tubercles. The operculum is narrow and oblong, the interoperculum, as usual, short and quadrate; these plates are in all cases ill preserved, so that little can be said of their external sculpture, save that it seems to be of a striated character. The maxilla is of the usual palæoniscoid shape, and has its broad postorbital portion covered with wavy and contorted ridges, which in most instances pass into a narrow band of irregularly shaped tubercles stretching along the dentary margin. The mandible is very stout, its depth posteriorly equalling $\frac{2}{7}$ of its length, in shape it rapidly tapers towards the symphysis. Externally it is covered with closely set, slightly wavy ridges, which, running from behind forwards, diverge from each other along a longitudinal line placed rather below the middle of the bone, on whose upper and lower margins they obliquely impinge, but the striæ forming the lower side of this somewhat feather-like pattern are much more horizontal in direction than those on the upper. The jaws are armed with conical teeth of two sizes, large ones being placed at short intervals inside a row of minute external teeth.

The bones of the shoulder girdle are striated with tolerably coarse wavy ridges, which on the upper or vertical part of the clavicle are again fretted with minute transverse indentations.

The scales of the body are of moderate size, rhomboidal, and tolerably thick. On the front part of the flank (figs. 2,3) they are tolerably equilateral, with slightly concave upper and convex lower margin; the covered area is very narrow, the articular spine moderate in size, and the keel of the attached surface only slightly developed. Towards the tail (fig. 5) and along the back the scales become smaller and more oblique, and in front of the dorsal fin there are four or five imbricating median scales of a larger size. Along the belly (fig. 4) they become very low and narrow, and on the caudal body-prolongation, as usual, small and acutely lozenge-shaped, while imbricating V-scales clothe the upper margin of this part. The scales are marked externally by a very ornate and easily recognised sculpture, though it is excessively difficult by means of words to give anything like an adequate description of its peculiarities. It consists of sharp furrows or grooves, sometimes interrupted and intercalated, some of which run parallel with the anterior and inferior margins, while others run more or less diagonally across the remaining portion of the sculptured area. According to the flatness or elevation of the interspaces between these furrows, a greater or less appearance of ridging is produced in different specimens, and in all the ridged appearance is pretty strongly developed in the scales of the back between the dorsal fin and the occiput. The ornament becomes less sharp posteriorly, but nevertheless it is developed to a greater or less extent even on the scales of the caudal body-prolongation. Some amount of a tolerably coarse denticulation is also observable, especially on the flank-scales, and, as very commonly happens, disappearing towards the tail and the margin of the body.

The pectoral fin is tolerably preserved only in one specimen, and is acuminate in shape; its length equals about $\frac{3}{4}$ that of the head. So far as can be made out by careful examination with a good lens, its principal rays seem to be articulated up to very near their origins,—a feature which is certainly at variance with the characters of the genus *Rhadinichthys*, hence the query which I have appended above. The ventral fin, situated between the pectoral and anal, is ill preserved; it seems however to have been small, with its rays moderately closely articulated, and fretted with a striated pattern. The dorsal fin is placed behind the arch of the back, its anterior commencement being only very slightly in front of that of the nearly opposed anal; it is moderate in size, acutely triangular-acuminate in shape, the extent of its base measuring only about half that of its height in front. Its rays are about 30 in number, delicate, bifurcating towards their extremities, their joints longer than broad, but becoming shorter distally, and in the hindermost rays; they are externally smooth, or with a single longitudinal furrow. The anal is not so well preserved in any of the specimens, but is apparently of the same form and structure as the dorsal. The caudal is powerful, deeply cleft, and inequilobate, the upper lobe being nearly twice as long as the lower; its rays are delicate, smooth, dichotomising towards their extremities, and divided by tolerably distant transverse articulations. The anterior margins of all the fins are minutely fulcrated.

Remarks.—The characteristic features of the above described beautiful Palæoniscid are so distinct and so novel, that we are fortunately free from any troublesome doubts and questions as to species, for even although the scale markings may show some amount of individual variation as to the strength and sharpness, it is, as already stated, easy to pick out its fragmentary remains and place them together as belonging to one well-defined form. Superficially it reminds us of the well known and typical *Rhadinichthys ornatissimus* of the Lower Carboniferous rocks of Central Scotland, but the differences in scale-sculpture and general proportions come into such strong relief the moment a critical examination is entered into that a detailed comparison is quite unnecessary. Indeed, the structure of the pectoral fin seems to forbid its being placed in the genus *Rhadinichthys* at all, for that member, so far as can be seen, has its rays articulated as in the species of *Elonichthys* of the "*Robisoni*" type, from which it is however excluded by the backward position of the dorsal fin. However, rather than hastily to proceed to the creation of a new genus upon that character alone, I have placed it provisionally in *Rhadinichthys*, which it certainly resembles more than any other in general contour.

Genus *Cycloptychius* (Huxley), Young, 1865.

(Young, British Assoc. Reports, 1865, vol. xxxv. p. 318; Traquair, Geol. Mag. Decade II. vol. i. No. 6, June 1874).

Cycloptychius concentricus, sp. nov., Traquair.

Pl. II. figs. 17–20.

Description.—The largest specimen attains a length of 4¾ inches, if we allow for a small portion of the front of the head which is broken off. The length of the head is contained about 5 times, the greatest depth of the body 6½ times, in the estimated total, up to the extreme end of the upper caudal lobe. The contour of the fish is therefore peculiarly slender and graceful, the depth of the body continuing pretty uniform as far as the origin of the posteriorly placed dorsal fin, whence it tapers to the moderately stout tail pedicle.

The head is somewhat elongated, with very oblique suspensorium, extensive gape, anteriorly placed orbit, and well marked ethmoidal prominence. The sculpture of the cranial roof bones is not exhibited; on the other bones of the head it appears to be of a striated character, but it is only distinctly seen in the case of the maxilla and mandible. The former has its broad post-orbital portion covered with closely set ridges, which pass into an irregular tuberculation along the dentary margin; the mandible, slender and tapering in shape, has also a narrow band of tuberculation along its upper margin, but below this the surface is striated with fine ridges, which proceed diagonally from above downwards and forwards, and increase in obliquity from behind forwards. Small conical teeth of different sizes may be observed in several specimens.

The bones of the shoulder girdle present nothing peculiar in their configuration, and, so far as their external sculpture is visible, it consists of wavy subparallel ridges.

The scales of the flank (fig 19) are somewhat large for the size of the fish, and *are higher than broad, with their posterior inferior angles obtuse;* towards the back, belly, and tail, they become smaller, and assume the usual rhomboidal shape. The articular spine is well marked though small; the keel of the attached surface is central and sharply defined. The scale markings are peculiar and characteristic. Along the sides of the body, as far as the tail pedicle, the exposed surface of the scale is ornamented by somewhat coarse and closely placed ridges, which, commencing at the upper margin, descend in such a way as to form one median ridge, surrounded by several others, which running parallel with each other, and with the anterior and posterior margins, join each other below round the lower extremity of the median one; or—to put the matter in another way—we have a set of concentric ridges parallel with the anterior, inferior, and posterior margins, with an odd one in the middle, or sometimes with two uniting in a loop; in addition, there are often one or two fine vertical striæ along the anterior margin. A somewhat different pattern is observable along the back (fig 18), extending downwards to, and including the second longitudinal row of scales above the lateral line. Here there is ordinarily only one marginal ridge, running closely along the anterior, inferior, and posterior margins, within which the area is, according to the size of the scale, occupied by from two to five diagonal and parallel ridges, passing from before downwards and backwards. The caudal body prolongation is comparatively weak and narrow; its minute lozenge-shaped scales are ornamented by diagonal ridges only; striæ of a similar description characterising also the large V-shaped scales which run along its upper margin.

The pectoral fin is small, its length being hardly more than half that of the head; it is acuminate in shape, and consists of about twelve rays, of which the principal ones are unarticulated till towards their terminations. The ventrals are in no specimen well preserved, but seem to have been likewise small, and with their rays somewhat distantly articulated. The median fins are, on the contrary, of tolerably large size. The dorsal is situated far back, and is triangular-acuminate in shape; its rays, the number of which cannot be accurately ascertained, are slender, smooth, and distantly articulated. The anal may be said to be placed opposite the dorsal, though in some specimens it seems to commence slightly in front of it, and to be also somewhat larger; it is sharply acuminate in front, with concavely excavated posterior margin; the rays are of the same character as those of the dorsal. The caudal is well developed, deeply cleft, and inequilobate; its rays resemble those of the other median fins.

Remarks.—This is one of the most beautiful of the many beautiful fishes which the Eskdale strata have yielded, and nothing can be more strikingly new than its specific characters, of which the first which arrests the attention is the unusually bold sculpture of the scales, together with the peculiar form of those on the anterior part of the flank. Of hitherto described species, the only one which bears any resemblance to it is the *Cycloptychius carbonarius* of Huxley, the points of likeness being—the slender elongated form of the body, the position and structure of the fins, the obtuseness of the posterior-inferior angles of the scales, and, last but not least, the possession of a peculiar scale ornament, consisting of ridges running parallel with the anterior, inferior, and posterior margins of the scale. These considerations indicate that *Cycloptychius* is the most appropriate genus to which to refer the present species, while, at the same time, the distinctions between it and *Cycloptychius carbonarius* are apparent at the first glance. In *Cycloptychius carbonarius*, the ridges on the scales are very much finer, that along the posterior margin being also more or less zigzagged in contour, while there is not that difference in the sculpture scales along the back which is so prominent a character in *Cycloptychius concentricus*. The shape of the flank-scales also differs to a considerable extent; for while in the former species the posterior-inferior angles are simply rounded off, in *Cycloptychius concentricus* they are absolutely obtuse, so that the inferior margin looks as much backwards as downwards.

The genus *Cycloptychius* has not hitherto occurred below the horizon of the Millstone Grit.

Position and Locality.—Near Glencartholm, Eskdale, in the Cement-stone group of the Calciferous Sandstone series.

Phanerosteon, gen. nov. Traquair.

Shape fusiform; head typically palæoniscoid in structure; body for the most part destitute of scales, so that the internal skeleton is well exhibited. Fins well developed; anal commencing opposite the middle of the dorsal; caudal heterocercal, only feebly bifurcated.

Phanerosteon mirabile, sp. nov. Traquair.

Pl. III. figs. 6–8.

The entire length of the most perfect specimen is 2¾ inches, and in this measurement the length of the head is contained 4¼ times. The cranial roof bones are granulated with minute and occasionally confluent tubercles. The suspensorium is oblique, the operculum oblong, with rounded-off posterior-superior angle, and showing traces of fine ridges, corresponding with the lines of growth; the interoperculum is somewhat quadrate-rhomboidal, with convex posterior margin. The maxilla, of the typical palæoniscoid shape, has its post-orbital portion marked with fine ridges, running parallel with the posterior and superior margins; the dentary margin and infra-orbital process appear to be finely tuberculated. The slender mandible displays on its outer surface numerous delicate ridges obliquely inpinging on its upper margin; a few delicately striated branchiostegal plates are seen below it; no teeth can be distinctly made out on either jaw. The orbit is large, but is, as usual, anteriorly placed, and the ethmoid forms a rounded prominence above the mouth. The bones of the shoulder girdle present nothing peculiar in their configuration and arrangement.

Immediately behind the upper limb of the clavicle, a few scales are visible, apparently the remnants of two or three dorso-ventral bands; they are very indistinctly preserved, yet their shape appears to be rhomboidal, and somewhat higher than long; and, though traces of ganoine appear on their surfaces, no sculptured pattern is visible. From this part, as far as the caudal fin, not the slightest trace of scales of any kind can be perceived,* except in one specimen, where there are four well-preserved median scales in front of the dorsal fin. But in all, the caudal body-prolongation is furnished with scales, which are as solid and as well preserved as in any other ganoid of similar size from the same beds. Along the upper margin of this part we find the usual median row of pointed imbricating scales, and simultaneously with these there commences a band of lateral ones, clothing the side of the prolonged body axis, these being very minute, acutely lozenge-shaped, and marked each with a few fine diagonal grooves; this band of lateral scales does not, however, extend to the origin of the caudal fin rays until the base of the lower lobe is passed. A few imbricating median scales may also be seen just in front of the commencement of the lower lobes of the caudal fin.

The absence of body scales reveals the internal skeleton in a manner unusually distinct for fishes of this family. There is no trace of vertebral bodies, the position of the persistent notochord being indicated by an empty space. Above this there is a series of short neural spines, bifurcated proximally, and slightly dilated distally, sixteen of which very regularly placed may, in one specimen, be counted between the head and the dorsal fin, beyond which they are a little confused; but they are again seen in more undisturbed succession towards the tail, where they assume a much more backward inclination than in front. Again, above these the dorsal fin is supported by two sets of slender interspinous bones, proximal and distal. The proximal set are directly superimposed on the extremities of the neural spines, but they are more numerous and consequently more closely placed; their exact number is not ascertainable, though I count thirteen of them to seven spines. Their distal extremities articulate with the proximal ends of the second set, with which they correspond in number; the latter are somewhat shorter, and have both extremities somewhat dilated.

On the hæmal aspect of the notochordal space, there may be seen between

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* In the specimen figured, a tolerably large scale lies irregularly across the middle of the body; but this, being evidently a dorsal ridge scale, is clearly out of its place, and probably belonged to some other fish.

the head and the dorsal fin, a series of ossifications whose exact form is not easy determinable, though some of them look somewhat V-shaped, and they may have served to enclose the aortic trunk. No trace of anything like *ribs* is observable. A little behind the commencement of the dorsal fin distinct hæmal arches and spines appear as well as interspinous bones, supporting the anal; but they are unfortunately, in the region of the last named fin, somewhat confused and mixed up, so that it is impossible to ascertain if its supporting ossicles were in double series, like those of the dorsal. Behind the anal, however, the hæmal spines are regularly disposed, and when they are seen supporting the lower lobe of the caudal fin, they are laterally flatted and dilated at their extremities; further on they are concealed from view by the scales of the caudal body-prolongation.

At the origin of each ventral fin, something like a small triangular pelvic bone is observable.

The pectoral fins consist of very delicate rays, so delicate that, even with a powerful lens, it is difficult to decide as to the extent to which they are articulated. The small ventrals are situated midway between the pectorals and the anal, and have their rays a little coarser, as well as distinctly articulated. The dorsal fin, pretty well seen in two specimens, is considerably developed, but has not the usual triangular acuminate shape prevalent among Palæoniscidæ; on the contrary, its apex is rounded off, and its posterior rays are proportionally somewhat longer than is ordinarily the case. Its rays are tolerably coarse for the small size of the fish, bifurcating *once* towards their extremities, and divided by somewhat distant transverse articulations. The complete contour of the anal fin is not shown in any specimen, but it is seen to commence opposite the middle of the dorsal, and to extend close to the lower lobe of the caudal; its rays, so far as they are exhibited, are similar in character to those of the dorsal. The caudal, judging from its appearance in three specimens, seems to be not so deeply bifurcated as in the more typical representatives of this family, though it is very heterocercal and inequilobate; its rays, similar in general appearance to those of the dorsal, are, however, finely and minutely dichotomised towards their extremities. I have not, after most careful examination, been able to detect any fulcra on the anterior margin of any of the fins.

Remarks.—Independently of the apparent nakedness of the body, the specific novelty of this little fish is fully attested by the peculiar form of the dorsal fin, and seemingly also of the caudal, as well as by the absence of fin fulcra; these last considerations being almost of themselves sufficient to indicate a new genus. If the body be naked, then not only is a new genus requisite, but the occurrence of a Palæoniscoid fish with the squamation in a condition almost identical with that of *Polyodon*, is a most interesting fact in connection with certain important structural affinities which, some years ago I pointed out as existing between that living genus and the extinct Palæoniscidæ.*

This is, however, not the first case of the kind which has been recorded, for in a paper on the Fauna of the Lower Permian formation of Bohemia, by Prof. ANTON FRITSCH of Prague, I find the following brief notice :—

"*Amblypterus*, sp.—Ein kleiner schuppenloser Fisch mit grossen Flossen und erhaltenen innern Skeletresten.—Tremosná." †

No further particulars are here given, but we may look forward with pleasure and interest to its full description, as Prof. FRITSCH'S great work on the Amphibia and Fishes of these strata progresses towards completion.

With regard to the present instance, we may ask, Is it likely that the body may have been once clothed all over with scales like those of other Palæoniscidæ, but which had been dissolved away or removed by some process not at present understood, leaving the delicate bones of the internal skeleton uninjured? As lending some countenance to this view, three specimens of other fishes from the present collection may be quoted.

The first of these is a tail of a very small specimen of *Cœlacanthus Huxleyi*, to which I have already alluded (p. 21), and in which no scales are visible, though the internal bones are very distinctly preserved.

The second is the unique specimen, from Coldstream, of the little fish to be presently described as *Holurus ischypterus*, in which the scales are not preserved over the whole of the body, though the general form is intact.

Thirdly, in one of the two specimens of the remarkable form *Tarrasius problematicus*, scales are also invisible on the anterior part of the body.

With regard to the *Cœlacanthus*, it must be noted that scales are present on all the other examples of the species, four in number, though they get indistinct towards the tail. The scales of *Cœlacanthus* are always thin and delicate, and in shale specimens, at least, they never prevent the more robust internal bones being seen; it is, therefore, perhaps not very wonderful that they should have disappeared in the tail of so small a specimen as the one referred to.

Also in the *Holurus ischypterus* there seems to be evidence of the removal of scales by some process of decay, a black film being left on the parts of the body where they are absent. But here the process seems also to have affected the internal skeleton, which has also almost completely disappeared from the parts bare of scales, all that is seen of it being a few oblique lines indicating the neural spinous processes, and which are hardly visible

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* "Carboniferous Ganoid Fishes," pt. 1, Palæontogr. Soc. 1877, pp. 38–40.

† "Neue Uebersicht der in der Gaskohle und den Kalksteinen der Permformation in Böhmen vorgefundenen Thierreste."—Sitzungsb. der Kön. böhm., Gesellsch. der Wissenschaften, 21 März, 1879.

at all, save when the specimen is held in certain lights. The specimen being unique, we had as yet no means of comparing it with others.

Lastly, as regards the *Tarrasius,* the specimen in question is also unique, in showing the head and anterior part of the body, and further, its obscuration by an irreparable film of matrix, renders accurate conclusions really unattainable until better specimens be discovered. (See the descriptions of *Holurus ischypterus* and *Tarrasius problematicus,* at pages 66 and 64.)

But in the case of Phanerosteon, no lateral body scales are seen on *any* of the specimens, four in number,* in which the body is shown, with the sole exception of a few immediately behind the shoulder girdle in one example. On the other hand, in all the three which exhibit the tail, the caudal body-prolongation is clothed with a set of scales, limited in the very same manner in each, and these are as well preserved and as strong as the scales of any other Palæoniscid from the same beds. Although the azygous scales in front of the dorsal fin are only shown in one example, their being detached from such a situation, if not connected with lateral ones, may be readily understood.

If we then consider, finally, that all the other Palæoniscidæ which occur in the same beds along with the present species have their scales all over the body in an excellent state of preservation, the most obvious conclusion seems to be that, in this instance, lateral body scales were absent, excepting a few immediately behind the shoulder girdle; the only other alternative being to suppose that they were, if present, of an unusually thin and perishable nature. In either case the apparent nakedness of the sides of the body, along with the other peculiarities noted, seems amply to justify the erection of the genus *Phanerosteon.*

Position and Locality.—In the Cement-stone group of the Calciferous Sandstone series, near Glencartholm, Eskdale.

Holurus, gen. nov. Traquair.

Somewhat deeply fusiform; dorsal fin arising behind the middle of the back, not acuminate in front, long based, extending almost to the commencement of the tail pedicle; anal fin with a shorter base than the dorsal; caudal strongly heterocercal, but not bilobate, triangular, its rays gradually diminishing posteriorly; pectorals unknown; ventrals small, abdominal arising slightly in front of the dorsal. Scales rhomboidal, sculptured; a prominent row of median scales between the occiput and the commencement of the dorsal fin. Teeth small, cylindro-conical.

The structure of the head is decidedly palæoniscoid, with oblique suspensorium and wide gape, but none of the specimens afford any evidence of

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* Since the above description was written, a fifth specimen has occurred, with the body as destitute of scales as the previous four.

the superethmoidal prominence which is so marked a feature in the contour of the head in typical Palæoniscidæ.

Holurus Parki, sp. nov. Traquair.

Pl. III. figs. 9–12.

Length, $2\frac{3}{4}$ inches to apparently over 3 inches; shape fusiform, and rather deep; greatest depth of body contained about $3\frac{1}{2}$ times, and the length of the head a little over 4 times in the total.

Of the cranial roof bones, the parietals, squamosals, and frontals may be readily identified, and these are ornamented externally with sharp and delicate, sometimes passing into elongated tubercles. The suspensorium is oblique; the *opercular* bones seem rather small, and from defective preservation their external ornament is not well shown, though in the operculum a few raised striæ similar to those of the other cranial plates may be observed. The *maxilla* has its upper margin as usual cut away in front for the orbit, but not quite so suddenly as in most Palæoniscidæ; its broad post-orbital portion is ornamented with delicate ridges running parallel with the superior and posterior margins. The mandible is of medium stoutness; its outer surface shows traces of delicate striation. Only very few teeth can, with considerable difficulty, be detected; they are minute and cylindro-conical in shape.

So far as exhibited, the bones of the shoulder girdle are in every respect conformed according to the usual palæoniscoid type, and are ornamented externally with ridges similar to those of the head bones.

The *body scales* are rather small for the size of the fish, rhomboidal, and very ornately sculptured with minute and delicate, yet very distinctly marked ridges and furrows, whose general pattern on the flank scales (fig. 10) may be described as follows:—Below a diagonal running between the anterior, superior, and posterior-inferior angles of the scale, their ridges have a nearly horizontal direction, parallel with the lower margin, some of the lowest also turning up along the anterior margin; immediately above this diagonal some ridges are seen running downwards and backwards parallel with it, while the uppermost pass backwards parallel with the upper margin, and then turn down parallel with the upper part of the posterior one; a few denticulations of the posterior margin are usually seen about the middle. Further back the denticulations disappear, the pattern becomes less marked, the ridges tend to fuse together, and the intervening furrows to degenerate into streaks and punctures, till at last the minute lozenge-shaped scales on the sides of the powerful caudal body-prolongation are nearly smooth. Along the middle line of the back, commencing near the occiput and extending to the dorsal fin, is a row of large and conspicuous median imbricating scales (fig. 12), each emarginate in front, pointed behind, and becoming more and more acute as the dorsal fin is approached;

externally these scales are sculptured with prominent longitudinal ridges. Behind the dorsal fin acutely pointed scales run along the upper margin of the caudal body-prolongation in the usual manner.

No pectoral fin is seen in any of the specimens, and only in one are some imperfect remains of a ventral discoverable, this being placed slightly in front of the commencement of the dorsal. The *dorsal fin* commences behind the arch of the back and extends to the commencement of the tail pedicle; its longest rays have only about half the length of the base of the fin; and as they become very gradually elongated in front and remain pretty long behind, a peculiarly rounded and proportionally somewhat long-based form of dorsal is here produced, which is very different from the high triangular-acuminate contour which is prevalent in this family. The anal is somewhat similarly shaped, but has a shorter base, for although the termination of its base is opposite that of the dorsal, it commences a little further behind. The *caudal fin*, arising from the lower margin of a powerful body-prolongation, is not bifurcated, but assumes a somewhat triangular shape, with the posterior margin only gently concave; its anterior rays being comparatively short, and then gradually diminishing posteriorly. The rays of these median fins are nowhere seen to dichotomise, but become simply attenuated distally; they are divided by articulations which are distant enough to leave the joints larger then broad; externally they are ganoid, and distinctly striated in the direction of their length. No fulcral scales are observable on the anterior margins of any of the fins.

Remarks.—In its non-bifurcated caudal, and rounded non-acuminated and proportionally long-based dorsal fin, this remarkable fish, which I adopt as the type of the new genus *Holurus*, contradicts the definition of the Palæoniscidæ given by me in the first part of my monograph on Carboniferous Ganoids; and in the want of dichotomisation of the fin-rays, it also differs from all hitherto described genera belonging to this family. The apparent want of an ethmoidal prominence over the front of the mouth is possibly due to defective preservation; in other respects the structure of the head is so decidedly palæoniscoid, that I feel compelled to retain it in this family. After all, the differences in the configuration of the fins are of slender importance compared with the cranial osteology, and I am inclined to regard it as more convenient, for the present, to substitute a more comprehensive definition of the Palæoniscidæ than to institute a new subdivision in these characters alone. Of much greater weight are the deviations in the structure of the head, which we shall have to consider in connection with the next genus (*Canobius.*)

I have pleasure in naming this species after Mr Walter Park, Brooklyn Cottage, Langholm, by whose zealous co-operation some of the most interesting specimens of the Eskdale fishes were obtained.

Position and Locality.—Near Glencartholm, Eskdale, in the Cement-stone group of the Calciferous Sandstone series.

Holurus fulcratus, sp. nov. Traquair.

Pl. III. figs. 13, 14.

Only one imperfect specimen of this form has been obtained showing the greater part of the body with the dorsal margin and dorsal fin, but deficient in the head, the ventral margin, and the fins, except the dorsal.

Description.—Scales very similar in shape, proportions, and markings to those of *Holurus Parki,* but no denticulations are visible on the posterior margins even of the most anteriorly situated flank scales. A row of pointed imbricating azygos scales (fig. 14) extends along the middle line of the back, from the head to the dorsal fin, and these are *much stronger* and with *fewer and coarser ridges* than in *Holurus Parki.* At the commencement of the dorsal fin, these median scales pass into a few *large and prominent fulcra* placed along its anterior margin; the rest of the fin is conformed as in the preceding species, extending, as in it, to the commencement of the tail pedicle, but the transverse articulations of the rays seem a little more distant. Anteriorly, the impressions of a few similar fulcra are seen adpressed to the body, as if they had belonged to the pectoral.

Remarks.—The configuration of the scales and the position and shape of the dorsal fin clearly indicate this species as belonging to the same genus as *Holurus Parki,* which it also much resembles in general aspect. Specifically it is, however, at once distinguished by the great strength of the median dorsal scales, and by the large fulcra in front of the dorsal fin.

Geological Position and Locality.—Near Glencartholm, Eskdale, in the Cement-stone group of the Calciferous Sandstone series.

Canobius, gen. nov. Traquair.

Body shortly fusiform, rapidly tapering towards the tail; caudal fin very heterocercal, deeply cleft, inequilobate, the upper lobe elongated; dorsal and anal fins short-based, triangular-acuminate, nearly opposite each other, the former commencing only very slightly in front of the latter; pectorals and ventrals obscure. *Suspensorium nearly vertical;* snout rounded, slightly projecting over the mouth; orbit large, gape small or moderate; dentition unknown. Scales rhomboidal, in some cases a row of large imbricating scales between the occiput and the origin of the dorsal fin.

I propose to institute the new genus *Canobius* for the remarkable little fish *Canobius Ramsayi,* Traq., from the Eskdale beds, a form which to the general configuration of a Palæoniscid, unites a disposition of the suspensorial and opercular apparatus, which is almost identical with the condition of these parts in the Platysomid *Eurynotus.* Here again we have a fish which contradicts what I once considered an essential character of the Palæoniscidæ, namely, the obliquity of the suspensorium; but which, according to its other points of structure, it would be hard to exclude from that family. I have already expressed the opinion (p. 45), that it is meanwhile better to enlarge the definition of the group, than to proceed prematurely to break it up into other families.

It will also be convenient to include under *Canobius* several other new species of Palæoniscidæ, which closely resemble *Canobius Ramsayi* in external form as well as in the direction of the suspensorium, although in certain other points of cranial osteology they differ from that species as well as from each other. Two of these, namely, *Canobius pulchellus* and *Canobius politus*, which are rather more typically Palæoniscid than the others in the configuration of some of their head bones, I once thought of forming into another genus; but, especially seeing that the dentition is not yet ascertained in any of these forms, it seems also somewhat premature to proceed to the splitting of genera upon these distinctions.

The generic name is taken from Canobie, the district in which the fossiliferous beds of Glencartholm are situated.

Canobius Ramsayi, sp. nov. Traquair.

Pl. V. figs. 1–4.

Description.—Length $2\frac{1}{2}$ to 3 inches, shape shortly fusiform, deep in front and tapering rapidly towards the tail. The length of the head is contained five times, the greatest depth of the body little more than three times in the total.

The head is short and deep, with a very obtusely rounded snout in front, behind which and nearly right over the mouth is a circular orbit of considerable size. As far as can be made out, the bones of the cranial roof seem quite palæoniscid in their arrangement, their external surfaces are marked with comparatively coarse flattened corrugations. The suspensorium is nearly vertical, being only very slightly inclined backwards; the posterior margin of the opercular flap has a regularly curved semilunar contour. The operculum is small, its anterior margin is nearly vertical, but its inferior one so oblique as to look as much backwards as downwards, and consequently the posterior margin is considerably shorter than the anterior one—the superior being the shortest of all. It is succeeded below by an interoperculum of a somewhat rhomboidal shape, the acute angles being the posterior-superior and anterior-inferior; its vertical depth is fully as great as that of the operculum, and its anterior and posterior margins continue uninteruptedly in the gentle curvature of those of that plate. The præoperculum simulates that of *Eurynotus* and other Platysomidæ, being a narrow triangular plate, with acute superior and inferior angles, and a very obtuse anterior one; its long posterior margin, which fits on to the anterior margins of the operculum and interoperculum behind, is gently convex and nearly vertical in position; the other two short margins are gently concave, the anterior-superior being the longer, and fitting on to the posterior margin of an elongated suborbital, while the shorter anterior-inferior one is in contact with the hinder margin of the maxilla. The maxilla forms posteriorly a rather broad somewhat rhombic-shaped plate, whose anterior angle passes into a narrow process extending on below the orbit. The mandible is small, straight, and slender; below it are seen a few branchiostegal rays. Immediately in front of the anterior-superior margin of the præoperculum, and touching the maxilla below, is a narrow, slightly curved sub orbital; and again, in front of this, there is a circlet of narrow ossicles, whose number cannot be accurately ascertained, surrounding the entire orbit. The orbit is large, and is situated immediately behind the rounded snout, and above the anterior part of the maxilla.

Like the bones of the cranial roof, those of the face are ornamented externally with tortuous flattened rugæ, except the mandible, which is marked with finer and nearly parallel ridges, running from behind forwards, with a slight obliquity towards the superior margin.

No teeth are visible on either jaw.

The bones of the shoulder girdle are constructed on the usual palæoniscoid type, and ornamented with flattened rugæ, like those of the head.

The scales of the body are arranged as usual in dorso-ventral bands, of which 34 may be counted between the shoulder girdle and the commencement of the lower lobe of the caudal fin. They are of moderate size, largest on the anterior part of the flank, smaller dorsally and posteriorly, and low and narrow on the belly. A row of especially large median imbricating scales runs along the back from the occiput to the commencement of the dorsal fin. These median scales are marked each with a few tolerably well-pronounced longitudinal ridges, as are also the imbricating V-scales of the upper caudal lobe, but the body scales in general are comparatively smooth, being marked only with faint ridges and furrows, proceeding somewhat diagonally from before backwards and downwards, which usually stop short before they arrive at the posterior margin of the scale; in many specimens these striæ are nearly entirely obsolete on the scales below the lateral line. There may also often be observed on the flank scales a number of very delicate vertical grooves close to and parallel with the anterior margin of the ganoid area. For the most part the posterior margins of all the scales are even and entire, denticulations being only occasionally and indeed rarely visible.

The pectoral fin is shown only in one specimen; it is small, and composed of numerous delicate rays, which seem to be jointed for a considerable part of their length. No ventral is visible in any of the specimens. The dorsal is situated far back, so as to be nearly opposite the anal; both fins are short-based, triangular-acuminate in shape, and are composed of delicate, brilliantly ganoid and distantly articulated rays. The caudal is very heterocercal, deeply cleft and inequilobate, the upper lobe being about twice the length of the lower, and nearly equalling one-third of the entire length of the fish; its delicate rays are similar in character to those of the dorsal and anal. Delicate fulcra are observable on the anterior margins of all the fins.

I take the liberty of dedicating this highly interesting species to Professor Ramsay, Director of the Geological Survey of Great Britain, to whose kindness, and to that of Professor Geikie, I am indebted for the privilege of describing this remarkable collection of fossil fishes.

Geological Position and Locality.—Near Glencartholm, Eskdale, in the Cement-stone group of the Calciferous Sandstone series.

Canobius elegantulus, sp. nov. Traquair.

Pl. V. figs. 5–8.

Description.—Length from 2 to 2¾ inches; length of head contained nearly five times, greatest depth of the body about 3½ times in the total. Shape shortly fusiform, rapidly tapering towards the tail, the upper lobe of which is elongated.

The head is short and deep.

The cranial roof bones, which are Palæoniscoid in form and arrangement, are marked externally with tolerably sharp, tortuous, and often reticulating ridges. The direction of the suspensorium is nearly vertical, the posterior margin of the opercular flap evenly rounded. The operculum is a quadrate plate with rounded off posterior-superior angle, but its lower margin is *not quite so oblique* as in the last-described species; it is succeeded below by an interoperculum of nearly the same size, but having its posterior-inferior angle correspondingly rounded off. The præoperculum is very difficult of detection, but seems to me to be represented by a very narrow plate in front of the operculum and interoperculum. In front of this there is, instead of the one long vertical suborbital which we saw to exist in *Canobius Ramsayi*, a chain of three or four short ones, in front of which again there is a circle of long, narrow curved ossicles, whose number is uncertain, apparently surrounding the entire orbit, which is proportionally very large, and seems indeed to occupy almost the entire space between the snout and the opercular bones. There is considerable difficulty in making out the exact form of the jaw bones. One thing is however certain, viz., that the maxilla has not the shape usually found in the Palæoniscidæ, but has a somewhat triangular form, more resembling that in certain Platysomidæ, such as *Mesolepis*. The gape seems to be small, and the mandible delicate; no teeth can be seen on either jaw. The bones of the face are, like those of the cranial roof, sculptured externally with tolerably fine, and occasionally flattened, tortuous rugæ.

The bones of the shoulder girdle present nothing calling for special remark; their external surfaces are sculptured in a manner similar to the bones of the head.

The scales are moderate in size, of the usual rhomboidal shape over the body generally, but there is a median row of specially large imbricating ones, of a more or less oval shape, extending from the occiput to the origin of the dorsal fin, besides the usual V-scales along the upper lobe of the tail. There are about thirty oblique dorso-ventral bands of scales from the shoulder girdle to the commencement of the lower lobe of the caudal fin. The ganoid area of the flank scales shows, in the first place, a few delicate yet sharp vertical grooves close to and parallel with the anterior margin, succeeding which, the greater part of the exposed surface is sculptured with five or six *prominent straight ridges* running across the scale nearly parallel with the upper and lower margins, and *ending in sharp points* on the posterior margin. A very similar sculpture pervades the entire squamation, though the corresponding ridges on the median scales of the back are somewhat convergent, and the minute lozenge-shaped scales of the caudal body-prolongation are nearly smooth.

I have seen no trace of either pectoral or ventral fins. The dorsal and anal fins are nearly opposite each other, the former commencing only a little more anteriorly; both fins are very similar in shape, being short-based and triangular-acuminate; each contains about twenty rays, which are delicate, smooth, distantly articulated, and dichotomising towards their extremities. The caudal is very heterocercal, deeply cleft, and inequilobate, the upper lobe being elongated; the rays are delicate, smooth, and distantly articulated; the lower lobe contains about fourteen rays, but the number of those in the upper one cannot be accurately ascertained.

Remarks.—This very decidedly marked species closely resembles the foregoing in size, in the general form of the body and fins, in the shortness of the head with its large orbit, and in the direction of the suspensorium, but it may at the first glance be distinguished from it by the bold and peculiar sculpture of the scales; the ridges in the head bones are likewise different in character, and the dorsal and anal fins seem somewhat more anteriorly placed. In addition to these diagnostic characters, an examination of the head reveals certain osteological differences, which might easily be considered as indicating a distinction of genus. Of these differences the most striking is the form of the maxilla, which here assumes a somewhat triangular form, reminding us of that bone in *Mesolepis,* while in *Canobius Ramsayi* it is not so much modified from the ordinary palæoniscid type. Our knowledge of the osteology of the head of *Canobius elegantulus* being, however, still by no means complete, it will, I think, be at present more convenient to be satisfied with the more obvious resemblances of general configuration, and to leave it provisionally at least in the same genus with *Canobius Ramsayi.*

Geological Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, near Glencartholm, Eskdale.

Canobius pulchellus, sp. nov. Traquair.

Pl. V. figs. 9–13.

Description.—The length of one absolutely entire specimen is 2⅛ inches; that of another, larger, but deficient in the extremity of the upper lobe of the caudal fin, is 3¼ inches. The length of the latter specimen, when entire, would probably amount to ¼ inch more.

The length of the head is pretty nearly equal to the greatest depth of the body, and is contained slightly more than 4½ times in the total. The shape is fusiform, the body being deepest midway between the head and the commencement of the dorsal fin, and thence tapering rapidly and elegantly towards the tail pedicle.

The cranial roof bones are ornamented with small rounded tubercles, which sometimes tend to become elongated, specially on the posterior or parietal region. The ethmoidal region forms a rounded projection over the mouth; the orbit is large and anteriorly placed. The suspensorium is more oblique than in *Canobius Ramsayi* or *Canobius elegantulus*, but less so than in typical Palæoniscidæ; the posterior margins of the opercular and interopercular bones pass into each other so as to form a continuous gently curved line. The operculum is a small oblong plate, with rounded inferior margin and posterior-inferior angle; interoperculum, nearly equalling it in size, has its upper margin correspondingly concave, and its posterior-superior angle slightly produced upwards. The præoperculum cannot be very distinctly made out, but I rather suspect that it more resembles that bone in typical Palæoniscidæ than in *Canobius Ramsayi.* The maxilla is elongated, and its shape is decidedly palæoniscoid, though its broad posterior part is not so suddenly cut away for the orbit as in more typical forms; the mandible is slender and tapering, but neither in it nor in the maxilla are any teeth discernible. All the facial bones are ornamented with delicate ridges, usually flexuous, though on the mandible they are pretty straight, parallel with the inferior margin, and touching the superior one at acute angles, owing to the tapering shape of the bone. On the narrow infra-orbital part of the maxilla the ridges pass into rows of tubercles, which pass obliquely downwards and backwards, or, conversely, upwards and forwards. The scales are moderate in size; the median row of scales between the head and dorsal fin is rather conspicuous, but not so much so as in *Canobius Ramsayi* and *Canobius elegantulus.* Taking a flank scale as an example, the covered area is narrow, the ganoid one sculptured with closely set bold ridges and furrows, forming a pattern which, in its main features, is characteristic of a large number of Palæoniscidæ. There are first a few vertical ridges close to and parallel with the anterior margin, which then turn round below and run backwards parallel with the inferior one; the rest of the area is occupied with ridges parallel with the superior and inferior margins, but of course directed against the vertical portions of the first-mentioned set. Some amount of wavyness is frequently observed in these ridges, and where they come to the posterior margin of the scale they end on sharp denticulations. On other parts of the body, such as the back, belly, and tail, the ridges tend to pass into one set which traverse the scales somewhat diagonally from before backwards.

I have not observed either the pectoral or ventral fins. The dorsal and anal are nearly opposite each other, the former come only an almost inappreciable distance in advance of the latter; both fins are well developed, short-based, triangular-acuminate, composed of tolerably stout smooth rays, which dichotomise towards their extremities, and are divided by moderately distant articulations. The caudal is deeply cleft, very heterocercal and equilobate, the upper lobe appearing produced; its rays are similar in character to those of the dorsal and anal. Very distinct fulcra are observable along the anterior margins of all the fins.

Several examples have occurred of what seems to me to be only a variety of the above described form, the only appreciable difference being in the more delicate markings on the scales.

Remarks.—I know of no previously described fish with which the present species can be confounded. In general contour it resembles *Canobius Ramsayi* and *Canobius elegantulus*, but it may be at once distinguished from both by its scale-markings as well as by the more typically palæoniscoid configuration of its facial bones. In the configuration of the opercular bones and the direction of the suspensorium, a condition is presented which is somewhat intermediate between that in *Canobius Ramsayi* and in ordinary Palæoniscidæ, and which, as I have already mentioned, at first nearly induced me to institute a separate genus for this and the following species, but considering that so much still remains to be learned concerning the more minute characters of these small fishes, it is perhaps better to avoid premature multiplication of genera by including them provisionally in *Canobius,* to which they certainly bear a greater general resemblance than to any other genus.

Geological Position and Locality.—Near Glencartholm, Eskdale, in the Cement-stone group of the Calciferous Sandstone series.

Canobius politus, sp. nov. Traquair.

Pl. V. figs. 14–16.

Description.—The specimens of this form, none of which have the caudal fin perfectly preserved, represent a small fish of from 2½ to 3 inches in length, and of somewhat deeply fusiform proportions, the dorsal and ventral margins being pretty evenly and elegantly curved. The greatest depth of the body, midway between the head and the dorsal fin, is ¾ inch to 1 inch; the length of the head is contained approximately twice in the distance between the tip of the snout and the commencement of the dorsal fin, and thrice as far as the commencement of the caudal.

The cranial roof bones are ornamented with comparatively coarse ridges, frequently, and in some specimens more than others becoming broken up into rounded or elongated tubercles. The snout forms a rounded prominence over the mouth, and behind it is placed the orbit, of considerable size. The suspensorium is only *very slightly oblique* in its direction; the operculum and interoperculum are nearly of equal size, and where their external ornament is seen it consists of more or less concentric ridges. The shape of the præoperculum cannot be made out. The maxilla apparently resembles that of the preceding species in form, having a short broad posterior portion, passing into a narrow tapering process, which runs forward below the orbit. The mandible is short, stout, and straight, and ornamented with longitudinal and oblique ridges, which are somewhat finer than those on most of the other bones of the head; on its margin several minute sharp conical teeth may be distinguished.

The scales are of moderate size, largest and least oblique on the front of the flank, and diminishing in size posteriorly and towards the dorsal and ventral margins. Along the belly, between the pectoral and anal fins, the scales are also low and narrow; but those along the middle line of the back are *not specially large or prominent*, excepting a few just in front of the dorsal fin. Over nearly the whole of the body the scales are *nearly absolutely* smooth on their exposed surfaces, only on the back, near the middle line, do we observe a few grooved striations; and the flank scales of some specimens show some faint indications of obsolete ridges, passing with a slight obliquity from before backwards and downwards. The posterior margins of the scales of the side of the body are, as far back as the tail pedicle, marked with tolerably well-marked denticulations.

In one specimen a small pectoral fin is visible, but unfortunately its state of preservation is not such as to render a minute description warrantable; remains of the ventral are also seen midway between the pectoral and anal. The dorsal fin commences only very slightly in front of the anal; both are of the usual acuminate form, with tolerably delicate rays, which are smooth, distantly articulated, and dichotomising towards their terminations; well-developed fulcra are observable along their anterior margins. Only a small part of the caudal fin is present in one example, the rays being similar in character to those of the dorsal and anal.

Remarks.—This species is evidently very closely allied to the preceding, from which it may, however, be at once distinguished by the smoothness of the scales, and by the greater coarseness of the ornament on the cranial roof bones, which moreover always partakes more or less of a ridged character; the suspensorium seems also slightly more vertical in its direction. Both species are referred only provisionally to the genus *Canobius.*

Geological Position and Locality.—Near Glencartholm, Eskdale, in the Cement-stone group of the Calciferous Sandstone series.

Family Platysomidæ.

(See Traquair, Trans. Roy. Soc. Edin. vol. xxix. 1880, p. 343.)

Eurynotus, Agassiz, 1835.

(Agassiz, Poiss. Foss, vol. ii. pt. 2, p. 153.)

Eurynotus crenatus, Agassiz.

A scale indistinguishable from one of the flank scales of *Eurynotus crenatus*, so common a fish in the Calciferous Sandstone series of Edinburghshire and Fifeshire, occurs on a small portion of shale from Tweeden Burn, Liddisdale.

Eurynotus (?) *aprion*, sp. nov. Traquair.

Pl. V. fig. 20.

Only a few disjointed scales. One of these, a typical flank scale, measures $\frac{1}{8}$ inch in height by somewhat less in breadth, and closely resembles, in general form, a flank scale of *Eurynotus crenatus.* The well-marked anterior and overlapped area is very distinctly marked off from the posterior exposed one, which is rhomboidal, the acute angles being the posterior-superior and anterior-inferior; the ornament consists of tranverse, sometimes oblique, furrows, which are deeply marked anteriorly, but fade away towards the middle of the scale, where they are replaced by scattered punctures; *the posterior margin is quite entire,* and without any trace of serration or fimbrication. A similar character of ornament is displayed by smaller and more regularly rhomboidal scales, which evidently belonged to a part of the fish nearer the tail.

Remarks.—Evidently specifically new, these scales are doubtful as to genus, and I only refer them *provisionally* to *Eurynotus* on account of their general contour and aspect.

Geological Position and Locality.—Tweeden Burn, Liddesdale, in the Cement-stone group of the Calciferous Sandstone series. Identical scales are seen on a portion of grey arenaceous shale from the Lower Carboniferous of Moyheeland, Draperstown, Ireland, in the "Griffith Collection" belonging to the Science and Art Museum, Dublin, for an opportunity of examining which I am indebted to the courtesy of Dr Steele, Director, and Dr Carte, Keeper of the Natural History Department of that Institution.

Eurynotus, sp. indet.

Among the specimens from Glencartholm is a small *Eurynotus*, deficient in the head and fore part of the body, as well as in the fins, except the dorsal and ventral, which are also somewhat imperfectly preserved. The scales are striato-punctate, and sharply serrated posteriorly. From the information afforded by this specimen, I hesitate either to pronounce it as new, or to identify it with any previously described species.

Wardichthys, Traquair, 1875.

(Traquair, Ann. and Mag. Nat. Hist. (4), vol. xv. 1875, p. 262; Trans. Roy. Soc. Edin. vol. xxix. 1880, p. 361.)

Wardichthys cyclosoma (?), Traquair.

Pl. V. fig. 21.

A few scales from Tweeden Burn, Liddesdale, and a small fragment of a fish from Glencartholm, Eskdale, display characters which I cannot at present distinguish from those of *Wardichthys cyclosoma*, from the Lower Carboniferous shales near Newhaven; in consequence, however, of the scantiness of these remains, I have appended a query to this determination, so far as the species is concerned. The fragment from Eskdale shows merely a small portion of the back and shoulder.

[From Glencartholm there is also a specimen of what is apparently a new Platysomid fish, and which may possibly belong to the genus *Wardichthys*, or to some undescribed genus, but its state of preservation is so imperfect that, for the present, I abstain from bestowing a name upon it. The specimen wants both head and fins, though a portion of the caudal body-prolongation is preserved; it measures 3½ inches in length, by 1¾ in depth. The shape is more fusiform, less deep and circular than in *Wardichthys cyclosoma;* the tail pedicle is proportionally strong. The scales of the body, where their surface is preserved, are ornamented with coarse, irregular, tuberculo-corrugate sculpture; but on the tail pedicle and caudal body-prolongation their markings consist of comparatively delicate, wavy, and more or less diagonal furrows and ridges.]

Cheirodopsis, gen. nov. Traquair.

Body deep, rounded; dorsal fin arising behind the arch of the back. Scales very narrow. Cranial osteology and dentition as in *Cheirodus* (*Amphicentrum*, Young).

The striking difference in the contour of the body, caused by the absence of the dorsal, and probably also of the ventral peak, with the greater shortness of the dorsal fin, is sufficient to differentiate this genus from *Cheirodus*, M'Coy, to which, in cranial structure, it is most intimately allied. (See the author's description of *Cheirodus* in Trans. Roy. Soc. Edin. vol. xxix. 1880, p. 363).

Cheirodopsis Geikiei, sp. nov. Traquair.

Pl. V. figs. 17–19.

Description.—Two specimens of this very interesting form have occurred. The first consists of a pretty well preserved head, with the greater part of the body and the commencement of the dorsal fin, and when entire probably did not exceed 3¼ inches in length. The second (fig. 17) is considerably disjointed, but represents a somewhat larger fish. So far as it is revealed by the more perfect of the two examples, the shape of the fish seems to have been deep and rounded, with a very large head compared with the size of the body; but the absence of the posterior part of the specimen renders it impossible to lay down any proportional measurements.

The contour of the head slopes first gently, then, forming an obtuse rounded angle above and in front of the orbit, steeply downwards and forwards towards the snout; but the last named part not being preserved, it is impossible to say whether the præmaxilla formed the beak-shaped prominence seen in *Cheirodus*. Where the outer surface of any of the cranial roof bones is visible, it is seen to be brilliantly ganoid, and ornamented by tolerably coarse, tortuous, and reticulating corrugations.

Judging from the position of the opercular bones, the direction of the hyomandibular suspensorium was nearly vertical, or with a slight forward inclination. The operculum is not so high as the interoperculum, but both are higher than broad; in form they resemble pretty closely the corresponding plates in *Cheirodus*. Externally they are ornamented with tolerably coarse rugæ and tubercles; a diagonal line drawn from the anterior-superior to the posterior-inferior angle of the operculum; and again, turning from the posterior-superior to the anterior-inferior angle of the interoperculum, divides each plate into two diagonal halves; behind this line the ornamentation is in each case tubercular, while in front it consists of sub-parallel anastomosing ridges, running mainly in a horizontal direction. In front of these two plates is the interoperculum, shaped as in *Cheirodus*, but here seen only from its inner aspect; a small narrow additional plate seems to be intercalcated between it and the upper part of the anterior margin of the operculum. The orbit is placed pretty high up on the head, and right over the middle of the mouth; a narrow sickle-shaped suborbital is seen bounding it behind.

The mandible is short, deep, and stout, though pointed, beak-like, in front; where the upper margin of its dentary element is seen, it is thin and edentulous. The external surface of the mandible is shown in the second and larger specimen, both dentary and angular elements being sculptured with coarse flattened rugæ, sometimes anastomosing and interrupted, subparallel, and running obliquely from above and behind downwards and forwards. The impression of the outer aspect of the maxilla is seen in the counterpart of the same specimen; it is of the triangular shape seen in *Eurynotus* and *Cheirodus*, and is ornamented by rugæ similar in character to those of the mandible, but parallel to the posterior margin, and nearly vertical to the inferior or oral one. Its free or oral margin is sharp and edentulous as in *Cheirodus*, but probably enough, as in that genus, there was a supra-marginal band of tooth tubercles in the inner surface.

In the smaller specimen an excellent view is afforded of the inner or oral aspect of the pterygo-quadrate apparatus, which is conformed exactly as in *Cheirodus*. The pterygoid element, seen also isolated in the larger example, is somewhat oval in shape, convex below and internally; its internal surface shows a narrow band of small shining tubercles, while the lower margin displays two strong ridges, converging behind, and anteriorly carrying each a row of tooth tubercles, which are covered with a brilliant coating of enamel, and are more closely set than in *Cheirodus granulosus*.

Of the bones of the shoulder girdle the only one visible is the clavicle, whose form corresponds with that in *Cheirodus* and other Platysomid fishes.

The scales (fig. 19) are high and narrow, indeed remarkable for the narrowness of the exposed area, which is covered with a peculiar coarse tuberculo-corrugate ornamentation, which forms prominent serrations at the hinder margin. The articular spine is well marked, as is also the receiving fossette of the internal surface, but the vertical keel or so-called "scale rib" is broad, and only very slightly prominent.

The dorsal fin, as seen in the smaller specimen (fig. 17), commences behind the summit of the gently rounded line of the back; unfortunately the specimen is so cut off that the free margin of the fin is absent, though a considerable portion of the anterior margin, as well as of the base, is visible. The rays, very short at first, become rapidly elongated; they are slender and tolerably distantly articulated. A small portion of this fin is also seen in the second specimen, and here the presence of large and prominent fulcra along the anterior margin is very distinctly exhibited.

The collection contains also a fragment of a tail, which has certainly belonged to the counterpart of the last named specimen, the parts between it and the head having been lost. This displays part of the upper lobe of the strongly heterocercal caudal fin, with the posterior fringe-like extremity of the dorsal fin, the latter stopping short at the pedicle. The scales of what remains of the tail pedicle, and of the caudal body-prolongation, display the nearlyobsolete remains of an ornamentation similar in character to that which occurs in those of the body.

Remarks.—The rounded non-peaked form of the body, with the evidently much shorter dorsal fin, seems quite sufficient ground for erecting this remarkable new form into a genus distinct from *Cheirodus*.

I have much pleasure in naming this species after Professor Geikie, to whom I am indebted, on this as on other occasions, for so much kind and friendly assistance.

Geological Position and Locality.—Near Glencartholm, Eskdale, in the Cement-stone group of the Calciferous Sandstone series.

Platysomus, Agassiz, 1835.

(Agassiz, "Poissons Fossiles," vol. ii. pt. 1; Young, Quar. Journ. Geol. Soc. 1866; Traquair, Trans. Roy. Soc. Edin. xxix. 1880, p. 368.)

Platysomus superbus, sp. nov. Traquair.

Pl. VI.

Of several specimens of this splendid fish, one which is remarkably perfect may be selected for description. Its principal measurements are as follows:—

From the tip of the snout to opposite the termination of the caudal lobe, ...	6 inches.
From the tip of the snout to the bifurcation of the caudal fin, ...	$5\frac{1}{4}$ "
From the tip of the snout to opposite commencement of anal fin, ...	$3\frac{1}{8}$ "
From the tip of snout to opposite commencement of ventral fin, ...	$2\frac{1}{4}$ "
Greatest depth of the body from the commencement of the dorsal fin, at the highest point of the back, to the origin of the ventrals, ...	$4\frac{3}{8}$ "

The form of the body is therefore very deep; the back is rounded (though with a slight angle at the origin of the dorsal fin), and enormously gibbous; the ventral line is nearly straight as far as the origin of the anal fin, where it is obtusely angulated, and slopes upwards to the commencement of the tail pedicle.

So far as the osteology of the head is decipherable, it conforms to the type characteristic of this genus; the cranial bones are ornamented externally with delicate, close, wavy subparallel striæ, occasionally passing into minute tubercles. Very distinct imprints of teeth are seen upon the mandible, clearly showing that these were minute, cylindro-conical, slightly enlarged towards the apex, then bluntly pointed.

The shoulder girdle presents nothing specially worthy of remark.

The body scales are of moderate size, becoming indeed rather small towards the dorsal and ventral margins and the caudal extremity, where, as usual, they are also more equilateral. A typical scale from the flank, just behind the head, is high and narrow, with well-marked articular spine, and strong internal marginal rib or keel. The covered area is narrow; the exposed one rhombic, with very acute anterior-inferior and posterior-superior angles, and is ornamented with fine vertical striæ, about twelve in the space of ⅛ inch, perfectly parallel, and hardly ever bifurcating or intercalated. On the scales further back, and towards the margins, especially the ventral one, these striæ often become more irregular and wavy, while bifurcation and intercalation very commonly occur.

By careful working out on the counterpart immediately behind the lower part of the clavicle, I succeeded in uncovering a considerable part of the pectoral fin, but not in displaying its perfect contour. Its length is 1$\frac{1}{16}$ inch, being greater than the distance between its origin and that of the ventral.

A little in front of the origin of the anal fin a well-developed ventral is exhibited; it is one inch in length, short-based, and acuminate in form, and is composed of numerous rays, which are tolerably closely articulated, and dichotomise towards their terminations.

The dorsal fin is remarkable for the large size which it attains both from the length of its base and of its rays. It commences at the culminating point of the back, slightly in front of the origin of the ventrals, and forms a deep fringe extending to the tail pedicle. Its most anterior rays are very short, but they rapidly elongate till a length of 1½ inch is attained at the apex, behind which the contour of the fin again falls away somewhat, and passes back tolerably parallel with the base. The length of the rays in the posterior part is ¾ inch, but from the broken up appearance of their extremities, both here and towards the apex, it is evident that the full depth of the fin is not exhibited in the specimen, a conclusion amply borne out by a fine fragment of a smaller specimen to which I shall presently refer. The very numerous dorsal fin rays are ganoid externally, beautifully striated in the direction of their length, with fine straight ridges; anteriorly the transverse articulations are distant, forming joints which are considerably longer than broad; posteriorly they become closer, and the joints nearly square, though even here the articulations are more distant towards the extremities of the rays.

The anal fin is in a better state of preservation; its base, commencing $\frac{3}{4}$ inch behind the origin of the ventral, and extending to the tail pedicle, attains only one-half the length of that of the dorsal opposite. Anteriorly it is acuminate, the rays rapidly elongating until a length of $1\frac{1}{2}$ inch is attained at the eleventh, whence the contour of the fin again falls away, the posterior part being fringe-like, and with rays of about $\frac{1}{2}$ inch in length. The rays are similar in character to those of the dorsal, being finely striated longitudinally, and having their transverse articulations distant in the anterior and close in the posterior rays; they are also seen to dichotomise towards their extremities, while the anterior margin of the fin is set with very distinct fulcra.

The caudal is of moderate dimensions, heterocercal, and deeply cleft, but in this specimen the lower lobe is deficient towards the apex. The rays of the lower lobe are pretty stout, divided by closer articulations than those of the dorsal, and are rather punctured than striated, although striæ appear as we pass to the upper division of the fin; the anterior margin is distinctly fulcrated. The rays of the upper lobe are short and delicate, with rather close articulations, which, however, still leave the joints rather longer than broad. On the scales of this caudal body-prolongation regular striation has disappeared, the ornament being now reduced to indented furrows and punctures.

There are two fragmentary specimens in the collection, of which especial notice must be taken. One of these represents a portion of the back with the upper part of the head of a considerably smaller example than that last described, and showing the anterior part of the dorsal fin in a perfect condition. We have here a clear demonstration of the very large development of this fin, its longest rays, forming the apex, being larger by one-eighth than the distance between the commencement of the fin and the posterior margin of the parietal bone. Unfortunately, the hinder part of the fin is not included in the specimen, but it is evident that its free margin does not fall away behind the apex, as in the case of the anal, and that, consequently, the contour is not so acuminated. The anterior margin is distinctly fulcrated.

In another fragment the entire caudal and anal fins are shown with some remains of the ventral. The two latter yield no information beyond what may be learned from the first specimen, but the two lobes of the caudal are seen to be, as nearly as possible, of equal length. The caudal body-prolongation is, as is characteristic of this genus, weak and slender, but its scales are traceable to the extremity of the upper lobe.

Remarks.—This large and beautiful *Platysomus*, to which I have applied the specific name *superbus*, cannot possibly be confounded with any species previously described. Its salient features are—the great gibbosity of the back, the great depth of the dorsal fin, whose base is equal to twice the length of that of the anal. The scales have a delicate striation, somewhat similar to that of the Permian *Platysomus striatus*, but their exposed areæ are much more acutely rhomboidal, and the two species are furthermore widely separated by the form of the body and of the dorsal and anal fins.

It is interesting to find in a specimen, which in all respects is an undoubted *Platysomus*, so clear a demonstration of a large and well-developed ventral fin, as well as of slender styliform teeth in the jaw.

Platysomus has not hitherto been found in so low a horizon of the Carboniferous system.

Geological Position and Locality.—Near Glencartholm, Eskdale, in the Cement-stone group of the Calciferous Sandstone series.

Of Uncertain Subordinal Position.

Family Tarrasiidæ.

Scales rhombic, minute, shagreen-like. Notochord persistent. Neural and hæmal arches and spines well ossified; slender interspinous bones penetrate between the extremities of the vertebral spines as in teleostean fishes. A long dorsal fin composed of closely set jointed rays.

Tarrasius, gen. nov. Traquair.

Characters of the Family.—A fragment of a small fish, found by Mr Macconochie at Tarras Foot, Eskdale, displays, in spite of its imperfect condition, characters so startlingly novel, and so completely at variance with anything hitherto observed in the domain of palæozoic ichthyology, that I feel compelled to institute for its reception not merely a new genus, but likewise a new family. With this I associate a specimen from Glencartholm, which displays some of the same characters, and which, so far as evidence goes, seems also to belong to the same species. The family and generic names are taken from the first locality.

Tarrasius problematicus, sp. nov. Traquair.

Pl. IV. figs 4–6.

The specimen from Tarras Foot.—This is a fragment (Pl. IV. figs. 4, 5) displaying what is evidently the posterior or caudal part of a small fish, cut off both in front and behind, and measuring 1¼ inch. The shape of the portion of the body here shown is gently tapering, the depth in front being $\frac{7}{16}$ inch, and ¼ inch where it is cut off behind; the dorsal and ventral margins are nearly straight, being only very slightly convex. The whole surface is covered with regularly arranged, minute, but proportionally thick, rhombic, and apparently non-overlapping scales, each of which shows on its external brilliant surface a small shallow depression or sulcus. At the anterior part of the fragment the internal skeleton is clearly displayed by the removal of the scales next the eye of the observer. There are no vertebral bodies visible, but four neural(?) arches are seen, from which proceed obliquely upwards and backwards as many neural(?) spines, in front of which two others are seen, whose supporting arches are not included in the specimen. Above these spines comes a series of slender interspinous elements, distally enlarged and laterally flattened, while proximally they pass for a little way between the extremities of the neural(?) spines, after the manner of modern fishes. Appended to the extremities of the last described elements, and set at a slight angle, there seems to me to be a second set of interspinous elements, minute, short, and somewhat hour-glass-shaped, but owing to the minuteness of the parts it is not easy to distinguish them accurately from the proximal extremities of the suceeding fin-rays.

The whole of the dorsal(?) margin exhibited in the specimen is bordered by a continuous fin, the depth of which is equal to two thirds of that of the part of the body to which it is appended. This fin consists of innumerable closely set rays, distinctly articulated, and tapering distally to fine points, but so far as can be observed, not dichotomising. As in the continuous dorso-caudal fin of *Lepidosiren* and *Ceratodus*, their direction becomes posteriorly more and more oblique, until at the posterior end of the fragment they are in fact nearly horizontal. From this there can be hardly a doubt but that it is the tail of the fish with which we have to deal, that the caudal fin was diphycercal, and continuous with the dorsal and anal.

On the hæmal(?) aspect of the vertebral axis no arches or spines are distinctly exposed, but their presence is betrayed by oblique elevations of the scaly surface, exactly symmetrical with the spines of the opposite aspect. Along the ventral(?) margin also the impressions of a set of interspinous bones are seen, exactly corresponding with those which follow on the neural(?) spines opposite, so that although the fin itself is unfortunately lost, we may very safely assume the presence of one here also, symmetrical with that on the opposite aspect.

As indicated above, I believe this fragment to be the hinder end of a fish with continous diphycercal dorso- and ano-caudal fin; but as the want of the head and abdominal parts render it difficult to distinguish with accuracy the symmetrical *dorsal* and *ventral* margins, and *neural* and *hæmal* aspects, I have appended queries to these terms where it has been necessary to use them.

The specimen from Glencartholm.—This specimen (Pl. IV. fig. 6) is 2¾ inches in length, and presents us in the first place with a head, the length of which is ½ inch. Unfortunately, very little can be made out concerning the cranial structure. On the cranial roof two distinct frontal bones are observable, ganoid externally, and faintly sculptured with indented lines and punctures. A distinct opercular apparatus is seen consisting of broad plates; but owing to the crushing they have undergone, it is impossible to make out the number or shape of the individual elements. The suspensorium is not directed backwards as in typical Palæoniscidæ, but seems nearly vertical, if not indeed inclined slightly forwards. A considerable portion of a stoutish mandible is seen, marked externally with delicate longitudinal ridges, while above it is a portion of a maxilla, but no teeth are visible on either jaw. There is also an indication of the position of the orbit, right over the middle of the mouth.

Behind the opercular bones, and somewhat overlapped by them, are some traces of a pretty strong clavicle.

The body is almost completely covered up and obscured by an obstinately adherent thin layer of matrix, nevertheless, certain parts are seen, though faintly, as if through a veil. The body extends back for 2⅜ inches, or six times the length of the head before it is cut off by the edge of the stone; and as it is clear that a pretty considerable portion of the caudal extremity is wanting, the fish must have presented a somewhat narrow and elongated contour. The points of structure here observable are mainly indications of the internal skeleton. For nearly an inch behind the head these are very obscure, consisting principally of an irregular line, with here and there little bits of bone shining through, which are probably portions of neural arches; behind this, however, the line of the vertebral axis is very apparent, although the associated structures are very much more clearly seen on the neural than on the hæmal aspect. As in the specimen from Tarras Foot, there is no evidence of vertebral bodies, and the notochord may therefore be presumed to have been persistent. On the dorsal aspect of the axial line there is, as in the former specimen, a series of slender neural spines, inclined obliquely upwards and backwards; they are pointed distally, but proximally they are enlarged and apparently bifurcated so as to form neural arches. Surmounting these, there are also very clear indications of a set of slender interspinous bones, whose number is at least double that of the supporting neural spines, and whose pointed proximal extremities pass a little way down between the ends of the latter; while again, extending from where the fish is cut off behind for fully 1¼ inch towards the head, there are evident remains of a long fringe-like dorsal fin—in my opinion, a continuous dorso-caudal. Most probably it would be found to extend still further forwards could the matrix be removed.

On the hæmal aspect of the axis, clear evidences of hæmal arches and spines symmetrical with the neural ones above may be seen about two inches behind the head, and may be traced for half an inch backwards, beyond which the spines become hopelessly obscured, and nothing remains distinguishable but the arches from which they spring.

Finally, in the layer of matrix which obscures the hinder end of the specimen, and close to where it is cut off by the edge of the stone, are many minute rhombic glittering scales; at one spot, three of them, apparently portions of a dorso-ventral band, are seen in opposition. Each of these little scales has a central depression or sulcus, and is, in fact, indistinguishable from those which cover the body in the specimen from Tarras Foot.

Remarks.—The first question which arises concerning the two specimens described above, is whether or not they belong to the same species, and here difficulties are certainly interposed by the imperfect condition of both. It will be observed, however, that there is a very exact correspondence between the two as regards the structure of the internal skeleton, so far as this is exhibited, and in the long median fin, which extends along a margin which, in the Glencartholm specimen, is certainly the dorsal one. The few scales which are seen near the caudal extremity of the specimen last referred to, are certainly identical in form and appearance with those which thickly cover the surface in that from Tarras Foot, and this circumstance, along with the correspondence of the internal skeleton and median fin, has inclined me to consider the two as belonging to the same species. But it must also be observed that, whereas the scales in No. 1 cover the entire surface of what remains of the body, in No. 2 not a vestige of them is seen till near the posterior extremity. If the two specimens really represent the same species, we are reduced to supposing that in No. 2 the scales have either been loosened by decay and removed from the anterior parts (a state of matters which, though not impossible, seems hard to reconcile with the fact that the bones of the head and the vertebral apophyses are undisturbed so far as the film of matrix allows them to be seen); or that the obnoxious film of matrix hides them from view; or lastly, that scales were originally present only towards the caudal extremity. It must in any case be acknowledged that, until more material turns up, the layer of matrix by which the details of No. 2 are obscured, forms an insuperable obstacle to a thoroughly satisfactory conclusion on the subject.

But even if we leave the specimen from Glencartholm altogether out of consideration, the fragment from Tarras Foot presents us with peculiarities which seem to be quite irreconcilable with the characters of any previously defined family. We have scales like those of an Acanthodian, but a position in the Acanthodidæ is contradicted by the structure of the fin and internal skeleton. The general shape and the disposition of the median fin reminds us of the hinder part of the interesting Dipnoan (?) fish *Conchopoma gadiforme*, Kner, from the Lower Permian of Lebach; but in that form, as in ordinary Dipnoi, the neural and hæmal spines articulate with the interspinous bones, end to end, and the squamation is altogether different. It certainly bears no perceptible affinity to the Palæoniscidæ, nor can I assign to it a place in any known family, while, until further material may come to light, even its subordinal position is altogether problematical. I therefore propose to institute for it the new genus *Tarrasius* and family Tarrasiidæ, both names being taken from the locality in which the more characteristic specimen was found.

APPENDIX.

The two following species from Berwickshire were included in this Report by an oversight, as the specimens were not derived from the district under consideration. In order, however, not to delay their publication, I have transferred them from the body of the Report to the end, in the form of an "Appendix."

Holurus ischypterus, sp. nov. Traquair.

Pl. III. figs. 15, 16.

Description.—Length of the only specimen which has occurred, $2\frac{1}{8}$ inches; but if we allow for some deficiency both at the snout in front, and at the termination of the tail behind, the original length would probably be at least $2\frac{1}{2}$ inches. The other measurements are as follows:—

Greatest depth of body, ...	$\frac{7}{16}$	inch.
Length from the front to commencement of the dorsal fin,	$1\frac{1}{8}$	,,
Do. do. anal ,,	$1\frac{1}{4}$	,,
Do. do. caudal ,,	$1\frac{5}{8}$	,,

The shape of the fish is therefore somewhat striking; being elegantly fusiform, with a large and apparently non-bifurcated caudal fin attached.

The head is badly preserved, yet enough is seen to indicate its decidedly palæoniscoid structure. The suspensorium is oblique, the gape wide; the operculum is ornamented with a few comparatively coarse oblique ridges; and similar ridges, though somewhat more closely arranged, occur on the post-temporal and supraclavicular bones.

Although the outline of the fish is perfectly shown, only two patches of scales are preserved on the side of the body; one of these is situated on the anterior part of the flank immediately behind the head; the other is towards the caudal region, below the dorsal fin, and extends on to the prolongation of the body in the upper part of the caudal fin. As shown in these patches, the body scales are small, rhomboidal, *and marked with two to four very prominent ridges, running parallel with their upper and lower margins*, these ridges becoming less marked on the caudal region, where the scales are very minute. In front of the dorsal fin are seen some very strong pointed median scales, which become indistinct when traced forward; nevertheless it seems probable that they were continued as a distinct row as far as the head. Very strong imbricating V-scales are seen along the upper margin of the caudal body-prolongation, the sides of which are clothed with minute scales of the usual acutely lozenge-shaped contour.

A thin dark film occupies most of the body space where the scales are not preserved, and on this, in the region above the lateral line, are seen, especially when the specimen is held in certain directions, certain faint oblique lines passing in an upward and backward direction, which seem to indicate the vertebral spinous processes.

The pectoral fin is indicated on the counterpart of the specimen by a narrow remnant of its post-axial margin, from which it would seem that it nearly equalled the head in length. No traces of the ventrals are discoverable. The dorsal commences just behind the highest part of the arch of the back, and extends to the tail pedicle; as *H. Parki* and *H. fulcratus*, its anterior rays become gradually elongated, and remain long posteriorly, so that the contour of the fin rises very gradually in front and finishes off behind in a rounded flap-like manner. The anal is like the dorsal in general contour, but has a shorter base; for though the two fins terminate opposite each other, the former commences a little behind the latter. The caudal is largely developed, but unfortunately its termination is not preserved. Nevertheless, so far as we can judge, it seems to have been non-bifurcated, and without any distinct differentiation into upper and lower lobes, there being no sudden shortening of the rays as they proceed onwards towards the extremity; the caudal body-prolongation is powerfully developed.

The rays of all these median fins are very delicate, closely set, distantly articulated, and *without any trace of dichotomisation.* Very distinct remains of *strong and powerful long spicules occur at the bases of the anterior margins of the fins,* which I interpret as largely developed fulcra, which are even more out of proportion with the delicate rays which form the expanse of the fin than in the case of *Holurus fulcratus.*

Remarks.—This strange little fish cannot possibly be confounded specifically with any previously described form; the only question open to discussion is as to the genus in which it ought to be placed. The reasons for referring it to *Holurus* are found in the position and shape of the dorsal fin, the non-bifurcation of the caudal, and the want of dichotomisation in the fin rays. The strong fulcra ally it somewhat to *Holurus fulcratus*, but the ornament of the scales is very different from that in the other two species which I include in this genus.

I have already referred to the non-preservation of the scales over a large part of the body of this unique specimen, a condition which seems in this case at least to have been caused by some process of decay, which has left the fins and head bones, as well as some patches of the scales themselves, intact. There is certainly no evidence either of the original absence of scales from the bare spaces in question, or of their removal by any mechanical process.

Position and Locality.—In the Cement-stone group of the Calciferous Sandstone series, left bank of River Tweed, near Coldstream Bridge.

Canobius obscurus, sp. nov. Traquair.

Description.—Of this there are only a few fragmentary specimens, which indicate a fish of from 2 to 2½ inches in length, and resembling, in shape, the other species which I have referred to this genus, being shortly fusiform, rather deep in front, tapering rapidly towards the tail, with a short blunt head, posteriorly placed dorsal fin, and inequilobate deeply cleft caudal.

The head has its roof bones covered with fins and tolerably distant ridges, frequently interrupted, sometimes branched, and mainly running in a longitudinal direction, save on the ethmoid, where they are transverse. The rest of its osteology is very obscure, but the snout is bluntly rounded, and the suspensorium seems to be nearly vertical, or at least only slightly oblique; the bones of the face, whose outlines cannot be made out, are apparently ornamented with ridges similar in character to those of the cranial roof.

The scales, proportionally smaller than in the foregoing two species, are very regularly rhomboidal in shape, and are marked with from *three to five straight flattened ridges*, which pass *diagonally* from above downwards and backwards, and terminate in prominent denticulations of the posterior margin. I have observed no row of specially large median scales between the head and the dorsal fin, but the dorsal margin is in no instance very well preserved.

One specimen, more perfect than the others, though the head is wanting, shows the dorsal and caudal fins. The former is placed far back, and would be nearly opposite the anal, were that fin preserved; it is short-based, triangular-acuminate, and composed of very delicate rays. The caudal is deeply cleft, and judging from its proportions was doubtless very inequilobate, though the extremity of the lower lobe and a considerable part of the upper one are lost.

Remarks.—The comparatively coarse straight diagonal bars across the scales distinguish the species from all the others which I have brought under the genus *Canobius.* In general form it resembles the others, especially *C. Ramsayi,* but unfortunately very little is preserved of the structure of the head.

Geological Position and Locality.—Blackadder Water near Dunse, Berwickshire, in the Cement-stone group of the Calciferous Sandstone series.

EXPLANATION OF THE PLATES.

Throughout these figures the same letters apply to the same bones.

p.	Parietal.
sq.	Squamosal or dermal pterotic.
f.	Frontal.
p.f.	Posterior frontal or dermal sphenotic.
a.f.	Anterior frontal or dermal ectoethmoidal.
e.	Median superethmoidal.
p.mx.	Præmaxilla.
mx.	Maxilla.
pt.	Pterygoid.
m.pt.	Mesopterygoid.
h.m.	Hyomandibular.
ar.	Articular.
ag.	Angular.
d.	Dentary.
sp.	Splenial.
op.	Operculum.
i.op.	Interoperculum.
p.op.	Præoperculum.
br.	Branchiostegal.
s.o.	Suborbital.
c.o.	Circumorbital.
s.t.	Supra-temporal.
n.	Nasal opening.
or.	Orbit.
p.t.	Post-temporal.
s.cl.	Supra-clavicular.
cl.	Clavicle.
p.cl.	Post-clavicular.
i.cl.	Infra-clavicular.

Plate I.

Fig. 1.—*Cœlacanthus Huxleyi*, Traquair; natural size (p. 20).
Fig. 2.—Another specimen, enlarged by one-half.
Fig. 3.—Angular element of the mandible, magnified three diameters.
Fig. 4.—Scales of *Cœlacanthus Huxleyi*, magnified six diameters.
Fig. 5.—*Elonichthys serratus*, Traquair; natural size (p. 22).
Fig. 6.—Another specimen; natural size.
Fig. 7.—Scales from the flank of *Elonichthys serratus*, magnified six diameters.
Fig. 8.—Scales from the same species, towards the tail, magnified six diameters.
Fig. 9.—*Elonichthys pulcherrimus*, Traquair; natural size (p. 24).
Fig. 10.—Scales from the flank of *Elonichthys pulcherrimus*, magnified four diameters.
Fig. 11.—Scales of the same species, further back, magnified four diameters.
Fig. 12.—Surface of dorsal fin rays, magnified four diameters.
Fig. 13.—Restored outline of *Rhadinichthys Geikiei*, Traquair (p. 25).
Fig. 14.—Scales from the nape of the neck in *Rhadinichthys Geikiei*, magnified six diameters.
Fig. 15.—Flank scales, magnified six diameters.
Fig. 16.—The same, a less ornate variety, magnified six diameters.
Fig. 17.—Scales situated further back, towards the tail, magnified six diameters.
Fig. 18.—Narrow abdominal scales, magnified six diameters.

Plate II.

Fig. 1.—*Rhadinichthys Geikiei*, Traquair, var. *elegantulus;* natural size (p. 27).
Fig. 2.—Scales of the same, from the nape of the neck, magnified six diameters.
Fig. 3.—Flank scales of the same, magnified six diameters.

Fig. 4.—Scales towards the tails, magnified six diameters.
Fig. 5.—Sketch of the bones of the head, enlarged 2½ times.
Fig. 6.—*Rhadinichthys delicatulus*, Traquair; natural size (p. 29).
Fig. 7.—Sketch of the head, enlarged 2½ times.
Fig. 8.—Flank scales of the same, magnified six diameters.
Fig. 9.—Scales further back, magnified six diameters.
Fig. 10.—*Rhadinichthys* (?) *angustulus*, Traquair, magnified two diameters (p. 33).
Fig. 11.—Scales from another example of the same species, magnified six diameters.
Fig. 12.—*Rhadinichthys Macconochii*, Traquair; natural size (p. 30).
Fig. 13.—Scales from the nape of the neck in the same species, magnified six diameters.
Fig. 14.—Flank scales, magnified six diameters.
Fig. 15.—Scales further back, magnified six diameters.
Fig. 16.—Narrow ventral scales, magnified six diameters.
Fig. 17.—*Cycloptychius concentricus*, Traquair; natural size (p. 37).
Fig. 18.—Scale from the back above the lateral line, magnified six diameters.
Fig. 19.—Flank scales of the same species, magnified six diameters.
Fig. 20.—Scales towards the caudal extremity, magnified six diameters.

PLATE III.

Fig. 1.—*Rhadinichthys* (?) *fusiformis*, Traquair; natural size (p. 34).
Fig. 2.—Flank scales, magnified six diameters.
Fig. 3.—Flank Scales, from another specimen, magnified six diameters.
Fig. 4.—Narrow ventral scales, magnified six diameters.
Fig. 5.—Scales towards the tail, magnified six diameters.
Fig. 6. *Phanerosteon mirabile*, Traquair; natural size (p. 39).
Fig. 7.—Sketch of the head of *P. mirabile;* enlarged 2½ times.
Fig. 8.—Tail-fin of another specimen, enlarged 2½ times.
Fig. 9.—*Holurus Parki*, Traquair; natural size (p. 44).
Fig. 10.—Flank scales of the same species, magnified six diameters.
Fig. 11.—Scales further back, magnified six diameters.
Fig. 12.—Median dorsal scales, magnified four diameters.
Fig. 13.—*Holurus fulcratus*, Traquair; natural size (p. 46).
Fig. 14.—Median dorsal scales, magnified four diameters.
Fig. 15.—*Holurus ischypterus*, Traquair; natural size (p. 66).
Fig. 16.—Flank scales, magnified six diameters.

PLATE IV.

Fig. 1.—*Rhadinichthys tuberculatus*, Traquair; natural size (p. 31).
Fig. 2.—Flank scales, magnified six diameters.
Fig. 3.—Scales towards the caudal extremity, magnified six diameters.
Fig. 4.—*Tarrasius problematius*, Traquair; Tarras Foot, enlarged two diameters (p. 62).
Fig. 5.—Scales of the same specimen, magnified eight diameters.
Fig. 6.—Another specimen, probably referable to the same species, from Glencartholm; natural size (p. 63).

PLATE V.

Fig. 1.—*Canobius Ramsayi*, Traquair; natural size (p. 47).
Fig. 2.—Flank scale, magnified six diameters.
Fig. 3.—Scale further back, magnified six diameters.
Fig. 4.—Sketch of head of *Canobius Ramsayi;* magnified two diameters.
Fig. 5.—*Canobius elegantulus*, Traquair; natural size (p. 49).

Fig. 6.—Flank scale, magnified six diameters.
Fig. 7.—Scale further back, magnified six diameters.
Fig. 8.—Sketch of bones of the head in another specimen, magnified two diameters.
Fig. 9.—*Canobius pulchellus*, Traquair; natural size (p. 51).
Fig. 10.—Flank scale, magnified six diameters.
Fig. 11.—Scale further back, magnified six diameters.
Fig. 12.—*Canobius pulchellus* variety (p. 52).
Fig. 13.—Flank scale from the same specimen, magnified six diameters.
Fig. 14.—*Canobius politus*, Traquair; natural size (p. 53).
Fig. 15.—Flank scale, magnified six diameters.
Fig. 16.—Scale further back, magnified six diameters.
Fig. 17.—*Cheirodopsis Geikiei*, Traquair; natural size (p. 56.)
Fig. 18.—Pterygoid bone and outer surface of mandible, from another specimen, natural size.
Fig. 19.—Flank scales, magnified three diameters.
Fig. 20.—Scales of *Eurynotus* (?) *aprion*, Traquair; magnified four diameters (p. 54).
Fig. 21.—Scales of *Wardichthys cyclosoma*, Traquair; magnified four diameters. From Tweeden Burn, Liddesdale.

PLATE VI.

Fig. 1.—*Platysomus superbus*, Traquair; natural size (p. 58.)
Fig. 2.—Flank scales, magnified three diameters.
Fig. 3.—Scales towards the dorsal aspect, magnified three diameters.
Fig. 4.—Scales of tail pedicle, magnified three diameters.
Fig. 5.—Sculpture of rays of anterior part of dorsal fin, magnified four diameters.
Fig. 6.—Dentition of mandible, magnified four diameters.

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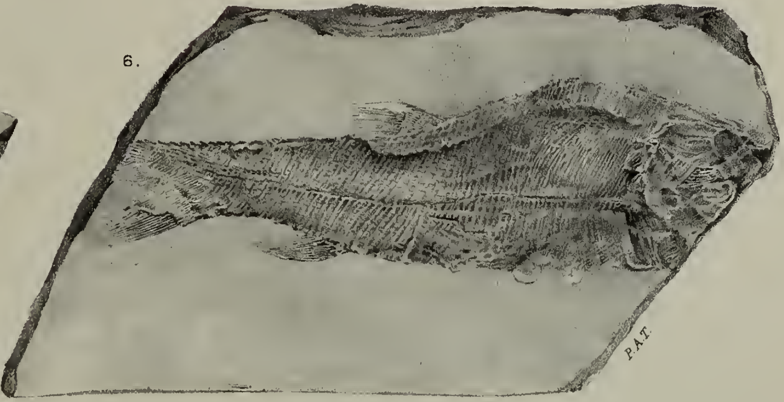

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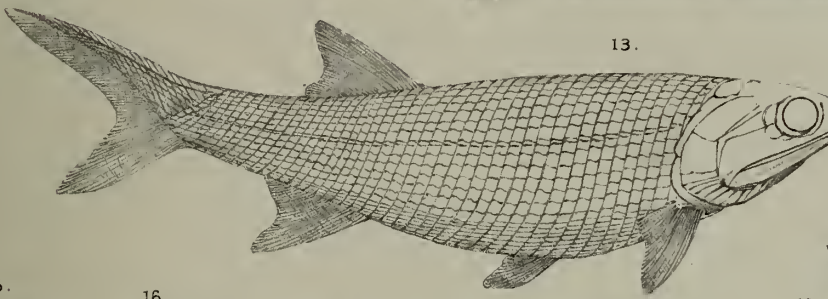

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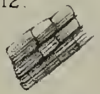

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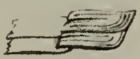

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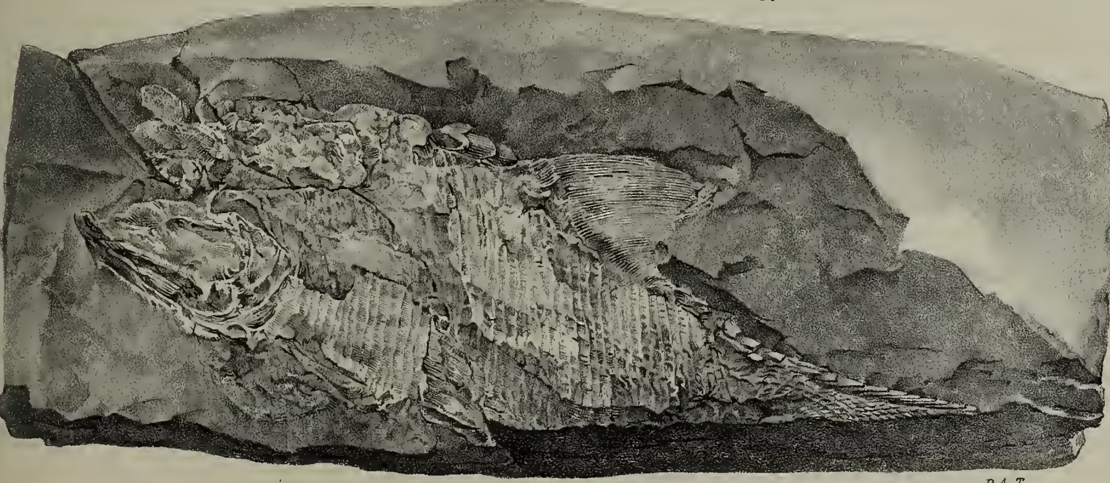

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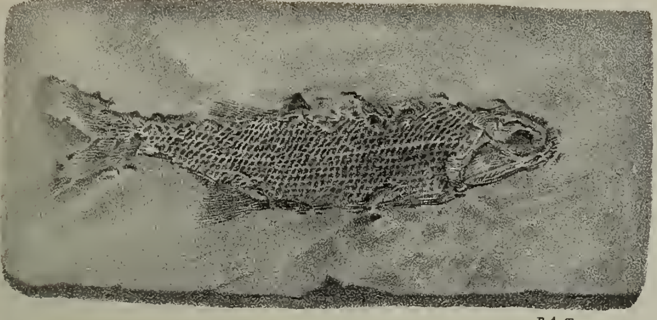

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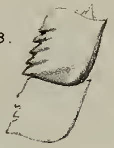

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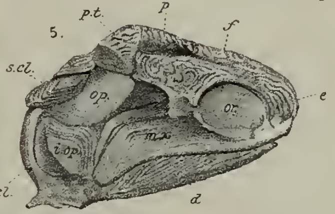

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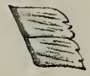

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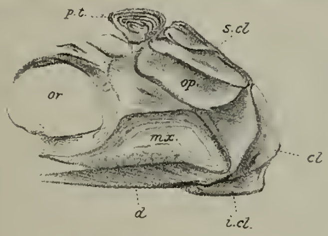

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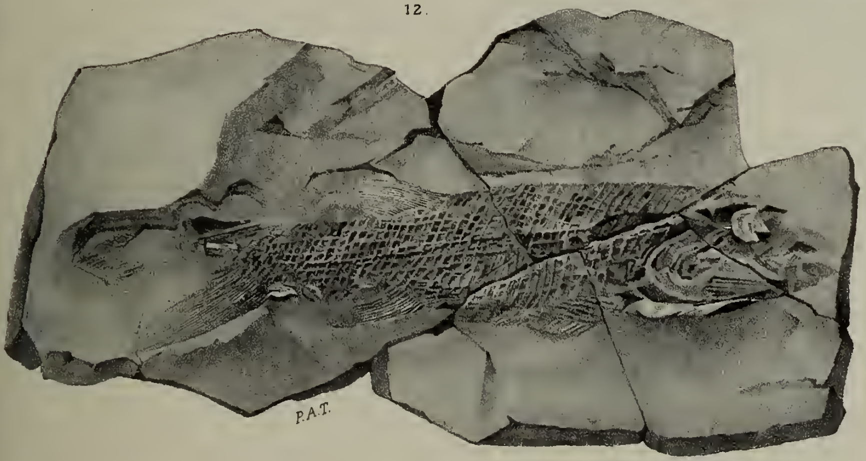

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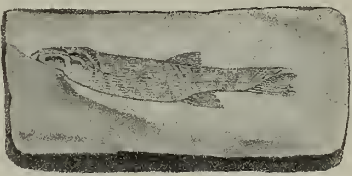

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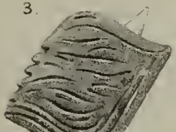

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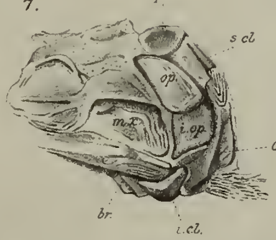

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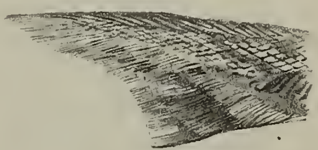

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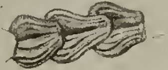

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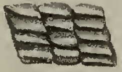

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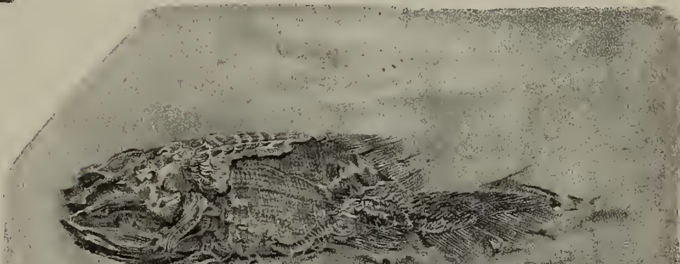

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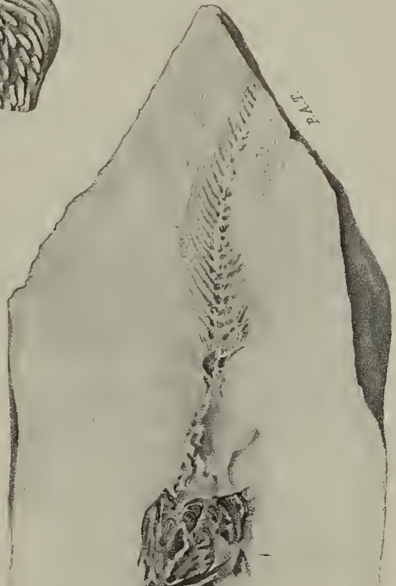

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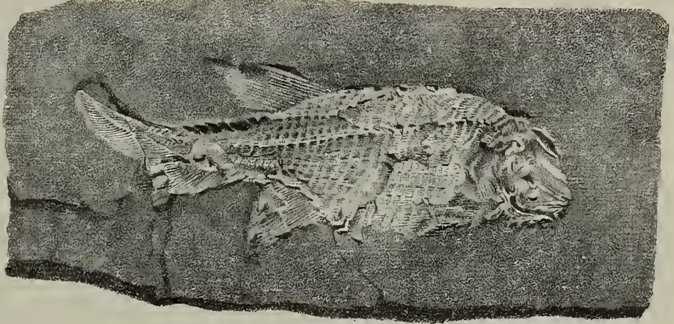

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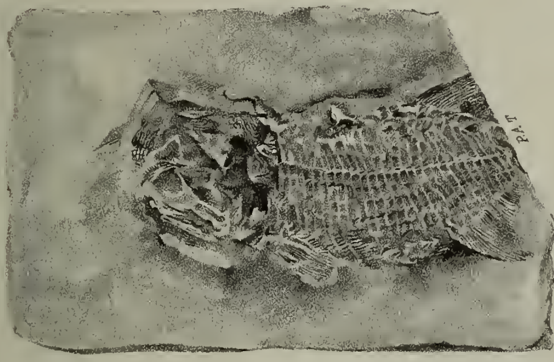

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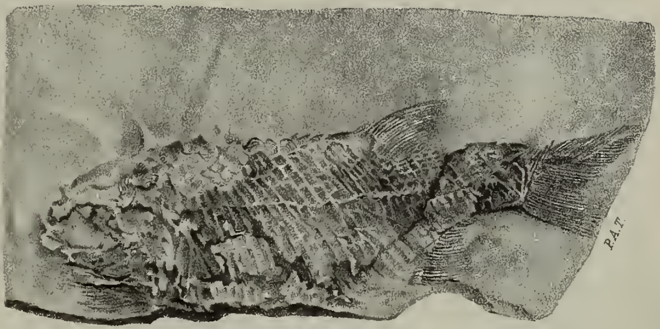

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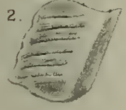

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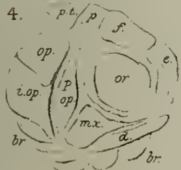

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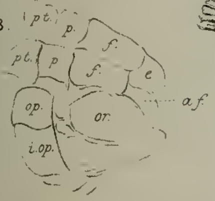

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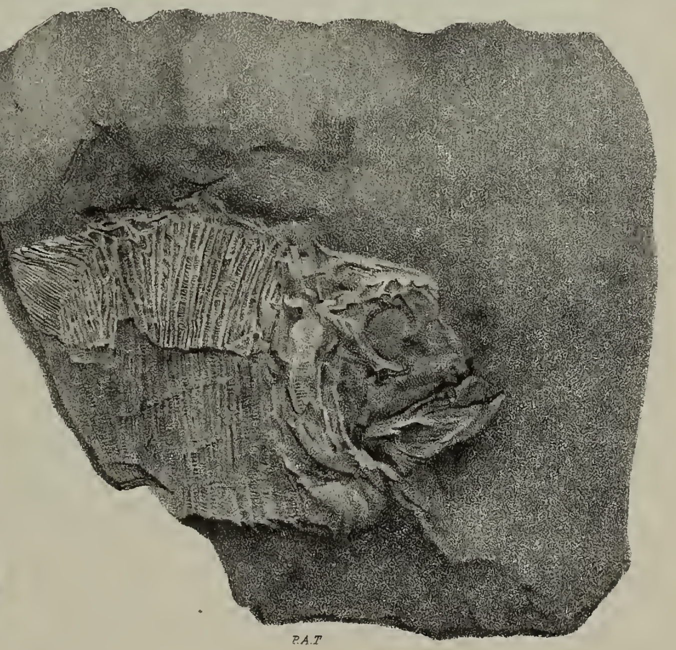

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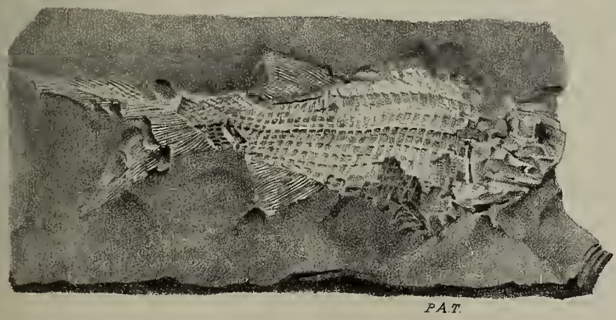

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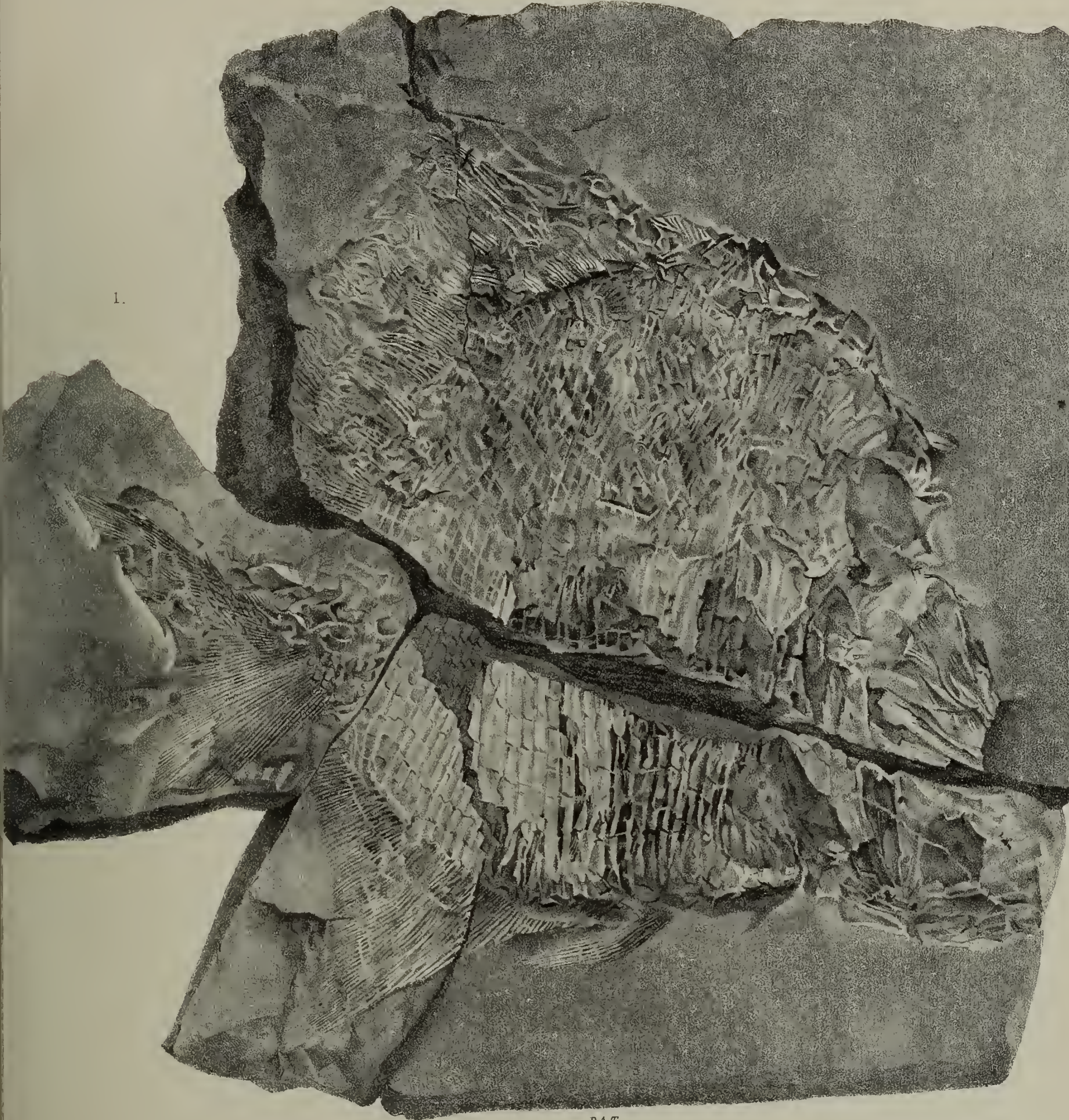

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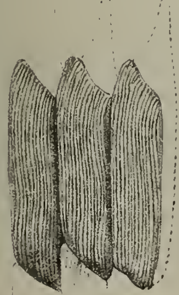

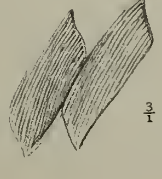

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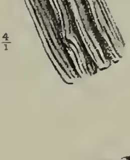

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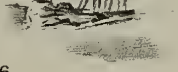

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IV.—*On some new Crustaceans from the Lower Carboniferous Rocks of Eskdale and Liddesdale.* By B. N. Peach, A.R.S.M., F.G.S., of the Geological Survey of Scotland. Communicated by Professor Geikie, F.R.S. (Plates VII. to X.)

(Read 19th July 1880.)

By the permission of Professor A. C. Ramsay, LL.D., F.R.S., Director-General of the Geological Survey of Great Britain and Ireland, and Professor Geikie, LL.D., F.R.S., Director of the Geological Survey of Scotland, I have been permitted to describe several new Crustaceans which have come under my notice in my capacity of Acting Palæontologist to the Scotch Survey. They are from the cement-stone group of the Calciferous Sandstone series of the Scottish border, and, with a very few exceptions, were got from one locality on the river Esk, about four miles south of Langholm, in Dumfriesshire, and were almost all collected by A. Macconochie, Fossil Collector to the Geological Survey of Scotland. They belong to two orders, viz., Phyllopoda and Decapoda.

I. *Phyllopoda.*

The Phyllopods as yet found in the Calciferous Sandstone series have been confined to the genera Dithyrocaris, Leaia, and Estheria. Some large carapaces, attributable to Ceratiocaris, have however been obtained from the Carboniferous Limestone, but as far as I have been able to make out, no body-segments have been described. In the collection above referred to a great many specimens occur, which appear to belong to two different species.

When compared with those found in the Upper Silurian Rocks they differ considerably in having the body relatively much larger than the carapace. The abdomen appears to be out of all proportion to the carapace if we take such well-known forms as *C. papilio* (Salter), or *C. stygius* (Salter), as our ideals. The tests are not ornamented by the same fine striations as these latter.

Ceratiocaris scorpioides, spec. nov. (Pl. VII. figs. 1 to 1*f*). Carapace about one-third the length of the body exclusive of telson, subovate in form, and produced into a blunt snout anteriorly, and posteriorly into a rounded lobe, which extends backwards beyond the median line of the posterior margin. The anterior, ventral, and posterior margins are slightly thickened. The dorsal line is almost straight, with a slight droop anteriorly. Jaws two in number, and placed within the carapace near its anterior ventral margin. They are hollow and denticulated, the toothed portion being much thickened. Body long and cylindrical, and made up of seven segments which extend beyond the carapace, and at least five which are covered by it. These latter are mere rings, and become shorter and shorter anteriorly. All are articulated and movable. The uncovered segments increase in length posteriorly. The third segment from the end is much the deepest, whence the body tapers each way. The ventral margin of this segment always exhibits a deep notch as if a piece were cut out of it. The seventh segment is almost twice as long as any of the others, and has articulated with it a strong hastate telson which is about equal in length to itself. The telson is broad at the base, tapers rapidly for a short distance, and then, more gradually, to a fine point with a slight upward curve. It is ornamented with at least five serrated flanges, a dorsal, a ventral, and two lateral ones on each side. The lateral flanges on the one side in part of their course are connected with each other at intervals, with buttresses or columns, so that a pattern is produced in the lateral groove. The telson is flanked by two other shorter conical spines, one on each side, which are also articulated to the last body-segment and striated longitudinally. Test, smooth or slightly wrinkled. Total length from 1 to 2½ inches.

Observations.—There is a considerable difference among the several specimens regarding the length and bluntness of the snout, and from none yet seen can the bivalve nature of the carapace be established.

The species is named from a fancied resemblance of the individuals to scorpions, not from any idea of immediate relationship.

Ceratiocaris elongatus, spec. nov. (Pl. VII. figs. 2 to 2*f*). Carapace about one-fourth of the length of the body without the telson, produced into a long snout in front and suddenly deepens where the jaws are seen to show through, whence it is produced backwards into a rounded lobe which extends considerably beyond the medial line of the posterior margin.

Jaws hollow and denticulated, and placed a little less than half-way from the tip of the snout to the posterior margin. They occur nearest the ventral side and sometimes project beyond the margin. Body-segments seven, uncovered and four or five covered by the carapace, all movable, the whole forming a cylindrical body which swells backwards till the third segment from the tail is reached, whence it tapers backwards. This segment too has a similar notch to that observed on *C. scorpioides,* as in that species the segments are each one larger than its immediately preceding neighbour. The telson is nearly twice as long as the last abdominal segment, and is highly oramented. In addition to five plain flanges it has in the grooves on each side of the dorsal flange a row of minute bosses, which, when magnified, have the appearance of the pine-pattern so common on Indian shawls. Lateral spines not observed. Length, including telson, 4½ to 8 inches.

Observations.—It is only necessary to point out where this species differs from *C. scorpioides.* In the first case its size and proportions are different. The snout of the carapace is much longer and narrower. It is in the tail spine that the greatest difference is found. Both of the above species differ from all others described in the enormously developed abdomen.

Though the side spines of the *C. elongatus* were not observed, yet the articular surface on the segment to which the telson is attached is much broader than there is any apparent need for. It is but natural therefore to infer that such spines may have dropped off in the interval between the death and the interment of the animals.

That those of *C. scorpioides* represent the side spines in the silurian species there can be little doubt though they have dwindled down so as to be out of all proportion to the central one. We had a shadowing of this, however, in *C. inequalis,* Bar.

Fig. 2*b* is interesting, as it shows the course of the intestinal canal, which appears to be a straight cylindrical tube opening on the ventral margin of the last segment near the insertion of the telson. Fortunately the creature is fossilised with the canal distended with food.

A noticeable feature in both species is that the pivots on which the abdominal segments move are placed nearer the ventral margin in the hinder than in the anterior segments, thus allowing of most play in the joints of the former (fig. 1*a*). In both species a row of circular pits is observable on the sides of the abdominal segments. These may represent the place of attachment of the gill feet with which they were probably provided.

II. *Decapoda macrura.*

Among the specimens are several species which differ in no essential respect from the Macrura of the present day. These go to swell the genera *Anthrapalæmon* and *Palæocrangon,* Salter. It should be borne in mind, however, that they are not to be considered as being more nearly allied to the genus Palæmon than to any other of our recent Macrura. As well as these there are several specimens of one species differing from the above in having their thoracic segments free to move on each other, and not covered by the carapace, which only extends over the cephalic region. These agree generally with the American genus *Palæocris*[*] of MEEK and WORTHEN, but the species is different from their *P. typus.*[†]

Genus *Anthrapalæmon,* Salter (1861), Quart. Journ. Geol. Soc. Lond., xvii. p. 529.

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[*] MEEK and WORTHEN, 1865, Proc. Acad. Nat. Sci., Philadelphia, p. 48.

[†] MEEK and WORTHEN, *Ibid.*, p. 49.

Anthrapalæmon Etheridgii, spec. nov. (Pl. VIII. figs. 3 to 3*g*; spec. char.). Carapace subovate, narrowest in front, and separated into two unequal areas by the cervical fold. It is strengthened by a marginal thickening, and produced anteriorly into a long serrated rostrum. The posterior angles are rounded, and the posterior margin slightly concave. It is further ornamented with five ridges, a central one which extends back from the apex of the V-shaped cervical fold to the posterior margin. In front of the cervical fold it is continued forward into the rostrum. On each side of this there is another ridge passing back to the cervical groove but not reaching the posterior margin. On the area in front each is continued as two oblong bosses placed upon a low mammiform protuberance. These are the supports of spines with which the three already mentioned ridges were furnished. The remaining two ridges run almost parallel with the lateral margins, but are not found in front of the cervical groove. Unlike the rest, these bear no traces of spines nor crenulations.

The rostrum, which is strong and conical, and about one-third of the length of the carapace, is ornamented with a central toothed crest and two lateral serrated flanges, and ends in a sharp point which is slightly bent upwards.

The eyes are large, reniform, and pedunculated, and placed at the angles made by the rostrum with the carapace which are rounded off into sockets.

The antennules are two, each made up of a propodite of at least three joints, broad, and horizontally flattened at the base and tapering forward. The last joint of each supports a pair of short tapering many-jointed setæ. The antennæ consist of a jointed propodite on each side, which supports a broad denticulated and corrugated basal scale. It also supports a long many-ringed lash, which seems thick at its base compared with the size of the animal.

The walking limbs, which appear to be five on each side, are stout and somewhat flattened laterally and directed forward. From what can be seen, they are made up of precisely the same elements as an ordinary monodactylate limb of a recent macrurous decapod. There is no evidence of any chelate limb.

The abdomen consists of six segments irrespective of the telson. The first two are narrow and highly facetted, allowing of a great deal of play in the joints. Seen from above the unfacetted part is very narrow, but it widens out laterally till past the pivots, when it expands into broad and rounded pleuræ. Those of the second segment overlap those of the adjoining ones both ways. Behind this the pleuræ are pointed, and overlap those of the succeeding segment. The third segment is also highly facetted, but is very much broader than any other of the abdominal rings. It is divided down the centre of the tergum by a depression in which rises a narrow ridge. The fourth and fifth are broad, but not divided medially. The sixth has a central ridge, which is continued into the telson. On each side it has a joint articulated with it, each of which supports a pair of expanded and rounded fin-like appendages, strengthened by a central or marginal thickening and fimbriated near their lower extremities. The telson is broad at its base, and tapers rapidly for about two-thirds of its length, where it becomes quite narrow. It then expands into a small, oblong, fimbriated flap, with which it terminates. At the points where the tapering ceases, a pair or perhaps two pairs of short spine-like appendages are articulated with it. Length, ¾ inch to 2 inches.

Observations.—The above characters have been made out from the study of over forty specimens, all of which were collected by A. MACCONOCHIE from Eskdale. The manner in which the animal is preserved shows that it must have been broader than deep, for out of the large number in the Survey collection, only one is found on its side. All the rest are preserved back upwards. When this is the case the three central ridges on the carapace appear but as if slightly crenulated, and it was only the specimen preserved on its side which showed that these were produced into spines which may be seen to be directed forwards (fig. 3). This taken together with the forward direction of the walking limbs, the overlapping of the pleuræ of the second abdominal segment both ways, and the overlapping of the pleuræ of those behind it only upon those of the next in succession, shows that this animal used the great tail-like apparatus made up of the telson and the flattened appendages of the sixth segment for swimming backwards, which is the mode of progression in the recent Macrura.

It is impossible from the manner in which the specimens are crushed to make out the relative position of the antennules and antennæ, and the maxillipedes are never recognisable. The characters on which the classification of the recent Macrura so much depend are therefore not reliable in the present case. The general symmetry of the parts best preserved has thus to be depended on for that purpose. This applies equally to the other Crustaceans here described. The thoracic segments in many cases show through the carapace in the manner described by Messrs MEEK and WORTHEN, and R. ETHERIDGE, junior, in the species described by them. Fig. 3*b* exhibits the endophragmal system of the thorax very completely. The segments are all soldered together except the hindermost. It also shows the gill supports ; five or six of these are well seen on one side lying in their proper position.

The only species already described with which this might be confounded is the *A. Woodwardi* of R. ETHERIDGE, junior,* my friend and predecessor in office, after whom I propose to call the present species. It is very much like it in general symmetry, though a much larger creature. It differs from it in the large size of its rostrum, which as well as the three central ridges of the carapace is produced into spines. It is considerably different in the abdominal segments, the third being much the largest, while in *A. Woodwardi* the last is the greatest. In *A. Etheridgii,* the telson broadens out at the tip while the

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* Quart. Journ. Geol. Soc. Lond., 1877, vol. xxxvii. p. 872, t. 27 ; vol. xxxv. p. 468, t. 23.

other is pointed. They differ also in the nature of the broadened tail-flaps of the sixth segment.

The ornamentation on the carapace and the broad basal scales of the antennæ distinguish it from *A. Gracilis,* Meek and Worthen.* The tail too is different, being not quite so complicated as in that species.

From *A. Hilliana,* Dawson,† the number of ridges on the carapace show it to be distinct.

Anthrapalæmon Parki, nov. spec. (Pl. IX. figs. 4 to 4*f*). Length from three to four inches, and breadth about one-third of the length, which is continued down to the sixth abdominal segment, where it expands into a remarkably wide tail.

Carapace two-fifths of whole length. When expanded it forms an irregular quadrilateral figure with rounded off corners, and which is a little narrower in front. The anterior margin is concave, and gives off a broad leaf-shaped rostrum. The posterior margin is also concave. The margins are strengthened by a broad thickening band, broadest at the posterior angles. A deep cervical groove, or folding in of the test, proceeds from the anterior angles forming an angle of 150° on the median line of the back and divides the carapace into two unequally sized areas. The posterior and larger is ornamented by seven ridges besides the marginal ones. The middle ridge alone is continued back from the cervical groove to the posterior margin, the next two on each side proceed from the cervical groove, but are lost before reaching it. The two remaining ridges are continued back from the cervical groove, and merge into the lateral thickened band at the posterior angles. The area in front is divided into several raised portions separated by depressions, but none of the ridges are continued on to it. One fold of the test overlaps the base of the rostrum, which is leaf-shaped, being narrow where it joins the carapace, expanding rapidly and then tapering off to a blunt point. The anterior portion is grooved medially and droops downwards. Neither the rostrum nor the ridges on the carapace bear any trace of spines or bosses. The test throughout is smooth or slightly wrinkled.

The Cephalic Appendages.—The eyes probably large, and set at the angles made by the rostrum with the carapace which are rounded into sockets. The antennules consist of two pairs of broadened and jointed peduncles, at least three joints are seen which are serrated at their bases, each of which supports two jointed setæ. The antennæ are two broad jointed peduncles which give off long jointed setæ. No broadened basal scale observed. The rest of the cephalic and thoracic appendages not observed. The abdomen consists of six segments without the telson. These are short in front, becoming gradually

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* Illinois Geol. Survey Report, 1866, vol. i. p. 407, pl. xxxii. fig. 4, *a*, *b*, *c*.

† Geol. Mag., 1877, vol. iv., new ser., fig. 1, p. 56.

longer, the sixth being the longest. The four posterior segments are ornamented by a broad marginal band anteriorly, which sends back an occasional buttress which is soon lost in the test, except in the case of the median one on the three last segments, which is continued to their posterior margins. Those in a line with the mesial and the two main lateral crests of the carapace are larger and more pronounced than the rest, and are continued down into the telson. As they approach that organ they become ornamented with occasional spines which gradually increase in size backwards. All the abdominal segments have large pleuræ pointed backwards. The appendages on the first five segments have not been observed. Those on the sixth consist of a broad joint articulated with it at the posterior angle on each side, each of which supports a pair of broad swimming flaps. That corresponding to the exopodite is strengthened by a strong, narrow, knife-blade-like rachis on its exterior margin. Its inner margin is supported by a conical spine which is directed towards the point of the knife-blade portion. The inferior and inner margins are broadened out into a flap, which is further strengthened by corrugations of the test. The endopodite is composed of a fin-like lobe with a central slender spine-like thickening, and is corrugated near the margins. The telson, which is broad at the base, tapers rapidly and increasingly for about half its length, whence it is continued into a long sharp spine and looks like the section of a boy's peg-top. At the angles made by what corresponds to the insertion of the peg, two pairs of short conical spines are articulated with it. The convexity of this species is slight, as it is invariably fossilised with its back upwards.

Observations.—Besides the above external characters, the specimens in the Survey collection show several points in its anatomy. The eyes as seen, fig. 4*a*, seem to have been large, but they are so much crushed that their original form cannot be made out. Nothing can be said about the maxillæ or maxillipedes, though there is little doubt that the confusion in the carapaces of figs. 4*a* and 4*b* is caused by their being crushed through it. Part of the confusion is, doubtless, owing to the hard parts of the stomach and the endophragmal system. In fig. 4 the thoracic segments are seen shining through the carapace, and on one side the branchial arches are also distinguishable. In the abdominal segments the sternal arches are seen to be pressed up through the tergum, fig. 4. Their epimera are almost as broad as the basis of the pleuræ, but the sternæ are very narrow, which shows that the segments to which these belong had a great deal of play. The tail is enormous compared with the size of the creature, and must have been a most effective organ for swimming backwards. As it is now found, in many cases the strengthening ridges only are preserved, as in figs. 4 and 4*a*, and these give to the creature a very formidable aspect. Fortunately other specimens, as in fig. 4*c*, show the true nature of them. The sharp knife-blade-like portion of the exopodite is ornamented on its exterior margin by five or six strong conical spines, the broken bases of which are seen in figs. 4 and 4*c*, set in hollows to receive them. Two little reniform bosses are seen on each of the abdominal segments as well as the telson. The tip of the rostrum has not been observed, as it usually buries itself into lower strata than the plane in which the body lies. The test is very thin, and probably contained very little calcium carbonate, as it is apt to be filled with calculi, such as that now found in the common shrimp. Where the test is thin these are mere scales; but in the spines and thickened portions they are semi-globular, the rounded part being mammilated. In every case, however, they have a central nucleus from which radiations proceed. The above remarks are equally applicable to all the Crustacea described in the present paper. Sometimes these calculi are sporadic, at other times they fill the whole tests of the creatures, forming an irregular polygonal net-work, which destroys the character of the test and gives it a granulated appearance. Even in this case the nucleus and radiations are observable. Fig. 4*g* represents a portion of the carapace of fig. 4, magnified about four diameters exhibiting these calculi. Fig. 4*h* is part of the test of the common shrimp *Grangon vulgaris*, affected in a similar manner and magnified about ten diameters. I propose to call this species after my friend Walter Park, Esq., Langholm, Dumfriesshire. Though A. Macconochie was the first discoverer of the species, Mr Park was the finder of the specimen from which fig. 4*d* is taken, which he not only handed over to the Geological Survey, but generously offered to its collection anything new which might turn up to his hammer. Dr Traquair was fortunate enough to disinter the magnificent specimen represented by fig. 4. The illustrations are all natural size. Fig. 4*d* is an outline drawing of a portion of the carapace and the abdomen to show to what a size this species sometimes attained. A portion of the right side of a carapace, shown in fig. 4*e*, must have belonged to a still larger individual.

Anthrapalæmon Traquairii, nov. spec. (Pl. X. figs. 5 to 5*f*). Carapace short compared to length of body, subovate, posterior margin concave, anterior margin produced into a rostrum as long as the rest of the carapace. The only ornament is a broadened margin slightly crenulated. Cervical fold not distinguishable from the other wrinkles of the test. Test smooth and exceedingly thin. Rostrum broad at the base and gradually tapering to a point, the upper line is slightly hollow and near the point is bent downwards. It is strengthened and deepened by a central keel beneath. A transverse section just in front of the eye would represent a capital T. Though there are several longitudinal grooves near its base, there appear to be no spines.

Cephalic and Thoracic Appendages.—Eyes stalked and placed on each side of rostrum, which is hollowed out to form with the margin of the carapace a sort of socket. Antennules consist of two lengthened, apparently jointed propodites, each supporting a pair of filamentous whips, which are cylindrical near their base, and then become flattened and broadened somewhat before they taper rapidly at the tips. Antennæ made up of jointed propodites with prodigiously large bidenticulated basal scales. Each propodite also supports a long cylindrical many-ringed lash. The remaining cephalic appendages not distinctly observable.

The walking legs, ten in number, are long and thin in their proportions, and somewhat flattened laterally. Their penultimate joints are even more so, and, as well, are strengthened by longitudinal flanges. The dactylopodites are sharp and spinose, and none of the limbs appear to be chelate.

Abdomen long, and tapering backwards, composed of six segments, the last being the longest and much the narrowest. Their only ornament is a slightly thickened band along their anterior margins and a fold of the test along the median line of the sixth segment. They all possess triangular, pointed pleuræ directed backwards. Those of the second segment overlap each way, the next three only overlapping those immediately in their rear. No appendages observable except on the sixth segment, which supports at each posterior angle a broad joint, to each of which are articulated a pair of expanded flaps. The strengthened part of the exopodite is much broader than in *A.Parki*. The telson is similar to that of *A. Parki*, but is narrower and more hastate. It also supports a pair of spine-like appendages on each side.

Observations.—This species somewhat resembles *A. Parki*, but is easily distinguished from it by the general shape being much more elongated and tapering backwards, by the absence of the ridges on the carapace, by the long rostrum, by the sudden tapering of the body at the spring of the tail, by the telson, and by its possessing large basal scales to its antennæ.

Other points in the anatomy of this species can be made out from some of the specimens. The pedipalps of the maxillipedes were in all probability very long, and extended in front to near the tip of the basal scales of the antennæ. The walking limbs seem all to have been simple, as in fig. 5*a*, ten limbs are accounted for, and none seems to be much more enlarged than the rest. They agree part for part with the hinder limbs of *Nephrops Norvegicus*, which they greatly resemble. In figs. 5*a* and 5*b* the coxopodites of five limbs on one side are observable attached to the thorax. Among the confusion produced by the crushing together of the gills and endophragmal system, exposed by the carapace being lifted in fig. 5*a*, one small fragment of the gill, apparently belonging to the fifth thoracic segment, is preserved. When magnified it shows a structure like that of the gill of *Palæmon*, fig. 5*e*.

The convexity of this species must have been considerable, for the individuals are as often found on their sides as with their backs upwards. When fossilized sideways the limbs are not crushed up into the body, and are more likely to be preserved in a state fit for studying (figs. 5*a*, *b*, and *c*). This also applies to all the other species.

I have named this species after my friend RAMSAY H. TRAQUAIR, M.D., who is describing the fishes got from the same beds with the above, and who has handed over to the Survey such Crustaceans as he has been enabled to collect during his visits to that locality.

Anthrapalæmon Macconochii, R. Etheridge, Jun; *Antrapalæmon Macconochii*, Quart. Journ. Geolog. Soc., 1879, vol. xxxv. p. 471, pl. 23, fig. 10, Pl. VIII. figs. 6 to 6*d*.

The description of the carapace of this species (all of it then known) by R. ETHERIDGE, Jun., is so complete that it is unnecessary to add to it. Two specimens have recently come to light among those since collected by Mr MACCONOCHIE which exhibit some of the cephalic appendages as well as the body segments and telson in place. The study of these entirely confirms Mr ETHERIDGE's opinion that the carapace he described belonged to a macrurous decapod.

Cephalic Appendages.—The eyes are large and stalked, and placed on each side of the rostrum. The antennules consist of two pairs of short conical many-jointed setæ, each pair supported upon a single peduncle, two joints of which appear beyond the apex of the rostrum. The antennæ are composed of broad peduncles, each of which supports a lash which is many-ringed. These are very thick at the base when the size of the animal is taken into consideration. No basal scale observed.

The abdomen is short compared with the carapace, and made up of six segments, the anterior ones being the narrower. The posterior angles of the carapace project backwards and inwards like horns, and overlap as far as the anterior margin of the fifth segment, so that all those so confined are necessarily narrow. The sixth expands considerably beyond the tips of the horns, and supports a joint on either side, to each of which are articulated a pair of broad, rounded, and flattened swimming flaps.

The telson is broad where articulated with the sixth segment, whence it tapers rapidly for a little over half its length, and then expands once more into a rounded and fimbriated flap. At the narrowest part it has articulated with it on each side a pair of small flaps, so that the tail, made up of all the above elements, is a most effective paddle.

Observations.—The tail greatly resembles that of *A. gracilis*, Meek and Worthen,* but the carapace is sufficient to distinguish it from that species at a glance.

Locality.—Tweeden Burn, Newcastleton, Liddesdale.

Horizon.—Cement-stone group, Calciferous Sandstone series.

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* Proceedings, Acad. Nat. Science, Philad., May 1865, p. 80.

Anthrapalæmon ornatissimus, nov. spec. (Pl. VIII. fig. 7). All that is known of this is obtained from the portions of two carapaces on one slab of grey cement-stone from Larriston Burn, near head of Liddesdale.

Carapace about half an inch long, subovate, and produced anteriorly into a long denticulated rostrum. The posterior angles and margin not observed.

It has a deep cervical groove, and is ornamented by a thickened margin, which bears two or three rows of small tubercles. The medial line of the back bears a slight ridge, which passes back from the apex of the cervical groove, is lost in the carapace before reaching half way to the posterior margin. It bears no tubercles, and does not occur in front of the cervical fold, where its place is represented by a large pyriform elevation. Another line of ridge on each side passes back from the cervical fold and runs almost parallel with the marginal one. This supports two or three rows of tubercles. At the cervical fold it bifurcates, and one branch crosses the fold, and merges into the margin at the anterior angle, the other branch coalesces with the margin behind the fold. The area in front of the cervical fold is further divided into several raised portions by deep sulci. The whole test is studded with minute bosses which are much the smallest on the parts of the carapace that are not ridged. It is from this character that it derives its name.

Observations.—This species resembles *A. Macconochii*, R. Etheridge, Jun., but is distinguished from it in having its test covered with minute bosses. The central ridge is not continued back to the posterior margin, does not appear on the area in front of the cervical fold, and does not bear large tubercles. The other ridges have a double or treble row of tubercles, and the rostrum is much larger and denticulated.

Locality.—Larriston Burn, Upper Liddesdale.

Horizon.—Cement-stone group, Lower Carboniferous.

Anthrapalæmon formosus, nov. spec. (Pl. VIII. fig. 8). Carapace quadrilateral, little narrower in front than behind. Anterior margin concave, and produced into a long-toothed rostrum. Posterior margin concave, and posterior angles rounded. Lateral margin bulging, and strengthened by a thickened band, which is broadest in front. There is a deep cervical groove. On the greater area behind this, only two ridges occur, one on each side, close to, and parallel with, the lateral margin. These pass from the cervical groove to the posterior margin; they end in front in a couple of spines, which overlook the groove. With the exception of these, they are quite plain. On a raised mound in front of the cervical groove a line of four or five separate spines passes from the interior angle of the fold into the median line of the rostrum. Two sulci divide this mound from two similar mounds, one on each side, each of which supports two separate spines. Along these latter a single spine is set behind the cervical groove. As well as the central ridge of spines, the rostrum bears two lateral serrations.

Observations.—This small species somewhat resembles *A. Etheridgii* in shape and in being spinose, but the absence of the three central ridges on the carapace possessed by that species distinguishes it. It is not likely to be confounded with any other described species.

Locality.—River Esk, 4 miles south of Langholm, Dumfriesshire.

Horizon.—Cement-stone group, Lower Carboniferous.

Genus, *Palæocrangon,* Salter, 1861; *Uronectes,* Salter, Trans. Royal Soc. Edinburgh, vol. xxii. p. 394; *Palæocrangon,* Salter, 1861, Quart. Journ. Geol. Soc. vol. xvii. p. 533.

Palæocrangon Eskdalensis, nov. spec. (Pl. VIII. figs. 9 to 9*i*). A shrimp-like creature, about 1½ to 2 inches in length. Carapace one-third of the length of the body without the appendages. Seen sideways, it is subquadrate, narrow, and blunt in front, and produced into rounded lobes posteriorly, which extend beyond the posterior margin on the middle line of the back, and overlap the pleuræ of the first abdominal segment. The only ornament is a slight marginal ridge, and the anterior margin is slightly serrated or denticulated. A fold of the test which runs almost parallel with and very near to the anterior margin, and which supports two or three denticles, may represent the cervical groove. The rostrum is not much larger than one of the denticles on the anterior margin. Eyes elongated and pedunculated. The antennules are made up of long three or four jointed propodites, upon each of which are placed two equally long jointed setæ. The antennæ are made up of long many-jointed flagellæ and broad basal scales, the tips of the latter not extending beyond the propodites of the antennules. Of the other appendages belonging to the cephalothorax only a doubtful appearance of a maxillipede has been observed, and represented in fig. 9*c*, but its component parts are not traceable.

The abdomen is cylindrical, and tapers each way from the third segment. It is made up of six segments, each slightly modified to suit the region where it is placed. The first is a mere narrow ring articulated with the last thoracic segment, and has small pleuræ. The pleuræ of the second expand into rounded saddle-flap like lobes, which overlap those of the segments both in front of it as well as behind. At the pivot where this one moves upon the first segment, the anterior margins of the pleuræ are bent forwards at almost a right angle till they touch and overlap the posterior lobe of the carapace, so that the pleuræ of the first segment are entirely hidden. The third, fourth, and fifth segments have pointed pleuræ directed backwards and overlapping their succeeding neighbours. The sixth segment is much longer than any of the rest, and forms a conspicuous feature.

Abdominal Appendages—The appendages on the first abdominal segments seem to be modified for sexual purposes. Figs. 9*b* and 9*c* show articulated with this a stout longish limb-like appendage, made up of five joints, which reminds one somewhat of the corresponding modified limb of the male cray fish, *Astacus fluvialitis,* only it is much larger in proportion. The best preserved case of this is shown magnified in fig. 9*f.* Analogy would incline one to look at those other individuals exhibiting the above character as males. The appendages on the next four segments appear as short and flattened, the segmentation not being traceable in the present state of preservation. The appendages of the sixth segment are made up of the broad propodites articulated with it at its posterior angles, each of which gives rise to a pair of swimming flaps with strengthened ridges ; those of the exopodite are blade-shaped and slightly curved outwards. The telson is long and hastate, and supports a couple of spines on each side. Test smooth, or only slightly pitted in appearance very like that of a shrimp.

Observations.—It will be at once observed, from the enlarged lobes of the second abdominal segment and their overlapping each way, that it was here the animal doubled itself while swimming, just as in our recent shrimps. Like *P. socialis,* Salter, it often occurs in great numbers. It differs from that species in the shape of the carapace and in the pleuræ of the first and second abdominal segments as well as in the more elongated telson.

Locality.—River Esk, 4 miles south of Langholm, Dumfriesshire.

Horizon.—Cement-stone group, Lower Carboniferous.

Note.—Since the above was written, the Rev. THOMAS BROWN, F.R.S.E., in whose possession the specimens of *P. socialis* are from which Mr SALTER made the genus, has kindly allowed me to see them. There is no doubt that our *P. Eskdalensis* belongs to the same genus, but there is sufficient difference to warrant its being ranked as a separate species.

Genus *Palæocaris,* Meek and Worthen, 1865, Proc. Acad. Nat. Sci., Philadelphia, 1865, p. 48.

Palæocaris Scoticus, nov. spec. (Pl. X. figs. 10 to 10*h*). Body long and narrow, and tapering backwards. Length from $\frac{1}{4}$ of an inch to 1 inch. The carapace only extends over the cephalic segments, and measures about two-sevenths of the body irrespective of telson and appendages. It is rounded in front, and its posterior margin somewhat concave. It is divided into several areas by deep sulci. One of these of a V-shape extends slightly back from the anterior margin, and has its apex directed backwards. Other two proceed from the anterior portion of the lateral margins, and reach the posterior margin after having performed crescent-like curves, the convex sides of which are directed inwards; from these latter short grooves inwards proceed, but do not meet on the median line.

Cephalic Appendages.—No eyes have with certainty been observed. Antennules two, each made up of a long propodite of three or four cylindrical joints supporting two many-jointed whips, the tips of which have not been preserved, so that nothing can be said as to whether the outer or inner be the longer. The antennæ consist of a shorter and thicker propodite, which supports a rounded basal scale and a many-jointed flagellum, which is much stouter than those of the antennules, and probably extended much beyond them, though only the bases are now preserved. The other cephalic appendages have not been observed.

Thorax and abdomen are composed of similar segments, which are twelve in number; those of the thorax not having the terga and pleura soldered together nor confluent with the carapace. All are free to move on each other, and are composed exactly like a typical abdominal segment of a decapod. Each ring exhibits a tergum flanked by pleuræ, which are marked off from it by a folding in of the test. These grooves are continued backwards from those already mentioned as occurring on the carapace to the anterior lateral margins of the telson. The pleuræ are pointed, and directed backwards. The body tapers gradually from the second thoracic segment. The three last abdominal segments are ornamented on the terga with two ridges, situated just within the grooves, and these are continued on the telson. No appendages have been with any certainty seen on any of the above segments, except on the last abdominal one, which supports a joint at each posterior angle. To each of these are attached a pair of broadened swimming flaps, the strengthening portions of which are usually alone preserved as flattened spines; those of the exopodite being the longer and more pronounced. The telson is shield-shaped, broad at the base and tapering almost to a point, and then suddenly broadening out spoon-fashion at the tip. At least one pair of small spines are attached to it immediately above its narrowest part. The tail is in character quite that of a macrurous decapod. The test is ornamented all over with slight corrugations, which, along with a metallic lustre the fossil usually presents, makes the slightest fragment recognisable.

Observations.—This species was found by A. Macconochie at the locality on the Esk where the other fossils were procured, and from which about thirty specimens have been obtained. From the nature of the matrix, which is a sandy and calcareous shale, and the fact that the test of even these tiny creatures are infested with innumerable calculi of the character already described, they cannot be studied as narrowly as might be wished. For instance, although in most of the specimens there occur small oblong bosses just in the place where their eyes should be, were they decapods, figs. 10–10*d*, yet the facets of the cornea have been looked for in vain. This is unfortunate, as it prevents one from saying with certainty that these are the eyes, though there is a strong presumption in favour of their being so. No sessile eyes have been observed on the carapace, neither has a trace of anything been observed that could be construed into such. The nature of the other cephalic appendages preserved is quite that of the decapods, and the same is the case with the tail (see figs. 10–10*e*). The general appearance of the thorax and abdomen much resembles the Isopods, but this is only seeming. Nothing can be said of the walking feet or those of the first five abdominal appendages, as in no specimen yet obtained have these been preserved in a state to be studied, though in some cases there is a faint appearance as if of something of the kind.

In the specimen represented by fig. 10*b*, which is among the few that has been fossilised on its side, the appearance of several segments shows through the carapace. The lobe of the carapace is wrinkled with lenticular sigmoid markings which may possibly represent the gill arches showing through. It also overlaps the pleura of the first thoracic segment so as to entirely hide it, which lends additional strength to this supposition, as it indicates how free it is. As far as the present specimens go to show the affinities of these small crustaceans, I am inclined to the belief that they are lowly decapods, somewhat like the opossum shrimp (Schizopods), though not necessarily identical with them. For comparison, I have reproduced the figures which Messrs MEEK and WORTHEN give of their *P. typus* in the Memoirs of the Geological Survey of Illinois, vol. ii. pl. xxxii. Fig. 10 is fossilised back up, as most of ours are. In it thirteen segments are shown in the combined thorax and abdomen, but the depressions which appear to form the first do not meet in the middle, I am inclined to look upon it as belonging to the head, and the sulci as analogous to those seen in the head of our specimens. The same may be said of fig. 10*g*. If that be the case, the number of segments in each is the same. The American specimens seem to be preserved more in the round than the present ones, hence their generally narrower appearance and their not exhibiting the lobes of the carapace. Fig. 10*h* is the restored tail of *P. typus*, alongside which, fig. 10*e*, a restoration of that of *P. Scoticus*, from the study of more than twenty specimens, is put for comparison.

As far as I am aware, this is the first species referable to the genus *Palæocaris* that has been procured from British strata.

Note 1.—The study of the tails of the macrurous decapods, described in the present paper, tends to confirm the opinion of those who hold that the telson in the Macrura is only a modified body segment, for all the telsons that are sufficiently well preserved to retain them have two small swimming flaps or spines articulated with them on each side. These appear to be modified appendages and probably represent the exopodites and endopodites of those of the other segments. Even the lowly *Palæocaris* exhibits these articulations.

In the interval between the reading the present paper and its printing, I have been enabled to study several more Carboniferous Macrura. Some new species of *Palæocragon,* each showing the swimming flaps flanking the telson and articulated with it; also a large suite of fossils of macrurous decapods intermediate between *Palæocaris* and *Anthrapalæmon,* in having only two or three of the thoracic segments covered by the carapace, and the sterna of these not soldered together, and they all exhibit the spines or flaps on the telson. The small spines articulated at the posterior angles of the telsons of our recent shrimps and prawns are evidently a survival of what has once been a useful character of their more ancient progenitors. It seems a pity to disturb the seemingly satisfactory and complete number twenty for the segments of the typical crustacean by adding another to make it twenty-one, but the present evidence favours the latter number.

Note 2.—Since the above was written, a paper read by M. P. Brocchi before the Geological Society of France, in Nov. 1879, and published in the Bulletin of that Society in March 1880, on a "Fossil Crustacean, from the Schistes d'Autun" (Upper Carboniferous or Lower Permian), has come before my notice. After a careful perusal of his paper, I have not been able to satisfy myself with the conclusions M. Brocchi arrives at regarding the systematic position he assigns to the genus *Palæocaris,* Meek and Worthen, which he includes in his new division of the Amphipoda, the *Nectotelsonides.* His reasoning, based upon the first thoracic limbs not being modified into prehensile organs, disappears in the light of such forms as *Anthrapalæmon Traquairii* and *A. Etheridgii* described in the above paper, or the recent *Palinurus vulgaris,* whose limbs are not so modified, but in which the decapod characters are undoubted. Such evidence as the specimens of *P. Scoticus* afford are in favour of decapod affinities, and I therefore retain the classification latterly adopted by Messrs Meek and Worthen, which M. Brocchi has apparently overlooked.*

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* Memoirs of the Geological Survey of Illinois, vol. iii. p. 552, 1868.

EXPLANATION OF PLATES.

PLATE VII.

Fig. 1.—*Ceratiocaris scorpioides,* showing the general form. The carapace is slightly displaced, and exposes some of the segments which during life were covered by it. Jaws seen near anterior margin of carapace. Nat. size. Locality—River Esk, 4 miles south of Langholm, Dumfriesshire.

Fig. 1*a.*—*Ceratiocaris scorpioides,* showing carapace slightly displaced, jaws, &c. Nat. size. Same locality.

Fig. 1*b.*—Cast of jaws of fig. 1, magnified.

Fig. 1*c.*—Crushed jaw of fig. 1*a,* magnified.

Fig. 1*d.*—Tail spines of fig. 1*a,* magnified.

Fig. 1*e.*—Magnified tail spines of another specimen of *Ceratiocaris scorpioides,* from the same locality.

Fig. 1*f.*—Magnified tail spines of another specimen of *Ceratiocaris scorpioides,* from the same locality.

Fig. 2.—*Ceratiocaris elongatus,* showing all but last joint and tail spines. Carapace displaced so as to show some of the segments which it should cover. Jaws seen *in situ.* Nat. size. Same locality.

Fig. 2*a.*—Anterior portion of *Ceratiocaris elongatus,* showing lobe of carapace wrinkled, and notch in ventral surface of third segment frontal. Nat. size. Same locality.

Fig. 2*b.*—*Ceratiocaris elongatus,* showing intestinal canal. Nat. size. Same locality.

Fig. 2*c.*—Showing natural size of last body segment and tail spines of *Ceratiocaris elongatus.*

Fig, 2*d.*—Portion of tail spine of fig. 2*c,* magnified, to show ornamentation.

Fig. 2*e.*—Tail of new species of *Ceratiocaris* from the Upper Silurian (Wenlock) Rocks of Roxburghshire, for comparison of ornament with fig. 2*d.*

Fig. 2*f.*—Ornament of 2*e* magnified.

PLATE VIII.

Fig. 3.—*Anthrapalæmon Etheridgii,* magnified 2 diameters. Locality—River Esk, 4 miles south of Langholm, Dumfriesshire.

Fig. 3*a.*—*Anthrapalæmon Etheridgii.* Nat. size. Same locality.

Fig. 3*b.*—*Anthrapalæmon Etheridgii,* to show endophragmal system and gill supports. Magnified 2 diameters. Same locality.

Fig. 3*c.*—Portion of carapace of *Anthrapalæmon Etheridgii,* to show the number and nature of its ridges. Nat. size. Same locality.

Fig. 3*d.*—*Anthrapalæmon Etheridgii,* anterior portion of carapace, to show the antennæ and their basal scales. Magnified about 3 diameters. Same locality.

Fig. 3*e.*—Magnified portion of specimen of *Anthrapalæmon Etheridgii,* to show eyes. Magnified about 3 diameters. Same locality.

Fig. 3*f.*—Magnified portion of another specimen of *Anthrapalæmon Etheridgii*, showing antennæ, with their basal scales. Magnified 4 diameters. Same locality.

Fig. 3*g.*—*Anthrapalæmon Etheridgii.* Magnified dorsal portion of second abdominal segment, to show nature of ornament of test. Same locality.

Fig. 6.—*Anthrapalæmon Macconochii*, R. Etheridge, Jun., showing body segments and cephalic appendages. Nat. size. Locality—Tweeden Burn, Newcastleton, Liddesdale.

Fig. 6*a.*—*Anthrapalæmon Macconochii.* Nat. size. Same locality as preceding.

Fig. 6*b.*—Carapace of *Anthrapalæmon Macconochii*, to show nature of ornament. Nat. size. Same locality.

Fig. 6*c.*—*Anthrapalæmon Macconochii.* Magnified anterior portion of fig. 6, showing eyes, antennules, and antennæ.

Fig. 6*d.*—Tail of *Anthrapalæmon Macconochii*, magnified from fig. 6.

Fig. 7.—*Anthrapalæmon ornatissimus.* Nat. size. Locality—Larriston Burn, Upper Liddesdale.

Fig. 8.—*Anthrapalæmon formosus.* Nat. size. Locality—River Esk, 4 miles south of Langholm, Dumfriesshire.

Fig. 9.—*Polæocrangon Eskdalensis.* Nat. size. Same locality.

Fig. 9*a.*—*Polæocrangon Eskdalensis*, showing eye, antennules and antennæ. Nat. size. Same locality.

Fig. 9*b.*—*Polæocrangon Eskdalensis*, showing antennules and basal scale of antenna, appendages, &c. Nat. size. Same locality.

Fig. 9*c.*—*Polæocrangon Eskdalensis*, exhibiting same as above. Nat. size. Same locality.

Fig. 9*d.*—*Polæocrangon Eskdalensis.* Nat. size. Same locality.

Fig. 9*e.*—Carapace and basal scales of antennæ of *Polæocrangon Eskdalensis.* Nat. size. Same locality.

Fig. 9*f.*—Modified appendage of first abdominal segment of *Polæocrangon Eskdalensis.* Magnified from Fig. 9*b.*

Fig. 9*g.*—Last abdominal segment and tail of *Polæocrangon Eskdalensis.* Nat. size. Same locality.

Fig. 9*h.*—*Polæocrangon Eskdalensis.* Last abdominal segment and tail. Nat. size. Same locality.

Fig. 9*i.*—Eye of fig. 9*a*, to show the crushed facets of cornea. Highly magnified.

Fig. 9*k.*—Restoration of tail of *Polæocrangon Eskdalensis*, from the study of a great number of specimens from the above locality.

PLATE IX.

Fig. 4.—*Anthrapalæmon Parki*, showing antennules, antennæ, rostrum, abdomen, and tail. Nat. size. Locality—River Esk, 4 miles south of Langholm, Dumfriesshire.

Fig. 4*a.*—*Anthrapalæmon Parki*, showing carapace, rostrum, eyes, antennæ, three abdominal segments, and tail. Nat. size. Same locality.

Fig. 4*b.*—*Anthrapalæmon Parki*, to show nature of ornament on carapace. Nat. size. Same locality.

Fig. 4*c.*—Last abdominal segment and tail of *Anthrapalæmon Parki*, showing that the spines in the other specimens are portions of fin-like lobes, shows spinelets on the outer margin of the exopodite and small spines articulated with telson. Nat. size. Same locality.

Fig. 4*d.*—Outline of specimen of *Anthrapalæmon Parki.* Natural size, to show to what a size they sometimes attained. Same locality.

Fig. 4*e.*—Outline of portion of right margin of carapace of still larger individual. Nat. size. Same locality.

Fig. 4*f.*—Restored tail of *Anthrapalæmon Parki*, made out from the study of a large suite of specimens.

Fig. 4*h.*—Portion of test of common shrimp (*Crangon vulgaris*), highly magnified as a transparent object, to show nature of calculi which infest it.

Fig. 4*g.*—Portion of carapace of fig. 4, *Anthrapalæmon Parki*, showing similar calculi in these ancient crustaceans, magnified 3 diameters, as an opaque object.

PLATE X.

Fig. 5.—*Anthrapalæmon Traquairii*, showing general proportions. Nat. size. Locality—River Esk, 4 miles south of Langholm, Dumfriesshire.

Fig. 5*a*.—*Anthrapalæmon Traquairii*, fossilised sideways, shows carapace, rostrum, eyes, antennules, antennæ, with basal scales, coxæ of walking limbs, walking limbs, gills, and portions of six abdominal segments. Nat. size. Same locality.

Fig. 5*b*.—*Anthrapalæmon Traquairii*, exhibits portions of ten walking limbs. Nat. size. Same locality.

Fig. 5*c*.—*Anthrapalæmon Traquairii*, showing walking limbs. Nat. size. Same locality.

Fig. 5*d*.—Basal scales of antennæ of *Anthrapalæmon Traquairii*. Nat. size. Same locality.

Fig. 5*e*.—Highly magnified portion of gill of fig. 5*a*.

Fig. 5*f*.—Restored tail of *Anthrapalæmon Traquairii*, made out from the study of several specimens which are not figured for comparison with that of *A. Parki*.

Fig. 10.—*Palæocaris Scoticus*, magnified 2½ diameters. Same locality.

Fig. 10*a*.—*Palæocaris Scoticus*, showing antennules, antennæ, with basal scale. Magnified 3 diameters. Same locality.

Fig. 10*b*.—*Palæocaris Scoticus*, fossilised sideways, shows rostrum, eye (?), segments appearing through carapace, and overlapping of lobe of carapace over the pleura of first thoracic segment. Magnified about 2 diameters. Same locality.

Fig. 10*c*.—Head and appendages of *Palæocaris Scoticus*, magnified 5 diameters to show rostrum, eyes (?), antennules, antennæ with basal scale, and folds of carapace. Same locality.

Fig. 10*d*.—Another specimen, magnified 5 diameters, showing the same cephalic appendages as fig. 10*c*. Same locality.

Fig. 10*e*.—Restoration of tail of *Palæocaris Scoticus*, from the study of over 20 specimens, to compare with fig. 10*h*.

Fig. 10*f*.—Reproduction of figure of *Palæocaris typus*, of Messrs Meek and Worthen, from the Memoirs of the Geological Survey of Illinois, U.S.A., vol. ii. plate 32, for comparison with *P. Scoticus*.

Fig. 10*g*.—*Palæocaris typus*. Reproduction of Messrs Meek and Worthen's figure, *ibid.*

Fig. 10*h*.—Reproduction of Messrs Meek and Worthen's restoration of their *Palæocaris typus*, *ibid.*, to compare with fig. 10*e*.


1.


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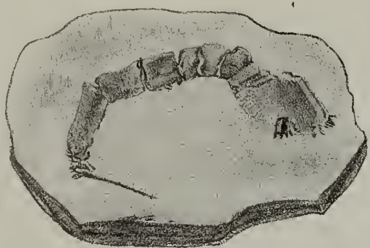
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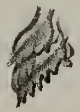
1 c.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1 e.

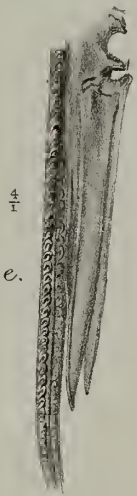

1 f.


2.


2 c.


2 a.


2 d.



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2 b.

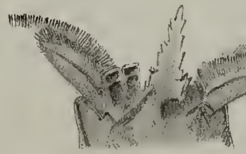

2 f.


3.


3c.


3b.


3g.


3d.


3a.

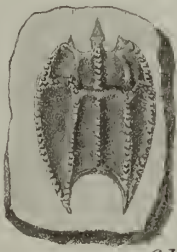

3f.


3e.


8.


6a.


6.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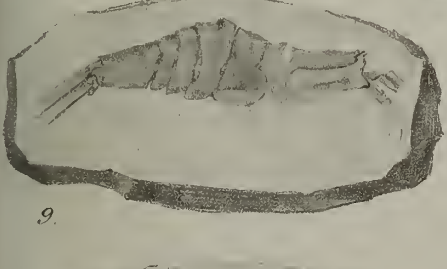
6c.


7.


6d.


9f.


9i.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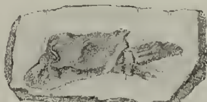
9b.


9c.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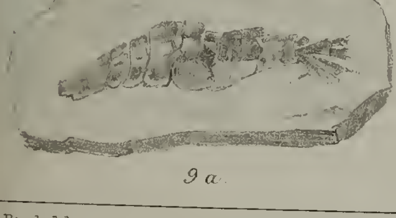

9a.


9k.


9g.


9h.


9d.

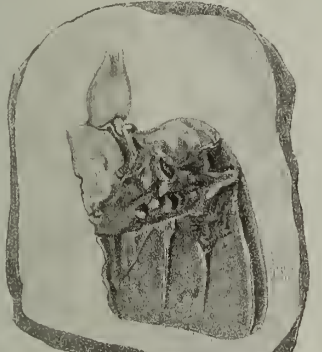
B N Peach, del.

F. Huth, Lithr. Edinr.

4.

4 e.

4 a.



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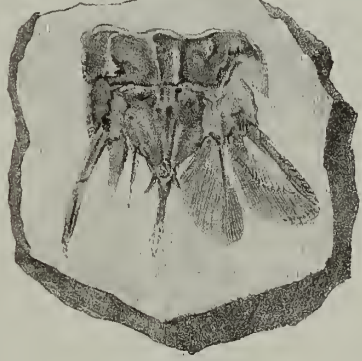

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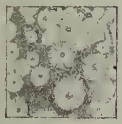

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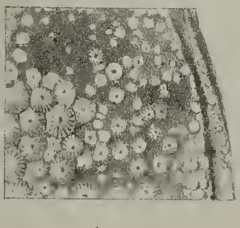
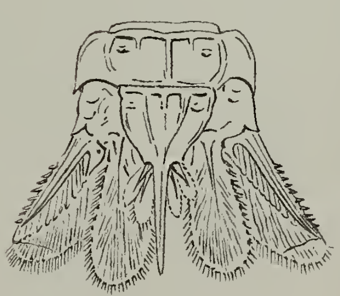


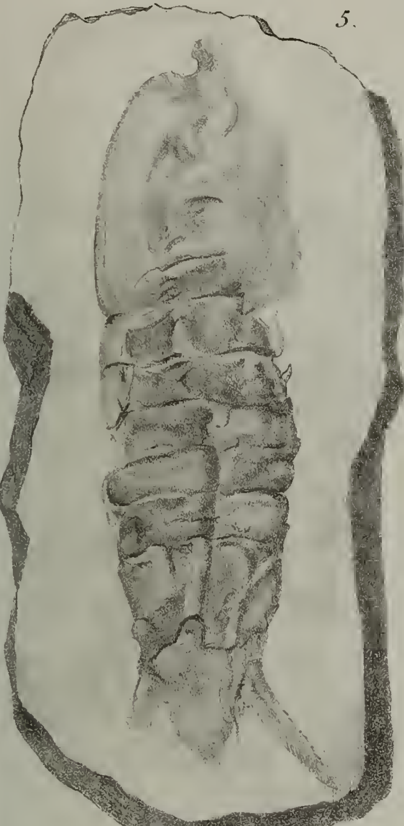
4 g.



4 f.

B N. Peach, del.

F. Huth, Lith^r Edin^r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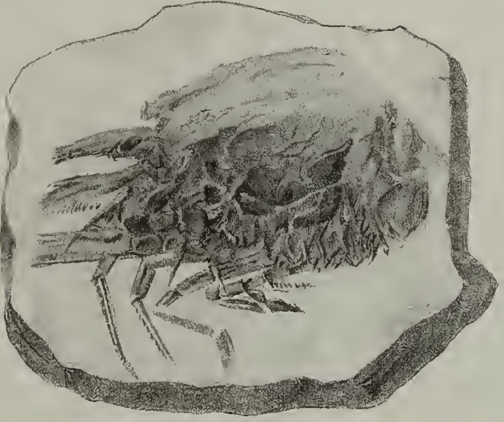
5 e.


5 a.


5 d.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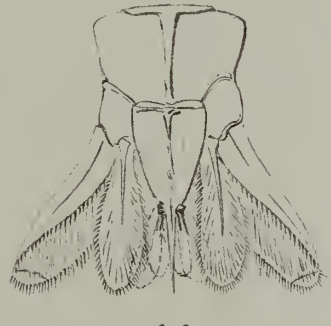
10 d.


5 c.


5 f.

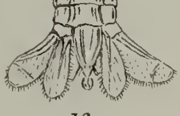

10 b.


10.


10 a


10 f.


10 g.


10 e.


10 h

10 c.

B N Peach, del. F. Huth, Lithʳ Edinʳ

V.—*Gaseous Spectra in Vacuum Tubes, under small Dispersion and at low Electric Temperature; including an Appendix* III., by Prof. Alexander S. Herschel, M.A., Newcastle-on-Tyne. By Piazzi Smyth, F.R.S.E., and Astronomer Royal for Scotland. (Read July 19, 1880).

CONTENTS.

GENERAL INTRODUCTION.

Of all the various spectra which the progress of experimental science has enabled man to observe in the present day, none are so rich, varied, and important, as those of gases. And no wonder! for it is only when matter has been reduced to the gaseous condition, that it is able to specialise itself and write its character with much of its history in any otherwise smooth, undefined, continuous spectrum; while, if in former times, men would have found it an impossibility to drive many of the more refractory substances into the state of incandescent vapour, what is there now anywhere on the surface of this earth which, in small quantity, can resist the action of a powerful and condensed induction spark of electricity; and what application of that spark is so neat, elegant, convenient, and economical, as when it is employed in conjunction with so-called gas-vacuum tubes.

In these tubes the infinitesimally small weight of the inch or two of almost utterly rarefied gas which they contain, offers immense facilities to the electricity for dealing with it, so that a moderate size of galvanic battery, and a very little coil or sparking apparatus is all the observer needs to produce whatever light and heat he requires; while a single small box with a dozen or two of thin glass vacuum tubes, each charged with a residuum of some particular gas, will enable him to inquire at any moment that he pleases, into the physical constitution of what makes up near half the universe. And this, too, without having to go through any chemical processes for procuring each gas whenever he wants it, in its extremest purity, and utter deadliness too, it may be.

The heroic maker of the tubes ran that danger, and the subsequent fortunate possessor of them when made and hermetically sealed, has only to observe the spectra which the gaseous traces give out from the depths of their transparent prison-house, according to their *labels*, if duly attested and warranted by the maker, when the spark is passed through them.

But what security, do you ask, can a mere label, though warranted by any maker, or even your own observed spectrum for that matter, give as to the reality and purity of the particular element of chemical matter supposed to be under examination? and do these tubes last? and do the gases in them never weaken, or change, or leak out, you wish to know? Well, all *that* is really very important, both to be inquired into and to be published upon; and it is, in fact, precisely what I have been looking into practically for a considerable length of time past; with great hopes too at last of helping this mode of research to become, if not easier and more elegant than it has already been made by others, yet safer, truer, and more powerful than ever.

The beginning of these latter-day attempts of mine was made in this way:—Twenty vacuum tubes of different gases and one or two volatilizable liquids and solids, such as alcohol, iodine and sulphur, were procured in duplicate from the late M. GEISSLER, in the form finally arranged with a capillary-central tube by the late Professor PLUCKER of Bonn. But when their spectra were found by me, generally faint, vague, and uncertain, a new arrangement and principle of viewing was invented, and twenty other pairs were procured on that different arrangement from M. SALLERON in Paris. That new arrangement was founded on and constructed agreeably with the end-on principle of viewing, which I had the honour of setting forth before the Royal Scottish Society of Arts, in February 1879, but which turns out to have been invented by Dr VON MONCKHOVEN of Gand, in Belgium, several years earlier. Since then, a slight, but still further improvement has been made in my tubes, by giving them longer internal polar wires, to assist the electricity in traversing the necessarily large bulbs where its light is not wanted, and then throw itself with all its energy and along with any molecules of the gas it has caught hold of, into the capillary tube, and hurry along that with lightning like speed, and light as well.

This capillary, when thus occupied by the incandescent rushing molecules and viewed end-on, presents a little disc, smaller than a pin's head, of light as to size; but of exceeding brightness as to anything ordinarily seen in vacuum tubes. So bright, indeed, that when viewed under small spectroscopic dispersion, one's eyes quail before the red and blue hydrogen lines as though they were glancing from the sun itself; while carbon *bands* appear more as solid things than haze; and Nitrogen is simply a many coloured glory to behold.

Of course that is a symptom in spectroscopy that those subjects will bear more dispersion: in which case by all means let them have it; for only in that way can we ascertain the degree of importance of gaseous spectra. From that mere name of gaseous you might almost justifiably expect, that if there is anything sharp to be seen in them with a low power, it must of course become hazy and foggy with a high one, when made thereby to subtend a larger angle; just as the edge of a cumulus cloud on the horizon, however well defined there, disappears *as an edge,* in soft formless vapour when we come close to it.

But it is not so here in spectroscoping the ten thousandth part of a grain of electric-illuminated, rarefied gas. Take the Cyanogen pin's head of white light as an example; stretch that little speck horizontally by spectroscopic power, just say to a finger's-breadth; or, as it can be made to appear in angular space in even the smallest spectroscope, to half a degree in length; and we have, with a broad slit, not much more than a very pretty spectrum, red at one end, citron in the middle, and violet at the other end; with some hazy transverse bars of greater or less than the general brightness.

Stretch it then a little more, say to 3 degrees; and behold, by means of that, only in so far, increased scale of length from red to violet we now behold the alternations of more or less brightness, as seen before, explain themselves as a beautiful set of bands; sharp as knife edges on one side, if the slit be rather narrowed and the focus improved, but indefinitely shading away at the other side; whilst here and there are single lines burning and shining like linear suns; only that in place of their being, in colour, all of them like our sun, yellowish-white, one is red, another orange, or citron, or green, or glaucous, or blue, or violet, or lavender, harmoniously with its spectrum place.

So stretch the little pin's head of light more still, say to a length of 12 degrees. Why the bands are still more beautiful than ever; still so sharp and solid on one side, but resolving themselves now into close linelets and ranks of the most needle-like lines on the other; lines defying the powers of the micrometer to count their number, or equal them in thinness, or to separate them fully and clearly one from another.

Wherefore now spare nothing; stretch the luminous pin's head by prism power and magnifying power combined, until it forms an environing circle all round the observer, or subtends to him an angle of 360°; and have you now destroyed the gift of rarefied gas in the spectroscope to look hard, solid, and sharp ? You have rather increased it, if your electric light keeps up well, and if your prisms are good, your spectroscope's slit perfect, and your objectives faultless; for as you now survey the whole angular extent with the telescope of the spectroscopic apparatus, all appearance of dull smooth undefined haze is gone; and almost everywhere, from the red on one side, right round the whole horizon until you come to the violet,—you see only luminous lines sharp and hard; lines that will suffer no more splitting up under prism power; no more dulling of their light by dispersion, though they may by the absorption of many more glass prisms. They have arrived then at their ultimate condition, and behold how exquisite they are; how beautifully ordered in their ranks, how varied in their groups, how perfect in structure, contrasted in intensity, and indexed ready to one's hand by colour. It is almost endless work merely to admire them; quite endless for poor, finite, human nature to try to measure them all.

The only thing to compare with it would be a ring of the whole Heavens at once, on a bright and starry night when the firmament is shining with the countless glories of distant moving suns, the so-called fixed stars. And each of these innumerable bright lines in the electric-lighted spectrum of the cyanogen tube is as fixed, practically for ever, in spectral distance, the one from another, as each of those starry orbs; so that a practical observer who should employ thereon throughout half his life all the angular forces of a mural circle, would by such observations be donating posterity with an heirloom of absolute knowledge of the most important and lasting kind.

But even then the spectrum task is only at its beginning; for on each occasion that the spectroscopist changes a tube of one, for any other, gas, instantly the whole angular round is peopled with a new set of spectral but eternal lines; each of which knows its own place, flies into it in less than the twinkling of an eye, and a new spectroscopic universe in lines of light is the result. Who would not, if he could, be an observer, to some extent, of such phenomena; and, as for the *cui bono* use of it, if "the trains of thought" it leads the intelligent mind to, be not enough reward for ever,—then scientific history shows that the discovery of such a mine of accuracy in measure of place, and perfection in number, will be sure to have its practical applications in human education, and many industrial pursuits as well, before long.

In this present paper permit me to begin simply as follows—

PRACTICAL COMMENCEMENT DESCRIBED.

This consisted, in my case, in the examination of the 20 tubes alluded to, with merely a single and simple prism power in the spectroscope, combined with a magnifying power of 10 on the telescope. So low a prism power was chosen at starting, to be certain of including everything even of the faint terminations, as well as of the brighter, but often discontinuous, portions of the middle, of any spectrum; and it is far too small to allow of accurate measures of place. But as spectroscopic place, with some slight reference to colour and brightness, is the great identifier of spectrum lines, I have attempted to measure the place of everything seen in the tubes (at least with care), and have reduced mere instrumental numbers to the absolute scale of wave-lengths of light. These wave-lengths are however for practical convenience given as the numbers of such undulations in an inch British; and go on increasing from 30,000 at the red, to 65,000 at the violet, end of the spectrum; between which limits all our eye-observable phenomena will be found included, though photography takes account of many more.

Examination of the observed quantities and elimination of "impurities."

(Tables of 20 gas-vacuum tubes, spectroscopically examined. For these see Appendix I.)

After the reader has examined each of the 20 gaseous spectra, as set forth in the Appendix above alluded to, the question may very properly be asked, how have they come out as to previous expectation, and to the promises made to inquire into the sufficiency of the makers' labels, for positive information touching the physical and chemical contents of each of the tubes?

The answer is, unfortunately, that a very little contrasting of one tabular statement with another will show superficial, perhaps, but most unexpected and annoying contradictions. We may have admired in one spectrum a certain group of lines, and thought them characteristic of the particular gas said to be contained there, especially as that was an elemental gas; but these tables show the very same set of lines in another tube, and another, and another still, no matter what their labels may declare for them, and whether they refer to elemental or compound gases.

This however implies a difficulty already well known in spectroscopy:—viz. that the chemists have not been able to prepare their products in sufficient purity, to resist the tests of the spectroscopist. But as *they* have done as well as they can, *we*, the observers, must now endeavour to eliminate the effects of practically unavoidable impurities by some virtual process; and the first steps in this proceeding are fortunately very easy.

Here for instance are four bright lines of Hydrogen, as measured by the late M. ANGSTROM.

Red	with place at	38,707,
Glaucous	„	52,255,
Violet	„	58,525, and
Lavender	„	61,932.

If these lines, viz. sharp lines at these places (the two first of them, and sometimes the third also, being usually very bright), are found in the tube of any other elemental gas,—you may mark them down as hydrogen impurities at once; or if in the tube of a compound gas containing hydrogen in its composition, it may be either an impurity, or the result of the dissociation of the compound by the electric spark, when each ultimate element gives out the lines belonging to it alone, as though the others were not present.

Similarly there is a list of 4 Oxygen lines, given by Dr Schuster,—

Orange at . . .	41,254,
Citron at . . .	46,729,
Green at . . .	47,659,
Violet at . . .	58,156,

and if only the 1st, 2d or 3d are found in any tube which is not oxygen itself, or has not oxygen as one of the chemically required constituents of its contents, —mark it off as an oxygen impurity there.

But when we come to the third most important gas in all terrestrial nature, Nitrogen, there is a difficulty; for Nitrogen at low electric temperature and seen under low dispersion, has no lines; only bands; and so numerous! With very low dispersion they number 50 or 60; and at somewhat higher dispersion not less than 170! Moreover there is the further mental or moral or social difficulty that one-half of the greater spectroscopists of the age follow MM. Angstrom and Thalen in declaring that the above spectrum of bands seen in a nitrogen tube is not the spectrum of nitrogen at all, but of a compound, viz. Oxide of Nitrogen.

Pure nitrogen gas they say has only one spectrum, and that is totally different to the above banded affair; being a spectrum of a few sharp, piercingly bright lines, but which require a very powerful and condensed spark to enable them to show at all. When ordinary small sparks are employed, the nitrogen, they insist, falls into combination with oxygen, and exhibits bands, as usual with all oxides; while oxygen is always present on such occasions, in consequence of the electric spark, however weak, dissociating the hydrogen and oxygen constituting the water of that infinitesimally small amount of moisture, which, it is averred, can never be perfectly driven out of the interior of glass tubes.

Yet other equally great authorities follow the late lamented Professor Plucker, and declare that the spectrum of 170 bands really is the Spectrum of Nitrogen, but at low spark-temperature; and that most gases have two or more perfectly different spectra according to temperature.

After trying both hypotheses on my tube observations, I incline to the latter of them; not so much from having been able to prove its absolute and perfect truth, as from having disproved the opposite view. Thus, in a Cyanogen tube, where there was no hydrogen line visible, there could not have been any oxygen either, if that had to be derived, simultaneously with the hydrogen, from the decomposition of water; and yet the bands of Nitrogen (said by the opposite school to be bands of an Oxide merely, because they were bands and not lines) were magnificently developed, broad, spreading, and true bands.

So also with the Carbon bands of the same tube, derived from its Cyanogen combination of Nitrogen and Carbon being dissociated. The Carbon *line* spectrum consists of only eleven lines, and never shows except in a very powerful and condensed spark. But its *band* spectrum can be called up by any, even the smallest, spark; and that band spectrum (said by ANGSTROM and THALEN to be necessarily belonging to an oxide of carbon because it is in bands) was brilliantly visible in this tube, where there could have been no oxygen for the carbon to oxidise with, *i.e.*, if, as before, the oxygen had to be derived from the decomposition of water; and the absence of hydrogen lines, inherently far brighter than those of oxygen, proved that such decomposition had not taken place. Hence, after virtually clearing my observations from Hydrogen and Oxygen, I proceeded in the same manner to get them free from traces of Nitrogen, Carbon, and the peculiar compound Carbo-hydrogen,—wherever these gases had no right of intended standing place. But still there were many lines left, and some of them very pronounced, common to several tubes with most diverse labels. What lines could they be?

By far the greater number turned out to be low temperature lines of Hydrogen. Almost a new class of lines in the spectroscopic world; even denied by some persons, yet clearly visible simultaneously with the four great and almost *classical* Hydrogen lines; which are properly high temperature emanations, but of such an intensity of vital force, as to be capable of living on, down through low temperatures also. And whenever they, the high-temperature lines, appeared in my low-temperature, but brilliantly lighted end-on tubes, there and then, in nearly the same proportions of relative intensity, appeared the crowds of the new low-temperature lines; not three or four only, but rather three or four hundred.

This discovery is involuntarily, but exemplarily given in a few of its principal features in the Tables of

APPENDIX II. (see the end of this paper);

which Tables show likewise the degree and manner in which impurities are distributed among the several tubes; an instructive thing in itself.

I have also prepared, but refrain here, for the cost's sake, from printing the practical deductions from Appendix I., in the shape of a set of resulting standard Tables of the places of leading features of gaseous spectra. The foundation for these places is always taken from the admirable observations of

M. Thalen of Upsala, so far as they go. Then come some of my new lines from Appendix II., based in part on M. Thalen, and in part upon the old standard places of several well-known chemical flames, and a few Solar lines; all of which are appended, for criticism and correction.

This too is probably very necessary, where extreme accuracy is concerned, even among the oldest and longest known lines; as particularly visible in the over large numbers for the place of the grand double line of Chlorine, in the best known Tabular statements thereof. For no such change of place, we hold, could have occurred in consequence of any varied mode of preparing the Chlorine, or treating it after being made; but solely from error in reading off a micrometer screw, or printing the numbers from MSS.

Changes with Time and Use.

So much for endeavouring merely to secure correct numerical accounts at the instant, whether in support of, or opposition to, the makers' labels on the tubes. But now we must take up the second part of our promised answer, and testify somewhat as to the lasting power of the tubes, and also as to any physical changes occurring in them, after their contents had once been formally recorded and the record preserved.

As to general lasting power of the tubes themselves, against the action of all ordinary and fair electric currents transmitted through them, and inclusive of an immense amount of sometimes not the gentlest handling in transferring them from their packing boxes to the electric holder, and *vice versâ*, including too, several journeys by rail,—not more than one tube in twenty has failed, broken, or become dead—*i.e.*, in all the specimens I have had longest, but whose glass-material was rather too soft, too easily fusible, and pervaded with some needless impurities. Very recently M. Salleron has adopted a harder glass; chiefly for the sake of greater purity in the interior; and that harder and less fusible glass is necessarily more brittle. But although it has given him an immense amount of trouble in the first formation of the tubes,—yet of six completed ones sent to me three months ago, they have stood all the trials well, and are exquisitely clear and transparent.

Next as to the lasting power of the gaseous contents of the tubes, and their continued ability to keep on giving out the same spectrum under similar illumination,—the principal features of most of the tubes are undoubtedly maintained to a great, if not quite an absolute, degree; and large changes have only occurred to two or three. But these have been note-worthy.

To begin with the Cyanogen tube. It was first noted that one of the bulbs was very prone to heat when in use; then that the capillary's light, at first brilliantly white, had become faint and pink; then that the bulbs were becoming fogged with brown colouring matter deposited on the inside, and finally the spectroscope showed that the carbon bands in its spectrum were disappearing, and various unknown and isolated lines were appearing instead, together with a growth or increase of Hydrogen manifestations.

Some of the new lines could be made to disappear momentarily by introducing a Leyden jar into the circuit, and were supposed therefore to belong to the compound gas Cyanogen; but others could not be made so to disappear, and they proved to be the low temperature Hydrogen lines. Again, under special management of the condensed spark, the tube would for a short time blaze up vividly, and exquisite lines were then seen, thinner, sharper, and brighter than anything previous,—and they, from their places and relative intensities, must have been a part of the *excelsior* line-spectrum of Nitrogen.

Several of these changes are noted in Appendix I.; where two separate tables refer really to one and the same Cyanogen tube, but with a considerable interval of time between them; and another refers to a second tube of Cyanogen furnished to me by the maker on the same occasion as the first, but differing thus curiously in its spectrum; viz., that while the first, in its earlier days, showed Nitrogen bands preponderating over those of Carbon, the second showed Carbon bands preponderating over Nitrogen; but both of them were remarkable then for little or no hydrogen indications.

The next tube to heat up, to change its light from white to pink, and to alter its spectrum, was Hydro-chloric acid. It had begun with chlorine lines brilliantly, some Hydrogen lines and faint Carbon bands. These last are now gone completely; also, or even more signally, every one of the chlorine lines absolutely; but the Hydrogen lines are all increased, and to such a degree as to compete with a pure Hydrogen tube for showing the Lavender as well as the other three principal and high temperature lines of Hydrogen, besides crowds of the new low temperature lines of that element. In fact I cannot distinguish its spectrum now from one of pure Hydrogen supplied by the maker as such; but call its tube, for the sake of distinction without a difference, "the tube of artificial hydrogen."

The pure chlorine tube still shows its chlorine lines, but they are becoming fainter; and carbon bands and hydrogen lines have appeared, making its spectrum look very like what that of the Hydro-chloric acid was at first.

Another tube that heats unduly, as if inclined for a change, and has much deposited haze in its interior, is Iodine: but no perceptible alteration of spectrum has yet been noted; and because, perhaps, the maker put so large a quantity of solid iodine inside, that there is no chance of its all being dissociated, or converted into something else by my weak, small sparks, within any moderate length of time;—if Iodine is really, as some persons are beginning to suspect, not the elementary body which the chemists believe, but a compound.

Thus far then the few violent cases of change have shown a tendency in a feebly connected compound like cyanogen, and a doubtful element like chlorine, either to turn into hydrogen, or to develope so much of that brilliantly lighting gas, as to extinguish the fainter traces of anything else which may be left outstanding when chlorine dies, and hydrogen appears. But there is a case of far more ultimate importance, though much slower in working out, connected with Nitrogen; and thus—

I had observed with the Nitrogenous Cyanogen tube in its earlier days, that the Nitrogen bands there were clearer, more regular, even more Nitrogen-like than in the so-called pure Nitrogen tube itself; but failed then to discover why! Now, however, after comparing new and old tubes, the reason is perfectly plain. It was because at that time there was no Hydrogen in that tube; but in proportion as that and other tubes have been used, so they have developed Hydrogen; and though the widely separated 4 classical lines of Hydrogen may be eliminated easily,—the enormous numbers of the new low-temperature lines of that gas between red and blue are not so to be dealt with; and they do in a manner take possession of, and tyrannise over, every band spectrum, utterly hiding or breaking up those fainter manifestations.

With a new tube of Nitrogen, in the hard glass, there is a minimum of Hydrogen; and the bands, as well as the groupings of bands, proper to Nitrogen throughout the red, orange, yellow and citron are the most delicate and beautiful series of gauzy veils, with sharp beginnings, imaginable, if viewed with a dispersion of 11° A to H, Mag. power 10; and for this one powerful reason specially, that "nothing interferes with them." But in an old tube of Nitrogen, though the same groupings of bands are seen beginning near the red hydrogen line, yet a little beyond that in the orange and yellow, the low-temperature lines of Hydrogen come in like a thicket; and then no more Nitrogen bands are identifiable, until we get beyond low-temperature Hydrogen's chief manifestations of its progeny, viz., into the blue and violet.

So far as these two just described tubes may be trusted, time and use with the spark, would seem to have actually developed hydrogen in the older of them, either out of the glass matter of the tubes, or from the "occluded" stores of gas in the Polar wires, or more probably out of the Nitrogen gas contents; and in that case, either by transforming Nitrogen positively into Hydrogen, or by dissociating it into its ultra-elements, of which the chief one must be Hydrogen, and the other something not yet recognised. These two latter hypotheses are of course dead against chemical theory as it now stands, but agree remarkably with some very different and more elevated lines of both spectroscopic and chemical research set forth a year ago by Mr NORMAN LOCKYER to the Royal Society, London.

There would also appear to be an astronomical application, which, if not fully made before by some one else, opens up now some most noteworthy views in the quasi-vital chronology of the stars of heaven itself.

Thus our Sun has been roasting for long geological, as well as human-historic periods in a temperature still higher than ordinary electric sparks; and what do we find there touching these two critical gases, Nitrogen and Hydrogen? That there is no Nitrogen, but overwhelming Hydrogen, in the Sun: or we might say, that its once supply of Nitrogen has been long since converted by continued supernal electric heating into Hydrogen.

But in that case the beginning of the Sun's luminous history was probably marked by Nitrogen preponderating over Hydrogen; and what do we find on recurring to Dr HUGGINS' remarkable observation on those agglomerating materials for Suns about to be, viz., the nebulæ?

The answer is, "one faint hydrogen, but a much stronger and double nitrogen, line."

ON RECENT OBSERVATIONS IN BELGIUM.

(*Paragraph added during printing.*)

If the question be next put, "why only one line of each of those gases was seen, when their usually admitted spectra contain several, or many,"—the answer was not only given by Dr HUGGINS himself, to the effect that the visible line in the Nebula, was in each case the brightest of the several lines in the terrestrial spectrum of either gas;—but special observations for the verification of, and with the effect most certainly of verifying, that great master-spectroscopist's view, have lately been made at the newly re-organized Royal Observatory of Brussels.

M. FIEVEZ, the spectroscopic *astronome-adjoint* there, had already communicated several researches on allied points in spectroscopy to the *Académie Royale de Belgique*, when he took up this question, with results now published in the Academy's *Bulletins*, 2^{me} serie, tom. lxix. N° 2, 1880; and his apparatus was so vastly superior to mine, as to supply some much desired data for its possible future extension and improvement. Thus, while M. FIEVEZ employed end-on tubes very like my own, he illuminated them, not by such wretched little sparks as I was confined to by private economy, viz. sparks generally under 1 inch, or even half an inch long,—but by sparks 20 inches long, procured from a very large induction coil, excited by a Bichromate battery of 8 couples (size not mentioned); and these sparks occasionally intensified by the use of a condenser of 6 square yards of surface, employed sometimes in tension and sometimes in quantity.

Now as *my* condenser consisted only of one quart-sized bottle, and I was even afraid of using that much lest the glass tubes should crack,—I wrote to M. FIEVEZ asking how he contrived to ensure the safety of his tubes, when tried in such almost fearful light and heat.

He kindly replied "that he always began by very slowly immersing the zincs of the battery into the acid solution, producing only a feeble current." Some instants afterwards he introduced the condenser *in tension* into the circuit, and then immersed the zincs a little more. Lastly he disposed the condenser in quantity (as a single element); but he was careful to keep it acting in that manner only for a few minutes because the heating of the capillary if the so illuminated vacuum tube became too considerable. He further added, that a tube of Hydrogen-vacuum which had served for many experiments of that kind, presents now a deposit of metallic aluminium (derived from the electrode wires) at one of its extremities.

Of course the brightness of the spectra presented by M. FIEVEZ' tubes under 20 inch sparks or their condensed equivalents, was magnificent, delightful to the observer to behold, and greatly promotive of exactness in any mensurational applications. Of course also his Nitrogen tubes showed the sharp linear, not the faint band, spectrum of that gas; and equally of course the 4 classical, high-temperature lines of

Hydrogen are the only ones he mentions seeing in the Hydrogen tube; while amongst them the palm of brilliancy is is not with the red, as it is so often in small sparks, but in the more refrangible region of the glaucous Hydrogen line at 52, 255 W.N. Place.

M. Fievez' observations then were conducted on an electric stage quite *above* that on which I worked; and he shows how any one else may attain to the same. I will therefore only add, that I believe there is another stage *below* mine again, which would yield most important results for some of the physics of the faint Cometary, and Sidereal systems, could it be practically realised and well worked; witness the following very recent case for it.

M. Jamin lately showed, in the Academy of Sciences in Paris, that the origination of the "proper" light in a Comet's tail, must be the illumination of its carburetted constituent molecules by electric discharges of some kind, mainly because the only other known possible method of illumination, *viz.* by combustion, was absurd and utterly inapplicable under the circumstances. Professor Young, of Princeton, U.S., the present Astronomer Royal at Greenwich, and others have on the contrary proved, by observation, and spectroscopic measurement of place, that the carburetted spectrum exhibited by a Comet's tail is *not* that of the carbon-band order of electric illumined gas-vacuum tubes,—but *is* that of combustion of coal-gas and common air in the blue base of any ordinary burning flame.

Now, as mentioned in the following pages, I have already found, on merely shortening and thickening the wire forming the outer helix of my very moderate induction coil, (and thereby reducing the intensity of its sparks) that the brighter features of certain carbo-hydrogen *combustion* bands could be seen in an olefiant-gas vacuum tube, and less than before of the carbon band *electric-lighted* tube spectrum as usually known. Could we then,—by employing some very different method to the induction coil, of producing luminous electricity, as by the friction machine, Holtz's machine, or others,—so much further still reduce the intensity, while still keeping up the quantity, of the illuminating spark, as to render visible to us the combustion spectrum only, without any trace of the only hitherto known *tube* spectrum (which is the electric carbon-band spectrum) of a carbo-hydrogen gas—we should accomplish this; viz., we should have reached the chief physical conditions of visibility of such a Comet as Tebbutt's great Comet of 1881, and harmonised at the same time the present apparently utter oppositions of M. Jamin's theory *versus* Professor Young's and Mr Christie's observations.

Of Prof. Alex. S. Herschel's Contribution of Appendix III.

With the same spectroscope, tubes, and sparking apparatus employed by myself, but with more powerful prisms inserted, and also some new tubes of his own, many observations have been made from time to time *con amore* by my friend Prof. Alex. S. Herschel; and when I found that he had very original theoretical ideas as to the arrangement of the lines and bands in many spectra, I invited him to lose no time in communicating them to the Royal Society, Edinburgh. This he kindly promised to do, if agreeable to the Society; and although several other modes of presenting his views occurred to us, and were discussed, he preferred the method of contributing an Appendix to the present paper; on the clear understanding, however, that he is not necessarily bound by anything which I have written in the preceding part of this, or in any other, spectroscopic paper, but by his own portion only, viz., Appendix III.

APPENDIX I.

SEPARATE TABLES OF OBSERVATIONS OF EACH OF 20 GASES.

Series of 20 End-on Tubes, observed in 1879 and 1880 with Aurora spectroscope, small dispersion (1 prism of 52° refracting angle of white flint, having 3°·3 Disp. from A to H), and small intensity of sparks (generally under 1 inch long, and latterly under 0·3 inch, but from an ordinary so-called 2-inch spark induction coil purposely reduced in intensity by replacing its outer helix of long thin wire, with another of thicker wire and less length; bichromate battery of 5 pots, the zincs measuring 2″·5 × 4″ each).

Names of the assumed Tube Fillings.	Symbol.	Elemental.	Compound.	Names of the Compounded Elements.
Air, ...	$N+O+$&c.	...	Mixture	Nitrogen, Oxygen, Watery Vapour, &c.
Alcohol, ...	C_2H_6O	...	Compound	Carbon, Hydrogen, and Oxygen
Ammonia, ...	NH_3	...	Compound	Nitrogen and Hydrogen
Carbonic Acid, . . .	CO_2	...	Compound	Carbonic Oxide and more Oxygen
Carbonic Oxide, . . .	CO	...	Compound	Carbon and Oxygen
Chlorine, ...	Cl	Elemental	...	...
Cyanogen (old), . . .	CN	...	Compound	Carbon and Nitrogen
Cyanogen (very old), . .	CN	...	Compound	Carbon and Nitrogen
Cyanogen (second example), .	CN	...	Compound	Carbon and Nitrogen
Hydrochloric Acid, . . .	HCl	...	Compound	Chlorine and Hydrogen
Hydrogen, ...	H	Elemental	...	...
Iodine, ...	I	Elemental	...	...
Marsh Gas, ...	CH_4	...	Compound	Carbon and Hydrogen
Nitrogen, ...	N	Elemental	...	...
Nitrous Oxide, ...	N_2O	...	Compound	Nitrogen and Oxygen
Olefiant Gas, ...	C_2H_4	...	Compound	Carbon and Hydrogen
Oxygen, ...	O	Elemental	...	...
Ozone, ...	O_3	Elemental	Allotropic	...
Salt-water, ...	H_2O+Na	...	Compound and Mixture	Hydrogen, Oxygen, and Salt
Water, ...	H_2O	...	Compound	Hydrogen and Oxygen

AIR. END-ON GAS VACUUM TUBE. *Observed Sept.* 26 *and* 27, 1879.

A Mixture of N + O + Watery Vapour, &c.

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Unclaimed for Air.
Crimson-Red.	Part 1.						None; and no solar telluric lines appear.
	Faint line, ...	0·5	|	33 790		Nitrogen	
Red.	Very faint band, ...	0·3	|≡|	36 764 37 078		Nitrogen	
Scarlet-Red.	Faint band, ...	0·7	|≡|	37 298 37 725		Nitrogen	
	Band, ...	1·0	|≡|	37 936 38 206		Nitrogen	
	Band, ...	1·0	|≡|	38 304 38 715		Nitrogen	
	Red hydrogen, ...	5·0	▌	38 715	Hydrogen		
	Part 2.						
	Red hydrogen, ...	5·0	▌	38 699	Hydrogen		
Light-Red.	Band, ...	1·0	|≡|	38 803 39 063		Nitrogen	
	Bright band, faint cleft down middle, ...	1·5	|≡|	39 219 39 557		Nitrogen	
	Do. do. do. . .	2·0	|≡|	39 687 39 937		Nitrogen	
Orange.	Do. do. do. . .	2·0	|≡|	40 093 40 509		Nitrogen	
	Narrower band, ...	2·0	|≡|	40 639 40 842		Nitrogen	
	Distinct line, with black line or space on either side, . . .	1·0	▌	40 967		Oxygen ?	?
	Unequal double line, . .	1·0 2·0	||	41 149 41 279		Oxygen ? Oxygen	?
	Close band of lines, . . .	2·0	|||||	41 409 41 462		Nitrogen	
	Strong beginning of narrow band, .	1·5	⁝	41 707		Nitrogen ?	
	Strong line beginning a graduated band, ...	2·0	⁞⁝∴	41 881	Carbon		
	End of that band, . .	1·0		42 115			
	Bright hazy line, ...	2·5	⁞|⁞	42 161	Hydrogen		
	Space intervenes full of lines, .	1	|||||			Nitrogen	
	Strong ending line of above, . .	2·5	▌	42 511	?		
	New band of many thin lines begins,	1	||||	42 608		Nitrogen	
	Strong ending line to that band, .	2	▌	42 815	Hydrogen		
Yellow.	Thin line follows, ...	0·5	▖	42 929	?		?
	Band; begins faintly, . . .	1	.:|:.	43 039	Hydrogen	Nitrogen	
	culminates in strength, .	3		43 141			
	ends faintly, . . .	1		43 288			
	A notable black line follows.						
	Part 3.						
	Band begins after a black line, .	1	⁞⁞	43 374		Nitrogen	
	Strong bright line ends band, .	2		43 561			
	Bright line perhaps double, . .	2·5	▌	43 700	New Hydrogen		
Citron.	Band of close lines, . . .	1·5	||||	43 816 44 017		Nitrogen	
	Hazy line, ...	1·5	⁞|⁞	44 152	Hydrogen	Nitrogen ?	
	Thick bright line, ...	3	▌	44 351	Hydrogen	Nitrogen ?	
	After this a notable broad dark space.						
	Faint features in the dark space, . . . Line	0·5	|	44 523	Hydrogen		
	Line	1	|	44 685	Hydrogen		
	Line	0·5	|	44 911		Nitrogen	
	Band	0·5	|	45 112			
	A band begins a brighter green region, ...	2	|≡|	45 245 45 478	Carbon	Nitrogen	
	A fainter band, ...	1·5	|=|	45 584 45 846		Nitrogen	
	Do. do.	1·5	|=|	45 979 46 234		Nitrogen	

AIR. END-ON GAS VACUUM TUBE—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Unclaimed for Air.
	Part 3—*continued.*						
Citron.	Hazy line, beginning of many such,	1	⁞	46 358		Nitrogen ?	?
	Stronger hazy line, . . .	1·5	⁞	46 551		Nitrogen ?	?
	Do. do.	1·2	⁞	46 706		Oxygen ?	?
	Do. do.	1·2	⁞	46 878		Nitrogen	
Green.	Do. do.	1·2	⁞	47 006		Nitrogen	
	Do. do.	1·0	⁞	47 176		Nitrogen	
	Do. do.	1·0	⁞	47 298		Nitrogen	
	Do. do.	1·0	⁞	47 420		Nitrogen	
	Thicker hazy line, . . .	2·0	▮	47 582		Oxygen	
	Dark space intervenes.						
	Thick hazy line, ...	1·7	▮	47 845	Hydrogen	Nitrogen	
	Band, ...	1·5	▤	48 129 48 312		Nitrogen ?	?
	Very faint hazy lines, . . .	0·5 0·5 0·5 0·5	| | | |	48 433 48 554 48 677 48 759		Nitrogen	
	Strong hazy line begins a band, .	3	⁞⁞:.	48 900	Carbon		
	Second line therein, . . .	2		49 041			
	Said band slowly fades out, . .	0·5		49 478			
Glaucous.	Line in region of faint haze, . .	1·5	.:⁞:.	50 121		Nitrogen	
	Fainter do. do. . .	0·7	.:⁞:.	50 481		Nitrogen	
	Do. do. do. . .	0·7	.:⁞:.	50 668	Carbon ? Hydrogen		
	Strong line begins a band, . .	2·0	⁞:.	51 071		Nitrogen	
	Said band ends weakly, . .	0·3	⁞:.	51 297			
	Faint hazy line, ...	1·0	⁞	51 526	Hydrogen ?	Nitrogen ?	
	Another like it, ...	1·0	⁞	51 710	?		?
	Glaucous hydrogen, . . .	4·5	▮	52 243	Hydrogen		
	Part 4.						
	Beginning of a faint band, . .	0·5	:	52 594	Carbon		
	Strong beginning of another band, .	1·5	⁞:.	52 812		Nitrogen	
	Tail of above band ends, . .	0·3	...	53 235			
	Strong beginning of another band, .	2·0	⁞:.	53 877		Nitrogen	
	Tail of band ends here, . . .	0·3	...	54 284			
	Hazy line, ...	1·3	⁞	54 507			
	Strong beginning of another band, .	2·0	⁞:.	54 678		Nitrogen	
	Tail of band ends here, . . .	0·3	...	55 046			
Blue.	Strong beginning of another band, .	2·0	⁞:.	55 613		Nitrogen	
	Tail ends hereabouts, . . .	0·3	.....	56 178			
	Strong beginning of another band, .	2·0	⁞:.	56 707		Nitrogen	
	Tail ends here, ...	0·3	.....	57 243			
Indigo.	Another band begins strongly, .	1·7	⁞:.	57 695		Nitrogen (No Oxygen visible here at 58 156.)	
	Tail ends here, ...	0·3	.....	58 211			
Violet.	Violet hydrogen, ...	2	▮	58 537	Hydrogen		
	Part 5.						
	Strong beginning of band, . .	1·5	⁞:.	58 725		Nitrogen	
	Tail of band, ...	0·3	.....	59 005			
	Beginning of another band, . .	1·5	⁞:.	59 667		Nitrogen	
	Tail of that band, ...	0·3	.....	60 020			
	Faint hazy line, ...	0·5	⁞	60 388	Carbon ?		
Lavender.	Strong beginning of another band, .	1·0	⁞:.	60 625		Nitrogen	
	Tail thereof	0·3	.....	61 026			
	Strong but hazy beginning of another band, ...	0·9	⁞:.	61 364		Nitrogen	
	Tail thereof, ...	0·3	.....	61 811			
	Hazy beginning of another band, .	0·6	⁞:.	62 092		Nitrogen	
	A hazy band, ...	0·4	⁞⁞	62 754		Nitrogen	
	Very faint band, ...	0·3	⁞	63 734		Nitrogen	
	Doubtful band, ...	0·1	:	64 465		Nitrogen	

In the Air-tube no change is perceptible over all the above Part 5 range (or known anywhere else) on changing the poles. No line comes in, such as M. de BOISBAUDRAN's strong *a* line in his *open-air* spark near the Negative Pole.

The impurities traced here are Hydrogen (strongly, though in few lines only) and Carbon (weakly); the constituents are Oxygen not very brightly; but Nitrogen overpoweringly in the number and often the strength of its bands.

Nothing of importance left for Air as a compound. No Telluric lines, as in the Solar spectrum, are indicated.

ALCOHOL TUBE, END-ON.

C_2H_6O. Carbon, Hydrogen, and Oxygen.

Observed 12th July 1879. From this date a more rigid system adopted of dividing the Spectrum into 5 parts, with special references, settings, and focussings for each. The references kept strictly apart from the observations.

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.		Impurities.	Constituents dissociated.	Unclaimed features left for Alcohol.
	Parts 1 and 2 of Spectrum—							None beyond ordinary Carbo-Hydrogen, and a portion of Marsh-gas.
Scarlet-Red.	Faint line, ...	1	|	38 351			Carbon	
	Red hydrogen, ...	8	█	38 707	×		Hydrogen	
Light-Red.	Broad haze band, . . .	2	≡	38 780 39 968		?		
	Narrow haze band, . . .	2	≡	40 141			Carbon ?	
	Hazy band, ...	3	▤	40 268 40 562			Carbon	
	Do.	3	▤	40 669 40 892			Hydrogen	
	Do.	3	▤	40 954 41 335			Hydrogen (no Oxygen appears.)	
Orange.	Do.	4	▤	41 384 41 626	×		Carbo-Hydrogen and Hydrogen	Carbo-Hydrogen
	Strong edge of band, . .	5	⣿	41 810	×		Carbon	
	Shaded-off edge of same, .	1	⋯	42 068				
	Hazy band, ...	4	▤	42 135 42 315	×		Hydrogen	
	Hazy band, ...	3	▤	42 467 42 658			?	
	Excessively thin line, . .	0·5	|	42 725		?		
	Hazy band, ...	2	▤	42 772 43 047			Hydrogen	
	Yellow line (not sodium), .	4	|	43 157	×		Hydrogen	
	Part 3 of Spectrum—					43 170		
	Former yellow line, . .	3	|	43 183				
Yellow.		1	|	43 589			Hydrogen	
	Strong yellow line, . . .	4	▮	43 737	×		Hydrogen	
	Haze intervenes, . . .		∷					
	Marked line, ...	2	▮	44 146			Hydrogen	
	Hazy line, ...	3	⦙	44 364			Hydrogen	
	Broad faint haze band, . .	1	≡	44 549 45 007		Nitrogen ?	+ Hydrogen	
	Line probably citron 1 of blow-pipe, ...	3	|	45 079			Carbo-Hydrogen	Carbo-Hydrogen
	Tube's citron band, sharp beginning, ...	4	⣿	45 264	×		Carbon	
Citron.	Do. do. extends faintly to	1	⋯	45 383				
	Haze further intervenes, .							
	Haze band, ...	2	≡	45 990			Carbo-Hydrogen ?	Carbo-Hydrogen
	Faint hazy region, . . .	1·5	∷	46 180 46 867			Carbo-Hydrogen ?	Carbo-Hydrogen
	Sharp beginning of band, .	2	⣿	47 067			Carbon	
	Faint hazy region, . . .	1	∷	47 540 47 961			Hydrogen ?	
	Faint hazy region, . . .	1	∷	48 122 48 375			Hydrogen ?	
	Green band's sharp beginning,	6	⣿	48 792	×		Carbon	
Green.	Blow-pipe's green giant therein,	8	█	49 173	×		Carbo-Hydrogen	Carbo-Hydrogen
	Part 4 of Spectrum—					49 176		
	Green giant in tube, . .	7	█	49 179	×			
	Its second line do., . .	3	▮	49 520	×		Carbo-Hydrogen	Carbo-Hydrogen

ALCOHOL TUBE, END-ON—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.		Impurities.	Constituents dissociated.	Unclaimed features left for Alcohol.
	Part 4 of Spectrum—*continued.*							
Glaucous.	Haze extends thus far, . .	0·5	···	50 443			Carbon	
	Faint band, ...	0·5	≡	50 527 50 848			Carbon ?	
	Fainter haze band, ...	0·3	≡	50 989 51 322			Carbon ?	–
	Hazy line, ...	1	⁞⁞	51 527		?	Hydrogen	
	Glaucous hydrogen, ...	6	█	52 240	×		Hydrogen	
	Blue band, tube's, ...	4	⁞⁞:.	52 502	×		Carbon	
	Tube's blue band extends faintly to, ...	0·5	···	53 172			Carbon	
	Line, supposed blow-pipe's blue band 1, ...	3	❙	53 631			Carbo-Hydrogen	Carbo-Hydrogen
	Do. do. line 2, .	1	❙	53 856			Carbo-Hydrogen	Carbo-Hydrogen
	Do. do. line 3, .	0·5	ı	54 050			Carbo-Hydrogen	Carbo-Hydrogen
	Hazy band, ...	1	⁞:.	54 244			Carbo-Hydrogen	Carbo-Hydrogen
	Hazy line, ...	1	⁞⁞	54 797			Hydrogen	
Blue.	Band begins sharply, . .	3	⁞⁞:.	56 330			Carbon	
	Part 5 of Spectrum—					56 325		
	Violet band begins sharp, .	3	⁞⁞:.	56 320	×			
Indigo.	Faint violet band, . . .	2	:.	57 830			Carbon	
Violet.	Violet hydrogen, . . .	2	|	58 515			Hydrogen	
	Band, supposed blow-pipe's intense, ...	2	⁞:.	58 895			Carbo-Hydrogen	
Lavender.	Line, supposed of Marsh-gas .	2	|	60 245			Marsh-gas	
	Another, ...	1	|	60 529			Marsh-gas	
	Another, ...	1	|	60 740			Marsh-gas	
	Hazy followers, from near to, .	0·3	::::	60 970			Marsh-gas	
	Do. do. up to, .			61 239			Marsh-gas	
	Lavender band begins, . .	2	⁞⁞:.	61 592			Carbon	
	Do. do. ends, . .	0·5	·····	62 002				
	Haze band, ...	1	≡	62 570			Carbon	
	All haze ends, . . .	0·2	···	63 068		?		

N.B.—Olefiant-gas tried after the above, has perhaps the faintest trace of No. 1 of Marsh-gas at 60 245. But Marsh-gas has that whole group splendidly, brilliantly, viz., from 60 243 to 62 139 ; or shows more of the lines and bands of it by far than Alcohol ; and Alcohol again than Olefiant-gas. Yet Olefiant-gas is far nearer in chemical constitution to Marsh-gas than Alcohol !

The Carbon, Hydrogen, and Carbo-hydrogen constituents of this tube appear abundantly ; but none of its Oxygen constituent !

More remarkable, however, is it to note in this Alcohol tube, over and above the carbon bands, known positively to be *electric-spark* carbonic manifestations, the appearance of other bands of a carburetted kind, but only known, or acknowledged hitherto as *combustion*, not as electric, bands. Yet here they are undoubtedly in nothing but faint, weak, electric illumination.

Thus the green band, whose sharp beginning is quoted above as being in W.N. Place = 48 792, is the electric, vacuum-tube, carbon or carbonic-oxide band of all electric observers ; and has never been seen in any lamp or candle burning freely in the open air.

But the other green band, which begins with a strong line at 49 176 of W.N. Place, is the band which may be seen in the blue base of every carbo-hydrogen flame, lamp, candle, or anything else ; has been taken hitherto as an example and type of a combustion spectrum ; and yet is the green band which is seen in comets, where, on principle, there can be no combustion, but may be faint electrical currents.

AMMONIA. END-ON TUBE. NH_3.

July 28, 1879.

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Unclaimed for Ammonia.
Crimson-Red.	Part 1.						
	First faint red band, . . .	0·5	≡	34 010		Nitrogen	
	Faintest haze intervenes, . .		...				
Red.	Faint band, ...	1	≡	36 858 37 202		Nitrogen	
Scarlet-Red.	Stronger and defined band, . .	1·7	│≡│	37 422 37 762		Nitrogen	
	Band well defined, . . .	2·5	│≡│	37 930 38 168		Nitrogen	
Scarlet-Red.	Part 2.						
	Band defined at sides, . . .	2·5	│≡│	38 272 38 558		Nitrogen	
	Red hydrogen line, brilliant, . .	8	█	38 707		Hydrogen	
Light-Red.	Band, ...	2·5	│≡│	38 802 39 055		Nitrogen	
	Band split down middle, . .	2·5	⁞⁞│⁞⁞	39 222 39 498		Nitrogen	
	Do. do. . .	2·5	⁞⁞│⁞⁞	39 628 39 950		Nitrogen	
	Bright hazy line, ...	2	⁞│⁞	40 132		Hydrogen	
	Do. do.	2	⁞│⁞	40 309		Hydrogen	
	Do. do.	2	⁞│⁞	40 487		Hydrogen	
	Band, ...	2	│≡│	40 652 40 795		Nitrogen	
	Definition generally admirable.						
Orange.	Sharp line, ...	3	│	40 943		Hydrogen ?	
	Line in haze, ...	1·5	⁞│⁞	41 128		Hydrogen ?	
	Haze intervenes, ...	0·5					
	Line in haze, ...	2	⁞│⁞	41 231	Oxygen ?		
	Line, ...	2	│	41 386		Hydrogen	
	Haze intervenes, ...	0·5	.....				
	Line, ...	2	│	41 479		Hydrogen	
	Line, ...	2	│	41 670		Nitrogen ?	?
	Haze intervenes, ...	0·5	.....				
	Line, ...	2	│	41 838		Hydrogen + + Nitrogen ?	
	Haze intervenes, ...	0·5	.....				
	Line, strong, ...	3	▌	42 114		Hydrogen + + Nitrogen ?	
	Fainter line, ...	1·5	▌	42 186		Nitrogen ?	?
	Still fainter line, ...	1	ı	42 298		Nitrogen ?	?
Orange.	Bundle of thin lines, . . .	2	││││	42 497		Nitrogen ?	?
	Haze intervenes, ...	0·5	.::				
	Bundle of thin lines, . . .	2	││││	42 792		Nitrogen ?	?
	Thin line, ...	1	ı	42 934		Hydrogen + + Nitrogen ?	
Yellow.	A signal and strong yellow line, but tested not to be in Sodium's place, but slightly beyond it, . .	3	▌	43 156	43 158		
Yellow.	Part 3.						
	The former yellow line, . . .	2	▌	43 161			
	Bundle of thin lines, . . .	1·5	││││	43 286		Nitrogen ?	?
	Line, ...	1	│	43 410		Nitrogen ?	?
	Line, ...	1·8	│	43 532		Hydrogen	
	Strongest line yet, ...	3·5	▌	43 690		Hydrogen	

Hazy region intervenes, nearly resolvable into lines.

AMMONIA. END-ON TUBE. NH_3—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance	W.N. Place.	Impurities.	Constituents dissociated.	Unclaimed for Ammonia.
	Part 3—*continued.*						
Yellow.	Line on heavy black ground,	1·1	|	43 874		Nitrogen ?	?
	Haze intervenes,		⁞⁞				
	Line in haze,	1·1	:ı:	43 991		Nitrogen ?	?
	Line,	1·5	|	44 114		Hydrogen	
Citron.	Broad line or bundle of thin ones,	3	|||	44 241 44 358		Hydrogen + + Nitrogen ?	
	Thinnest possible line,	0·2	ı	44 451		Hydrogen	
	Line,	1·5	|	44 548		Hydrogen + + Nitrogen ?	
	Line,	1·5	|	44 686		Hydrogen + + Nitrogen ?	
	Very thin line,	0·3	ı	44 798		Nitrogen ?	?
	Line,	1·3	|	44 882		Nitrogen ?	?
	Haze band,	0·7	≣	44 984 45 288		Nitrogen	
	Broad haze band, with line in centre,	0·5 2 0·5	⁞|⁞	45 268 45 384 45 468		Nitrogen	
	Faint haze intervenes,	0·2	.....				
	Semi-resolvable haze,	0·5	⁞⁞⁞	45 572 45 908			
	Bundle of thin hazy lines,	0·5	|||	46 016			
	Haze band,	1·0	|⁞⁞|	46 098 46 250		Nitrogen	
	Faint haze band,	0·5	|⁞⁞|	46 298 46 412		Nitrogen	
	Stronger haze band,	1·0	|⁞⁞|	46 458 46 602		Nitrogen	
Citron.	Hazy line,	1·0	:ı:	46 730	Oxygen ?	Nitrogen ?	
	Strong hazy line,	1·5	:|:	46 864		Nitrogen ?	?
	Bundle of thin lines,	0·8	||||	47 020		Nitrogen	?
Green.	Line,	1·0	|	47 158		Nitrogen ?	?
	Hazy line,	0·8	:|:	47 298		Nitrogen ?	?
	Hazy line,	0·5	:|:	47 442		Nitrogen ?	?
	Bundle of lines,	1·7	||||	47 590		Nitrogen	
	Single thin line,	1·0	ı	47 730	Oxygen ?		
	Bundle of thin lines,	1·5	||||	47 870		Nitrogen	
	Region of faint semi-resolvable haze,	0·5	⁞⁞	47 980 48 096		Nitrogen	
	Bundle of close thin lines,	2	||||||	48 160 48 216 48 280 48 320		Nitrogen	
	Faint hazy line,	1·0	:|:	48 428		Nitrogen	
	Line in fainter haze,	1·0	:|:	48 576		Nitrogen	
	Do. do.	0·8	:|:	48 628		Nitrogen	
	Faint haze band,	0·4	|⁞|	48 680 48 788		Nitrogen	
	Strongest line yet; and not altered by condenser,	3·5	❙	48 884	Carbon ? +	Nitrogen ?	Ammonia ?
	Another strong line, with decreasing haze beyond it, to further than the place of the Blow-pipe's Green Giant, and without symptom thereof,	3	❙⁞.	49 020		Nitrogen ?	Ammonia ?
Green.	Part 4. July 31, 1879.						
	End of semi-resolvable haze,	0·3	⁞⁞.	49 910		Nitrogen	
	Thin line,	1·0	ı	50 012			
Glaucous.	Strong line, beginning band of thin ones,	2·0	❙⁞.	50 170		Nitrogen	
	End of above band,	0·5	|||	50 424			

AMMONIA. END-ON TUBE. NH_3—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Unclaimed for Ammonia.
	Part 4—*continued.*						
Glaucous.	Distinct line,	1·0	|	50 512		Nitrogen	
	Line, beginning haze band,	2·0	⁞⁝	50 668	Carbon ?	Nitrogen ?	
	Strong line,	2·0	▮	51 064		Nitrogen ?	Ammonia ?
	Faint line close up to above,	1·0	ı	51 128		Nitrogen ?	?
	Thin line,	1·0	|	51 252	?		?
	Next double line followed by extra black space,	1·0	‖	51 472 51 534		Hydrogen	
	Decreasing band of thin faint lines,	0·7	⁞⁝	51 660 52 030		Nitrogen	
	Glaucous Hydrogen vividly bright,	10	█	52 252		Hydrogen	
	Faint haze beyond,	0·3	⁙	52 590	Carbon ?		
	Line beginning band,	2	⁞⁝	52 782		Nitrogen	
	Line beginning grand band,	3	⁞⁝	53 841		Nitrogen	
	End of that band at	0·5	.....	54 310			
	Faint line,	1·0	ı	54 480		Nitrogen ?	?
Glaucous.	A notable wide and blue double line,	2 2	▮ ▮	54 670 55 012		Nitrogen ?	?
Blue.	Line beginning graduated band,	2·5	⁞⁝	55 556		Nitrogen	
	Line beginning grand blue band,	3·0	⁞⁝	56 620		Nitrogen	
Indigo.	Part 5. August 2, 1879.						
Violet.	Similar line, beginning a similar band,	3	⁞⁝	57 555		Nitrogen	
	Another,	3	⁞⁝	58 354		Nitrogen	
	but closely followed by violet hydrogen,	4	▮	58 518		Hydrogen	
	End of band on which violet hydrogen is projected,	0·3		59 208			
Lavender.	Line beginning another band,	2·5	⁞⁝	59 500		Nitrogen ?	
	Faint hazy line,	1	ı	60 294	Marsh-gas ?		
	Line beginning band,	1·2	⁞⁝	60 480		Nitrogen	
	Line beginning band,	1·5	⁞⁝	61 290		Nitrogen	
	Mere haze band,	1	⁙	62 140		Nitrogen	
	Weak hazy line, beginning a faint indistinct band,	1·3	⁞⁝	62 690		?	
	Hazy beginning of a band,	0·7	⁝	63 750		?	

Spectrum ends here, excepting only some ultra-faint ghosts of haze-bands, derived apparently from false reflections.

Temperature of chamber and apparatus = 64°·0 Far. Spark = 0·7″ long.

Impurities here are very few and weak.

The constituents Hydrogen and Nitrogen are abundant; but the latter seems to tend more towards lines than bands, through all the middle of the Spectrum, than in a pure Nitrogen tube.

This Ammonia tube still further contrasts with the late Alcohol tube, inasmuch as there is here no trace of the *combustion* spectrum of carbon, carbo-hydrogen, &c.; and we may note at the same time how superior in brilliancy is the Glaucous, to the Red, hydrogen line; a symptom of higher electric temperature here, than in the Alcohol spectrum, wherein the Red was the brightest of all the hydrogen lines.

CARBONIC ACID. END-ON TUBE. *October* 6, 1879.

$=CO_2$.

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Left unclaimed for Carbonic Acid.
	Part 1.						
Red.	Faintest band, ...	0·5	≡	35 878		Carbon	
Scarlet-Red.	Faint haze intervenes, . . .	0·3	⁚				
	Hazy line on red haze, . . .	1	⁞	37 088		Carbon	
	Faint broad haze band, . . .	0·5	⁚	37 898		Carbon	
	Red line, or sharp beginning of a red band, ...	1·5	⁞	38 352		Carbon	
						38 366	
	Part 2.						
	Red line, or sharp beginning noticed before, ...	1·5	⁞	38 379		Carbon	
Light-Red.	Red Hydrogen, ...	5	▮	38 698	Hydrogen		
	Bundle of thin lines with haze,	1·5	|	39 308		Oxygen	
		1	⁞	39 420	Hydrogen		
		2·0	⁞	39 651	Hydrogen		
		0·5	⁞	39 858	Hydrogen		
Orange.	Single line rather hazy, . . .	1·0	⁞	40 091	Hydrogen		
	Red band, sharp beginning of, .	3·0	⁞	40 282		Carbon	
	fading end of, . .	0·5		40 622			
	Line terminating much haze, .	1·0	⁞	40 803	Hydrogen		
	Admirably clear, distinct lines,	2	|	40 948	Hydrogen		
		1	|	41 086	Hydrogen		
		2·5	|	41 238		Oxygen	
		1·5	|	41 387	Hydrogen		
		1·5	|	41 498	Hydrogen		
	Thin line in black space, . .	1·0	|	41 668	?		
	Orange band, intense beginning of,	4	⁞	41 771		Carbon	
	weak end of, . . .	0·5		42 049			
	A band of haze just resolvable into ultra-thin, close lines, . .	1·5	⁞	42 098	Nitrogen		
				42 387			
	Narrow band almost resolvable, .	1·3	⁞	42 525	Nitrogen		
Yellow.	Line beginning a band of nearly resolvable lines, . . .	1·3	⁞	42 803	Nitrogen		
	fainter end of said band, .	0·4		43 034			
	Line, ...	1·5	|	43 138	Hydrogen		
	Faint line, ...	1	|	43 261			
	Fainter line, ...	0·5	|	43 396			
	Line, ...	1·2	|	43 526	Hydrogen		
	Strong beginning of a band of faint thin lines, ...	2·5	⁞	43 675	Hydrogen +	+ Carbon	
					43 676		
	Part 3.						
	The strong line alluded to before, .	2	⁞	43 678			
Citron.	Band of just resolvable lines extends thus far, ...	1	⁞	44 041			
	A separate thin portion, . . .	1		44 125	Hydrogen		?
	Another separate broader streak, .	1	⁞	44 272	Hydrogen		
				44 363			
	Band { Weak beginning of, . .	1	⁞	44 495	Hydrogen		?
	Sharp end of, . . .	2		44 839			
	Very faint lines, ...	0·5	|	44 954			
		0·5	|	45 092			
		0·5	|	45 185			
	Citron band { Sharp beginning, .	4	⁞	45 262		Carbon	
	Faint ending, . .	1		45 757			
	Weak lines, ...	1	|	45 884	Hydrogen		
		0·5	|	46 075	Oxygen		
	Faint band, begins, ...	1	⁞	46 418			
Green.	ends, ...	1		46 866		Oxygen ?	
	Weak band, begins sharply, . .	1·5	⁞	47 061		Carbon	
	ends faintly, . .	0·5		47 311			

CARBONIC ACID. END-ON TUBE—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Left unclaimed for Carbonic Acid.
	Part 3—*continued.*						
Green.	Hazy lines,	1	⋮	47 446		Oxygen ?	
		1	⋮	47 646			
		1	⋮	47 875	Hydrogen		
	Faint band,	0·5		48 077			?
		1·5	.⁝	48 338			
	Fainter haze line,	0·3	⁚	48 559			
	Very dark space intervenes.						
	Exceedingly thin line in that space,	0·2	|	48 680			
	Green band begins sharply; with a weaker spark it is followed by a faint Carbo-hydrogen Green Giant. Ends in faint haze,	5	⁞⁞⁚.	48 841		Carbon	
		0·5		49 363			
Glaucous.	Faint band,	0·3		49 836	Hydrogen ?		
		1·0	.⁝	50 139			
	Faint hazy lines,	0·5	⁚	50 251			
		0·5	⁚	50 475			
	Faintest hazy bands,	1·0	⁞	50 774	Hydrogen +	Carbon	
		0·8	⁞	51 110	Hydrogen		
		0·5	⁞	51 542	Hydrogen + ?	Carbon ?	
		0·3	⁞	51 784			
	Glaucous Hydrogen,	3	▮	52 237	Hydrogen		
					52 246		
	Part 4.						
	Glaucous Hydrogen,	5	▮	52 256	Hydrogen		
	Blue band, sharp beginning,	4	⁞⁞⁚.	52 510		Carbon	
	weak end,	0·3		53 030			
	Very faint bands,	0·5	≡	53 288			
		1	≡	54 207		Carbon ?	
		0·7	≡	54 520			
		0·8	≡	55 149			
		0·5	≡	55 620			
Blue.	Violet band, Sharp beginning,	3	⁞⁞⁚.	56 224		Carbon	
	Faint ending,	0·3		56 641			
Indigo.	Faintest bands,	0·2	⁞⁚.	57 069			
		0·2	⁞⁚.	57 607			
	Second violet band, Sharp beginning,	2	⁞⁞⁚.	57 828		Carbon	
	Faint ending,	1		58 256		Oxygen ?	
	Violet hydrogen,	2·5	▮	58 521	Hydrogen		
	Part 5.						
Violet.	Violet Hydrogen,	3	▮	58 591	Hydrogen		
	Faint band,	1	⁞⁚.	58 996		Carbon	
		0·2		59 262			
	Faint band,	1	⁞⁚.	59 576			
		0·2		59 961			
	Faint band,	1	⁞⁚.	60 388		Carbon	
		0·2		61 132			
Lavender.	Stronger grey band,	2·0	⁞⁞⁚.	61 670		Carbon	
		0·3		62 126			

End of Spectrum.

Mems.—Hydrogen and some probabilities of Nitrogen are the only impurities here.

This spectrum is very rich in Carbon bands; but weak in Oxygen, and still more in Carbo-Hydrogen.

Carbonic Oxide *looks* the same identical thing as the above Carbonic Acid; or as explained by THALEN, the Carbonic Acid spectrum is that of Carbonic Oxide, one portion of its oxygen being inert.

Both Marsh-gas and Olefiant-gas resemble the above in the Carbon bands, but differ by having the lines and the bands of Carbo-hydrogen also and strongly.

The commencing red lines were re-observed on April 7: 1st at 35 839; 2nd at $\left\{\begin{matrix}36\ 980\\37\ 280\end{matrix}\right\}$; and 3rd at $\left\{\begin{matrix}37\ 522\\38\ 122\end{matrix}\right\}$.

CARBONIC OXIDE. End-on Tube. *October* 13, 1879.

=CO.

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Unclaimed for CO.
Red.	Part 1.						
	Faint hazy bands, ...	0·5	⁞⁞	35 738 36 353		Carbon	
		0·7	⁞⁞	36 613 37 419		Carbon	
		0·8	⁞⁞	37 579 38 170		Carbon	
	Part 2.						
Scarlet-Red.	Red line, ...	1·0	▮	38 433		Carbon ?	
	Red Hydrogen, ...	6·0	█	38 715	Hydrogen		
Light-Red.	Broad band of barely resolvable lines, ...	1·0	⁞⁞⁞	39 103 39 935		Oxygen ?+	
Orange.	Hazy line, ...	0·7	⁝	40 141	Hydrogen		
	Narrow but solid band, . . .	2·0	⁞⁞	40 300 40 533	Nitrogen ?	Carbon	
	Dark space with faint, close, bright lines, ...	0·7	ǀǀǀǀǀǀ	40 533 40 878			
	Very black but narrow space intervenes.						
	Pale haze band of resolved lines, .	1·0	ǀǀǀǀǀ	40 893 41 196			
	Strong line, ...	2	▮	41 246		Oxygen	
	Pale band of resolved lines, . .	1·0	ǀǀǀǀǀ	41 321 41 588			
	Solitary haze line, ...	1·0	⁝	41 655			
	Strong orange band—						
	Sharp beginning, . . .	3	⁞⁞:	41 784	Nitrogen ?	Carbon	
	Faint ending, . . .	1		42 058			
	Band begins solid, . . .	2·5	⁞⁞⁞:	42 128			
	and ends faint in resolvable lines,	1		42 432			
	Do. do. .	1·5 0·5	⁞:	42 454 42 665	Nitrogen ?		
	Do. do. .	1·2 0·3	⁞:	42 760 43 034	Nitrogen ?		
Yellow.	Yellow line (not the Salt-line), .	2·0	▮	43 142	Hydrogen 43 141		
	Part 3.						
	The yellow line left off with in Part 2, ...	1·5	▮	43 140			
	Faint hazy space with resolvable lines, ...	0·5	ǀǀǀǀ	43 233 43 465			
	Sharp line, ...	1·0	▮	43 534			
	Strong line, ...	2·0	▮	43 706	Hydrogen		
	Broad hazy space of resolved lines,	1·0	ǀǀǀǀ	43 768 44 140			?
Citron.	Very narrow band, . . .	1·0	≡	44 339 44 376	Hydrogen		
	Broad space of just resolvable haze,	2·0	⁞⁞⁞	44 502 44 883			?
	Dark space with faintest close lines,	0·5	·····	44 967 45 192			
	Grand Citron band—						
	Sharp beginning, . . .	4·0	⁞⁞:	45 281		Carbon	
	Faint end, ...	1·0	⁞⁞:	45 855			
	Second still fainter end, .	0·4	·····	46 392			
Green.	Group of faint lines and haze, .	1·5	⁞	47 124		Carbon	
		0·7	ǀ	47 435			
		1·0	ǀ	47 677		Oxygen ?	
		1·0	ǀ	47 884	Hydrogen		
	Haze band, ...	1·5	.:⁞	48 202 48 385			?
	Faint lines in haze, . . .	1·0	ǀ	48 503			
		1·0	ǀ	48 721			

CARBONIC OXIDE. END-ON TUBE—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Unclaimed for CO.
	Part 3—*continued.*						
Green.	Grand beginning of green band, .	5	⁞⁞⁞:.	48 842		Carbon	
	Faint show of Green Giant, . .	2	|	49 201	Carbo-Hydrogen		
	Tail of Green band extends thus far,	0·5	····	49 877		Carbon	
	Haze band, ...	1·5	.⁞⁞:.	49 953	Hydrogen ?		
				50 140			
	Hazy lines, ...	1·2	⁞	50 235			
		0·7	⋮	50 380			
		1·2	⁞	50 492			
	Resolvable haze band, . . .	0·5	.:⁞⁞	50 567	Hydrogen ×	Carbon ?	
		1·0		50 862			
	Faint resolvable haze band, faint beginning,	0·5	.:⁞⁞	50 964			
	sharp end, .	1·0		51 263			
	Hazy line, ...	1·0	⋮	51 505	?	Carbon ?	?
	Very faint hazy space follows, .	0·4	⁞⁞				
Glaucous.	Glaucous Hydrogen, . . .	5	█	52 256	Hydrogen		
	Part 4.				52 258		
	Glaucous Hydrogen, . . .	4	█	52 260	Hydrogen		
	Grand blue band; sharp beginning of,	3	⁞⁞⁞:.	52 523		Carbon	
	Do. do. weak end of, .	0·5		53 008			
	Faint hazy lines, in still fainter haze, ...	1	⋮	53 775			
		1	⋮	54 220			
		0·5	⋮	54 749	Hydrogen ?		
		0·5	⋮	55 177			
Blue.		1	⋮	55 514	Hydrogen ?		
	Violet band; sharp beginning, .	2	⁞⁞⁞:.	56 240		Carbon	
	Do. faint ending, . .	1		56 652			
Indigo.	Hazy lines, ...	0·3	⋮	57 037			
		1·0	⋮	57 512			
	Second violet band; sharp beginning, ...	1·5	⁞⁞⁞:.	57 807		Carbon	
	Do. do. faint ending, .	0·3		58 235			
	Violet Hydrogen, ...	2·0	▌	58 512	Hydrogen		
Violet.	Part 5.				58 511		
	Violet Hydrogen, ...	1·5	▌	58 510	Hydrogen		
	Faint band; sharp beginning of, .	1·0	⁞⁞⁞:.	58 817		Carbon	
	Do. faint end, . . .	0·3		59 083			
	Do. do. . . .	1·0	⁞⁞⁞:.	59 376			
		0·3		59 760			
	Hazy line, ...	0·5	⋮	60 211			
	Faint band, ...	1·0	⁞⁞⁞:.	60 410		Carbon	
		0·3		61 028			
Lavender.	Rather stronger and greyer band, .	1·5	⁞⁞⁞:.	61 582		Carbon	
		0·4		62 017			
	Very faint band, ...	0·5	⁞:.	62 716		Carbon ?	
	Suspected line, ...	0·1	·····	63 689	?		

End of visible Spectrum.

When viewed with higher dispersive powers as 11°, 22°, and 33° Dispersion A to H, the large bands of this spectrum, however solid, smooth, and compact they may appear to small dispersion, separate in the most marvellous manner into thin hard separate and as well-defined lines as any we could wish to see; but it would take weeks to measure them all.

Meanwhile, with this spectrum, Hydrogen is the only large and certain impurity; Carbon is the chief, and Oxygen a minor, constituent. The yellow unnamed lines 43 141 and 43 706 appear; also the doubtful 51 505, to be low temperature Hydrogen lines.

CHLORINE. *January* 16, 1880.

Cl.

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Chlorine Spectrum from 6-inch spark by other observers.		Left unclaimed and probable for Chlorine in a 1-inch spark only.
						Intensity.	W.N. Place.	
Crimson-Red.	Part 1. A certain, but thin and sharp line, ...	1	│	34 870				34 870
Red.	Band,	1·5	≣	37 963		2	37 472	
Scarlet-Red.	Strong red line, probably Red Hydrogen, . . .	5	▮	38 702	Hydrogen	2	37 955	
						2	38 110	
					38 687	2	38 223	
	Part 2. Strong Red Hydrogen, . .	3	▮	38 671	Hydrogen			
Light-Red.	Faint group of lines or haze, .	1	.....	38 956				
	Hazy band of lines, . .	2	⁞⁞⁞	39 398	Nitrogen ?			
	Thin line, ...	0·5	│	39 677	Hydrogen ?			
Orange.	Faint lines in a still fainter illuminated region, . .	0·5	···	40 528	Hydrogen ?			
	Very thin line, terminating faint haze, ...	0·3	...│	41 046				
	Faint line or group of lines, .	1·0	❘	41 210	Oxygen ?			
	Distinct line, black space on either side, ...	2·0	▮	41 375	?			41 375 ?
	Do. do. .	1·0	❘	41 557		8	41 584	41 557 ?
	Do. do. .	2·0	▮	41 714	?			41 714 ?
	Faint broad flat haze band, .	1·0	......	41 816 42 536	Hydrogen ?			
	Band of almost resolved lines,	1·0	⁞⁞⁞	42 681 42 867	Nitrogen ?	1 1	42 675 42 804	
Yellow.	Do. do. .	1·0	⁞⁞⁞	43 052 43 279	Nitrogen ?			
	Part 3. Thin line in faintest haze, .	0·4	❘	43 475				
Citron.	Line in hazy region, . .	1·0	│	43 862		2	43 882	43 862 ?
	Lines bounding a faint band, .	0·5	⁞⁞	44 205 44 379	Nitrogen ?	2	44 436	
	Very faint hazy line, . .	0·3	❘	45 078		2	44 679	45 078
	Line, ...	1·0	│	45 325		2	44 765	45 325 ?
	Very faint line, . . .	0·3	¦	45 560		2	45 035	
	Faint band, ...	0·5	···	46 005		2	45 347	45 560 ?
						2	45 543	
						2	45 848	
						2	45 905	
	Exceedingly brilliant line in black space, . . .	5	▮	46 548		10	46 520	46 548
	Another do. do. .	5·5	▮	46 686		10	46 657	46 686
Green.	Another do. do. .	6·0	█	46 869		10	46 847	46 869
	Another do. do. .	4·0	▮	47 146		10	47 167	47 146
	Faint line, ...	1	❘	47 614		2	47 512	47 614 ?
	Faint line, ...	1	❘	47 902		2	47 699	47 902 ?
	Faint line, ...	1	❘	48 109		4	48 160	48 109 ?
	Brilliant solitary line, shown by higher dispersion to be double; its true place seems on re-examination to be rather smaller, say 48 685, and by no means increased like the tabular 6″ spectral place, which I suspect therefore to be in error, . .	7	█	48 716		10 10	48 733 48 799	48 716

CHLORINE—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Chlorine Spectrum from 6-inch spark by other observers.		Left unclaimed and probable for Chlorine in a 1-inch spark only.
						Intensity.	W.N. Place.	
	Part 3—*continued.*							
	Faint line,	1	ı	48 964		2	49 033	
	Faint line,	1	ı	49 128		2	49 072	
	Do.	1	ı	49 295		2	49 215	
	Stronger line,	2	❙	49 824		2	49 225	49 824
	Do.	2	❙	50 054		2	49 319	50 054 ?
	Line,	1	|	50 872		2	49 338	50 872 ?
Glaucous.						4	49 793	
						6	49 813	
						6	50 030	
						1	50 138	
						1	50 358	
						2	50 738	
						2	50 759	
						4	50 818	
						4	51 065	
						2	51 335	
						2	51 396	
						4	51 520	
	Line with haze before it,	1·5	....|	51 644		4	51 584	51 644 ?
	Line,	2	|	51 776		6	51 762	51 776 ?
	Line,	2	|	51 860		6	51 845	51 860 ?
	Merest suspicion of Glaucous H.	0·1	.	52 244	Hydrogen			
Glaucous.								
	Part 4.							
		4	❚	52 671		10	52 642	52 671
	Triplet of most notable lines,	4	❚	52 804		10	52 762	52 804
		4	❚	52 960		10	52 916	52 960
		0·5	ı	53 160		2	53 025	
		0·5	ı	53 606		6	53 070	
	All faintest lines with suspicions of bands to some,	1·0	|....	53 901		1	53 115	
		0·5	ı...	54 660		2	53 160	
		0·5	ı	55 123		6	53 170	
Blue.		1·0	⁞::::	55 548		2	53 305	55 548 ?
		0·5	ı	55 927		8	53 484	
	Do. do.	1·0	⁞:::	56 477		1	53 917	
Indigo.		1·0	⁞:::	57 414		2	54 624	
		1·5	:⁞:	58 327		2	54 813	
						2	55 039	
						2	55 337	
						≡	55 469	
							55 530	
	Tube tested and found quite cool,					10	58 445	
Violet.	Part 5.							
	Group of lines in haze,	2	⁞⁞⁞	58 456		2	58 551	58 456 ?
	Hazy line,	0·3	:⁞:	58 935		4	58 934	58 935 ?
	Hazy band,	2	⁞⁞:.	59 554		2	59 165	59 554 ?
	Hazy band,	2	⁞⁞:.	60 646		1	59 343	
	Fainter band,	1	⁞:.	61 459		1	59 386	
Lavender.	Very faint band,	0·3	.....	62 236		4	59 651	
	Do. do.	0·3	.....	62 686				
	Do. do.	0·2	...	63 574				

End of Spectrum.

None of the powerful bands of Carbon are here, as they are eminently in Hydrochloric Acid.

The Hydrogen lines here are weak as impurities only, compared with what they are in Hydrochloric Acid, where they are a constituent. But the Chlorine lines are far stronger here.

Chlorine, however, is peculiarly absent from all the other tubes, absolutely too if tested by its chief line, the close double 48 716.

The column of 6-inch spark, or high-temperature, Chlorine lines is derived from Thalens, Huggins, and others who have so observed, and is curious for both its agreements and disagreements with my low-temperature, small spark, spectrum lines.

CYANOGEN. OLD TUBE.

Symbol=Cy or CN. Carbon and Nitrogen.

An *old* and rather used-up example; so that its light is no longer white but pink; and the inside of the bulbs hazy. Observed July 8, 1879.

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Unclaimed features left for Cyanogen, Old.
	Visions of bands, like those which follow, but only of	0·1					
Red.	Line, faint, ...	1	|	36 250		Nitrogen	
	Band, first and faintest of a very regular series, ...	2	⁞⁞⁞	36 720 37 080		Nitrogen	
Scarlet-Red.	Another and brighter, . . .	2·5	⁞⁞⁞	37 228 37 620		Nitrogen	
	Do. do.	3	⁞⁞⁞⁞	37 823 38 165		Nitrogen	
	Do. do.	3·5	⁞⁞⁞⁞	38 302 38 612		Nitrogen	
	Red Hydrogen (the merest trace), .	0·3	|	38 712	Hydrogen		
	Band again, ...	3·5	⁞⁞⁞⁞	38 765 39 015		Nitrogen	
Light-Red.	Do.	3·5	⁞⁞⁞⁞	39 230 39 500		Nitrogen	
	Do.	3·2	⁞⁞⁞⁞	39 624 39 980		Nitrogen	
Orange.	Do.	2·7	⁞⁞⁞	40 115 40 445		Nitrogen	
	Do.	2·5	⁞⁞⁞	40 580 40 935		Nitrogen	
	Do.	2	⁞⁞⁞	41 038 41 365	(No Oxygen)	Nitrogen?	
	Do.	1·3	⁞⁞⁞	41 465 41 705		Nitrogen?	
	This last band faintest of the set of 11 similar breadth bands, also split down the middle by a black line; afterwards begins a new and bright series of 7 similar breadth bands; as in THALEN's Nitrous Oxide, by others called Nitrogen.						
	Very strong, well-defined band, . .	4	⁞⁞⁞⁞	41 805 42 145		Nitrogen	
	Do. do. . .	4	⁞⁞⁞⁞	42 230 42 570		Nitrogen	
	Do. do. . .	4	⁞⁞⁞⁞	42 610 42 902		Nitrogen	
	Do. do. . .	4	⁞⁞⁞⁞	42 974 43 242		Nitrogen	
Yellow.	Do. do. . .	4	⁞⁞⁞⁞	43 310 43 640		Nitrogen	
	Do. do. . .	4	⁞⁞⁞⁞	43 415 44 010		Nitrogen	
Citron.	Last band of this set, ...	4	⁞⁞⁞⁞	44 090 44 380		Nitrogen	
	These two series of most remarkable and regular bands in Cyanogen are still more like THALEN's Bi-oxide of Azote, other's Nitrogen, than the Nitrogen tube itself. The Hydrogen has only lately come into view.						

CYANOGEN. OLD TUBE—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Unclaimed features left for Cyanogen, Old.
Citron.	A black space follows, faint line therein, developes afterwards into a cyanogen line, ...	1	ı	44 878			Cyanogen 44 878
	Sharp edge of a citron band, . .	3	⁞⁞:.	45 200		Carbon	
Green.	A band after a region of thin close lines,	2	:.	47 806		Nitrogen ?	
	Very sharp line begins a band of lines,	4	▌....	48 582			Cyanogen 48 582
	Green band begins, ...	4	⁞⁞:.	48 862		Carbon	
	A line in that band, ...	4	⁞▌⁞	49 050		Nitrogen ?	
	An isolated line, ...	3	▌	49 350		Nitrogen ?	Cyanogen 49 350
	N.B.—The above two lines are certainly not Blow-pipe's, or Carbo-hydrogen's green-giant and its second following line, which read as now measured specially in a flame close by, 49 178 and 49 516.						
	Faint band begins, ...	2	:.	49 996		Nitrogen ?	Cyanogen ?
Glaucous.	Stronger band with central line, . .	3	⁞▌⁞	50 170		Nitrogen ?	
	Line, ...	3	|	50 510		Nitrogen ?	
	Line, ...	3	|	50 728	?		?
	Line, ...	3	|	51 100		Nitrogen ?	
	Fainter line, ...	2	|	51 260	?		?
	Sharp beginning of graduated band, .	4	⁞⁞|:.	51 650		Nitrogen	
	Glaucous Hydrogen, ...	2	|	52 250	Hydrogen		
	Very faint haze band, . . .	2	:.	52 585		Carbon	
	Sharp beginning of strong band, .	4	⁞⁞:.	52 794		Nitrogen	
	Faint line, ...	1	ı	53 836	?		
	Sharp beginning of strong band, .	4	⁞⁞:.	53 960			Cyanogen 53 963
	Faint line, ...	1	ı	54 460		Nitrogen	
	Band begins, ...	3	⁞:.	54 642		Nitrogen	
Blue.	Line, ...	2	|	55 271	?	?	?
	Sharp beginning of strong band, .	4	⁞⁞:.	55 630		Nitrogen	
	Very weak band, ...	0·5	:.	56 370		Carbon	
	Graduated band begins, . . .	3	⁞:.	56 645		Nitrogen	
Indigo.	Do. do. . . .	3	⁞:.	57 602		Nitrogen	
	Faint band begins, ...	1	:.	58 290	?	?	
Violet.	Strong linear beginning of a band, .	3	⁞:.	58 530		Nitrogen	
	Grand line peculiar to Cyanogen, .	5	▌:.	59 405			Cyanogen 59 405
	Strong beginning of a band, . .	4	⁞⁞:.	59 511		Nitrogen	
Lavender.	Very faint band, ...	2	:.	60 015	?	?	Cyanogen 60 015
	Band begins, ...	3	⁞:.	60 535		Nitrogen	
	Faint band begins, ...	2	:.	61 335		Nitrogen	
	Very faint do.	1	:.	62 065		Nitrogen	
	Stronger band begins, . . .	3	⁞:.	62 625		Nitrogen	
	Faint band begins, ...	2	:.	63 496		Nitrogen	

End of Spectrum.

This Cyanogen tube, remarkable at *first* for its bright white light to the eye,—so that its end-on view reminded me of a little full Moon high in the sky,—possessed then large carbon bands, no hydrogen at all, most brilliant lines and bands in the violet, and a more regular vertical stratification of what are here called Nitrogen bands, in the red, orange, and yellow, than what the Nitrogen tube itself showed.

Now the light is pink, hazy, and faint. The Carbon bands far smaller; a little hydrogen has come into view; the extra regularity of the Nitrogen bands being still partly kept up.

The powerful violet line at 59 405, may become useful as a reference for place to many observers.

CYANOGEN. Very Old Tube (End-on). *February* 28, 1880.

(CN. Carbon and Nitrogen.)

Six months further change are seen here on the "Old Cyanogen tube" observed in July 1879; Hydrogen impurity has grown largely. Carbon bands have notably decreased, also those of Nitrogen; but special Cyanogen lines are stronger and more numerous.

Colour.	Subject of Observation.	Intensity.	Appearance.	W. N. Place.	Impurities.	Constituents dissociated.	Left unclaimed for Cyanogen (very Old).
Red.	Part 1.						
	Three faint Nitrogen-like bands, .	0·2 0·4 0·5	⁙ ⁙ ⁙	36 877 37 596 37 991		Nitrogen Nitrogen Nitrogen	
Scarlet-Red.	Part 2. Nitrogen-like band, . . .	1·5	⁙	38 455		Nitrogen	
	Red Hydrogen (grown ! !) . .	3·5	▮	38 727	Hydrogen		
		1·5	⁞	38 934		Nitrogen	
		1·6	⁞	39 349		Nitrogen	
Light-Red.	Nitrogen-like bands, . . .	2·0	⁙	39 660 39 970		Nitrogen	
		2·5	⁙	40 123 40 451		Nitrogen	
		2·5	⁙	40 580 40 891		Nitrogen	
Orange.	Strong line followed by a band, .	2·0	▮⁙	41 146	Oxygen ? Hydrogen ?		?
	Another line, haze, . . . and then a very black space.	2·0	▮⁙	41 552			Cyanogen
	Very firm band, ...	3	⁙	41 810 42 156	Hydrogen ?+	Carbon ? and Nitrogen ?	
	Do. do.	2·5	⁙	42 251 42 575		Nitrogen	
	Do., but fainter, . . .	1·5	⁙	42 622 42 904		Nitrogen	
	Salt line apparently ! . . .	3	▮	43 109	Sodium		
Yellow.	Part 3. Salt line repeated, . . .	3	▮	43 109			
	Three Nitrogen-like bands, . .	1·0	⁙	43 285 43 619		Nitrogen	
		1·5	⁙	43 735 44 017		Nitrogen	
		2·0	⁙	44 099 44 348		Nitrogen ?	
	Thin line in a black space, . .	0·4	│	44 491	Hydrogen ?		
Citron.	Very remarkable group of clean graduated lines in black space, .	2·0 1·0 0·3	▮│ı	44 706 44 841 44 946			True Cyanogen group beginning 44 706
	Remains of Carbon's Citron band, .	2·0 0·3	▮⁙	45 293 45 469		Carbon	
	A band in a now beginning hazy region, ...	1·0	⁙	45 672		Nitrogen	
	Do. do. .	1·0	⁙	45 940		Nitrogen ?	
	Band of haze, almost resolvable into lines, ...	1·0	⁙	46 322 46 608		Nitrogen	
	Line in hazy region, ...	1·0	⁙	46 879	?	?	
	Broad band of just resolved lines, .	1·0	ǀǀǀǀǀ	47 314 47 792	?	?	
	Very black space follows.						
Green.	Grand clean green line, ...	3	▮	48 562			Cyanogen 48 562
	Remains of Carbon's Green band, .	2·0	▮⁙	48 846 49 135		Carbon	
	Black space in midst of which Green Giant should be, but it is absolutely not.						

CYANOGEN. VERY OLD TUBE (END-ON)—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W. N. Place.	Impurities.	Constituents dissociated.	Left unclaimed for Cyanogen (very Old).
	Part 3—*continued.*						
Green.	Grand line followed by faint haze,	2·5	│⁞	49 335 49 526			Cyanogen 49 335
Glaucous.	Very black space follows.						
	System of clean lines, but utterly altered if condensed spark be employed,	2 1 0·3	▌││	50 019 50 191 50 287	Hydrogen ?	?	Cyanogen-group
	Black space follows.						
	Inverted band ending sharply, but changed by condensed spark into a double line, the brightest of the whole spectrum,	1 2	⁞│	50 629 50 779	Hydrogen +	?	Cyanogen-band
	Black space follows.						
	Group of very thin lines,	1	│││	51 117 51 275	?		
	Very thin line,	0·5	│	51 465	Hydrogen ?		
	Hazy and thin line,	0·6	⁞│⁞	51 707	?	Nitrogen ?	
	Signal line, clear and sharp; not altered by condensed spark,	2	│	52 019	?		
	Another similar, supposed Glaucous Hydrogen, not altered by condensed spark,	3	▌	52 257	Hydrogen		
	Part 4.						
	Perfectly sharp lines in black space,	0·2 1·0 2·0 0·8 0·3 0·3	, │ ▌ │ │ │	52 282 52 423 52 863 53 328 53 659 53 795		Nitrogen ?	Cyanogen Cyanogen 52 863
	Signally bright line followed by haze (not Nitrogen nor Carbon),	3 0·2	│⁞	53 963 54 260			Cyanogen 53 963
Blue.	Clear lines in black space,	2 0·7 0·7 1·0 0·8 0·5	▌ │ │ ▌ │ │	54 570 54 694 54 796 55 050 55 189 55 310	 Hydrogen ? Hydrogen ?		Cyanogen ?
	Haze band,	0·3	⁞	55 782			
Indigo.	Do.	1·0	⁞⁞	56 589			
	Do.	1·3	⁞⁞	57 354			
	Thin line,	1·0	│	57 744			
Violet.	Haze band,	0·7	⁞⁞	57 987			
	Do.	0·5	⁞⁞	58 159	Oxygen ?		
	Hazy line (perhaps faint violet H),	1·0	⁞▌⁞	58 461	Hydrogen		
	Hazy band,	0·5	⁞⁞	58 613			
	Very black space follows.						
	Part 5. Black space.						
	Grandly strong violet line, followed by a band, specially characteristic of Cyanogen,	3·5 0·3	▌⁞⁞	59 389 59 646			Cyanogen 59 389
Lavender.	Line begins a band,	2 0·2	│⁞	59 961 60 356	?		Cyanogen ?
	Line,	1·0	│	60 541		Nitrogen ?	
	General faint haze follows,		.....				
	Hazy line,	1·0	⁞⁞	61 284		Nitrogen ?	
	Black space follows.						
	Line begins a haze band,	1·5	│⁞	62 691		Nitrogen ?	
	Faint haze band,	0·3	⁞⁞	63 808			
	Very faint haze,	0·1	⁞	64 836			

End of Spectrum.

CYANOGEN, Another example of, long laid by unused. END ON TUBE.

October 10, 1879.

=CN.

This tube gives an eminently brilliant and white light to the eye; just as did the former old and much-used tube, before it went wrong, became pink in colour, pale and hazy, besides apparently sparking from the polar wires inside their glass fixings. In the spectroscope this tube showed 12 grand bands of Carbon, and 41 lesser of Nitrogen, its proper constituents; also some Hydrogen, and also Carbo-hydrogen, or Blow-pipe flame, lines as impurities, but no Oxygen; and has not been deemed worthy of being printed at length.

HYDROCHLORIC ACID. *January* 23, 1880.

HCl=Hydrogen Chloride.

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities	Constituents dissociated.	Left unclaimed for Hydrochloric Acid.
	Part 1.						
Crimson-Red.	Very clear and distinct line,	1·5	❘	34 960		Chlorine	
	Broad faint haze,	0·5	·····	36 162	Carbon		
Red.	Strong band,	1·5	⁞⁞⁞⁞	37 049 37 429	Carbon		
	Fainter band,	1·0	⁞⁞⁞	37 628 38 123	Carbon		
Scarlet-Red.	Line or band just before Red Hydrogen,	1·5	⁞⁞	38 414	Carbon		
					38 419		
	Part 2.						
	The line or band beginning just before Red Hydrogen,	1	⁞⁞	38 424	Carbon		
	Red Hydrogen,	5	█	38 742		Hydrogen	
	Bundle of lines in haze,	1 1	⁞⁞	39 352 39 506	Oxygen? and Nitrogen		
Light-Red.	Thick broad or multiple line,	2	‖	39 715			
	Band,	1·5	⁞⁞⁞⁞	40 035 40 246	Nitrogen?		
	Band,	1·5	⁞⁞⁞⁞	40 377 40 607	Carbon?		
	Band,	1·5	⁞⁞⁞⁞	40 676 40 899	Nitrogen?		
	Broad line,	2·0	▮	41 022	?	Chlorine	?
	Strong line,	2·5	▮	41 291	Oxygen?		
	Strong line,	2·5	▮	41 466		Chlorine	
	Faint narrow band,	1·3	❙	41 588		Chlorine	
Orange.	Faint bundle of lines,	1	⁞⁞	41 731	Carbon?	+Chlorine	
	Strongest line in a faint bundle accompanied by a Red band,	2·5	⁞⁞⁞⁞	41 920	Carbon?		
	Thin line,	0·7	❘	42 029			
	Strong line among thin ones,	2·5	❘❘▮❘❘	42 187		Hydrogen?	
	Close thin lines intervene,		❘❘❘❘				
	Strong central bundle,	2	▮	42 540		Chlorine?	
	Close thin lines intervene,		❘❘❘❘				
	Bundle of close lines,	2	❘▮▮❘	42 784		Hydrogen? Chlorine	
	Thin line,	1	❘	42 919			
	A yellow line, slightly beyond Sodium, &c.,	2	▮	43 116	?	Hydrogen?	?
	Part 3.						
Yellow.	Bundle of thin lines, after last terminal line,	0·7	❘❘❘❘	43 303		Chlorine?	
	Very thin line,	0·3	❘	43 445			
	Stronger line,	1·0	❙	43 506		Hydrogen?	
	Exceedingly sharp, bright intrinsically line,	3	▮	43 702	?	Hydrogen	?
	Intervenes a space, full of sharp lines,	0·3	❘❘❘❘	43 721 44 114		Chlorine?	

HYDROCHLORIC ACID—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Left unclaimed for Hydro-chloric Acid.
	Part 3—*continued.*						
Citron.	Terminal line of that space,	1·5	❘	44 133		Hydrogen	
	Narrow band of lines,	2	⁞	44 277 44 395		Hydrogen +	
	Dual lines in a region of linelets,	1·5 1·5	‖	44 549 44 696		Hydrogen	
	Single line in a region of fainter lines,	1·0	:ı:	44 920			
	Single line in do. do.—perhaps Citron 1, of Blow-pipe flame,	1·5	:ı:	45 113		Chlorine	
	Grand Citron band, sharp beginning of,	4	⁞⁞:.	45 250	Carbon		
	Line on tail of above,	1	ı	45 508		Chlorine	
	Line still on tail of Citron band,	2	▌	45 930		Hydrogen ?	
	Line, after a region of linelets,	1	ı	46 571		Chlorine	
	Line,	1·5	▌	46 663		Chlorine	
Green.	Line in hazy region,	2·0	⁞▌⁞	46 854		Chlorine	
	Lines in region of half-resolved linelets,	1·5	:▌:	47 118		Chlorine	
		0·5	:ı:	47 407	?		
		0·5	:ı:	47 666		Chlorine ?	
		0·3	:ı:	47 919		Chlorine ?	
	Peculiar nebulous band, amongst linelets,	0·5	⁞⁞	48 272			
	Strong line, after half-resolved linelets,	2·0	▌	48 662		Chlorine	
	Grand green Carbon band,	5	⁞⁞:.	48 840	Carbon		
	Blow-pipe's green giant on tail of band,	2·5	▌	49 175	Carbo-Hydrogen		
	Line,	0·5	ı	49 396		Hydrogen ?	
	Line, possibly green giant 2,	1·0	▌	49 538	Carbo-Hydrogen		
Glaucous.	Line,	1·5	❘	49 789		Chlorine ?	
	Sharp beginning of faint band,	0·7	⁞:.	50 202			
	Do. do.	0·5	⁞:.	50 584			
	Do. do.	0·5	⁞:.	50 791		Chlorine ?	
	Do. do.	1·0	⁞:	51 008			
	Possibly a dual line in faint haze,	1·5	⁞	51 468			
	Brilliant Glaucous Hydrogen,	6·0	█	52 229		Hydrogen	
	Blue band begins,	4	⁞⁞:.	52 502	Carbon		
	Part 4.						
	Exceeding sharp, thin line,	1·5	❘	52 721		Chlorine	
	Sharp line,	2	❘	52 821		Chlorine	
	Sharp distinct line,	2·5	❘	52 983		Chlorine	
Blue.	Faint band,	0·7	···	55 488 55 804		Chlorine	
	Band begins sharply, ends less sharply,	2	⁞:.	56 334 56 816	Carbon		
Indigo.	Line,	0·5	ı	57 557			
	Band,	1·0	::	58 012	Carbon		
Violet.	Sharp line, probably Violet Hydrogen,	1·5	▌	58 538	58 526	Hydrogen	
	Part 5.						
	Line, supposed Violet Hydrogen,	2·5	▌	58 514		Hydrogen	
	Line, fainter,	1·5	▌	58 936		Chlorine	
	Band,	0·5	:::	59 440 59 669		Chlorine	
Lavender.	Line,	1·0	ı	60 289	Marsh-gas		
	Do.	1·5	▌	60 530	Marsh-gas ?		
	Do.	0·5	ı	60 823	Marsh-gas ?		
	Faint line or band,	1·5	⁞	61 675	Marsh-gas ?		
	Faint band,	0·3	···	62 618			
	Last certain light,	0·1	▪	63 942			

January 26.—After much trying of various prisms on this tube, I was struck to-day with its light being now generally pink in place of blue,—with the standard Hydrogen lines being very strong,—and with large groups of lines in the Red, Orange, and Yellow, *being like those in a Hydrogen tube;* also like those produced in old Cyanogen tubes, by too abundant practice and use; while the Chlorine lines are becoming marvellously faint! and the Carbon bands are nearly gone! The Carbon may very probably be burned and deposited out; but is the Chlorine changing into Hydrogen?

HYDROGEN. END-ON TUBE. *August* 23, 1879.

=H.

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	6″ condensed spark Tables.	Left for low temp. Hydrogen.
	Part 1.						
Crimson-Red.	Sharp line,	0·3	|	32 616	Oxygen		
	Hazy band,	0·2	⁞⁞	33 020 34 200	Nitrogen		
Red.	Faint haze begins,	0·1	.....	35 602	Carbon		
	Line in haze,	0·3	.⁞.	36 230	Oxygen		
	Haze band,	0·3	⁞⁞	37 090	Carbon		
	Haze band,	0·3	⁞⁞	37 736	Carbon		
Scarlet-Red.	Red Hydrogen, excessively bright,	10	▮	38 707	38 707	38 707	38 707
	Part 2.						
	Red Hydrogen repeated,	10	▮	38 707			
Light-Red.	Broad haze band,	1	⁞⁞	39 000			
	Line in the haze,	2	|	39 314	Oxygen		
	Second line,	1·5	|	39 466			39 466
	Haze intervenes,	1	⁞⁞				
	Line,	1·5	|	39 666			39 666
	Haze intervenes,	0·7	⁞⁞				
	Line,	1·5	|	39 885			39 885
Orange.	Broad line,	3	▮	40 114			40 114
	Narrow line,	1	|	40 286			40 286
	Broad and hazy line,	2·5	⁞▮⁞	40 489			40 489
	Broadest line yet,	3	▮	40 666 40 822			40 744
	Very black space intervenes.						
	A line,	2·5	|	40 968			40 968
	A fainter line,	1·5	|	41 120			41 120
	Brightest line yet,	4	▮	41 225	Oxygen		
	Double line,	1·5	‖	41 354 41 510			41 354 41 510
	Very black space intervenes.						
	Broad band with bright line in middle,	2 3 2	⁞▮⁞	41 704 41 812 42 010	Carbon, &c.		41 812
	Broadest *cum* brightest line yet,	4·5	▮	42 060 42 210			42 135
	Thin line,	1	|	42 302			
	Band of closely packed thin lines,	2	||||	42 401 42 609			
	Close double line,	2	▮	42 810			42 810
Yellow.	Single line,	1	|	42 950			
	Very dark space intervenes,						
	Strong line,	3	▮	43 148	43 150		43 150
	Part 3.						
	Yellow line of last part,	3	▮	43 151			
	Faint double or treble line,	1·5	▮	43 310	?		
	Faint double,	1	▮	43 430	?		
	Thin but sharp and strong line,	2	|	43 545			43 544
	Brightest line yet in this part,	4	▮	43 698			43 698
Citron.	Band of infinitely fine lines, with a stronger near the middle,	1	|||||	43 747 43 862 44 000			
	Strong line,	2·5	▮	44 112			44 112
	Very black space intervenes,						
	Hard band or thick line,	3·5	▮	44 225 44 363	44 294		44 294
	Very thin line,	0·5	|	44 455			
	Thin bright line,	2	|	44 547			44 547
	Haze of fainter lines intervenes,						
	Thin bright line,	2	|	44 693			44 693
	Haze of fainter lines intervenes.						
	Thin bright line,	1	|	44 900			
	End of the fainter intervening line-haze,	0·5	.....	45 130			

Now begins a Citron-green region with background of light resolvable haze more evenly distributed than before, so that there is no more of the very black interspaces previously noted.

HYDROGEN. End-on Tube—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	6″ condensed spark Tables.	Left for low temp. Hydrogen.
Citron.	Part 3—*continued.*						
	A band,	2	⁞⁞	45 268 45 406	Carbon		
	Haze just resolvable continues up to this line,	1·5	▌	45 893			45 893
	Resolvable haze of thin lines intervenes.						
	A distinctly double line,	2	‖	46 748 46 880	Oxygen ?		
Green.	Rather strong line,	1·5	▌	47 143			
	A haze of thin close lines intervenes,	0·7	·····				
	Stronger line,	2	▌	47 668	Oxygen		
	Line haze intervenes,		·····				
	Evident line in the haze,	1·5	▌	47 920			47 920
	Haze of lines intervenes,		·····				
	Hard haze band,	1·5	⁞⁞	48 190 48 390			
	Haze of lines intervenes,		·····				
	Sharp beginning of a grand green band,	4	⁞⁞⁞:.	48 860	Carbon		
	Line just visible in that band's tail,	2	▌	49 180	Carbo-Hydrogen		
	Another fainter,	1	❘	49 380			49 380
	Decreasing haze of lines intervenes.						
	Beginning of a band of hazy lines,	2	⁞⁞:.	49 970			49 970
Glaucous.	Stronger lines than others,	2·5	▌	50 649			50 649
	Band of faint lines,	1·5	❘❘❘	50 982 51 278	?		
	A close hazy double line; subsequently found cleaner and clearer, and simply a double line,	2	‖⁞	51 463 51 537			51 463 51 537
	Glaucous Hydrogen, painfully bright,	12	█	52 254	52 252	52 255	52 252
	Part 4.						
	Glaucous Hydrogen,	10	█	52 250			
	Sharp beginning of band, graduated band,	2	⁞⁞:.	52 538	Carbon		
	Faint line in haze,	0·5	:ı:	53 764			
	Another rather stronger line,	1·0	:ı:	54 242			
Blue.	Sharp line, strongest between Glaucous Hydrogen and Violet Hydrogen; its place elsewhere made = 54 773,	2·0	▌	54 799			54 799
	Sharp beginning of graduated band,	1·5	⁞⁞:.	55 358			55 358
	Faint band,	0·9	⁞⁞	56 246 56 304	Carbon		
Indigo.	Fainter band,	0·4	⁞⁞	57 080 57 570			
Violet.	Still fainter band,	0·3	⁞⁞	57 806 58 212	Carbon		
	Violet Hydrogen,	4	▌	58 521	58 523	58 525	58 523
	Part 5.						
	Violet Hydrogen,	3	▌	58 525			
Lavender.	Sharp beginning of faint violet band,	1	⁞:.	58 930	Carbon		
	Line, beginning of faint band,	1	⁞:.	60 260	Carbon		
	Probable thin line,	0·3	⁞⁞	60 860			
	Lavender Hydrogen,	1·5	▌	61 932		61 932	61 932
	Possible faint haze extends thus far,	0·1	·····	63 090			

IODINE (=I). *March* 6 *and* 8, 1880.

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	6″ condensed spark lines of Iodine.		Left for Iodine at low, as well as high, temperature.
						Intensity.	W.N. Place.	
Red.	Part 1.							
	Clear line, ...	1·5	│	36 490		2	37 020	
	Do. do.	0·8	│	36 768		2	37 216	
	Do. do.	2·0	│	37 334		2	37 590	
	Do. do.	0·5	│	37 792		2	37 967	
Scarlet-Red.	Part 2.							
	Strong line, ...	2	▌	38 097				
	Band of perhaps finer lines, .	1	⁞	38 337		2	38 252	×
	Strong line, ...	1·5	▌	38 566		2	38 625	×
Light-Red.	This is apparently Red Hydrogen, ...	1·8	▌	38 711	Hydrogen			
	Haze bands in a region of haze, or scarcely resolved linelets,	1 &	⁞ ⁞ ⁞	39 151		2	39 113	×
		0·5		39 408				
				39 843				
Orange.	All clear and rather coarse lines, ...	2·0	▌	40 049		2	40 069	×
		0·2	│	40 203				
		0·4	│	40 354		2	40 368	×
		0·4	│	40 428				
		0·4	│	40 502				
		2·0	▌	40 586		4	40 594	×
		1·0	│	40 734				
		2·3	▌	40 935		4	40 901	×
		1 &	▌│	41 235		2	41 172	
		0·7		41 316		2	41 273	
		3	▌	41 466		10	41 428	×
		1 &	│▌	41 741		2	41 727	
		2·5		41 854		10	41 824	×
		1·0	▌	42 051		2	41 865	
Yellow.	Faint double line, . . .	0·7	│	42 250				
	Band of exquisitely graduated thin lines, ...	1·0 &	‖‖│││	42 404				
		0·1		42 579				
	Brightest line yet, . . .	3·5	▌	42 709		10	42 646	×
	Strong line, ...	1·3	│	42 911		2	42 906	×
	Line, ...	0·9	│	43 088		2	43 131	×
	Part 3.							
	Clear line, ...	0·6	│	43 236		1	43 299	×
	Faint line, ...	0·3	│	43 423				
	Stronger line, ...	0·6	│	43 540				
	Do. do.	0·6	│	43 680		2	43 634	×
Citron.	All these lines clear and with black space between, but they are thick and coarse, .	2	▌	43 867		4	43 867	×
		4	▌	43 971		10	43 968	×
		3	▌	44 097		10	44 074	×
		4	▌	44 269		10	44 258	×
		3	▌	44 479		10	44 460	×
		3	▌	44 620		10	44 591	×
		2	▌	44 723		10	44 695	×
		1	│	45 011		2	44 964	×
		5	█	45 146		10	45 100	×
		1	│	45 245		4	45 196	×
						4	45 300	
		2·5	▌	45 357		2	45 356	×
		0·2	│	45 442				
		0·5	│	45 603				
		1	│	45 738		2	45 700	×
		1	│	45 971		2	45 931	×
		1	│	46 114		4	46 089	×
		6·0	█	46 216		10	46 189	×
		1·0	│	46 335		2	46 232	×
						2	46 333	
		7·0	█	46 462		10	46 451	×
		6·0	█	46 698		8	46 683	×
		1·0	│	46 827		2	46 847	×
		7·0	█	46 982		10	47 018	×

IODINE—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	6″ condensed spark lines of Iodine.		Left for Iodine at low, as well as high temperature.
						Intensity.	W.N. Place.	
Green.	Part 3—*continued.*							
	All these lines are pretty clear and strong as such, but rather coarse, . . .	0·5	│	47 203		2	47 237	×
		3	▌	47 300		8	47 344	×
		5 & 5	▌▌	47 510		10	47 574	×
				47 582		10	47 655	×
		1·0	▌	47 684				
		0·5	▌	47 829		2	47 799	×
		1·0	▌	47 910				
		0·7	▌	48 016		2	47 996	×
		2·0	▌	48 179		4	48 270	
		4·0	█	48 380		4	48 316	×
		1·5		48 541		8	48 520	×
		3·0	▌	48 676		2	48 678	×
		0·3	‖	48 778		6	48 761	×
		0·3		48 868				
		2·0	‖	48 965				
		1·5		49 063		2	49 073	×
	This brightest line of *this* Iodine, is wanting in the condensed spark spectra; but is certainly here, having been independently identified by blow-pipe's Green Giant, .	10	█	49 189	Carbo-Hydrogen	2	49 167	? absent, or very weak, in 6″ spark spectrum
		2	▌	49 316		2	49 320	
	A grand line (Int. 10, W.N. = 49 437) of the condensed sparks' standard tables is wanting here, and should be re-observed, . . .	1		49 507	Carbo-Hydrogen	10	49 437	
		0·3	▪	49 546				
		1·2	▌	49 639				
Glaucous.	These Carbo-hydrogen references may be mere accidental coincidences, . . .	0·3	▌	49 787	Carbo-Hydrogen	2	49 737	
		1·2		49 863		2	49 783	
		3·0	▌	50 108		6	50 158	×
	All lines of various thicknesses,	2	│	50 307		2	50 327	
		0·5	│	50 375				
		2	│	50 475		2	50 518	
		2	│	50 683				
		0·1	│	50 762				
		0·1	│	50 837				
		4	▌	50 893		2	50 901	×
		2	‖	51 097		2	51 086	
		2		51 212		2	51 209	
		2·5	│	51 372		2	51 353	
	Baud of thin lines, . .	0·5	‖	51 525				
				51 620		2	51 605	
		3	▌	51 726				
		4	▌	52 002		2	51 986	×
	Faint Glaucous Hydrogen, .	3	▌	52 224	Hydrogen			
	Part 4.							
	Trace of Glaucous Hydrogen, .	3		52 261	Hydrogen			
	Lines again, but of coarse quality, ...	3	▌	52 386		4	52 340	×
		1·5	‖	52 556		1	52 502	
		1·5		52 627		1	52 565	
		3	▌	52 845		2	52 818	
		0·3		52 978				
		2	│	53 085				
		3	▌	53 337				
		2	‖‖	53 474				
		0·4		53 616				
		2	│	53 707				
		1·5	│	53 911				

IODINE—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	6″ condensed spark spectral lines of Iodine.		Left for Iodine at low, as well as high, temperature.
						Intensity.	W.N. Place.	
	Part 4—*continued.*							
Glaucous.		0·5	ı	53 990				
		0·7	ı	54 152				
		4	ǀǀ	54 270				
		4		54 386				
		1	ı	54 480				
		3	▌ǀǀ	54 690				
		2		54 777		4	54 788	×
		2		54 900				
Blue.		1·5	ǀ	55 038				
		1·5	ǀ	55 168				
		0·7	ıı	55 280				
		0·7		55 340				
	Strong line preceded by a faint one,	2	ı▌	55 452				
		1	ı	55 665				
		1·3	ı	55 851				
		1·3	ı	56 050				
		1·4	ı	56 238				
		1	ı	56 442				
		1	ı	56 560				
		1·5	ı	56 743				
		1·3	ı	56 887				
Indigo.		2·0	▌	57 023				
		1·5	ı	57 127				
	Black space follows.							
		2·0	⁞▌	57 393				
	All these iodine lines are bright and clear, but thick and coarse,	0·3	ı	57 501				
		2·0	▌	57 583				
		1·5	ǀ	57 727				
		1·5	ǀ	58 030				
		1·0	ǀ	58 208				
Violet.		1·3	ǀ	58 396				
		1·2	ǀ	58 501				
	Faint indication,	0·5	⁞	58 560	58 530			
	Part 5.							
	Trace of Violet Hydrogen,	0·6	ı	58 499				
	Line,	1·0	▌	58 554				
	A faint band,	0·3	⁞	58 786				
				59 022				
	Hazy band of lines,	1·0	⁞	59 268				
	Hazy line,	0·7	⁞ı⁞	59 381				
	Hazy band,	0·5	⁞	59 718				
		1·0	ı	60 032				
		1·3	▌	60 258				
Lavender.	Hazy band	1·0	⁞	60 931				
	Broader haze band,	1·2	⁞⁞	61 509				
		0·5	⁞	62 530				
		0·2	.....	63 104				

End of Spectrum.

This spectrum is most peculiar for its freedom from nearly all known impurities of the other gases, and for consisting almost entirely of lines; not however the sharpest order of lines, for they remind one more of straws than needles. They seem generally in position, very like the 6″ condensed spark spectra lines; especially if we allow that the one only strong case of divergence, viz., that in the Green, is due to an error in the tabular spectrum referred to.

MARSH-GAS. END-ON TUBE. *October* 8, 1879.

= Methyl Hydride = Light Carburetted Hydrogen = CH_4.

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Unclaimed for Marsh-Gas.
Red.	Part 1.						A few, and only a few, of the ordinary Carbo-hydrogen, but a grand violet series of its own.
	Faint thick band,	0·5	⁞⁞	36 964 37 402		Carbon	
	Haze band,	0·8	⁞	37 616		Carbon	
Scarlet-Red.	Stronger hazy band,	1·0	⁞⁞	37 830 38 152		Carbon	
	Part 2.						
	Beginning of band going past Red Hydrogen's place,	1·0	⁞	38 359		Carbon ?	
Light-Red.	Red Hydrogen,	5	▮	38 707		Hydrogen	
	End of previous faint band,	0·5	≡	39 050			
	Band cleft down middle,	1·5	|||	39 151 39 532	Nitrogen		
	Broad band,	2·0	⁞⁞	39 630 39 992	Nitrogen		
Orange.	Narrow band,	2·0	|||	40 151		Hydrogen	
	Solid band,	2·5	⁞⁞	40 262 40 532		Carbon	
	Narrow solid band,	2·5	⁞	40 630 40 832	Nitrogen		
	Strong line,	2·5	▮	40 984		Hydrogen	
	Band of just resolvable lines,	2·0	⁞⁞	41 085 41 290	Nitrogen		
	Solid-like band,	2·5	⁞⁞	41 390 41 542		Hydrogen	
	Band begins hazily,	1·5	⁞⁞	41 638		Hydrogen ? + Carbon ?	
	Band culminates in a line,	2·5	▮	41 865			
Yellow.	Band ends hazily,	1·5	⁞	42 018			
	Very solid narrow band,	3	⁞⁞	42 069 42 246		Hydrogen	
	Faint space of resolvable lines,	1·5	⁞⁞				
	Band line,	2	▮	42 537	?		
	Faint space of resolvable lines,	1·0	⁞⁞				
	Band line,	2	▮	42 815		Hydrogen	
	Dark space, with faintest resolvable lines,	0·5	⁞				
	Stronger band line,	2·5	▮	43 163	43 160	Hydrogen	
	Part 3.						
	Line left off with in Part 2,	2·5	▮	43 157			
	Fainter line,	1·5	|	43 282			
	Dark space with faintest close lines intervenes,	0·3	⁞				
	Thick hazy line,	2·0	⁞⁞	43 504		Hydrogen	
	Strongest line about,	3·0	▮	43 676		Hydrogen	
Citron.	Band of just resolvable lines,	1·5	⁞⁞	43 723 44 024		Carbon ?	
	Probable double line,	1·8	‖	44 094		Hydrogen	
	Strong thick green line,	2·5	▮	44 296		Hydrogen	
	Band of just resolvable lines begins,	1·0	⁞	44 456		Hydrogen	
	culminates in a thin bright line,	2·0		44 688			
	ends,	1·0		44 943			
	Narrow band of resolvable lines,	1·0	⁞	45 012 45 148	Carbo-Hydrogen		Carbo-Hydrogen
	Citron band begins sharp,	4	⁞⁞	45 250		Carbon	
	ends in haze,	1		45 588			
	Then haze follows,	0·5	⁞				
	Hazy line,	1·5	|	45 842	Carbo-Hydrogen		Carbo-Hydrogen
	Haze intervenes,		⁞				
	Hazy line,	1·5	|	46 195	Carbo-Hydrogen		Carbo-Hydrogen
	Haze intervenes,		⁞				

MARSH-GAS—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Unclaimed for Marsh-Gas.
	Part 2—*continued.*						
Citron.	Hazy line,	1·5	|	46 534	?		?
	Haze intervenes,		⁞				
	Stronger line,	2·0	▮	46 876	?		?
	Stronger line,	2·0	▮	47 137	?		?
	Resolvable haze intervenes,		⁞				
	Line,	1·5	|	47 636	Oxygen ?		
	Resolvable haze intervenes,		⁞				
	Thin line,	1·0	|	47 900		Hydrogen	
	Resolvable haze intervenes,		⁞				
	Hazy band,	2·0	⁞	48 263	Nitrogen ?		
	Very black space follows.						
Green.	Grand Green band begins sharp,	5	⁞	48 838		Carbon	
	Faint view of Blow-pipe Green Giant,	1		49 181	Carbo-Hydrogen		
	Fainter end of Green-band,	0·5	.....	49 410			
	Resolvable haze band,	1·5	⁞	49 896 50 356			
	Hazy line,	1·3	⁞	50 682		Carbon ? Hydrogen ?	
	Hazy line,	1·0	⁞	50 839			
	Hazy line,	1·7	⁞	51 067	Nitrogen ?		
	Fainter hazy line,	1·0	:	51 275	?		?
	Narrow band,	2	⁞	51 463 51 559		Hydrogen	
	Very faint hazy line,	0·5	⁞	51 726	Nitrogen ?		
	Glaucous Hydrogen,	4	▮	52 256		Hydrogen	
	Part 4.				52 258		
Glaucous.	Glaucous Hydrogen,	4	▮	52 260			
	Blue band { Begins sharply,	3	⁞	52 544		Carbon	
	Blue band { Ends faintly,	0·8		53 112			
	Faint band { Begins sharp,	1·0	⁞	53 803	?		?
	Faint band { Ends weak,	0·3		53 993			
	Hazy lines,	0·5	⁞	54 182			
		0·5	⁞	54 420			
		0·5	⁞	54 628			
	Stronger hazy line,	1·0	⁞	54 787		Hydrogen	
	Faintest hazy line,	0·2	⁞	55 094			
	Band { Begins sharply,	1·5	⁞	55 326		Hydrogen	
	Band { Ends weakly,	0·5		55 740			
Blue.	Faint haze,	0·3	⁞	55 954			
	Faint haze,	0·3	⁞	56 054			
	Strong haze band, begins,	2·5	⁞	56 200		Carbon	
	ends,	1·0		56 732			
Indigo.	Haze bands,	1·5	⁞	57 488			?
		1·0	⁞	57 897			?
		0·7	⁞	58 147			?
	A haze band begins, including Violet Hydrogen,	1·0	⁞	58 342			
	Violet Hydrogen,	1·5		58 515		Hydrogen	
	Part 5.				58 514		
	Violet Hydrogen,	2·5	▮	58 512			
Violet.	Faint line,	1	|	58 927	Carbo-Hydrogen		Carbo-Hydrogen
	Line beginning a faint band,	2·0	|	59 474	Nitrogen ?		
	End of that band,	0·3	.....	59 700			
	Very black space follows,	0					
	Leader of peculiar Marsh-gas series,	3	▮	60 243			60 243
	Second, a hazy line,	2·0	⁞	60 534			60 534
	Third line, hazy,	1·5	⁞	60 704			60 704
	Remaining lines of "Marsh-gas series" weaker, hazier and broader,	1·0	⁞	60 948			60 948
		0·8	⁞	61 161			61 161
Lavender.		0·7	⁞	61 355			61 355
		0·5	⁞	61 563			61 563
		0·3	⁞	61 865			61 865
		0·4	⁞	62 139			62 139

MARSH-GAS—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Unclaimed for Marsh-Gas.
	Part 5—*continued.*						
Lavender.	Solitary hazy line, . . .	1·0	:|:	62 548		Carbon ?	62 548
	Very faint haze band, . . .	0·3	…..	63 791			63 791
Gray.	Faint but sharp beginning of a band, looking suspiciously like a reflection, ...	0·5	∷.	65 610			65 610

End of Spectrum.

The beautiful violet series of lines and bands, beginning at 60 243, and continuing to 62 000 nearly, in decreasing intensity was discovered by Prof. A. S. HERSCHEL in these End-on tubes in 1879, and confirmed therein by myself; with the result of finding traces of them in some other hydro-carbons, as Alcohol; but always far weaker than in Marsh-Gas.

In hardly any Hydro-Carbon is there so little of the Marsh-Gas series to be seen as in Olefiant Gas; and yet that is so near in chemical constitution to Marsh-Gas, which has the series so splendidly, that it must belong to that gas; and it is certainly the spectrum of a compound, and not an elemental, gas, because it vanishes with greater intensity of spark and dissociating power.

NITROGEN. END-ON TUBE. *Observed July* 16, 1879.

Symbol=N.

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Unclaimed features left for Nitrogen.
	Part 1.						
Crimson-Red.	Very faint hazy line, . . .	0·5	:|:	32 555	Oxygen		
	Hazy line, ...	1	:|:	33 975			33 975
Red.	Haze band, ...	0·5	∷	34 973			34 973
	Haze band, ...	0·8	∷	36 189			36 189
Scarlet-Red.	Do. do.	1·0	∷	37 075			37 075
	Do. do.	1·5	▦	37 555			37 555
	Do. do.	1·5	▦	37 996			37 996
	Do. do.	1·5	▦	38 430			38 430
	Red Hydrogen, ...	8·0	█	38 705	Hydrogen		
	Part 2.						
	Red Hydrogen, ...	8	█	38 708	Hydrogen		
	Faint band, ...	0·5	∷	38 988			38 988
Light-Red.	Hazy band, ...	2	▦	39 260 39 588			39 260 39 588
Orange.	Do. do.	2	▦	39 692 40 024			39 692 40 024
	Do. do.	2	▦	40 150 40 514			40 150 40 514
	Do. do.	2	▦	40 628 40 930			40 628 40 930
	Hazy line, ...	1	:|:	40 997	Hydrogen ?		
	Do. do.	1	:|:	41 130	Hydrogen ?		
	The Oxygen line, ...	3	▌	41 255	Oxygen		
	Faint hazy band, ...	1	∷	41 460 41 736			41 460 41 736
	Hazy band line in haze, . .	3	▦	41 818 42 005 ·	Carbon and Nitrogen		41 818 42 005
Yellow.	Do. do. . . .	3	▦	42 120 42 320		?	42 120 42 320

NITROGEN. END-ON TUBE—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Unclaimed features left for Nitrogen.
Yellow.	Part 3—*continued.*						
	Hazy band line in haze, . .	3	░	42 402 42 588		?	42 402 42 588
	Do. do. . . . . (reading altered from 42 746).	3	░	42 719 42 946			42 719 42 946
	Do. do. . . .	3	░	43 041 43 296			43 041 43 294
	Do. do. . . .	3	░	43 364 43 582		?	43 364 43 582
	Yellow line in haze, . . .	3	░▌░	43 673	Hydrogen 43 680		
	Part 3.						
	Yellow line in haze, . . .	3	░▌░	43 687			
Citron.	Haze band, ...	3	░	43 783 44 009			43 783 44 009
	Faint haze band, ...	2	░	44 109 44 239			44 109 44 239
	Broad line, ...	3	█	44 290 44 423	Hydrogen		
	Region of broad dark faint bands generally, ...	0·5	░	44 500 45 224			44 500 45 224
	First of several bright haze bands in haze, ...	4	░	45 241 45 496	Carbon and Nitrogen		45 241 45 496
	Bright haze band in haze, . .	4	░	45 634 45 884			45 634 45 884
	Do. do.	4	░	45 995 46 230			45 995 46 230
	Haze band in haze, . . .	3	░	46 379			46 379
	Narrow band in haze, . . .	4	░▌░	46 547			46 547
	Do. do.	4	░▌░	46 733	Oxygen ?		
	Do. do.	4	░▌░	46 867			46 867
Green.	Band in haze, ...	4	░	46 993 47 210			46 993 47 210
	Faint bands, and then comes a strong sharp-edged band still in haze, ...	4	░	47 488 47 716	Nitrogen and Oxygen		47 488 47 716
	Narrow band in haze, . . .	3	░▌░	47 800 47 920			47 800 47 920
	Band in haze, ...	3	░	48 120 48 316			48 120 48 316
	Congeries of faint lines in haze, .	2	░	48 442 48 750			48 442 48 750
	Grand Green band begins sharp, . It is composed thus, viz.—	5	▌░	48 822	Carbon and Nitrogen		
	Strong hazy band, . . .	5	░▌░	48 802 48 929		?	48 802 48 929
	Less strong, ...	3	░	48 967 49 062			48 967 49 062
	Very faint, ...	1	░	49 142 49 242			49 142 49 242
	Decreasing nebulous haze; no Green Giant of Blow-pipe appears, .	0·7 to 0·1	░	49 270 50 070			49 270 50 070
	(Blow-pipe's Green Giant's place by a separate Alcohol tube is . .	7	█░	49 172)			
	Part 4.						
Glaucous.	A fainter Green band begins, .	3	▌░	50 068			50 068
	Glaucous band, ...	3	▌░	50 962			50 962
	Second glaucous band, . . .	2	░	51 577			51 577
	Glaucous Hydrogen, . . .	10	█	52 209	Hydrogen		

NITROGEN. END-ON TUBE—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Unclaimed features left for Nitrogen.
	Part 4—*continued.*						
	Glaucous blue band, ...	3	⁙	52 488	Carbon		
	Another band close upon it, . .	3	⁙	52 719			52 719
Glaucous.		3	⁙	53 780			53 780
	A doubled band, ...	3 4	⁙	54 435 54 634			54 435 54 634
	Bright bars at beginning, then shade, and finally blackness before the next bright bar, . .	4	⁙	55 515			55 565
Blue.	*N.B.*—In the Green the last of each band's space was hazy, not dark.						
					} 55 565		
	Part 5.						
	Beginning of band, repeated, . .	4	⁙	55 615			55 565
	Do. do. . .	1	⁙	56 310	Carbon		
	Do. do. . .	4	⁙	56 555			56 555
Indigo.	Do. do. . .	4	⁙	57 470			57 470
	Do. do. . .	3	⁙	58 256			58 256
	Violet Hydrogen, centre of line, .	4	▮	58 489	Hydrogen		
Violet.		0·5	⁙	59 351			
	Sharp beginning of band, . .	4	⁙	59 444			59 444
	Haze band, ...	1	⁙	60 247	Carbon ?		
	Sharp beginning of band, . .	4	⁙	60 458			60 458
	Do. do. . .	3	⁙	61 320			61 320
	Do. do. . .	2·5	⁙	62 040			62 040
Lavender.	Do. do. . .	2·5	⁙	62 636			62 636
	Do. do. . .	2	⁙	63 638			63 638
	Very faint and uncertain, . .	0·5	⁙	64 605		?	64 605

One more band still, but it looks like a glare-reflection of Violet Hydrogen and its close preceding bands, and reads = W.N. 65 517, but it may be the band seen following the Marsh-gas series and in that case probably *Carbon.*

After this, darkness, and the end of the Spectrum.

This spectrum, looked on by M. PLUCKER as the Spectrum of pure Nitrogen, but the band, or compound-line, or low temperature, form of the same,—is stated by M. THALEN to be, on the contrary, the spectrum of the Compound of Nitrogen and Oxygen (bi-oxide of Azote); and if asked whence the oxygen for the Nitrogen of the tube to compound with,—he would say, from the two dissociated elements of watery vapour lurking in the tube, for see how large an uncombined amount of the other element, hydrogen, there is present.

But if our "Water" and "Salt-Water" tubes show little or no dissociated elements of water,—we conclude that our weak sparks cannot dissociate accidental moisture of water either; and that there are in this tube, pure nitrogen giving a band spectrum, a large amount of hydrogen impurity, a small quantity of carbon, perhaps carbo-hydrogen, impurity, but only a trace of oxygen impurity.

Whence then has come so large an amount of Hydrogen by itself?

It may have been liberated by the action of the spark in the vacuous tube out of the electrode wires and their "occluded" stores; or out of the material of the glass itself. Or again it may be another example of the cases mentioned in the Introduction (pp. 101 to 103), of nitrogen, when acted on in a high state of rarefaction by the electric spark, changing into, or giving out, hydrogen.

NITROUS OXIDE. LAUGHING-GAS. END-ON TUBE.

August 19, 1879.

$=N_2O$.

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Left unclaimed for Nitrous Oxide.
Crimson-Red.	Part 1.						
	Hazy maximum line of a band of haze, ...	0·2	⁙	33 560	?		None of any importance.
Red.	Another like it, ...	0·2	⁙	33 860		Nitrogen	
	Others similar as far as, . .	0·3	⁙	36 920	?		
	Haze band, ...	1·0	⁙	36 970 37 224		Nitrogen	
	Do. do.	1·0	⁙	37 426 37 758		Nitrogen	
	Do. do.	1·5	⁙	37 856 38 234		Nitrogen	
	(*N.B.*—One more such band ; and then comes Red Hydrogen.)						
Scarlet-Red.	Part 2.						
	Haze band, ...	1·5	⁙	38 285 38 340		Nitrogen	
	Red Hydrogen (not very strong, only an impurity), . . .	5	▮	38 701	Hydrogen		
Light-Red.	Haze band, ...	1·5	⁙	38 894 39 110		Nitrogen	
	Do. do.	1·5	⁙	39 262 39 532		Nitrogen	
Orange.	Do. do.	2·0	⁙	39 674 40 046		Nitrogen	
	Hard-edged haze band, . . .	2·0	⁙	40 130 40 442		Nitrogen	
	Do. do. . . .	2·0	⁙	40 578 40 890		Nitrogen	
	A distinct line (Ox.?) on Neb. haze, ...	2·0	⁙▮⁙	41 234		Oxygen	
	Fainter line in haze region, . .	1·0	⁙▮⁙	41 470	Hydrogen	Nitrogen	
	Sudden beginning of hard, bright haze bands generally with faint, dark, double line down middle, .	3	⁙	41 714 42 130	Carbon and Nitrogen		
Yellow.	Do. do. .	3	⁙	42 162 42 470		Nitrogen	
	Do. do. .	3	⁙	42 600 42 912		Nitrogen	
	Do. do. .	3	⁙	43 006 43 360		Nitrogen	
	Part 3.						
	Hard haze band, ...	3	⁙	43 342 43 664		Nitrogen	
Citron.	Do. do.	2·5	⁙	43 756 44 032		Nitrogen	
	Do. do.	3	⁙	44 124 44 400		Nitrogen	
	Last sharp edge of broad haze band,	1·5	⁙	44 799		Nitrogen	
	Several thin lines, ...	1·0	‖‖‖	44 845 45 167		Nitrogen	
	Sharp edge of brilliant band, . .	4	⁙	45 245	Carbon		
	Region of excessively thin close lines, ...	2	‖‖‖	45 613 46 081		Nitrogen	
	Line among fainter ones, . . .	2	..|..	46 429		Nitrogen	
	Do. do. . .	2	..|..	46 561		Nitrogen	
	Do. do. . .	2	..|..	46 725		Oxygen ?	

NITROUS OXIDE—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Left unclaimed for Nitrous Oxide.
	Part 3—*continued.*						
Citron.	Line among fainter ones, . .	2	..|..	46 889		Nitrogen	
Green.	Broad faint resolvable band, . .	1·5	||||	47 010 47 440		Nitrogen	
	Bright line on faint haze, . .	2	|	47 850	Hydrogen?	Oxygen?	
	Resolvable fainter haze intervenes.						
	Haze band ended by a line, . .	1	.:⁞	48 130 48 450		Nitrogen	
	Bright beginning of a grand band,	6	⁞⁞:..	48 850	Carbon		
	A line just visible near middle of that band, ...	2	|	49 170	Carbo-Hydrogen		
	Part 4.						
	From Green Giant's place, there is faint haze to this line, . .	1·5	|	50 124		Nitrogen	
Glaucous.	Haze intervenes, then this line, .	1	|	50 437		Nitrogen	
	Fainter haze, and then this line-band,	1	⁞:.	51 030		Nitrogen	
	Do. do. do.	1	⁞:.	51 632		Nitrogen	
	Faint haze follows.						
	Glaucous Hydrogen, not very bright,	4	❙	52 230	Hydrogen		
	Beginning of a flat band, . .	3	⁞⁞⁞	52 505	Carbon		
	Sharp beginning of a graduated band, ...	3	⁞⁞:.	52 752		Nitrogen	
	Sharp beginning of a band, . .	2·5	⁞⁞:.	53 794		Nitrogen	
	Beginning of a flat band, . .	2	⁞⁞	54 420			
Blue.	Sharp beginning of a graduated band, ...	2	⁞:.	54 640		Nitrogen	
	Sharp beginning of a graduated single band, ...	3	⁞⁞:.	55 484		Nitrogen	
	3rd case Beginning of a flat band,	2	⁞⁞	56 280	Carbon		
	3rd case Sharp beginning of a graduated band, . .	2·5	⁞⁞:.	56 610		Nitrogen	
Indigo.	Sharp beginning of a graduated band, ...	2	⁞:.	57 560		Nitrogen	
	Do. do.	1·5	⁞:.	58 340		Nitrogen	
Violet.	Violet Hydrogen cuts in on the above, ...	2	❙	58 528	Hydrogen 58 524		
	Part 5.						
	Violet Hydrogen, ...	2	❙	58 519			
	Line or rib, beginning graduated band, ...	3	⁞⁞:.	59 530		Nitrogen	
	Very faint line, ...	0·3	|	60 278	Carbon		
Lavender.	Rib beginning band, . . .	2	⁞⁞	60 500		Nitrogen	
	Do. do.	1·5	⁞:.	61 350		Nitrogen	
	Do. do.	1·3	⁞:.	62 102		Nitrogen	
	Do. do.	0·9	⁞:.	62 672		Nitrogen	
	Do. do.	0·5	⁞:.	63 706		Nitrogen	
	Problematical, ...	0·1	::	64 560		Nitrogen	

End of Spectrum.

This spectrum is very like that of Nitrogen; but with less than half the amount of Hydrogen impurity, and a similarly small proportion of Oxygen, though that should be present as a constituent dissociated, at the same time that the Nitrogen was freed; but Oxygen is undoubtedly a bad illuminator. There are also large traces of Carbon, and smaller of Carbo-hydrogen, impurities.

OLEFIANT GAS. END-ON TUBE. *October* 9, 1879.

=Ethylene=Heavy Carburetted Hydrogen=C_2H_4.

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Left unclaimed for Olefiant Gas.
Red.	Part 1.						None distinct from Carbo-hydrogen; but *that*, Olefiant gas claims the utmost part in, of all the gases here tried.
	Faint haze band, ...	0·3	∴	35 846		Carbon	
	Do. do.	0·4	∴	36 721			
	Broad haze band, ...	1·0	⁞⁞	36 895 37 372		Carbon	
Scarlet-Red.	Do. do.	1·0	⁞⁞	37 642 38 020		Carbon	
	Part 2.						
	Red line beginning a band, . .	1·5	⁞	38 397		Carbon	
Light-Red.	Red Hydrogen breaks in on that band, ...	6	▮	38 715		Hydrogen	
	Bundle of haze bands begins, .	1·0	∴	39 055			
	Brighter lines therein, . .	1·5	⁞	39 277	Oxygen?		
		1·5	⁞	39 452		Hydrogen	
		1·5	⁞	39 678		Hydrogen	
	End of the bundle of haze, . .	0·5	∴	39 958		Hydrogen	
Orange.	Narrow band or broad line, . .	2	▌	40 138		Hydrogen	
	Band almost resolvable into lines, .	2·5	⁞⁞	40 288 40 561		Carbon? and Hydrogen?	
	A very thin line intervenes, . .	1·0	|	40 591		Hydrogen	
	Resolvable band, ...	2·5	⁞⁞	40 617 40 875		Hydrogen	
	Very black but narrow space follows.						
	Broad line, ...	2·5	▌	41 003		Hydrogen	
	Resolvable band, ...	2·0	⁞⁞	41 096 41 308	Oxygen?		
	A brighter resolvable band, . .	2·5	⁞⁞	41 373 41 560		Hydrogen	
	Very black line or space intervenes.						
	Resolvable band begins, . .	1·0	⁞	41 663		Hydrogen ? Carbon ?	
Yellow.	Bright line therein, . .	3·5	▌	41 748			
	ends, . . .	1·0	⁞	42 044			
	Narrow hard band, . . .	3	⁞	42 133 42 288		Hydrogen	
	After a dark space, a resolvable band, ...	2·0	⁞⁞	42 430 42 612			
	Dark space with very thin lines, .	0·5					
	Thin double line?	2	‖	42 799		Hydrogen	
	Dark space with very thin bright lines, ...	0·5	∴				
	Another bright line, . . .	2		43 157	43 167	Hydrogen	
	Part 3.						
	Bright line left off at before, . .	2	▌	43 177			
	End of the attendant resolvable band, ...	1·0	∴	43 367			
	Thick faint line, ...	1·5	▌	43 575		Hydrogen	
	Very bright line perhaps double, .	3·5	▌	43 746		Hydrogen	
	Faint band of just resolvable lines,	1·0	∴	43 783 44 166		Hydrogen?	
Citron.	Narrow band, ...	2·0	⁞	44 273 44 398		Hydrogen	
	Broad beginning of another band,	1	∴	44 490		Hydrogen	
	Thin bright line, . . .	2	|	44 721			
	End of that band, . . .	0·3	∴	44 944			
	Strong line (Citron line 1), . .	3	▌	45 099	Carbo-Hydrogen		Carbo-Hydrogen
	Sharp beginning of band, . .	4	⁞⁞	45 316		Carbon	
	Supposed Citron line 2, . .	2	▌	45 521	Carbo-Hydrogen		Carbo-Hydrogen
	After haze, another line, . .	2	▌	45 901	Carbo-Hydrogen		Carbo-Hydrogen
	After more haze, another line, .	1·5	|	46 201	Carbo-Hydrogen		Carbo-Hydrogen

OLEFIANT GAS—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Left unclaimed for Olefiant Gas.
Citron.	Part 3—*continued.*						
	After more haze, another line,	1·0	▮	46 495	Carbo-Hydrogen ?		Carbo-Hydrogen
	Sharp concluding edge of a band,	1·5	⁞	46 901			
Green.	Hazy lines,	2	⁞	47 143		Carbon ?	
		1·5	⁞	47 427			
		1·0	⁞	47 651	Oxygen ?		
		0·7	⁞	47 914		Hydrogen ?	
	Narrow band ends sharply,	2	⁞	48 120 48 298			
	Dark space follows.						
	Sharp beginning of Green Band,	5	∷	48 844		Carbon	
	Green Giant of Carbo-Hydrogen and Blow-Pipe,	7	▮	49 178	Carbo-Hydrogen		Carbo-Hydrogen
	Decreasing haze of the band follows,	2	∷				
	Second line of Carbo-hydrogen,	4	▮	49 548	Carbo-Hydrogen		Carbo-Hydrogen
	Decreasing haze follows,	0·5	∷				
	Bundle of haze, resolvable, begins,	1·0	▦	49 874			
	maximum,	2·0		50 179		Hydrogen ?	
	ends,	0·5		50 454			
	Narrow haze band,	2	⁞	50 638		Carbon	
		1		50 847			
Glaucous.	Band,	1·5	∷	50 996			
		1·5		51 304			
	Possible double line,	2	‖	51 457			
		2		51 536			
	Glaucous Hydrogen,	4	▮	52 263		Hydrogen	
	Part 4.				52 262		
	Glaucous Hydrogen,	4	▮	52 262		Hydrogen	
	Blue band begins sharp,	3	∷	52 544		Carbon	
	ends weak,	0·5		53 056			
	Very thin faint line,	0·5	⁞	53 258			
	(Probable blue band line of Carbo-Hydrogen) Line,	1·5	▮	53 660	Carbo-Hydrogen		Carbo-Hydrogen
	Narrow band,	1·0	∷	53 891	Carbo-Hydrogen		Carbo-Hydrogen
	Broad haze band Begins,	0·5	▦	54 129			
	Broad haze band Maximum,	1·2		54 258		Carbon	
	Broad haze band Ends,	0·5		54 468			
	Sharp line,	2·0	▮	54 790		Hydrogen	
Blue.	Band begins, very sharply,	1·5	∷	55 391		Hydrogen	
	ends faintly,	0·3		55 607			
	Grand violet band begins,	2·5	∷	56 266		Carbon	
	ends,	0·3		56 776			
Indigo.	Faint haze band,	0·5	∷	57 137			
	Faint haze band,	0·5	∷	57 512			
Violet.	Second violet band, begins,	2	∷	57 807		Carbon	
	ends,	0·5		58 259			
	Violet Hydrogen,	1·5	▮	58 539		Hydrogen	
	Part 5.				58 540		
	Violet Hydrogen,	1·5	▮	58 542			
	A band beginning with a sharp line,	1·8	∷	58 911	Carbo-Hydrogen	Carbon	Carbo-Hydrogen
	ends,	0·4		59 117			
Lavender.	End of broad haze extending from last,	0·4	∷	61 207			
	Black space follows.						
	Gray band begins sharply,	1·5	∷	61 567		Carbon	
	ends weakly,	0·2		62 213			
	End of all haze light,	0·1		62 972			

End of Spectrum.

In this spectrum there is merely a trace of impurities absolute of Nitrogen and Oxygen. The Constituents Carbon and Hydrogen are marked, but not extravagantly; partly perhaps because they also appear together as Carbo-hydrogen lines rather signally. No Marsh-gas series appears here; but Marsh-gas had not the Carbo-hydrogen lines by any means so strongly.

OXYGEN. End-on Tube. Spark=0″·8. *August* 11, 1879.

Symbol=O.

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Left unclaimed for Oxygen.
Crimson-Red.	Part I.						
	Faint but thin sharp line,	0·5	|	32 600			32 600
Red.	Faint beginning of haze, Sharp ending of same haze,	1·0	⁞	33 150 34 240	?		
Scarlet-Red.	Sharp line (Ox.?),	1·5	|	36 270			36 270
	Haze,	0·7	⁞	36 636 37 950	?		
	Part 2.						
	Red Hydrogen, brilliant but blurred,	10	▮⁞	38 705	Hydrogen		
	Strong line (Ox.),	3	▮	39 360			39 360
Light-Red.	Broad haze band,	1	⁞	39 600 39 964	?		
Orange.	Narrow haze band,	1	⁞	40 126	Hydrogen		
	Resolvable haze band,	2	⁞	40 308 40 610	Carbon ? & Hydrogen ?		
	Resolvable haze band,	2	⁞	40 662 40 870	Hydrogen ?		
	Hazy line,	1·5	⁞|⁞	40 954	Hydrogen		
	Infinitely thin line,	0·2	|	41 110	Hydrogen		
	Grand (Ox ?) line,	4	▮	41 266			41 266
	Infinitely thin line,	0·2	|	41 662			
	Hard edged band,	1·5	▮⁞	41 766 41 922	Carbon ? Hydrogen ?		
	Line with haze background,	1·5	|⁞	42 026	?		
Yellow.	Double line in haze,	1·5	⁞||⁞	42 120 42 220	Hydrogen		
	Faint but resolvable band,	1·0	⁞	42 310 42 552	?		
	A single line,	1·7	|	42 640			42 640
	Line, perhaps double,	1·0	▮	42 809	Hydrogen		
	Band of lines,	0·7	|||	42 964	Hydrogen ?		
	Thick line (a yellow line past Sod. α),	1·3	▮	43 152	Hydrogen 43 142		
	Part 3.						
	The last yellow line (not Sod. α)	1·5	▮	43 132			
	Several thin sharp, but faint lines,	0·7 0·7 0·7	| | |	43 250 43 394 43 530	Hydrogen ? Hydrogen		
	Strongest line yet,	2	▮	43 683	Hydrogen		
	Lines in haze,	1 1 1	⁞▮⁞ ⁞▮⁞ ⁞▮⁞	43 806 43 990 44 128	 Hydrogen		
Citron.	Broad line,	1·5	▮	44 312	Hydrogen		
	Line in haze,	1	⁞▮⁞	44 532	Hydrogen		
	Faint line in haze,	0·7	⁞|⁞	44 647	Hydrogen		
	Band just resolvable into lines,	0·5	⁞	44 794 45 166	?		
	Sharp beginning of a brilliant band,	4	▮⁞	45 248	Carbon		
	Thin lines in the long tail of above band,	1 0·5 1 1	| | | |	45 754 45 900 46 108 46 520	 Hydrogen ?		 46 109
	Brilliant clean line (Ox ?),	3	▮	46 724			46 724
Green.	Faint, but edged band,	0·5	▮⁞	47 090 47 458			

OXYGEN. END-ON TUBE—*continued.*

Colour.	Subject of Observation.	Intensity.	Appearance.	W.N. Place.	Impurities.	Constituents dissociated.	Left unclaimed for Oxygen.
Green.	Part 3—*continued.*						
	Another sharp brilliant line, . .	4		47 676			47 659
	Ultra faint haze band, . . .	0·2	:::	48 130 48 450			
	Very thin faint line, . . .	0·1	|	48 710			
	Sharp beginning of Green band, .	5	⁞::::	48 840	Carbon		
	Thin line in that band, . . .	1	|	49 360	Hydrogen ? 49 365		
	Part 4.						
	The thin line last alluded to, .	1	|	49 370			
	Faint, semi-resolvable haze, . .	0·5	:::	49 896 50 452	Hydrogen ?		
	Faint but hard edged band, . .	0·5	⁞:::	50 588 50 858	Carbon ? Hydrogen ?		
Glaucous.	Faint line, ...	1	|	51 120			
	Fainter haze intervenes, . .	0·3	:::				
	Faint line, ...	1	|	51 490	Hydrogen		
	Glaucous Hydrogen, excessively bright, ...	9	█	52 246	Hydrogen		
	Glaucous Hydrogen, repeated after improving focus, . . .	9	█	52 250	Hydrogen		
	Blue band, ...	3	⁞::.	52 514	Carbon		
	Faint hazy line, in fainter haze, .	1	::::::	54 020	Carbon ?		
	Do. do.	0·7	:::	54 286			
Blue.	Do. do.	0·7	:::	54 820			
	End of broad faint haze, . .	0·3	::	55 990			
	Sharp beginning of faint band, .	1·5	⁞::.	56 286	Carbon		
	Sharp beginning of flat band, .	0·5	:::	57 804	Carbon		
Indigo.	Strong line ends it. (Ox.) . .	2		58 160			58 156
Violet.	Violet Hydrogen, ...	3	▌	58 525	Hydrogen 58 532		
	Part 5.						
	Violet Hydrogen, ...	3	▌	58 540	Hydrogen		
	Beginning of faint haze, . .	0·3	:::	58 930	Carbon ?		
Lavender.	End of same, ...	0·1	::	61 160			
	Gray band, ...	0·3	:::	61 658 61 840			
	Gray line, ...	1·0	,	61 904	Hydrogen		

End of Spectrum.

No Nitrogen appears here.

But much Carbon and Hydrogen impurity, as well as the proper Oxygen; the latter too in far greater force than in any other tube.

The two first red lines re-observed on April 7th as 32 568 and 36 134.

Of the other and stronger Oxygen lines, two certainly, and probably four, are very close, exceedingly close and beautifully sharp, doubles; of which I hope to give a further account on a future occasion, after completing some arrangements now in progress for increasing both the dispersion and the magnifying power of my present spectroscope.

OZONE. END-ON TUBE. Spark$=0''\cdot85$. *August* 4, 1879.

Symbol$=O_3$.

This spectrum has much Carbon, also Hydrogen, impurity; but otherwise only shows pure Oxygen lines like an Oxygen tube, but not quite so brightly. Its tables therefore have been dispensed with for economy of printing.

SALT WATER. END-ON TUBE. *October* 3, 1879.

H_2O+Na.

This tube yielded plenty of Hydrogen lines, but none of Oxygen, none of Na, or common Salt, and no Solar "rain-band" lines. Its numerical tables have therefore been suppressed.

WATER. END-ON TUBE. *September* 29, 1879.

Compound$=H_2O$.

This tube showed strong Hydrogen, but no Oxygen and no Solar "rain-band" lines. Its numerical tables have therefore been suppressed.

It seems probable now, that "rain-band" lines, or the lines and bands of Watery vapour as seen in the Solar spectrum, are not *emission* lines reversed, but pure absorption effects. I was indeed told some years ago by a great spectroscopist, that *any* induction spark in ordinary moist air, on a drizzly day, would show the water-vapour lines of the solar telluric spectrum as bright lines: but the only printed observation he has furnished me with, refers to a band of lines that can be photographed far away in the ultra-violet, non-visible, region of the spectrum: and all the experiments I have tried myself with such induction sparks as I have hitherto been able to command (very small and poor unfortunately) have never shown me anything bright connected with water or steam in free air, or small tubes, in the spectrum places, or with the characters of Solar little *a* and its preliminary band of lines, the lines grouping about C′, or the lines forming the chief practical rain-band for Meteorology, viz., the band on the red side of D.

The artificial production, and final proof, of these will probably never be obtained, until very long tubes both of water and steam (such as only the nation, not an individual, could afford to set up) are used to intercept a strong light of known spectral quality. In so far, as in M. JANSSEN's celebrated experiment with the high-pressure steam-tube, but whose observations have never been clearly or numerically published.

Equally too do all the known gases and their fluids, both elemental and compound, require to be experimented upon, as to their sheer absorption effects and nothing else; while I have had some recent proofs with a good spectroscope, that the lines forming the foundations of some usually hazy absorption bands, are often as sharp, distinct and characteristically grouped, as anything ever exhibited by emission lines, whether direct, *i.e.* as *bright* lines, like all those which are noted in this collection of gaseous spectra (though the symbols for them are, for practical printing, made black on white),—or reversed, *i.e.* as *black* lines on a continuous bright spectrum, as with the ordinary "Fraunhofer" so-called lines in the spectrum of the Sun.

APPENDIX II.

TABLES OF GASEOUS IMPURITIES, THEIR CHARACTERISTICS AND ELIMINATIONS.

This enquiry is followed out in these tables in conjunction with the search for, or identification of, new lines in various of the gases: the main principle assumed being, that any new or faint line of any gas, ought to be more or less visible in every tube, according to the visibility therein of the brighter known lines of that gas.

With Hydrogen therefore (whose four standard lines there is no question about as to place),—I have begun its tables, with four double columns giving both a numerical expression for the intensity of its appearance, and a graphical reminder of the shape thereof, in each of the said four lines, in every tube observed. The Hydrogen tube, where alone these lines have full right to appear, has its number printed in the heaviest type. Other tubes which have hydrogen in their chemical composition associated with something else, have their numbers printed in less heavy type: but the tubes where the alleged contents have no chemical claim whatever to hydrogen, and yet show its spectral lines, have their numbers given in thin type.

Hence it may easily be seen, but with some surprise, that Oxygen and Ozone tubes show, besides their own lines, those of Hydrogen with even maxmimum force, though no Hydrogen *ought* to be there. Much Hydrogen appears also in Alcohol and Ammonia, but their compound formations claim Hydrogen as one of their constituents. Olefiant-gas and Marsh-gas have the same right to Hydrogen, but do not show so much of it in pure Hydrogen lines; partly perhaps because some of it is retained with them to show the perfectly different lines of Carbo-hydrogen compound, or what is seen in the base of ordinary coal-gas flames.

Turning then to, say the hitherto unclaimed line at 43 698 W.N. Place, and finding it strong in Hydrogen, Oxygen, Ozone, Olefiant-gas, Nitrogen, Marsh-gas, Alcohol, Ammonia, and all the *tubes* which have the known Hydrogen lines strong,—but absent in Chlorine, Cyanogen and others, when the known Hydrogen lines are either completely, or nearly absent,—we may say that we find the above hitherto unclaimed line appearing everywhere as a function of Hydrogen; whence we seem entitled to claim it here as one of our new, low-temperature, lines of Hydrogen.

SEARCH FOR NEW HYDROGEN LINES AFTER HYDROGEN *a*.

The portion before Hydrogen *a*, which is very faint, was specially examined on April 7, 1880, but only on 3 or 4 tubes, and without any notable result.

Names of Tubes searched in.	Chemical Designation.	Appearance of the old, well-known, high-temperature Hydrogen lines.								1·5		39 466	1·5	▮	39 666	1·5	▮	39 885	3	■	40 114
		W.N.Place. 37 707		W.N.Place. 52 255		W.N.Place. 58 525		W.N.Place. 61 932		1·5	?	39 456	1·5	▮	39 668	1·5	▮	39 880	3	■	40 129
		Intensity.	App.	Intensity.	App.	Intensity.	App.	Intensity.	App.												
Air,	$N+O+$&c.	5	▮	4·5	▮	2	▮								?			?			
Alcohol,	C_2H_6O	**8**	■	**6**	▮	**2**	▮												2	⋮	40 141
Ammonia,	NH_3	**8**	■	**10**	■	**4**	▮												2	⋮	40 132
Carbonic Acid,	CO_2	5	▮	3	▮	2·7	▮			1	⁞	39 420				0·5	⁞	39 858	1·0	┼	40 091
Carbonic Oxide,	CO	6	▮	4	▮	1·7	▮											?	0·7	⋮	40 141
Chlorine,	Cl	3	▮	0·1	·								0·5	⋮	39 677						
Cyanogen (new),	CN	4	▮	2·5	▮	2·5	▮														
Cyanogen (old),	CN	0·3	·	2	▮																
Cyanogen (very old),	CN	3·5	▮	3	▮	1·0															
Hydrochloric Acid,	HCl	**5**	▮	**6**	■	**2·0**	▮														
Hydrogen,	H	**10**	■	**11**	■	**3·5**		**1·5**	▮	1·5	▮	39 466	1·5	▮	39 666	1·5	▮	39 885	3	■	40 114
Iodine,	I	1·8	·	3·0	▮	0·6															
Marsh Gas,	CH_4	**5**	▮	**4**	▮	**2**	▮												2	▮	40 151
Nitrogen,	N	8	■	10	■	4	▮														
Nitrous Oxide,	N_2O	5	▮	4	▮	2	▮														
Olefiant Gas,	C_2H_4	**6**	▮	**4**	▮	**1·5**				1·5	⋮	39 452	1·5	⋮	39 678				2	▮	40 138
Oxygen,	O	10	■	9	■	3	▮	1	▮										1	⁞	40 126
Ozone,	O_3	10	■	10	■	4	▮	1·5	▮												
Salt Water,	H_2O+Na	4	▮	0·5	·																
Water,	H_2O	3	▮	2·5	▮	1·5	▮			1·3	⋮	39 486									

SEARCH FOR NEW HYDROGEN LINES—*continued.*

Names of Tubes searched in.	Chemical Designation.	1	|	40 286	2·5	▌	40 489	3·0	▌	40 744	2·5	▌	40 968	1·5	|	41 120	1·5	‖	41 { 354 510	3	▦	41 812
		1	|	42 298	2·5	▌	40 488	3	▌	40 744	2·5	▌	40 976	1·5	|	41 124	1·5	‖	41 { 364 527	3	▦	41 836
Air, . . .	$N+O+$&c.			?							1·0	|	40 967	1·0	|	41 149				for	see below ⁞	band.
Alcohol, . . .	C_2H_6O																			5	⁞	41 810
Ammonia, . .	NH_3	2	▌	40 309	2	⁞	40 487				3	▌	40 943	1·5	⁞	41 128	2	‖	41 { 386 479	2	▌	41 838
Carbonic Acid, .	CO_2										2	▌	40 948	1	|	41 086	1·5	‖	41 { 387 498	4	⁞	41 771
Carbonic Oxide, .	CO																1·0	|||	41 { 322 588	3	⁞	41 784
Chlorine, . .	Cl																					
Cyanogen (new), .	CN																			5	⁞	41 760
Cyanogen (old), .	CN																					
Cyanogen (very old),	CN													2	⁞	41 146						
Hydrochloric Acid, .	HCl																			2·5	⁞	41 920
Hydrogen, . .	H	1	|	40 286	2·5	⁞	40 489	3	▌	40 { 666 744 822	2·5	▌	40 968	1·5		41 120	1·5	‖	41 { 354 510	3	▦	41 812
Iodine, . . .	I																					
Marsh Gas, . .	CH_4										2·5	▌	40 984							2·5	ılı	41 865
Nitrogen, . .	N										1	⁞	40 997	1	⁞	41 130						
Nitrous Oxide, .	N_2O																					
Olefiant Gas, . .	C_2H_4										2·5	▌	41 003				2·5	|||	41 { 373 560	3·5	⁞	41 748
Oxygen, . . .	O										1·5	▌	40 954	0·2		41 110				1·5	⁞	41 844
Ozone, . . .	O_3																			2	⁞	41 752
Salt Water, . .	H_2O+Na																			5	⁞	41 747
Water, . . .	H_2O																					

A Carbon band in some tubes thus ⁞ at 41 789.

SEARCH FOR NEW HYDROGEN LINES—*continued.*

Names of Tubes searched in.	Chemical Designation.																					
		4·5	█	42 $\left\{\begin{array}{l}060\\210\end{array}\right.$	2	‖‖	42 810	3	▮	43 151	2	▮	43 545	4	▮	43 698	2·5	▮	44 112	3·5	▮	44 294
		4	⁞▮⁞	42 155	2	⁞	42 813	3	▮	43 147	2	▮	43 544	4	█	43 698	2·5	▮	44 125	3·5	▮	44 328
Air, . . .	$N+O+$&c.	2·5	⁞▮⁞	42 161	2	|	42 815	3	⁞▮⁞	43 141	2	▮	43 561	2·5	▮	43 700	1·5	⁞▮⁞	44 152	3·1	▮	44 351
Alcohol, . . .	C_2H_6O							3	▮	43 170	1	▮	43 589	4	█	43 737	2	▮	44 146	3·0	⁞▮⁞	44 364
Ammonia, . .	NH_3	3	▮	42 114	2	‖‖	42 792	3	█	43 158	1·8	▮	43 532	3·5	▮	43 690	1·5	▮	44 114	3·0	⁞▮⁞	44 300
Carbonic Acid, .	CO_2	1·5	⁞	?	1·3	⁞.	?	1·5	▮	43 138	1·2	▮	43 526	2·5	▮	43 676	1	▮	44 125	1	⁞|⁞	44 318
Carbonic Oxide, .	CO				1·2	⁞.	?	1·8	▮	43 141	1·0	▮	43 534	2	▮	43 706				1	⁞|⁞	44 355
Chlorine, . .	Cl																					
Cyanogen (new), .	CN																					
Cyanogen (old), .	CN																					
Cyanogen (very old),	CN																					
Hydrochloric Acid, .	HCl	2·5	.|:.	42 187	2	‖‖	42 784	2·0	▮	43 116				3	▮	43 702	1·5	▮	44 133	2	⁞|⁞	44 336
Hydrogen, . .	H	4·5	█	42 135	2	‖‖	42 810	3·0	▮	43 151	2	▮	43 545	4	█	43 698	2·5	▮	44 112	3·5		44 294
Iodine, . . .	I													0·6	▮	43 680						
Marsh Gas, . .	CH_4	3	⁞▮⁞	42 157	2	⁞	42 815	2·5	▮	43 157	2	⁞|⁞	43 504	3	█	43 676	1·8	‖	44 094	2·5	▮	44 296
Nitrogen, . .	N													3	⁞▮⁞	43 680				3	▮	44 356
Nitrous Oxide, .	N_2O																					
Olefiant Gas, . .	C_2H_4			?	2	‖	42 799	2	▮	43 177	1·5	▮	43 575	3·5	▮	43 746			?	3	▮	44 336
Oxygen, . . .	O	1·5	⁞▮⁞	42 170	1·0	‖	42 809	1·4	▮	43 142				2	▮	43 683				1·5		44 312
Ozone, . . .	O_3				1·0	::	42 885	2·2	⁞▮⁞	43 130	1·0	▮	43 536	3	█	43 697				1·5		44 322
Salt Water, . .	H_2O+Na																					
Water, . . .	H_2O																			1·0	⁞|⁞	44 331

SEARCH FOR NEW HYDROGEN LINES—*continued.*

Names of Tubes searched in.	Chemical Designation.	2	▌	44 547	2	▌	44 693	1·5	|	45 893	not 1·5	Ox. |	at 46 748 46 880	1·5	|	47 143	1·5	Ox. |	47 659 47 920
		2	▌	44 541	2	▌	44 690	1·5	|	45 903	2·0	▌	46 873	1·5	|	47 146	1·5	|	47 881 ?
Air, ...	N + O + &c.				1	|	44 685				1·2	⁞	46 878	1·0	⁞	47 176			or Nitrogen
Alcohol, . . .	C_2H_6O																		
Ammonia, . . .	NH_3	1·5	|	44 548	1·5	|	44 686				1·5	⁞	46 864	1·0	|	47 158			
Carbonic Acid, . .	CO_2																		
Carbonic Oxide, . .	CO																1·0	|	47 884
Chlorine, . . .	Cl										6·0	█	46 869	4·0	▌	47 146	1	|	47 902
Cyanogen (new), . .	CN	1·0	|	44 520													2	▌	47 832
Cyanogen (old), . .	CN																		
Cyanogen (very old), .	CN										1·0	|	46 879						
Hydrochloric Acid, .	HCl				1·5	|	44 696	2	▌	45 930	2·0	▌	46 854	1·5	|	47 118			
Hydrogen, . . .	H	2	▌	44 547	2	▌	44 693	1·5	|	45 893	1·5	|	46 880	1·5	|	47 143	1·5	|	47 920
Iodine, ...	I																		
Marsh Gas, . . .	CH_4				2	▌	44 688	1·5	|	45 842	2·0	▌	46 876	2·0	▌	47 137	1·0	|	47 900
Nitrogen, . . .	N										4	┇	46 867						
Nitrous Oxide, . .	N_2O										2	⁞	46 889				2	▌	47 850
Olefiant Gas, . . .	C_2H_4							2	▌	45 901									
Oxygen, . . .	O																		
Ozone, ...	O_3							2	▌	45 939									
Salt Water, . . .	$H_2O + Na$							1	|	45 912			*			†			
Water, ...	H_2O																		

* A strong Chlorine line is nearly in the same place.

† Chlorine has a rather strong line nearly in the same place.

SEARCH FOR NEW HYDROGEN LINES—*continued.*

Names of Tubes searched in	Chemical Designation.	1	|	49 380	2	❙	49 976	2·5	❙	50 649	2	⁞❙⁞	51 463 51 537	2·0	❙	54 799	1·5	⁞	55 358
		1·5	|	49 372 ?	2	❙⁞	49 995 !	2·5	❙	50 659	2	❙❙	51 470 51 546	2·0	❙	54 799	1·5	⁞	55 358
Air, ...	N + O + &c.		or or	Oxygen Cyanogen		or	Cyanogen				1·0	⁞	51 526						
Alcohol, . . .	C_2H_6O										1	⁞	51 527	1	⁞	54 797			
Ammonia, . . .	NH_3							2·0	⁞	50 668	1	||	51 472 51 534						
Carbonic Acid, . .	CO_2																		
Carbonic Oxide, . .	CO										1·0	⁞	51 505						
Chlorine, . . .	Cl																		
Cyanogen (new), . .	CN																		
Cyanogen (old), . .	CN	3	❙	49 350	2	⁞	49 996												
Cyanogen (very old) .	CN	2·5	|⁞	49 335	2	❙	50 019												
Hydrochloric Acid, .	HCl	0·5	|	49 396															
Hydrogen, . . .	H	1	|	49 380	2	❙	49 970	2·5	⁞❙⁞	50 649	2	⁞❙⁞	51 463 51 537	2·0	❙	54 799	1·5	⁞	55 358
Iodine, ...	I																		
Marsh Gas, . . .	CH_4							1·3	⁞	50 682	2	⁞❙⁞	51 463 51 559	1·0	⁞	54 787	1·5	⁞	55 326
Nitrogen, . . .	N																		
Nitrous Oxide, . .	N_2O																		
Olefiant Gas, . . .	C_2H_4							2	⁞	50 638	2 2	❙❙	51 457 51 536	2·0	❙	54 790	1·5	⁞	55 391
Oxygen, . . .	O	1		49 365							1	|	51 490	0·7	⁞	54 820			
Ozone, ...	O_3	0·5		49 364															
Salt Water, . . .	$H_2O + Na$	1	⁞	49 412															
Water, ...	H_2O																		

SEARCH FOR NEW OXYGEN LINES.

Names of Tubes searched in.	Chemical Designation.	Intensity of appearance there of the old Oxygen lines.				0·5	ǀ	32 600	1·5	ǀ	36 270	3	▍	39 360	1·5	⁞	42 026
		W.N. Place. 41 254	W.N. Place. 46 729	W.N. Place. 47 659	W.N. Place. 58 156	0·5	ǀ	32 590	1·5	ǀ	36 231	3	▍	39 336	1·5	ǀ	42 026?
		Intensity.	Intensity.	Intensity.	Intensity.												Ammonia?
Air,	N + O + &c.	2·0	1·2	2·0													
Alcohol,	C_2H_6O																
Ammonia,	NH_3	2·0	1·0	1·0											3	▍	42 114
Carbonic Acid,	CO_2	2·5		1·0													
Carbonic Oxide,	CO	2·0		1·0													
Chlorine,	Cl	1·0		1·0													
Cyanogen (new),	CN	2·5?															
Cyanogen (old),	CN								1	ǀ	36 250						
Cyanogen (very old),	CN				0·5?							1·6	⁞▍⁞	39 349			
Hydrochloric Acid,	HCl	2·5	1·5?	0·5								1	⁞	39 352?			
Hydrogen,	H	4	2	2		0·3	ǀ	32 616	0·3	⁞	36 230	2	▍	39 314			
Iodine,	I	1·0!		1·0													
Marsh Gas,	CH_4			1·5	0·7												
Nitrogen,	N	3·0	4?	?													
Nitrous Oxide,	N_2O	2·0	2·0	2·0													
Olefiant Gas,	C_2H_4			1·0?													
Oxygen,	O	4	3	4	2	0·5	ǀ	32 600	1·5	ǀ	36 270	3	▍	39 360	1·5	ǀ	42 026
Ozone,	O_3	5	3	4	2·5				1·0	ǀ	36 204	2	▍	39 305			
Salt Water,	H_2O + Na			1?													
Water,	H_2O																

SEARCH FOR NEW OXYGEN LINES—*continued.*

Names of Tubes searched in.	Chemical Designation.	Intensity of appearance there of the old Oxygen lines.				1·7	⁞	42 640	1·0	⁞	46 108	1·0	│	46 520	1	│	51 120
		W.N. Place. 41 254	W.N. Place. 46 729	W.N. Place. 47 659	W.N. Place. 58 156	1·7	│	42 641	1·5	│	46 109			*			†
		Intensity.	Intensity.	Intensity.	Intensity.												
Air, . . .	N + O + &c.	2·0	1·2	2·0								1·5	⁞	46 551			
Alcohol, . . .	C_2H_6O																
Ammonia, . .	NH_3	2·0	1·0	1·0											2	┃	51 064
Carbonic Acid, .	CO_2	2·5		1·0													
Carbonic Oxide, .	CO	2·0		1·0													
Chlorine, . .	Cl	1·0		1·0								5	█	46 548			
Cyanogen (new), .	CN	2·5 ?													1·5	│	51 092
Cyanogen (old), .	CN														3	┃	51 100
Cyanogen (very old),	CN				0·5 ?												
Hydrochloric Acid, .	HCl	2·5	1·5 ?	0·5								1	│	46 571			
Hydrogen, . .	H	4	2	2													
Iodine, . . .	I	1·0 ?		1·0													
Marsh Gas, . .	CH_4			1·5	0·7							1·5	⁞	46 534	1·7	⁞	51 067
Nitrogen, . .	N	3·0	4 ?	?								4	⁞┃⁞	46 547			
Nitrous Oxide, .	N_2O	2·0	2·0	2·0								2	⁞	46 561			
Olefiant Gas, . .	C_2H_4			1·0 ?													
Oxygen, . . .	O	4	3	4	2	1·7	│	42 640	1	│	46 108	1	│	46 520	1	│	51 120
Ozone, . . .	O_3	5	3	4	2·5	1·5	│	42 642	2	┃	46 092						
Salt Water, . .	$H_2O + Na$			1 ?					1		46 128						
Water, . . .	H_2O														1	⁞	51 126

* 5 │ █ │ 46 547, Chlorine or Nitrogen.

† 2 │ ┃ │ 51 095, Ammonia or Cyanogen.

Search for new Nitrogen lines or bands, Carbon lines or bands, and Chlorine lines was made in the same manner, but without any very distinct results. The actual tables of these are therefore suppressed for economy in printing.

APPENDIX III.

ON THE MAGNIFICENT FEATURES EXHIBITED BY END-ON VIEWS OF GAS-SPECTRA UNDER HIGH DISPERSION.

By Professor A. S. Herschel, M.A., F.R.A.S.

I have enjoyed rare and exceptional opportunities during the last two years of often beholding, although with very little leisure for studying them minutely, the splendid spectacles presented by fluted and other spectra of incandescent gases in the optically exquisite, and surpassingly powerful compound-prism spectroscope erected by Professor Piazzi Smyth for examining Auroræ.

My first views through the instrument, in April 1878, were chiefly confined to detecting and observing impurities of the rarefied gases said to be contained in the fine series of lateral view Geissler-tubes which Professor Piazzi Smyth had obtained from the late Mr Geissler himself, for his investigations. The admirable disposition of the pointer, and means of producing and shutting off immediately, close to the upper and lower edges of a spectrum under examination the spectra of comparison tubes, combined with the extraordinary dispersion and transparency of the prisms, and the precision and solidity of all the movements and adjustments, made this first reconnaissance of the apparatus no laborious investigation, but on the contrary a brief enjoyment of the most unexampled luxury of ease and celerity in ocular discriminations which can very well be desired or arrived at with the spectroscope.

Among my numerous notes of this first acquaintance, it will suffice to mention as an important observation, that the bands of carbon received especial attention; and that their individual variations in strength from tube to tube (for *scarcely any tube* seemed to be free from them), unaccompanied by any visible alterations of their positions, is a subject which well merits the foremost share of recognition in a circumstantial description.

It is well known that the blow-pipe-flame green, citron, and orange bands differ in the spectral places of their leading edges and shaft-lines from the corresponding carbon band-edge positions observed with the extraordinary ubiquity just described in vacuum tubes. Superposed upon the vacuum-tube carbon-bands they yet in general also exhibit their complementary array with a varying degree of strength, more or less prominently, as intruders. These two distinct orange-citron-green confederations certainly have an independent origin. One of the two is absent and not at all discernible in the blow-pipe-flame, while in almost every vacuum tube it can either be traced perceptibly, or it is even troublesomely conspicuous; and it is especially resplendent in tubes of carbonic oxide and carbonic acid. If it is anywhere very much subdued, it is so principally in an olefiant-gas vacuum tube, where the tricoloured band-system of the blow-pipe-flame, on the contrary, supersedes it almost entirely. In other tubes the two systems are simply superposed upon each other, or mingled together in various proportions of intensity.

Similar to the independent variations of the two orange-citron-green band-combinations, I noticed a marked character of individuality in the dark blue blow-pipe-flame band at the solar line G, which with its faint precursor, and with one strong blue band (near F) between it and those two sets just noticed, also constitute together very persistent features of carbon impurities in gas vacuum tubes. This most refrangible blow-pipe-flame band makes its appearance together with a prodigious development, just following it between G and H, of the six or seven-rayed violet line-cluster which Professors LIVEING and DEWAR have recently ascribed, in a Paper presented to the Royal Society of London, to Cyanogen, with extraordinary luminosity in a marsh-gas tube. The latter line-cluster I have observed as a single and solitary *lucidum* in the beautifully blue arc of flame between the pure carbon poles burned in the Brush's, or Anglo-American Company's Electric light. Its freedom in each of these two cases from any simultaneous traces of the less refrangible band or cluster midway between $H\beta$ and $H\gamma$, also referred by the same writers to Cyanogen, but which I have never yet detected in gas vacuum tubes, makes me doubt the correctness of their interpretation that it belongs to cyanogen, and to venture to attribute the six-lined blue-violet clusture just beyond G, and perhaps also the most refrangible band at G of the blow-pipe-flame spectrum, to the incandescence of marsh-gas.

Ably supported as the assumption is, no doubt, that there exist low-temperature spectra of the chemical elements, particularly of the metalloids, and sound as some of the evidence is, without question, by which the important theory has been established, yet the identification of the low-temperature spectrum of carbon, if it exists, cannot be said yet to be unanimously represented as accomplished. The independent radiancies of the several individual bands and band-combinations which together constitute the carbon impurities of gas vacuum tubes, including that presented in the blow-pipe flame, are so strikingly various and unconnected, that a choice among the band-series produced respectively by olefiant-gas, by carbonic oxide, by marsh-gas, by cyanogen, and it may be by other carbon compounds, is one of some difficulty, before it can be positively affirmed which of all these is the low-temperature spectrum of elemental carbon by itself. That several spectra of different degrees of temperature may exist, will scarcely explain the predominance under the same conditions, of three different spectral systems in such tubes as those of carbonic oxide, olefiant-gas, and marsh-gas, nor for the arbitrary admixtures of these three separate systems which high dispersion and accurate measurements easily detect as present in various abundances as common impurities in ordinary gas vacuum tubes.

The following measurements of the linelets and of some intruding shaft-lines in the citron-band of a carbonic acid tube, made a year later with the improved tubes allowing end-on vision, but with the same prisms and micrometer-screw of the aurora-spectroscope, will show the precision of detail of which the instrument was capable, and at the same time the regular and definite character of these two kinds of carbon lines and bands which present themselves in vacuum tubes as intruders one upon the other. A translation of the readings into wave-numbers per British inch, made at the time, although not possessing the accuracy which Professor PIAZZI SMYTH'S later conversion tables for the instrument's readings would have given them, is added to the measures of the list. A certain regularity of the intervals among the linelets (although not among the intruding lines) is discernible, which may, perhaps, not be only apparent, but may have a natural signification. This easy measurement with high dispersion will serve as a small pendant to the vast stock of observations with lower power set forth by Professor PIAZZI SMYTH in the foregoing paper, in illustration of the prodigious multitudes of details observable in a single shaded band, with the spectroscope's utmost resolving power.

In comparison with other observations it may also, perhaps, suggest hypotheses of some slight use and interest for future explanations, in the confident hope which may now be fairly entertained, that the speeding advances of theory and observation will at no very distant time, by their joint discoveries, penetrate the physical meaning, and interpret the beautiful chromatic harmony of these close-ruled spectral bands.

Micrometer Readings (revolutions).		Wave-numbers to an inch.		Average Intervals.
Intrusive Blow-pipe Citron Lines.	CO_2 Citron Band Linelets.	Lines and Linelets.	Intervals.	
28·500 (citron line, 1).		(45,066)		
	28·893	45,260		
	·950*	285	25	10 intervals of 13·0 each (?)
	·978	300	15	
	29·008	312	12	
	·035	325	13	
	·068	340	15	
	·100*	356	16	
	·138	373	17	
	·177	390	17	
	·225	410	20	6 intervals of 25·3 each = 2 × 12·67.
	·277	431	21	
	·335	457	26	
29·360 (citron line, 2).		(45,468)		
	·395	482	25	
	·470	514	32	
	·538	542	28	
	·616	576	34	5 intervals of 38·8 each = 3 × 12·93.
	·702	612	36	
	·796	651	39	
	·894	691	40	
	·994	733	42	
Intrusive Blowpipe Citron Lines. (continued.)	CO_2 Citron Band Linelets. (contd.)	Lines and Linelets. (continued.)	Intervals. (contd.)	Average Intervals. (continued.)
	29·994	45,733		
	30·098	45,778	45	8 intervals of 50·37 each = 4 × 12·59.
	·205	825	47	
30·245 (citron line, 3).		(45,840)		
	·325	875	50	
	·448	924	49	
	·575	977	53	
	·700	46,026	49	
	·850	084	58	
	·980	136	52	
31·000 (citron line, 4).		(46,146)		
	31·124	196	60	5 intervals of 63·2 each = 5 × 12·64.
	·280	258	62	
	·440	323	65	
	·605	386	63	
31·700 (citron line, 5).		(46,420)		
	·777	452	66	
	·930 ?	508 ?	56 ?	
	32·100 ?	571 ?	63 ?	
	32·323 ?	656 ?	85 ?	

The linelets end here in haze.

Citron-band in an end-on CO_2 tube, with intrusive blowpipe citron lines. Prism 9 ; dispersion 33° from A to H. April 1879. *N.B.*—The linelets of this group from wave-number 45,400 onwards (width 1 or 2 wave-numbers), are really exceedingly close pairs, opening gradually in width to 30 wave-numbers apart at last, but each pair is only noted here by its mean place, as if it were a single linelet.

A similar set of measurements to these was taken very rapidly in July 1879, of the fluted spectrum of Nitrogen, a translation into wave-numbers of the excellent Table of that spectrum in ÅNGSTRÖM and THALÉN'S Memoir on "The Spectra of the Metalloids,"† having presented unmistakable indications of an arithmetical progression in the wave frequencies of its lines in the red to green portion of the spectrum. Tubes of sufficient purity to show this Nitrogen close-fluting or serration without interruptions or obliterations from the red to the green end, are however of rare occurrence; and neither those of air, nor of Nitrogen and its oxides presenting

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* Dull and band-like ; probably double lines (?)

† Nova Acta Reg. Soc. Sc. Upsal., Ser. iii. vol. ix.

good end-on views of it, I had abandoned the project of repeating the Swedish experimenters' measurements, and I obtained instead some rapid measures of a superb series of red and yellow flutings in a new end-on cyanogen tube, and had completed its astonishing survey before it occurred to me to compare the series with the imperfect but very similar colonnades visible in the other nitrogen-containing tubes. A rather weaker display seen in the tube marked "Nitrogen" was measured, and it was immediately seen to be identical with the series in the cyanogen tube. The identity of the same series in all the compound-of-Nitrogen tubes which I have since tested also leaves no doubt of the absolute constancy of its appearance, as far as it is visible without confusion and obliteration by other substances in these tubes. Thus the wished-for end of its remeasurement was already attained in the set of readings noted of the magnificent array of linelet groups seen ruling the red and yellow portions of the cyanogen spectrum.*

In this marvellously beautiful array of triplets (the tube has now lost its original perfection), one following another at a little interval, a small intrusive line in one of the intervals did not conform to the measures. A suspicion of its origin being thereupon excited, the hydrogen comparison tube was lighted up, and it immediately proved to be Hα. A mere trace of hydrogen so weak and feeble as this was, is, from the ordinary prevalence of aqueous vapour, rather an exceptional occurrence in a vacuum tube. The conclusion, however, which may be drawn from its scarcity in this instance is a point of special moment to the theory of these channeled spectra, the explanation of which was given to me on the occasion of this occurrence by Professor PIAZZI SMYTH. As the proposal to contribute this Appendix has prompted and invited me to the fullest freedom of communication, I gladly avail myself of the liberty with which I am thus entrusted to reproduce it here, in order to show upon what small and apparently insignificant appearances, sound and just views of the nature and origin of gaseous spectra may sometimes come to be correctly founded.

The absence or deficiency of hydrogen is demonstrative of the sensible absence or remarkable deficiency of aqueous vapour, and consequently (admitting the purity of the included gas from air) of disposable oxygen in the cyanogen tube. Yet not only is the serried nitrogen colonnade most resplendent in its electric spectrum, but so also are those vacuum tube carbon bands which are best known as constituting the electric spectrum of carbonic oxide and carbonic acid vacuum tubes. Of all the lateral and end-on tubes examined, these latter bands, like those of Nitrogen, were noticed by Professor PIAZZI SMYTH *to be most brilliant in* this Cyanogen one, in which yet there can hardly be assumed to exist more than a mere trace of Oxygen set free, to combine with the carbon and nitrogen, by the electric spark! A new Cyanogen tube supplied to me quite recently by M. SALLERON yields an electric spectrum of the very same description. The opinion held by ANGSTROM and THALEN, therefore in their Memoir appears to be scarcely tenable, that the fluted and banded spectra just mentioned are those of the oxides of Nitrogen and Carbon, but it seems more probable that these are in fact the true low temperature spectra of those metalloids. The coal-gas or blow-pipe flame spectrum, on the other hand, is probably attributable to olefiant-gas.† A similar band spectrum is recognised by Professors LIVEING and DEWAR as

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* SALET, as well as PLÜCKER and HITTORFF, struck by the identity of this spectrum in all the nitrogen-bearing tubes, was led to the opinion from its constancy that the real source of the fluted spectrum is nitrogen itself.

† A different view of this spectrum is, however, taken by Mr LOCKYER, in whose opinion it is one form of the spectrum of elemental carbon. The smooth-shaded tube-carbon bands, in fact, resolve themselves into the line-bearing gas-flame ones on simply strengthening the induction discharge with a condenser, and especially on introducing at the same time an air-break also in its course. The experiment was tried after the present paper was read, with the above described carbonic acid and cyanogen vacuum-tubes, on July 23, 1880, on its prescription by Mr LOCKYER to the writer of the paper, and to Professor PIAZZI SMYTH, and it succeeded in the presence of its suggester, literally as he expected!

belonging to Cyanogen (unless it may be due partially to marsh-gas), and the proper spectra of the oxides of Carbon and Nitrogen if these gases exist at such high temperatures undecomposed may in the course of further trials and examinations of the spectra of ignited gases eventually come to be discovered.* Multitudes of fixed bright lines in the spectrum of vacuum tubes enclosing pure hydrogen, are confidently regarded by Professor PIAZZI SMYTH as constituting together the low temperature spectrum of hydrogen; and it is assumable that as no attempts to produce the spectrum of aqueous vapour in vacuum tubes have yet been attended with success, so also the oxides of the metalloids may be too easily decomposable by the electric spark to allow the natural spectra of the oxides of Carbon and Nitrogen to be easily exhibited in Geissler tubes.

New end-on tubes of exceedingly hard glass, made and filled this year for Professor PIAZZI SMYTH by M. SALLERON, have afforded new means of measuring the least refrangible section of the nitrogen channeled spectrum in Nitrogen, Nitric Oxide, and Cyanogen, with the advantage of the fuller conversion tables now constructed for translating into British wave-numbers the readings of the several prism-combinations of the aurora-spectroscope.

The general appearance under high dispersion of each successive escarpment of the nitrogen serration is that of a double-notched band,† whose two teeth or bright edges face towards the red; on the downward or fading slope (towards the violet) of each toothlet's descent are two lines besides the leading line at the edge, of diminishing brightness like the haze on which they lie. They divide the first slope into three apparently equal parts, while on the second slope the two lines are to appearance similarly placed, but the slope extends to once or twice their joint range further, before it fades out and leaves a dark space of a little breadth before the same double-notched escarpment begins again. There are also two lines preceding the new escarpment edge very similarly spaced asunder, and from the edge, to the other linelets of the group; and this space between two adjacent linelets is only a fifth part wider (in wave frequency) than the interval between the two chief sodium-lines (Naa_1, a_2). It embraced on the average six divisions of the micrometer screw-head, in the No. 9 prism, whose repeated readings of the same line seldom varied so much as one division, and in general only a few tenths of a division of the screw; but haziness, expansion, division, and supplanting of the lines due to coexisting impurities of other spectra in the tubes rendered exact readings of the fainter of the above lines mostly difficult and sometimes impossible. The only good measurements secured and entered in the accompanying Table were those of the three linelets on the first tooth, together with the leading line only of the second tooth. The results for the remaining lines lying between the second tooth and the first tooth or edge of the following escarpment, are so devoid of regularity, that, perhaps from their faintness and speedy effacement by carbon and hydrogen impurities, no fixed system can be recognised among them. The relative brightnesses of the four recurring linelets a, b, b', c, whose positions are tabulated, are generally about 5, 3, 1, 3; and it is the triplet of them a, b, c, whose positions, in metrical wave-lengths, are given for their recurring groups, in ÅNGSTRÖM'S and THALÉN'S Table.

In the present Table's columns of the linelet a, the metrical wave-length and wave-number are followed by the wave-length and wave-number in a British inch, so as to facilitate

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* Professors LIVEING and DEWAR'S, and Dr HUGGINS' simultaneous recognitions of the remarkable ultra-violet spectrum of aqueous vapour in the light of all hydrogen-bearing flames ('Proceedings of the Royal Society of London,' June 1880), although announced just previously to the presentation of the above reflections, had not yet been received. But they afford as yet no certain evidence that the same spectrum, indicative of aqueous vapour, is also producible by electrical discharges in gas-vacuum tubes.

† (a, c, See the accompanying sketch, p. 157).

direct comparison of the new measures in the latter kind of wave-numbers (entered in the fourth and translated into metrical wave-lengths in the first column) with the chief linelet's wave-positions actually recorded in the Swedish observers' Memoir. The metrical wave-lengths of ÅNGSTRÖM'S Table have also been translated accurately into British wave-numbers; but they are only preserved in their original form (for the purpose of admitting a direct comparison) in the case of the leading-lines *a* of the triplet groups. Among the other triplet-lines, comparisons of metrical wave-lengths are for brevity omitted, and only the equivalent values are retained in wave-numbers to an inch. Throughout all the comparisons presented in the Table, ÅNGSTRÖM'S and THALÉN'S measures in their metrical or British values occupy the upper line in the space accorded to the position-observations of the several doubly-measured groups. The next, or middle line in duplicated groups, gives the measurement with the aurora-spectroscope; and under both are written average values of the two independently observed positions. Finally, the interval of the average value of each subordinate line's wave-number from that of its leading triplet-line, is inserted in the next following column contiguous to it, so that the regularity or degree of variation of these intervals in the successive groups and sections of the spectrum can be apprehended at a glance. The last of the intervals, on the right hand side of the Table, denotes the increase of wave-number from the first line of one linear group to the first line of that following it (repeated in position for this purpose in the next preceding column), or denotes the distance in wave-numbers between the first lines of successive groups.

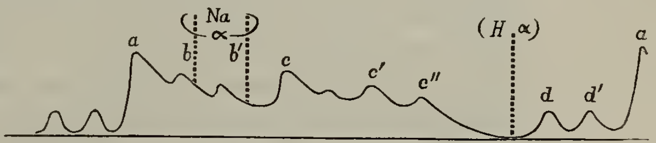
A mere inspection of the Table shows that while all the other intervals which it presents are sensibly invariable, or practically constant, the latter interval between the leading lines of successive groups is a constantly decreasing one. There are large and marked steps of this decrease at the 4th and 16th groups of the Table, followed by a rapid fall for one or two groups, and then a nearly constant interval for a long period of six or ten groups afterwards. In the remaining half of the flutings mapped by ÅNGSTRÖM and THALÉN, but not now remeasured as they merge into the carbon-citron band, the same phenomenon is presented. At one or two groups after the carbon intrusion, the group interval falls abruptly from about 360 to 300, and remains at the average value of 295 for the remaining fifteen or sixteen groups to the green end of the series. Throughout the whole range of about forty groups mapped by ÅNGSTRÖM, the interval *ac*, nevertheless preserves a constant average value of 163 English wave-numbers between the two peaks of the double-notched serration. As far as ÅNGSTRÖM'S and THALÉN'S groups are remeasured in the present Table, the common averages of the subordinate intervals of them are placed at the foot of their columns; and it appears that the line-intervals *ab*, *ab'* on the first slope have an arithmetical progression from the edge of the slope, or a common interval from line to line of about 52·3. The interval *ac* is perhaps not conformable to the progression, as although the tendency in measuring a bright edge is to place the pointer rather far upon it, and the excessive value of the interval $ac=163{\cdot}5$, shown in the average of the Table, might in this way possibly be accounted for, yet a different account of the discordance may perhaps be given from the following consideration: while in the remaining eight or ten complete ranks of ÅNGSTRÖM'S list (following those here remeasured) the interval *ac* has a pretty constant value, as before, of about 162, the interval *ab*, though very uniform, has an average value of only 42·5, and this is not more conformable to the space of 162 or 163, than the former common difference of 52·3; while it differs entirely from that regular interval in the earlier portion of the spectrum.

It appears probable, therefore from this review, that the two notch-edges of the nitrogen

WAVE-LENGTHS of NITROGEN LINELETS between the extreme Red and Yellow; (1) measured in a Cyanogen, and in a Deutoxide of Nitrogen End-on Vacuum Tube, with Prisms of the Aurora-Spectroscope giving a Dispersion from A to H of 22°; compared with Measurements of the same Lines by ÅNGSTRÖM and THALÉN. (References are made by numerals in the Table, to the brief list of Notes appended to it at the end.)

	a				*b*	(*ab*)	*b′*	(*ab′*)	*c*	(*ac*)	*a*	(*aa*)	Appearances; and standard-line adopted places, in metrical wave-lengths, and in British wave-numbers.	
	Wave-length; tenth-metres.	Wave-number in a mil-met.	Wave-length; British inch.	Wave-number in a British inch.										
1(?)	7774·6	1286·23	0·000, 030,609	32,670	…	…	…	…	…	…	…		An air-line; C.P.S. (? oxygen.)(2)	
2(?)	…	…	…	…	…	…	…	…	…	…	33,820	1150 (=2 × 575?)	$K\alpha_1$, 7700 $K\alpha_2$, 7669	=32,987 =33,140
1	7510·3	1331·51	29,568	33,820	…	…	…	…	34,003	183	34,355	535	First two (*ac*) of a bright, sharp-lined quartet (*a c*, and *c″ d*?).(3)	
2	7393·3	1352·57	29,108	34,355	34,411	55	34,469	114	34,536	181	34,911	556		
3	7275·6	1374·46	28,644	34,911	…	…	…	…	35,085	174	35,463	552		
4	7162·3	1396·19	28,198	35,463	…	…	35,573	110	…	…	35,950 ?	487		
5	7065·3?	1415·37?	27,816	35,950 ?	…	…	…	…	36,122	172	36,451	501	(Minimum).	
6	6968·2	1435·09	27,434	36,451	…	…	36,559	108	36,639	188	36,918	467		
7	[6870·0(4) 6880·1	1455·60 1453·48	27,087	… 36,918	36,972?] 36,959 965	… 47?	37,015	97	37,096	178	37,416	498		
8	6785·7 6791·6	1473·69 1472·41	26,715 26,738	37,432 37,400 416	37,471 37,463 467	51	37,522	106	37,574 (37,601?) 587	171	37,900	484	Liα, 6705·5	=37,879
9	6701·0 6702·8	1492·31 1491·92	26,382 26,389	37,905 37,895 900	37,948 37,955 951	51	38,002 ?	102 ?	38,061 38,081 071	171	38,362	462		
10	6621·8 6620·2	1510·16 1510·54	26,070 26,064	38,358 38,367 362	38,403 38,435 419	57	38,477	115	38,516 38,537 526	164	38,827	465	Hα, 6562	=38,707
11	6542·3 6541·0	1528·48 1528·82	25,757 25,753	38,824 38,831 827	38,875 38,897 886	59	38,931	104	38,979 38,989 984	157	39,282	455		
12	6465·5 6466·5	1546·67 1546·43	25,455 25,459	39,285 39,279 282	39,327 39,335 331	49	39,386	104	39,437 39,445 441	159	39,734	452	Oxygen(faint) 6456·5	=39,340
13	6392·5 6392·3	1564·33 1564·37	25,167 25,167	39,734 39,735 734	39,782 39,794 788	54	39,831	97	39,894 39,902 898	164	40,182	448		
14	6321·0 6321·3	1582·03 1581·95	24,886 24,887	40,183 40,181 182	40,229 40,240 234	52	40,292	110	40,350 40,343 346	164	40,641	459	(Maximum). Tube-C. (faint red) 6298·5	=40,327
15	6249·2 6250·5	1600·20 1599·89	24,603 24,608	40,645 40,637 641	40,688 40,694 691	50	40,737–66 751	110	40,800 40,800 800	159	41,075	434		
16	6183·2 6184·3	1617·29 1617·02	24,343 24,347	41,079 41,072 075	41,133 41,137 135	60	41,152–204 178	103	41,246 41,253 249	174	41,470	395	(Minimum). O (strong) 6157	=41,254
17	6125·4 6124·4	1632·55 1632·82	24,115 24,111	41,467 41,474 470	41,511 41,527 519	49	41,573	103	41,625 41,642 633	163	41,871	401	Li β, 6102	=41,625
Carry forward (numbers and) sums of intervals,						(10)532		(10)1054		(10)1646				

	a				*b*	(*ab*)	*b′*	(*ab′*)	*c*	(*ac*)	*a*	(*aa*)	Appearances; and standard-line adopted places, in metrical wave-lengths, and in British wave-numbers.	
Brought forward (numbers and) sums of intervals,						(10)532		(10)1054		(10)1646				
	Wave-length; tenth-metres.	Wave-number in a mil-met.	Wave-length; British inch.	Wave-number in a British inch.										
18	6066·3	1648·48	0·000, 023,883	41,871	…				42,030				Tube-C. (str. orange) 6078	=41,789
	6066·3	1648·48	23,883	41,871	…		41,976		42,026					
				871	…			105	028	157	42,255	384		
19	6011·8	1663·40	23,669	42,250	42,301				42,419					
	6010·3	1663·79	23,663	42,260	42,309		…		42,420					
				255	305	50			419	164	42,638	383		
20	5957·3	1678·64	23,454	42,637	42,685				42,809					
	5956·9	1678·76	23,452	42,640	42,694		42,741		42,801					
				638	689	51		103	805	167	43,018	380		
21	5904·6	1693·59	23,247	43,017	43,069				43,179				Naα_1, 5895	=43,086
	5904·2	1693·71	23,245	43,020	43,073		43,099–133		43,184				Naα_2, 5889	=43,130
				018	071	53	116	98	181	163	43,400	382		
22	5853·0	1708·53	23,043	43,397	43,448				43,564					
	5852·2	1708·77	23,040	43,403	43,440		43,494–527		43,570					
				400	444	44	510	110	567	167	43,780	380		
23	5801·8	1723·60	22,842	43,779	43,829				43,940				(Maximum). Hydrogen (faint) 5812·5	=43,698
	5801·5	1723·68	22,841	43,781	43,840		43,871–905		43,946					
				780	834	54	888	108	943	163	44,158	378		
24	5752·0	1738·53	22,645	44,159	44,208				44,323					
	5752·1	1738·49	22,646	44,158	44,209		44,244–283		44,325					
				158	208	50	263	105	324	166	44,531	373		
25	5703·8	1753·22	22,456	44,532					44,699					
	5704·1	1753·14	22,457	44,530	44,577		44,610–643		44,678					
				531		46	626	95	688	157	44,888	357		
26	5657·9	1767·44	22,275	44,893					45,058				Gas-fl. Citr. line 1, 5633·5	=45,086
	5659·0	1767·89	22,280	44,884	44,950		44,986		45,030					
				888		62		98	044	156	45,250	362		
27	5612·6	1781·71	22,097	45,255					45,404		45,619		Tube-C. Citr. edge, 5608	=45,289
	5613·7	1781·36	22,109–	45,231–61	…		…							
			–22,094	250						154		369		
Total (numbers and) averages of intervals,						(18)52·33		(18)104·22		(19)163·47				



(¹) Double-notched band of a Nitrogen Serration.—The dotted lines show how Hα and Naα, fall among the linelets of the ridged band in which each of them occurs separately, in the red and yellow portions respectively of the channelled field. Only measurements of the linelets *a*, *b*, *b′*, *c* of the flutings included in its range, are recorded in this Table.

(²) An extreme red ray, possibly a new oxygen line (?), seen with prisms of moderate dispersion in an air-vacuum tube; as observed and measured in a paper on "End-on Vision in Private Spectroscopy" by Professor Piazzi Smyth.

(³) A fine close-membered cluster, disclosed by end-on vision at the extreme-red end of the spectrum in both of the Cyanogen and Nitrogen-deutoxide tubes. It consisted, when best exhibited and observed in them, of four not far from equidistant, about equally bright and exceedingly sharp lines. In one of the two measurements obtained of its positions before it lost its brightness in the tubes, it only showed three lines, by the loss apparently (as comparison with the four-line measurement seems to indicate) of its leading line. It forms at the red end of the spectrum a grandly protruding and detached, somewhat distinctly formed, first linelet-group of the uninterrupted train of them there springing up. Its followers, or after-groups, though weak at first, soon brighten up into the long row of close flutings of the red-to-green Nitrogen serration. The observed wave-numbers of its third and fourth lines, 34,134 and 34,237 to a British inch (or wave-lengths 7441·2 and 7423·1 tenth-metres) appear to agree best (although not quite precisely) with the average positions in the other groups, of the linelets marked in the above figure by the ridge-tops *c″* and *d* (?)

(⁴) This is the first spectral line noted in Ångström and Thalén's Table. Although recorded there as a "first line," (*a*), its measure in English wave-number is here ranged under the same group's second line *b*, with whose remeasured place it more nearly corresponds. The secondary pair *bb′*, in fact, of this first-noted fluting (the next before that which comprises Liα, and the next but two before that in which Hα is included), a little outshines the leading line *a*, by blending together into a stronger blurred maximum of brightness at the beginning of the group.

The varying intensities of the flutings are noted in the column of "Appearances" as "maximum" and "minimum," as they are given by Ångström and Thalén, and as they present themselves in the spectrum. Of the standard-lines noted in the same column, only Hα (faintly), and edge-places of the three Tube-carbon orange and citron bands (strongly visible) were measured in the Nitrogen tubes themselves, comparison-spectra being used to show the places and to furnish micrometer-readings of the other standard lines entered in that column.

flutings are really independent from each other in their derivations, and that the array of lines on their two slopes are not fellow-representatives of a common arithmetical progression, The general want of conformity among the line-intervals of the second slope may perhaps arise, accordingly, from the superposition upon each other of the two unconformable line systems of the two interfering slopes; and a character which seems to be essential to the linelets of the second slope independently of every influence of conflicting impurities in the tube upon their comparatively slender strengths, possibly receives from a conjecture of this kind a satisfactory interpretation. That ruled and lined bands like those of olefiant-gas and other "carbon"-spectra possess, it would seem, insular characters in a spectrum, the minuteness of whose description, as revealed in the imposing tables of green gas-flame, and green tube-carbon bands drawn up by Professor PIAZZI SMYTH, surpasses comprehension, and almost registration, will I believe be granted from a close inspection of his observations and reductions. But if the inherent complexity of these shaded bands' internal structures proves to be so prodigious as the application of extraordinary dispersion shows, it is scarcely to be expected that among the close array of these ruled wedge-like luminosities crowded thickly into the nitrogen procession, order should reign among their leading, or frontier lines. Systems well studied on a larger scale appear here to be repeated, and innumerably multiplied in miniature. A comprehensive and far-reaching theory of banded and fluted spectra will therefore probably be required to include and account intelligibly for all the singular changes of orderly succession that the nitrogen flutings present when the positions of their leading edges, or in other words the space-intervals from spur, or terrace-edge to terrace-edge of the long serration, are further brought into comparison with each other.

In the extreme red, numerous groups were seen with the powerful end-on illumination, preceding any of those pictured and mapped by PLÜCKER and HITTORFF, and by ÅNGSTRÖM and THALÉN. A few measures among these revealed a far-off line, star-like in its brightness, which proved to be a triple, and even quadruple line when brought into the middle of the field of view. It had already been measured and recorded accurately with low dispersion by Professor PIAZZI SMYTH as a Nitrogen-line; and the result of the new measures of this part of the Nitrogen spectrum was to connect it, as shown in the Table, with a well-observed series of extreme-red nitrogen groups, of which it formed the first visible commencement. Its two least refrangible lines agree in their spectral positions with the two spurs or leading edges of a double-toothed serration, while its two more refrangible ones lie upon the fading flank of the second tooth's slope, at nearly the same equal distances asunder. In both Cyanogen and Nitrogen they were equally sharp and bright, like weak hydrogen or lithium lines, quite free from the haze and haziness connected with the corresponding linelets in other portions of the spectrum.

But if end-on vision has revealed an outwork so substantial and remote as this of the dark red portion of the nitrogen procession, what may perhaps be gathered from the announcement of a "fine line" at the head of the list, in a view of the spectrum *of air* in an end-on vacuum tube, contained in a record of that spectrum as measured with a prism of ordinary dispersion, communicated by Professor PIAZZI SMYTH last year in his Paper on "End-on Illumination in Private Spectroscopy" to the Royal Scottish Society of Arts, the spectral position of which is 1150 inch-units lower in its wave-number than this frontier line of nitrogen, and which is actually but little more refrangible than the dark-red Potassium-line itself?* The interval to

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* In a careful search for low-temperature lines in an oxygen gas vacuum tube, Professor PIAZZI SMYTH has met with an extreme-red line at W. No. 32,600 (*circa*), which may perhaps be identical with that above noticed as mapped in an "air-spectrum" at about W. No. 32,670. The latter line, in that case may perhaps be an oxygen-line, and not a nitrogen-line as here supposed.

this line, supposing its wave-number and that of the primary red nitrogen line to be very exactly fixed, is 1150 units, or two intervals of 575 inch-units each, which is about the length that the course of the intervals in the rest of the spectrum up to this unexplored portion, would lead us to expect. It may therefore be conjectured that the "air-line" noted in this place is a nitrogen-line, like the primary extreme-red one, of considerable brightness. The first object in the "air-spectrum" noted after it is a strong haze band occupying the place of the grand nitrogen leader, followed by two weaker haze bands in the places of the two next nitrogen groups; and finally in the extreme-red portion of the " air-spectrum" as seen and mapped with end-on vision by Professor Piazzi Smyth in the above mentioned Table, there are, from the first visible one, to the red hydrogen line, ten nitrogen haze-bands or serrations very well recorded in appearance and position, none of the places of at least half of which had ever been made sufficiently visible before for measurement, so as to afford useful data for instrumental determinations and for theoretical discussions.

The special capabilities of end-on illumination, for bringing under notice and exact observation an immense number of details not before investigable or described, were exceedingly well displayed in this example. Data of the richest value, it cannot be doubted, are now being gathered, and views of the greatest insight and originality are in a fair way to be formed and fostered by the application of end-on vision and high optical perfection and dispersion to gas-spectroscopy; but to have beheld the field of observation, and to have assisted the process as an admiring looker-on, has impressed me at the same time with the formidable as well as with some of the beautiful and splendid features of the scene! It may be hoped that photography, in its now greatly improved practice both as regards general sensibility, and especially in that sensibility which relates to the red end of the spectrum, will ere long come to the spectroscopist's assistance, and relieve him of much the most serious and hindering portion of his labours, of disentangling and recording correctly what he sees.

Now that it is well established that for a few lines sought to be produced and studied in a vacuum tube, a train of foreign lines and bands of contaminating gases commonly muster in the field, and blurr and confuse the natural spectrum sought to be examined almost beyond recognition, and when we further reflect that the intended spectra, if they are obtained in sufficient strength and purity to endure very great dispersion, are found to be of such exceeding intricacy as even then to surpass the means of accurate description, it will readily be admitted that photography would supply the spectroscopist most effectually with records of many little particulars of spectra containing important elucidations for his purpose, which pressure on his space and time constrains him, whatever art and skill he bestows upon their registration, to pass over unrecorded. Some sources of the irregularities of the nitrogen-spectrum-places were thus, it was thought, recognised in these observations, depending apparently on carbon and hydrogen contaminations; but they are too long and various in their nature to be here narrated.

A common spectacle, however, both in the cyanogen and nitric-oxide tubes was a duplication of the linelet b' (noted by the mean of the line-pair's places in the Table), and occurrences of extra linelets, sometimes between a and b, but more frequently on the fading-off declivity beyond c of the second down-slope of the double-notch. Although no doubt instructive, discussions of these diminutive characters of the spectrum, denoting perhaps only deficiencies of its strength and purity, would lead to very long and laborious descriptions. A list of standard line places, including three tube-carbon band-edges (red, orange, and citron) are therefore added to the Table, to assist in distinguishing the groups, and to supply, in case of more exact determinations being hereafter attempted of them, guides and possible explanations of some of their major variations. The tracts of dimness and brightness noted in the Table, which the range of groups present when they are most perfectly developed, are borrowed from ÅNGSTRÖM'S and THALÉN'S Table in the above quoted Memoir, those observers, as well as PLÜCKER and HITTORFF, in the admirable pictures which they have respectively published of it, having apparently mapped and noted the banded, or low-temperature spectrum of nitrogen, although not with all the structural details which it possesses, yet in its whole extent under the finest and most favourable conditions of completeness and perfection.

ERRATA.

Page 103, line 13, *erase* " and double."

Page 104, line 2, *delete* the second word.

Page 143, top of 3rd column, *for* 37,707 *read* 38,707.

On Plate XII., lowest spectrum strip, the single black line at 45 200 nearly, should be closer up to 45 000, or over the first line of the Citron band of the carbo-hydrogen group below,

P. S.

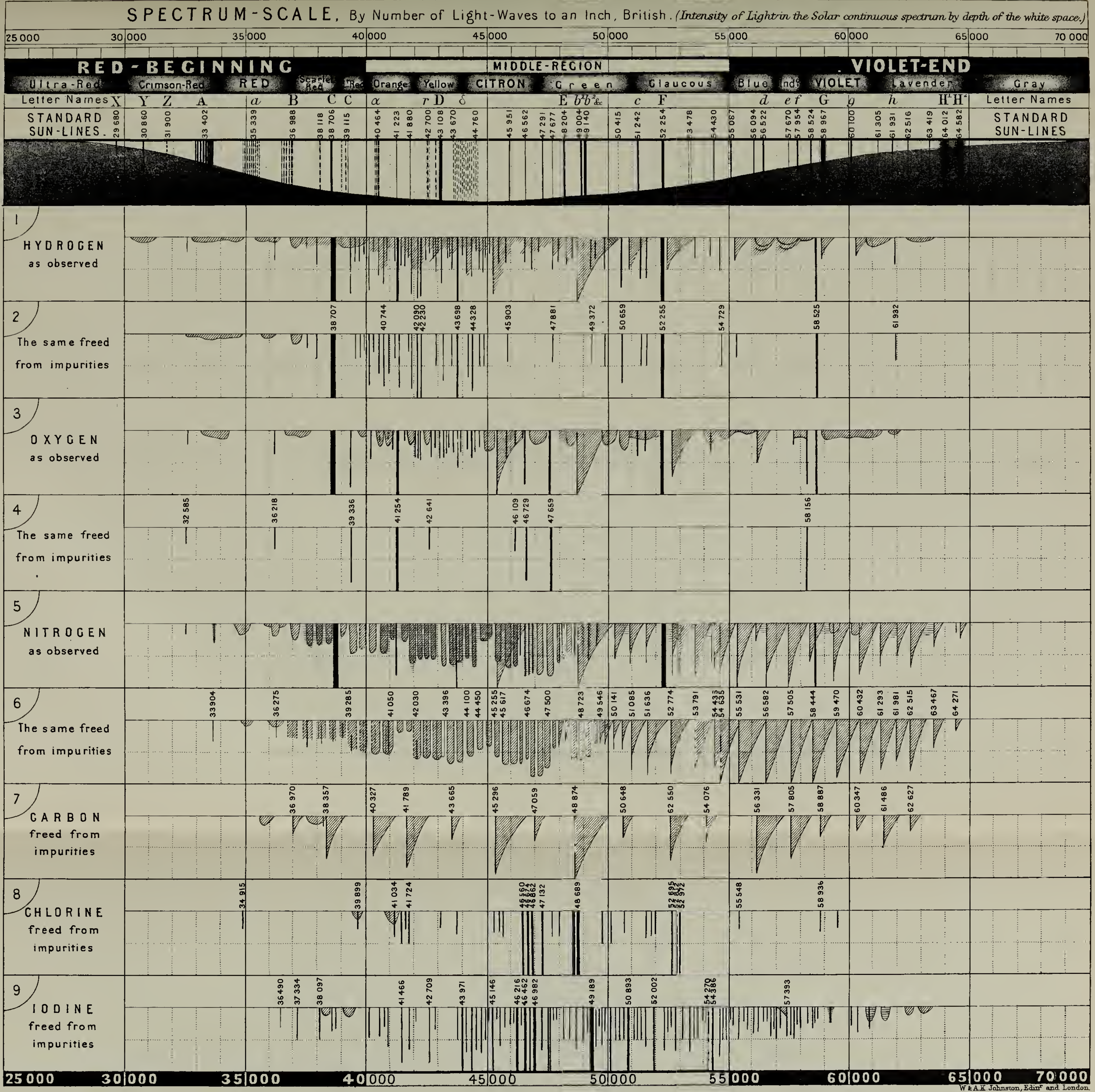
i.e., 3° *from A to H; Mag. Power* – 10. *Observations made in 1879 and 1880.*

Light is represented in these Gaseous Spectra by Black: intense according to Vertical depth. Lines dotted, or wavy, or in any other direction than Vertical, stand for shading, or haze, only.

Trans. Roy. Soc. Edinr.

ELEMENTAL-GASES.

Plate 11. Vol. XXX.



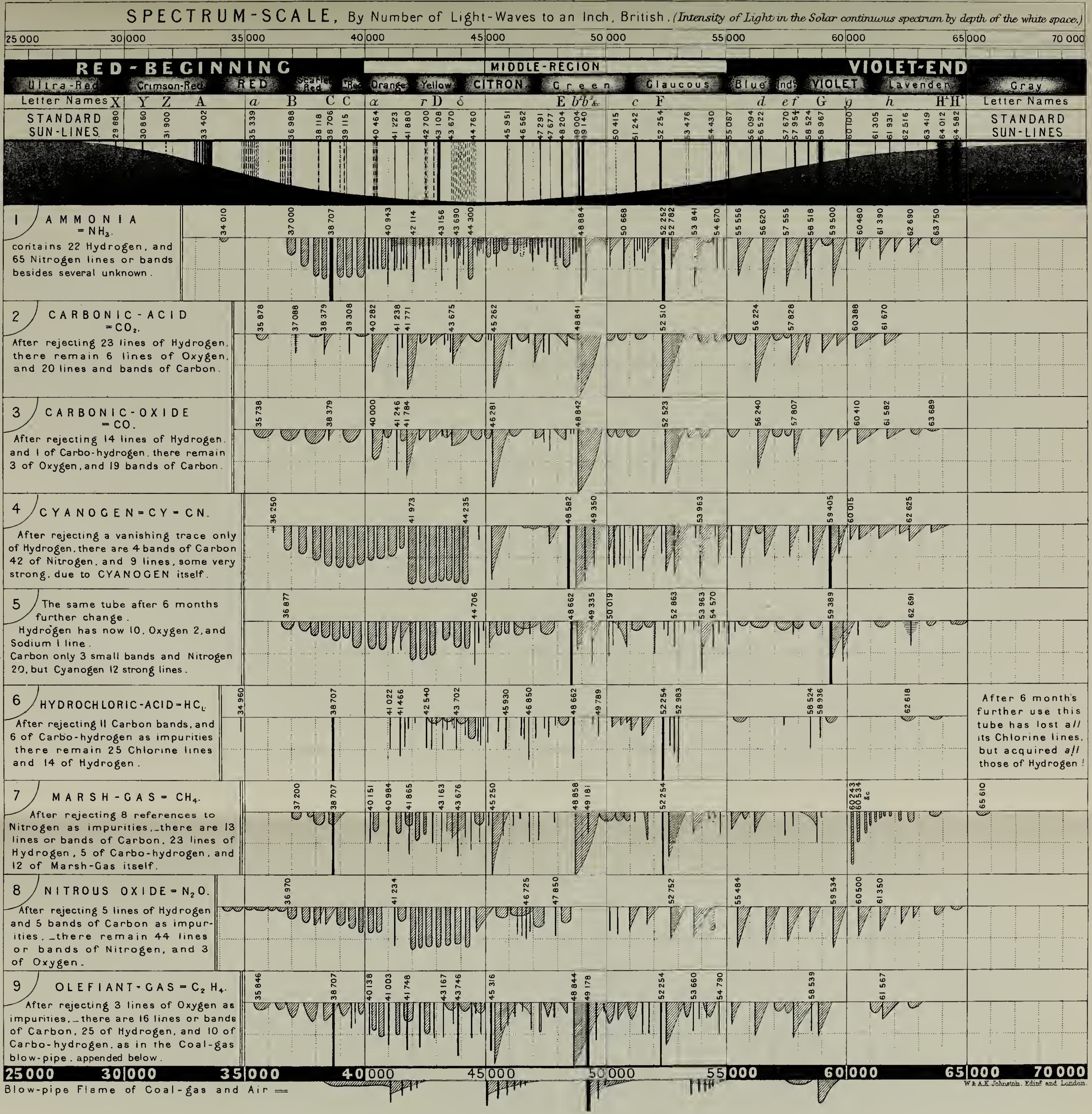
W & A.K. Johnston, Edinr. and London.

VACUUM-TUBE SPECTRA IN WEAK LOW-TEMPERATURE

i.e., 3 from A to H; Mag. Power = 10. Observations made in 1879 and 1880.

Light is represented in these Gaseous Spectra by Black: intense according to Vertical depth. Lines dotted, or wavy, or in any other direction than Vertical, stand for shading, or haze, only.

COMPOUND-GASES.



1 AMMONIA = NH_3.

contains 22 Hydrogen, and 65 Nitrogen lines or bands besides several unknown.

2 CARBONIC-ACID = CO_2.

After rejecting 23 lines of Hydrogen, there remain 6 lines of Oxygen, and 20 lines and bands of Carbon.

3 CARBONIC-OXIDE = CO.

After rejecting 14 lines of Hydrogen, and 1 of Carbo-hydrogen, there remain 3 of Oxygen, and 19 bands of Carbon.

4 CYANOGEN = CY = CN.

After rejecting a vanishing trace only of Hydrogen, there are 4 bands of Carbon 42 of Nitrogen, and 9 lines, some very strong, due to CYANOGEN itself.

5 The same tube after 6 months further change.

Hydrogen has now 10, Oxygen 2, and Sodium 1 line.

Carbon only 3 small bands and Nitrogen 20, but Cyanogen 12 strong lines.

6 HYDROCHLORIC-ACID = HC_L.

After rejecting 11 Carbon bands, and 6 of Carbo-hydrogen as impurities there remain 25 Chlorine lines and 14 of Hydrogen.

After 6 month's further use this tube has lost *all* its Chlorine lines, but acquired *all* those of Hydrogen!

7 MARSH-GAS = CH_4.

After rejecting 8 references to Nitrogen as impurities, _there are 13 lines or bands of Carbon, 23 lines of Hydrogen, 5 of Carbo-hydrogen, and 12 of Marsh-Gas itself.

8 NITROUS OXIDE = N_2O.

After rejecting 5 lines of Hydrogen and 5 bands of Carbon as impurities, _there remain 44 lines or bands of Nitrogen, and 3 of Oxygen.

9 OLEFIANT-GAS = C_2H_4.

After rejecting 3 lines of Oxygen as impurities, _there are 16 lines or bands of Carbon, 25 of Hydrogen, and 10 of Carbo-hydrogen, as in the Coal-gas blow-pipe, appended below.

Blow-pipe Flame of Coal-gas and Air =

W. & A.K. Johnston, Edinr and London.

VI.—*On a Special Class of Sturmians.* By Professor CHRYSTAL.

(Read 20th June 1881.)

If S_n be a rational integral function of x of the n^{th} degree, and $S_{n-1}\,S_{n-2}\ldots S_1\,S_0$ a series of such functions of the $n-1^{\text{th}}$, $n-2^{\text{th}}$, &c., degrees, so related to S_n that, when any one of the whole series $S_0\,S_1\,\ldots\,S_n$ vanishes, the two on opposite sides have opposite signs, and farther S_{n-1} and S_n have always opposite signs when x is just less than any real root of $S_n=0$, then $S_0\,S_1\,\ldots\,S_{n-1}$ may be called a set of Sturmians to S_n. It is obvious that the problem of finding such a set of functions admit of an infinite number of solutions. The first discovery of such a set was made by STURM, and the researches of SYLVESTER, HERMITE, and others have shown how other solutions of the problem may be obtained.

It occurred to me while working at some physical questions that the properties of symmetrical determinants would furnish us with the means of constructing a particular class of Sturmians. I thought when I found the result that it was new, but a little research led me to a paper by JOACHIMSTHAL (CRELLE'S Journal, Bd. xlviii. p. 386), where the very same series is given. The method by which I independently arrived at the result is so simple and so different from that of JOACHIMSTHAL that I have thought it worth while to lay it before the Society.

1. Let

$$\Delta=\begin{vmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{12} & \cdots & a_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{vmatrix}$$

be a symmetrical determinant, so that $a_{12}=a_{21}$, &c.; and let us call the determinant formed by deleting the first row and first column, the first two rows and the first two columns, and so on, its first, second, &c., principal minors.

Then we have the well-known proposition that, if any principal minor vanish, the next higher and the next lower have opposite signs. This is easily proved as follows:—Let A_{11} A_{12}, &c., the first minors corresponding to a_{11} a_{12}, &c., then (see SALMON, "Higher Algebra," p. 29) we have

$$A_{11}\,A_{22}-A_{12}{}^2=(a_{11}\ \ldots\ a_{nn})(a_{33}\ \ldots\ a_{nn})\,.$$

Hence, if $\qquad A_{11}$, *i.e.* $(a_{22}\ \ldots\ a_{nn})$, vanish,

$$(a_{11}\ \ldots\ a_{nn})(a_{33}\ \ldots\ a_{nn})=-A_{12}{}^2\,,$$

i.e., the determinant and its second principal minor must have opposite signs; and similarly for the other cases, since all the principal minors are symmetrical determinants.

2. In the next place, we have by the multiplication of matrices,

$$\Sigma(\alpha_1\,\alpha_2\ \ldots\ \alpha_r)^p\zeta(\alpha_1\,\alpha_2\ \ldots\ \alpha_r)(x-\alpha_1)(x-\alpha_2)\ \ldots\ (x-\alpha_r)$$

$$=(-1)^r\begin{vmatrix} 1 & 1 & \ldots & 1 \\ x & \alpha_1 & \ldots & \alpha_n \\ x^2 & \alpha_1{}^2 & \ldots & \alpha_n{}^2 \\ \vdots & \vdots & & \vdots \\ \vdots & \vdots & & \vdots \\ x^r & \alpha_1{}^r & \ldots & \alpha_n{}^r \end{vmatrix}\times\begin{vmatrix} 1 & 0 & \ldots & 0 \\ 0 & \alpha_1{}^p & \ldots & \alpha_n{}^p \\ 0 & \alpha_1{}^{p+1} & \ldots & \alpha_n{}^{p+1} \\ \vdots & \vdots & & \vdots \\ \vdots & \vdots & & \vdots \\ 0 & \alpha_1{}^{p+r-1} & \ldots & \alpha_n{}^{p+r-1} \end{vmatrix}$$

$$=(-1)^r\begin{vmatrix} 1 & s_p & \ldots & s_{p+r-1} \\ x & s_{p+1} & \ldots & s_{p+r} \\ x^2 & s_{p+2} & \ldots & s_{p+r+1} \\ \vdots & \vdots & & \vdots \\ \vdots & \vdots & & \vdots \\ x^r & s_{p+r} & \ldots & s_{p+2r-1} \end{vmatrix}=S_r(x)\text{ say,}$$

Here $\alpha_1\ \ldots\ \alpha_n$ are any n quantities real or imaginary; $\zeta(\alpha_1\,\alpha_2\ \ldots\ \alpha_r)$ denotes, according to SYLVESTER'S notation, the product of the squares of all possible differences of $\alpha_1\,\alpha_2\ \ldots\ \alpha_r$; and Σ denotes summation with reference to all possible groups r at a time of the n quantities.

It is obvious that, if $r>n$, then $S_r(x)\equiv 0$; and if $r=n$,

$$S_n(x)=(-1)^n\begin{vmatrix} 1 & x & x^2 & \ldots & x^n \\ s & s_{p+1} & s_{p+2} & \ldots & s_{p+n} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ s_{p+n-1} & s_{p+n} & s_{p+n+1} & \ldots & s_{p+2n-1} \end{vmatrix}$$

$$=(\alpha_1\alpha_2\ \ldots\ \alpha_n)^p\zeta(\alpha_1\ \ldots\ \alpha_n)(x-\alpha_1)(x-\alpha_2)\ \ldots\ (x-\alpha_n)$$

$$=(\alpha_1\alpha_2\ \ldots\ \alpha_n)^p\zeta(\alpha_1\ \ldots\ \alpha_n)(x^n+p_1x^{n-1}+p_2x^{n-2}+\ \ldots\ +p_n)\,;$$

if $\alpha_1\ \alpha_2\ \ldots\ \alpha_n$ be the roots of

$$x^n+p_1x^{n-1}+\ \ldots\ +p_n=0\,.$$

3. When $x=\alpha_1$

$$\frac{d\mathrm{S}_n(x)}{dx}\text{ becomes }(\alpha_1\alpha_2\ldots\alpha_n)^p\zeta(\alpha_1\ldots\alpha_n)(\alpha_1-\alpha_2)\ldots(\alpha_1-\alpha_n)$$

and

$$\mathrm{S}_{n-1}(x)\text{ becomes }(\alpha_2\alpha_3\ldots\alpha_n)^p\zeta(\alpha_2\ldots\alpha_n)(\alpha_1-\alpha_2)\ldots(\alpha_1-\alpha_n)\,.$$

Hence, when $x=\alpha_1$

$$\frac{d\mathrm{S}_n(x)}{dx}\Big/\ \mathrm{S}_{n-1}(x)=\alpha_1{}^p\{(\alpha_1-\alpha_2)(\alpha_1-\alpha_3)\ldots(\alpha_1-\alpha_n)\}^2\,.$$

Now, if α_1 be real, and p be an even positive or negative integer, this ratio will be real and positive; for $\alpha_1\ \alpha_2\ \ldots\ \alpha_n$ being by supposition the root of an equation with real coefficients, for every imaginary in the series $\alpha_1-\alpha_2$, $\alpha_1-\alpha_3\ldots\alpha_1-\alpha_n$, there will occur a corresponding conjugate imaginary so that the product of them all will be real.

It follows that $\mathrm{S}_{n-1}(x)$ and $\mathrm{S}_n(x)$ have opposite signs when x is just less than any real root of

$$\mathrm{S}_n(x)=0\,,$$

which is the second characteristic of the first two functions of a Sturmian series.

The restriction as to p being even may be removed if positive and negative roots be considered separately; but for simplicity I shall suppose p to be always even.

4. If we take the determinantal expression for S_n, multiply each column by x, and subtract the next following, leaving of course the last column unchanged, we get, denoting for brevity s_px-s_{p+1} by (p), $s_{p+1}x-s_{p+2}$ by $(p+1)$, &c.,

$$\mathrm{S}_n(x)=\begin{vmatrix} (p) & (p+1) & (p+2) & \ldots & (p+n-1) \\ (p+1) & (p+2) & (p+3) & \ldots & (p+n) \\ (p+2) & (p+3) & (p+4) & \ldots & (p+n+1) \\ \cdot & \cdot & \cdot & \cdot\ \cdot\ \cdot & \cdot \\ (p+n-1) & (p+n) & (p+n+1) & \ldots & (p+2n-2) \end{vmatrix}$$

which it will be observed is a symmetrical determinant. $\mathrm{S}_{n-1}(x)$, similarly transformed, becomes the first principal minor of this obtained by deleting the last row and the last column, and so on. Hence, by (1), $\mathrm{S}_n(x)$, $\mathrm{S}_{n-1}(x)\ \ldots\ \mathrm{S}_1(x)\ \mathrm{S}_0(x)$, the last being any positive constant, have the property that, when any one of the series vanishes, the next higher and the next lower have opposite signs.

5. It has now been shown that $S_n(x)$, $S_{n-1}(x)$, . . . $S_1(x)$, $S_0(x)$ form a Sturmian series. By giving particular even values to p, we get of course an infinite number of such series.

If it were desirable to employ these functions for the purposes of root discrimination, s_p, s_{p-1}, &c., could be calculated by NEWTON'S method, and by giving a proper negative value to p, the labour could be diminished by nearly half in the most general case.

For example, if we take the cubic equation

$$x^3+px+q=0,$$

and put $p=-2$, the Sturmian's are

$$S_3=-\begin{vmatrix} 1 & x & x^2 & x^3 \\ s_{-2} & s_{-1} & s_0 & s_1 \\ s_{-1} & s_0 & s_1 & s_2 \\ s_0 & s_1 & s_2 & s_3 \end{vmatrix}, \quad S_2=+\begin{vmatrix} 1 & x & x^2 \\ s_{-2} & s_{-1} & s_0 \\ s_{-1} & s_0 & s_1 \\ s_0 & s_1 & s_2 \end{vmatrix}, \quad S_1=-\begin{vmatrix} 1 & x \\ s_{-2} & s_{-1} \\ s_{-1} & s_0 \end{vmatrix}, \quad S_0=+1.$$

6. If we wish simply to find how many real roots there are, then we have simply to consider the signs of the coefficients of the highest powers of x in the Sturmians. This gives us the following theorem :—

There are as many pairs of imaginary roots of the equation

$$x^n+p_1x^{n-1}+\ \dots\ +p_n=0$$

as there are variations of sign in the series

$$+1,\ s_p,\ \begin{vmatrix} s_p & s_{p+1} \\ s_{p+1} & s_{p+2} \end{vmatrix},\ \begin{vmatrix} s_p & s_{p+1} & s_{p+2} \\ s_{p+1} & s_{p+2} & s_{p+3} \\ s_{p+2} & s_{p+3} & s_{p+4} \end{vmatrix},\ \text{\&c.}$$

when $p=0$ this gives a well-known theorem (see SALMON, "Higher Algebra," p. 49).

If we put $p=0$, the series for the cubic

$$x^3+px+q=0,$$

neglecting certain positive multipliers, is

$$+1,\ +3,\ -6p,\ -(4p^3+27q^2).$$

If we put $p = -2$, we get

$$+1\,,\quad +p^2\,,\quad +2p^2\,,\quad -(4p^3+27q^2)\,.$$

Each of these leads to the well-known condition for the reality of the roots of the cubic.

7. It follows at once from (2) that, if two roots of the equation be equal, then $S_n(x)$ vanishes identically, and $S_{n-1}(x)$, $S_{n-2}(x)$, . . . $S_0(x)$, form a Sturmian series for the roots all supposed single. If three roots be equal to one another, or if two pairs be equal, then $S_n(x)$ and $S_{n-1}(x)$ vanish identically, and the rest form a Sturmian series for all the roots supposed single; and so on. The present class of Sturmians present therefore an instructive contrast to the ordinary series obtained by the method of the greatest common measure.

VII.—*On the Cranial Osteology of* Rhizodopsis. By Ramsay H. Traquair, M.D., F.R.S., Keeper of the Natural History Collections in the Museum of Science and Art, Edinburgh.

(Read May 21, 1877. Received for Press July 22, 1881. Abstract in "Proceedings," vol. ix. p. 444.)

In a paper by Mr E. W. Binney on the Fossil Fishes of the Pendleton Coal Field, published in 1841, the dentary bone of *Rhizodopsis* is figured as the "upper jaw of a new species of *Holoptychius*," to which, however, he did not attach any specific name. In the same paper its scales are also figured and referred to the same genus.* Scales belonging to the same fish were afterwards figured by Professor Williamson under the name of *Holoptychius sauroides*,† and again by Mr Salter, as those of *Rhizodus granulatus*.‡ Both of these specific names occur under *Holoptychius* in Agassiz's general list of Ganoids published in 1843, but as they were unaccompanied either by figures or descriptions, it is really immaterial which of them, if indeed either, was applied by him to the fish in question. The authority for the term "*sauroides*" as applied to the common species of *Rhizodopsis*, the only species of the genus which is as yet known with certainty, must therefore remain with Professor Williamson. *Holoptychius sauroides* of Binney § and of Messrs Kirkby and Atthey || is quite another fish, now also distinguished generically as *Strepsodus*, and for it the specific name "*sauroides*" is therefore equally valid.

In 1866 Professor Young published a description of the entire fish, under the name of *Rhizodopsis sauroides*, Williamson, sp., the authorship of the new generic title being attributed to Professor Huxley.¶ From Professor Young's description, we learn that the position of *Rhizodopsis*, in Professor Huxley's classification of the Ganoids, is in the cycliferous division of the Glyptodipterine family of the suborder Crossopterygidæ, and that it possesses subacutely lobate pectoral fins, two dorsals, and a heterocercal tail. Some of the bones of the head are noticed, such as the parietals, the three dermal plates of the occipital region, the opercular bones, the maxilla, and the mandible. No præmaxilla

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* Trans. Geol. Soc. Manchester, vol. i. (1841), pp. 153–178, pl. v. figs. 6, 8, and 10.

† "On the Microscopic Structure of the Scales and Dermal Teeth of some Ganoid and Placoid Fish,' Phil. Trans., 1849, p. 457, pl. xlii. figs. 21–23.

‡ "Iron Ores of Great Britain," Mem. Geol. Survey, 1861, p. 223, pl. i. figs. 4–6.

§ *Op. cit.*, pl. v. fig. 7.

|| Trans. Tyneside Nat. Field Club, vol. vi. (1863–64), p. 234, pl. vi. figs. 5 and 6.

¶ "Notice of New Genera of Carboniferous Glyptodipterines," Quart. Journ. Geol. Soc., 1866, pp. 596–598.

was, however, observed by Professor YOUNG, and he states that the jugular plates are "in two pairs, principal and posterior," and that there is no trace of median or lateral plates. The characters of the scales and of the vertebræ, whose centra are in the form of osseous rings, are described as well as the dentition; the teeth of the maxilla being fine, equal, and conical, while those of the mandible are of two sizes. The non-trenchant character of the mandibular laniaries distinguishes the genus from *Rhizodus,* while as separating it from *Holoptychius,* Professor YOUNG gives the thinness of the scales, the nature of their ornament, and the presence of teeth of two sizes.

Two years later a notice of this fish was published by Messrs HANCOCK and ATTHEY, from specimens found in the shales of the Northumberland Coal Field,* in which the authors state that in all respects their specimens "agree well with Dr YOUNG's description of the species." Their description contains, however, two points specially worthy of notice, viz., the detection, on the anterior margins of some of the fins, of peculiar fulcral scales similar to those which occur in *Megalichthys* and other Saurodipterines, and the determination of a peculiarly shaped dentigerous bone as "*præmaxilla.*" Moreover, according to Messrs HANCOCK and ATTHEY, the piscine genera and species *Dittodus parallelus, Ganolodus Craggesii,* and *Characodus confertus,* and the supposed Amphibian *Gastrodus,* all founded by Professor OWEN on specimens of teeth from the same coal-field, are only synonyms of *Rhizodopsis sauroides.*

Rhizodopsis is also noticed by Mr T. P. BARKAS,† who accepts Messrs HANCOCK and ATTHEY's interpretation of the bone supposed by them to be a præmaxilla. So also does Mr J. W. BARKAS,‡ who solves the problem regarding the specific nomenclature of the fish by quoting *Rhizodopsis sauroides* and *granulatus* as distinct species, without, however, giving any reasons in support of the supposed distinction.

Being struck by the total dissimilarity of form presented by the bone interpreted by Messrs HANCOCK and ATTHEY as the præmaxilla of *Rhizodopsis,* when compared with that element in other Crossopterygii, I carefully examined the subject with the aid of a beautiful series of specimens from North Staffordshire, kindly lent me by my friend Mr JOHN WARD, F.G.S., and with the result of finding that the reputed præmaxilla is in reality the dentary element of the mandible. Moreover, the mandible of *Rhizodopsis* is of a very complex structure, and that structure finds itself in all essential respects repeated and explained in the mandible of the much more bulky *Rhizodus Hibberti.* These observations were published in the "Annals and Magazine of Natural

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* "Note on the Remains of some Reptiles and Fishes from the Shales of the Northumberland Coal Field," Ann. Nat. Hist. (4), vol. i. (1868), pp. 346–378.

† "Manual of Coal Measure Palæontology," London, 1873, pp. 23–25, Atlas, figs. 59–66.

‡ Monthly Review of Dental Surgery, vol. iv. No. x., March 1876.

History" for April of the present year (1877). In the present communication I propose, with the aid of a few restored outline drawings, to consider the entire subject of the cranial osteology of *Rhizodopsis*, the greater part of the material for which belongs to the collection of Mr Ward. My thanks are also due to Mr John Plant of Salford, for the loan of a number of shale specimens, showing isolated bones, from the Manchester coal-field.

Rhizodopsis sauroides, Williamson, sp.

Cranium proper.—The cranial roof bones form a "buckler," which in its configuration and composition is very similar to that in *Osteolepis*, *Megalichthys*, &c. As in these forms it falls into two principal parts, anterior and posterior, of which the posterior, or parietal portion, is slightly longer than the anterior or fronto-ethmoidal. The parietal portion is about twice as broad posteriorly as it is in front, each external margin passing, a little behind the middle, first inwards at an obtuse angle and then nearly straight forwards; the anterior and posterior margins are nearly straight. This portion of the buckler is composed of six paired ossifications, two of which (*pa.* fig. 1) extend along its whole length, articulating with each other in the middle line; their form is rather narrow and elongated, and they are also broader behind than in front. These two plates may very safely be reckoned as the *parietals;* as such the corresponding plates have been, in *Osteolepis* and *Megalichthys*, designated by Pander, by Huxley in *Glyptolæmus*, and by Agassiz in *Osteolepis*, although the last-named author has marked the very same bones in *Megalichthys* as "frontals." Along the outer edge of each parietal are two smaller plates, anterior (*p.f.*) and posterior (*sq.*), regarding the signification of which, in allied forms, some pretty serious difference of opinion is found in the works of different writers. By Agassiz the anterior one was, in *Osteolepis*, considered to be the post-frontal, the posterior to be the "mastoid," while in *Megalichthys*, he considered the very same plates to be equivalent to the chain of intercalary ossicles placed along the external margins of the cranial shield in *Polypterus*. By Pander the latter interpretation is accepted both for *Osteolepis* and *Megalichthys;* while by Professor Huxley, these two plates, anterior and posterior, are in *Glyptolæmus* respectively termed

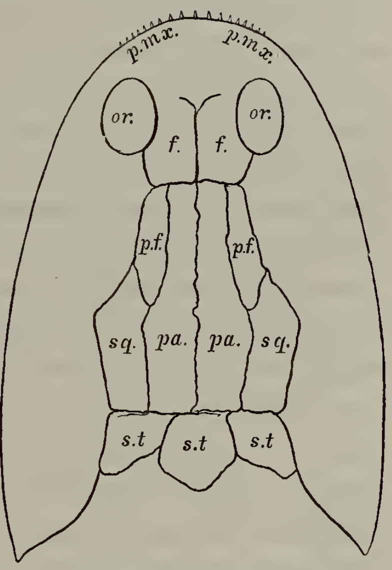

Fig. 1.—Upper Surface of the Head of *Rhizodopsis sauroides*.

s.t. supratemporal; *pa.* parietal; *sq.* squamosal; *p.f.* posterior frontal; *f.* frontal; *or.* orbit; *p.mx.* præmaxilla.

"post-frontal" and "squamosal." Now, as the bones of the skull of Teleostean fishes, known in the Cuvierian system of nomenclature as "post-frontal" and "mastoid," are ossifications in the periotic portion of the primoidial cranium (*sphenotic* and *pterotic* of Parker), and as the disputed bones in the cranial buckler of the Crossopterygian Ganoids above referred to are evidently dermal in their nature, the latter may be considered as really partaking more of the nature of the ossa intercalaria in *Polypterus.* But as to their being considered exactly the equivalents of those little plates in *Polypterus,* there are some pretty serious, and to my mind fatal objections. They are firmly united by suture to the outer margin of each parietal, with which they form an integral part of the cranial buckler. In the Lepidosteoid Ganoids (*Lepidosteus, Lepidotus,* &c.), there is, external to each parietal, a plate (*squamosal*) evidently corresponding to the posterior of the two in *Rhizodopsis,* &c., and which no one has ever thought of considering homologous with the Polypterine intercalaries. The same plate is found in *Amia,* and there is in addition another smaller one in front of it corresponding to the anterior of the two in *Rhizodopsis,* but which, from the relatively greater shortness of the parietal, and the corresponding greater extension backwards of the frontal, comes to lie external to the posterior part of the outer margin of the latter. In the Palæoniscidæ there are also two corresponding plates, but the anterior of these, which I have lettered as post-frontal in my memoir on the structure of this family,* is placed relatively to the frontal still further forwards, owing to the greater proportional length of the squamosal behind it. In *Acipenser* there is also, external to the plates which seem to represent the parietals and frontals of other fishes, a chain of two or more smaller plates, which apparently represent those in question, and which, firmly articulated with the others covering the cranial cartilage, lie *inside* the position of the spiracle. There is no spiracle in *Lepidosteus* or *Amia,* and no evidence of it in the Palæoniscidæ, or in either the Rhombo- or Cyclodipterine Crossopterygii, but in *Polypterus* there is, and the chain of intercalary ossicles, loosely articulated to the margin of the cranial shield, lies *external* to the spiracular slit, which passes down between two of them and the side of the cranium proper. It therefore seems to me inappropriate to consider the bones *p.f.* and *sq.* of the cranial shield of *Rhizodopsis* and allied forms to be the homologues of the intercalary ossicles in *Polypterus,* and better to follow Professor HUXLEY in designating them respectively as *post-frontal* and *squamosal,* always bearing in mind, however, that the former has nothing to do with the post-frontal of Cuvier, for which it is better to adopt the term "sphenotic" as proposed by PARKER. In *Amia,* in fact, a well-developed *sphenotic* coexists with the more superficial plate to which I have referred as "post-frontal."

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* "Carboniferous Ganoids," Palæontographical Society, 1877.

The anterior, or fronto-ethmoidal division of the cranial shield is not so well preserved, so that it is not possible to map out its constituent ossifications with completeness; in no case are its external or orbital margins well defined, and its upper surface is more or less broken and crushed. Nevertheless, the form and constitution of its anterior margin are unmistakeable. This is crescentically expanded, forming the rounded depressed snout; and to the two dentigerous bones, the *præmaxillæ* forming its oral edge, we shall presently return in describing the bones of the jaws. I have not been able to detect the nasal openings.

The external surfaces of these cranial plates are ornamented with minute tubercles and short ridges, frequently arranged in lines radiating from the centres of ossification.

Facial Bones.—Immediately behind the posterior margin of the cranial shield are the usual three plates (*s.t.*, fig. 1), one median and two lateral, which are of such constant occurrence in fishes of the Rhombo- and Cyclodipterine families. I have already, in my memoir on the structure of *Tristichopterus alatus,** expressed my opinion that these are equivalent to the transverse chain of *supra-temporal* ossicles in *Polypterus, Lepidosteus,* &c.

The *hyomandibular* is a somewhat elongated bone, extending downwards with a slightly backward inclination from below the squamosal to just behind the articulation of the lower jaw; it is also slightly curved, the concavity being directed forwards. Above, where it articulates with the cranium, it is flattened for about a little less than one-third of its length; this flattened portion, to which the superior anterior angle of the operculum is articulated, becomes very suddenly cut away on the posterior aspect, below which the bone becomes slender and cylindrical, expanding, however, in thickness in its lower half. Remains of a powerfully developed *palato-quadrate* apparatus are seen in several specimens, but not exposed with sufficient completeness to admit of any description of its component elements; its outer margin is for some distance articulated with the inner aspect of the maxilla, behind which it recedes a little inwards to admit of the passage of the masticatory muscles to the coronoid part of the lower jaw.

By reason of the slightly backward slope of the hyomandibular, the gape is wide, and in three specimens, it is exposed all round the head, so that the bones forming the edges of the mouth are very completely seen. In nearly all the heads preserved in nodules the upper margin of the *maxilla* (*mx.* fig. 2) is injured, but its complete contour is well exhibited in detached shale specimens. In shape it resembles very closely the maxilla of *Megalichthys,* being of an elongated triangular form, broadest about the junction of its posterior and middle thirds, and narrowly tapering anteriorly. Its posterior extremity forms

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* Trans. Roy. Soc. Edinburgh, vol. xxvii. (1874) p. 386.

a tolerably acute angle, from which the inferior margin slopes first a little downwards and forwards, and then passes nearly straight forwards; the short posterior margin slopes gently upwards and forwards to the very obtuse and usually more or less truncated superior angle, from which the superior margin then slopes downwards and forwards to the anterior extremity, just before attaining which it sends off a small articular process directed obliquely upwards and forwards. The external surface is ornamented with minute pits and delicate reticulating ridges; the inner surface shows a delicate ledge running longitudinally a little above the inferior margin and nearly parallel with it. The inferior margin of the maxilla is set with a single row of small teeth, cylindro-conical, acutely pointed, slightly incurved, and of equal size. Their external surfaces are quite smooth and glistening under an ordinary lens; they are usually placed pretty closely together, though some irregularity in their distances from each other is not unfrequently observed. Each of these teeth measures about $\frac{1}{40}$ inch from base to apex in a maxilla of $1\frac{1}{4}$ inch in length.

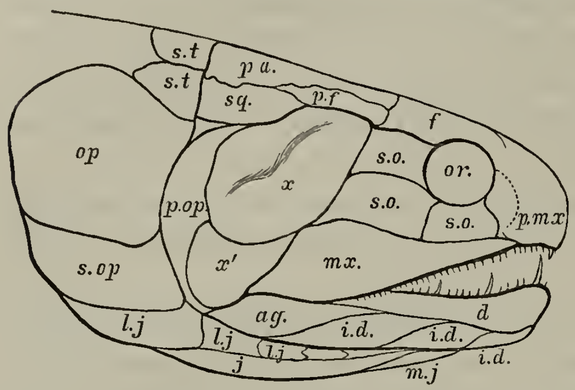

Fig. 2.—Lateral View of the Head of *Rhizodopsis sauroides*. *op.* operculum; *s.op.* suboperculum; *p.op.* præoperculum; *x.x'.* plates on the cheek; *j.* principal jugular; *l.j.* lateral jugular; *m.j.* median jugular; *mx.* maxilla; *d.* dentary; *ag.* angular; *i.d.* infradentary; *or.* orbit; *s.o.* suborbital; *s.t.* supratemporal; *pa.* parietal; *sq.* squamosal; *p.f.* posterior frontal; *f.* frontal; *p.mx.* præmaxilla.

In several specimens are seen the sharp imprints of two small dentigerous bones (*p.mx.*) forming the front edge of the mouth below the snout, and placed between and articulating with the anterior extremities of the right and left maxillæ, while they are joined with each other in the middle line. Each of these two bones is nearly as high as long; they are firmly fixed to each other, and also to the front of the cranial shield; the posterior extremity of each fits into the angle between the anterior extremity of the maxilla and the little articular process already mentioned in the description of the last-named bone; the attached teeth, seen in impression and in section, resemble those of the maxilla. That we have here the true *præmaxillæ* cannot for a moment be doubted; it is therefore abundantly clear that this element in *Rhizodopsis* does not in the least resemble the bone interpreted as such by Messrs Hancock and Atthey, but that on the other hand it is quite conformable to the type of præmaxilla found in other Crossopterygii, as indeed in the Ganoids generally.

The *mandible* is longer than both præmaxilla and maxilla put together, reaching, as it does, a little further back than the posterior extremity of the latter. Its depth is contained about four times in its length, its upper and lower margins are tolerably parallel save just at the anterior extremity, where the upper one bulges a little upwards in a slight convexity, and at the posterior extremity where the same margin suddenly slopes downwards and backwards at an obtuse angle, meeting the lower one, which likewise curves upwards towards it, in a posteriorly directed point. Nothing has been said in the works of previous writers concerning the constitution of the mandible, though it might be inferred to be a composite structure, as it is in all fishes with ossified skeleton, and more especially in the Ganoidei. In one specimen we find that over a considerable area the bony matter of the outer aspect has flaked off, leaving behind it a pretty sharp cast with sutural lines. On close examination a suture is seen commencing near the posterior extremity of the upper margin of the jaw, which, passing gradually downwards and forwards, marks off as *dentary* (*d.* fig. 2) an element precisely the counterpart in shape of the bone reckoned by Messrs HANCOCK and ATTHEY " præmaxilla," but here placed with its toothed margin *upwards* instead of downwards as supposed by them. These two bones, right and left, are in many specimens indisputably seen forming the lower margin of the mouth and meeting each other at the symphysis. Each dentary bone is of a somewhat narrow and elongated form, truncated and somewhat expanded at the anterior or symphyseal extremity, and pointed at the other or posterior. The upper margin, nearly straight, save just in front where it shows a slight convexity, is set with a single row of small pointed teeth of nearly uniform size, but the anterior extremity bears in addition a single more or less incurved laniary tooth, much larger than the others, and also more internal in its position; the opposite margin, thin and sharp, displays a gently flexuous contour. Seen from the inner aspect, the anterior extremity of the bone presents a conspicuous thickening, in which the large laniary tooth is socketed, and which at the dental margin passes into a delicate ledge, which runs back for some distance along the roots of the smaller teeth. The teeth borne by this bone are round in transverse section, slender-conical in shape, brilliantly polished, and apparently smooth externally, but under a lens the surface is seen to be delicately fretted with minute longitudinal groovings, disappearing towards the point; the large laniary is also very distinctly fluted or plicate at its base.

The rest of the outer surface of the mandible is composed of at least three additional bony plates, separated from each other by sutures which pass obliquely forwards and upwards. The posterior and largest of these (*ag.* fig. 2) covering over the articular region, may be considered as equivalent to the *angular* element, though it also occupies very much the place of a supra-angular; the other two (*d.*) in front of the latter and below the dentary, may be called *infradentary.* The presence and contour of these large infradentary plates is perfectly clear, the evidence as to additional ones is obscure.

From the appearance presented by one specially large mandible, I rather suspect there is a third small one, as there is in *Rhizodus,* just below the symphyseal extremity of the dentary, and I have in my paper in the "Annals" referred to some doubtful evidence of still another, situated posteriorly on the lower margin of the jaw, and here separating the angular from the first infra-dentary for a little distance, but on this I am not prepared to insist.

We have as yet accounted for the attachment of one laniary tooth, the one at the symphysis. But the mandible of *Rhizodopsis,* when perfect, shows not merely one large tooth in front, but several additional ones (usually three in number) behind it and internal to the series of smaller teeth. What has become of these in the dentary bone when disarticulated and detached?

A ready explanation of this is found in the structure of the lower jaw of certain Old Red Sandstone "Dendrodonts" in which the laniary teeth are not attached to the dentary bone proper, but to a series of accessory "internal dentary" pieces articulated to its inner side.* Should this also be the case with the posterior laniaries of the mandible of *Rhizodopsis,* then in cases where its elements are broken up and separated, these additional pieces will also get detached, and the absence of all but the anterior laniary in the isolated dentary bone will thus be amply accounted for.

At the time I wrote the notice in the "Annals," already quoted, I had not obtained a clear view of the ossicles supporting the posterior laniaries in *Rhizodopsis,* and consequently referred to the analogy of the structure of the lower jaw in *Rhizodus,* in which I had most certainly found them, as amounting to a moral certainty of their existence also in the former genus. My attention has subsequently been directed to a specimen in the Edinburgh Museum of Science and Art, which completely confirms the view I then took.

This is a slab of shale, not localitated, but probably from the Edinburgh Coal Field, over which scales of *Rhizodopsis* of large size lie thickly scattered, some of which are over 1 inch in length and nearly ¾ in breadth. This is indeed an unusually large size, but is by no means an isolated example of the bulk which *Rhizodopsis* must sometimes have attained, and the form and sculpture of the scales here exhibited unmistakeably demonstrate the genus to which they belong. Lying in the midst of the scales is a mandible, evidently belonging to the same fish, and seen from the internal aspect. The splenial is gone, as is likewise the bony substance of the symphyseal part of the entire mandible, though a rough impression of it remains on the stone; the hinder extremity is also injured, as well as the posterior part of the lower margin; such impressions of the external surface, as remain when the bone has splintered off, indicate a sculpture of the usual minutely pitted-rugose character

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* See PANDER'S "Saurodipterinen, Dendrodonten, &c., des devonischen Systems," pp. 41–43, tab. x. figs. 2, 3, 4, 14, 22.

of the mandibular elements of this genus. The depth of this jaw is $1\frac{3}{10}$ inch; its entire length, including the impressions of its anterior and posterior extremities, is $5\frac{1}{2}$ inches. The upper edge of the dentary element is seen extending from the obtuse angle of the posterior extremity of the upper aspect of the jaw to where it is broken off, apparently $1\frac{1}{4}$ inch from its symphyseal termination, as indicated by the impression, and is set with a single row of small conical teeth, placed on an average at distances from each other of $\frac{1}{16}$ inch, though they are more closely set anteriorly, where a few empty sockets are also seen. Some of the hinder ones are entire, and measure $\frac{1}{8}$ inch in length; they are sharp, slightly incurved, their bases plicate, the surface fretted with very minute striæ, visible only under a strong lens. Anteriorly they are all broken off at various heights, the sections showing a large internal pulp cavity, the walls of which become very simply plicate at the base. Now, articulated just below this dentary margin is a longitudinal chain of two separate ossicles and the hinder part of a third. Each of these (*int. d.*) is of an oblong shape, contracted at the extremities, and in the middle showing first an empty socket, and, immediately in front of this, the broken off root of a large laniary tooth, at once recognisable by the complex folded structure of its constituent dentine. The anterior of these ossicles is obliquely broken off right through the empty socket, at the bottom of which are the remains of dentinal plicæ, showing how here too a large tooth had once existed and had been broken off; and in front of this, and just above where the root of the actual laniary had been, is a part of the impression, upon the matrix, of the very tooth itself. Nothing can be more distinct than the sutures which separate these accessory or internal dentary ossicles from each other, and from the contiguous dentary element proper—the remaining bony matter beneath, consisting of the plates previously referred to as angular and infradentary, is thin and traversed by numerous cracks and fractures, so that very careful examination is here required for the determination of sutures. Nevertheless, with due attention, the lines of demarcation between the angular and the two large infradentaries may be made out, and just behind the position of the symphysis there is an indication of another suture passing upwards and forwards from the lower margin of the jaw, and separating off the third and smaller infradentary already alluded to. Lying on the margin of the slab, $2\frac{1}{2}$ inches from the above-described jaw, is a broken-off piece of bone having a large tooth attached to it, the latter measuring $\frac{5}{6}$ inch in length by $\frac{1}{4}$ inch in diameter at the base. Its length was originally in all probability greater, as it is obliquely fractured, and the fractured surfaces ride over each other a little. Its base is plicate, above which the surface of the tooth is very minutely and delicately striated up to $\frac{1}{6}$ inch from the point, which is perfectly smooth. Close beside this large tooth, and apparently attached to the same piece of bone, are two smaller ones, each about $\frac{1}{6}$ inch in length, so that I rather think we have here a fragment of the anterior extremity of the dentary bone of the other side of the head, with the symphyseal laniary.

Returning to the examination of the smaller specimens, a portion of the *splenial* element is seen in one specimen, exposed by the breaking out of a portion of the middle of the mandible. The *articular* element, which was doubtless also present, is not exhibited in any specimen I have seen.

The *opercular* bones are largely developed. The *operculum* (*op.* fig. 2) is a large, somewhat square-shaped plate, though broader above than below, and behind than in front. Its posterior-superior angle is rounded off; its inferior margin overlaps another plate, which may be considered to be the *suboperculum* (*s. op.*). This is somewhat narrower, and has its posterior-inferior angle much rounded off; its upper and lower margins are nearly parallel, and from the former, just at the anterior-superior angle of the bone, there projects a short pointed process, producing the anterior margin a little way upwards.

In front of the operculum, and covering a large part of the cheek, is a plate (*x*) of a somewhat oval shape, and somewhat obliquely placed, so that its long axis runs from below upwards and forwards. Above, it is in contact with the outer edge of the cranial shield; its posterior margin is separated from the operculum by a smaller plate (*p.op.*). The latter is of a narrower shape, rather pointed above and a little less so below; its long axis is pretty parallel to the direction of the hyomandibular which it covers; its posterior margin, in contact with the operculum, is gently convex; its anterior one, somewhat angulated, articulates with the large plate *x*, and below also with the smaller one *x'*. This third plate *x'* lies immediately above the articular extremity of the mandible; its posterior margin, covering the lower extremity of the hyomandibular, is in contact with the suboperculum below, touching also the plate *p.op.* above; its upper margin is articulated with the plate *x*, while in front it comes into relation with the oblique posterior margin of the maxilla. As figured by AGASSIZ, three precisely similar plates occur in the same position in *Megalichthys*,* of which he compares both the upper and posterior to the so-called præ-operculum of *Polypterus*, while the lower one he compares to the little bone fixed above the posterior edge of the maxilla in the Salmonidæ, &c., and which by Mr PARKER is considered to be the homologue of the malar bone of other vertebrata.† In *Osteolepis*, according to PANDER, the corresponding space on the cheek is occupied by one large plate, denominated by him "præoperculum," on which, however, lines are visible indicating a division into three similar component parts. On comparing the arrangement with what is seen in

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* "Poisson's Fossiles," vol. ii. part 2, p. 92; "Atlas," vol. ii. pl. lxiii.*a*, figs. 1 and 3, *i*, *k*, *l*.

† "On the Structure and Development of the Skull in the Salmon" (*Salmo salar*, L.), Phil. Trans., 1872, p. 100.

Polypterus, it is, I think, pretty evident that the bone *p.op.*, together with the one *x* in *Rhizodopsis*, corresponds to the large cheek plate in the former genus, considered by Agassiz to consist of the equivalents of the cheek cuirass in *Lepidosteus* united with the præoperculum, while the lower one (*x′*) apparently corresponds to the posterior of the two small plates, which in *Polypterus* are placed below the inferior margin of the large one and behind the maxilla. The bone *p.op.* in *Rhizodopsis* may then be considered as the *præoperculum*, the two others, *x* and *x′*, as equivalent to the cheek cuirass in *Lepidosteus*, or to the posterior set of sub-orbitals in other Lepidosteids (*e.g.*, *Lepidotus*), and in the Palæoniscidæ.

In front of the bone *x*, and above the maxilla, there are in some specimens evident enough remains of the proper sub-orbitals, which seem to have corresponded in number and position pretty closely to those in *Osteolepis*. Two of them (*s.o.* fig. 2)), corresponding respectively to the posterior-inferior and anterior-inferior parts of the boundary of the orbit, are clearly seen in many specimens, but the unfortunate manner in which the heads are crushed renders any further description hardly possible.

The space between the right and left mandibular rami is occupied by a set of *jugular plates*. Professor Young has described these as consisting of "two pairs, principal and posterior," and has also stated that there is "no trace of median or lateral plates."[*] The specimens before me, however, do not corroborate the views above quoted. I find two principal jugulars (*j.* figs. 2 and 3) occupying almost the whole of the space. Each of these is of the usual oblong shape, and broader behind than in front. The short and rounded posterior margin passes uninterruptedly into the internal one, which is more convex than the external for the greater part of its length; near the front, however, the internal and external margins converge and meet in an acute angle. What Professor Young means by a "posterior" jugular I am unable to determine, unless he has mistaken for such a plate the broad infra-clavicular element of the shoulder girdle, which, as in the recent *Polypterus*, is overlapped by the posterior margin of the principal jugular. The presence of *lateral jugulars*

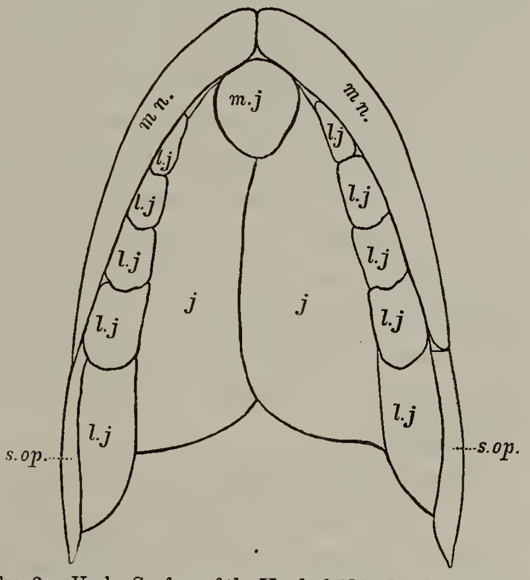

Fig. 3.—Under Surface of the Head of *Rhizodopsis sauroides*. *mn.* mandible; *j.* principal jugular; *l.j.* lateral jugular; *m.j.* median jugular; *s.op.* suboperculum.

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[*] *Op. cit.*, p. 596.

(*l.j.*) is clearly shown in several specimens, and are at least five in number on each side. Of these, the hindermost is also the largest, and is situated below the lower margin of the suboperculum, extending also beyond the posterior margin of the principal jugular; the remaining four are placed between the last-named plate and the mandible, and diminish in size regularly from behind forwards. There is also the clearest possible evidence of a median jugular (*m.j.*), of a somewhat oval-acuminate form, placed immediately behind the symphysis of the mandible, and overlapping to some extent the anterior extremities of the principal jugulars. That the lateral and median jugular plates were not noticed by Professor YOUNG, is clearly due to the more imperfect material then at his command.

CONCLUSION.

The foregoing investigation into the osteology of the head of *Rhizodopsis,* deficient as it is with regard to the more internally situated parts, nevertheless brings out, in a very striking manner, the affinity of that genus to the rhombic-scaled Saurodipterini, and supplies further evidence, were that now required, of the comparatively small value of the mere external forms of scales as indicating the natural affinities of ganoid fishes.

No one acquainted with the structure of *Megalichthys* can fail to be struck with the extreme resemblance which its cranial osteology bears to that of *Rhizodopsis,* not only in general arrangement but in the shapes of individual bones,—a resemblance shared in as well by the teeth with their labyrinthically plicated bases, by the shoulder bones, by the fins in their structure and position, and by the vertebral column with its ring-shaped centra. Beyond a doubt, the affinities of *Rhizodopsis* are much more with the rhombiferous Saurodipterini than with the cycliferous Holoptychiidæ, although, on account of the form of the scales, both *Rhizodopsis* and *Rhizodus* were once included in the genus *Holoptychius.*

Very distinct family characters are, however, presented by the Saurodipterini in the scales having assumed a sharply rhombic contour, in their free surfaces, as well as those of the cranial bones and fin rays, being covered with a layer of brilliant ganoine, and in the tendency of many of the bones of the head to fusion with each other. In *Megalichthys,* for example, the mandible though closely resembling that of *Rhizodopsis* in external contour and in the form and arrangement of its teeth, has the elements—which in the latter genus I have designated as *angular, dentary, infradentary,* and *internal dentary*—all fused into one piece, an oblique line on the outside of the jaw usually indicating the original separation of the dentary. In some Old Red Sandstone Saurodipterini the original separation of the *parietal, squamosal,* and *posterior frontal* elements of the cranial buckler, is on the surface almost entirely obliterated. These circumstances would lead us to the conclusion that the Saurodipterini constitute a more specialised type than the Cyclodipteridæ, in which, in a previous essay,* I have included the genera *Rhizodus, Rhizodopsis, Strepsodus, Archichthys,* and *Tristichopterus,* the Glyptolæmini being probably intermediate.

Note added July 20, 1881.—For the term "Cyclodipteridæ," which I have hitherto used for the family to which *Rhizodopsis, Rhizodus,* &c., belong, and which I borrowed from Dr Lütken ("Begrenzung und Eintheilung der Ganoiden," German edition, p. 47), though excluding the *Holoptychii,* which were also here placed by him, I propose in future to substitute "Rhizodontidæ," as being in every way more appropriate.

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* "On the Structure and Affinities of *Tristichopterus alatus,*" Trans. Roy. Soc. Ed., 1874.

VIII.—*On the Action of Phosphide of Sodium on Haloid Ethers and on the Salts of Tetrabenzyl-Phosphonium.* By Professor LETTS and N. COLLIE, Esq.

The phosphines, or substances derived from phosphuretted hydrogen by the partial or complete replacement of its hydrogen by hydrocarbon radicals, have formed the subject of many valuable researches; but although their discovery was anterior to that of the compound ammonias, their study has made comparatively little progress. This is no doubt mainly due to the difficulty attending their preparation, a fact which is immediately forced upon the notice of any one who wishes to investigate them.

In spite of the undoubted analogies existing between phosphines and amines, the methods employed for obtaining the former are, with one exception, different from those by which the latter are usually prepared. The reason for this we may find in the great differences between the elements phosphorus and nitrogen—differences which are in many cases still apparent in their compounds. Thus, phosphorus forms no compound with carbon analogous to cyanogen; nor have any phosphorised bodies been obtained up to the present time analogous to the cyanides of hydrocarbon radicals. Neither has a phosphorised cyanic acid, (HCPO), nor its hydrocarbon salts been obtained.

And we have another link wanting in the chain of analogies existing between nitrogen and phosphorus, in the absence of compounds of the latter element analogous to the nitro-bodies. Now, the amines are usually prepared by one or other of the four following processes:—

1. Action of nascent hydrogen on the cyanide of a hydrocarbon radical.
2. Action of caustic potash on the cyanate of a hydrocarbon radical.
3. Action of nascent hydrogen on a nitro-body.
4. Action of ammonia on a compound of a hydrocarbon radical with a halogen.

For the reasons given above, the phosphines cannot be prepared by processes corresponding with the first three of these methods; but HOFMANN, in his masterly researches on these bodies, has shown that it is possible to directly replace hydrogen in phosphuretted hydrogen by hydrocarbon radicals, in a manner similar to that employed in the fourth of the above processes.

But this is not the only process we possess for obtaining the phosphines, although it is the only one analogous to any of those employed for preparing amines; and we shall give a short sketch of the other methods by which, from time to time, the phosphines have been prepared.

Paul Thenard was the discoverer of the first organic phosphorus compounds.[*] In the year 1843 he investigated the action of chloride of methyl on phosphide of calcium; and in 1847 he communicated to the Academy further results as to the nature of the bodies obtained in the reaction. The investigation was attended with great difficulties, owing to the labour involved in separating the different products, and in obtaining them in the pure state; also, on account of their explosive and inflammable nature, and their poisonous properties.

In spite, however, of these difficulties, Thenard appears to have isolated trimethyl-phosphine; a substance analogous to kakodyle, $P_2(CH_3)_4$; and a substance analogous to solid phosphide of hydrogen, $P_4(CH_3)_2$. The last he describes as an inert solid body; but the second, as a spontaneously inflammable liquid boiling at 250° C.—very explosive, poisonous, and unstable.

Thenard recognised the relations existing between trimethyl-phosphine and ammonia, and predicted the existence of the then undiscovered organic compounds of nitrogen, arsenic, and antimony. In the meantime, Würtz and Hofmann had verified Thenard's predictions, having discovered the compound ammonias; and Loewig and Schweitzer had obtained stib-ethyl.

Hofmann and Cahours[†] turned their attention in 1855 to the study of the phosphines, and repeated Thenard's experiments, with this difference, however, that they substituted phosphide of sodium for phosphide of calcium. They obtained trimethyl-phosphine, Thenard's phosphorus kakodyle and iodide of tetramethyl-phosphonium—but only after great difficulty. Speaking of the action of phosphide of sodium on iodide of methyl, they say,—"The action is very energetic when the two are heated together (*à chaud*). Moreover, inflammable and detonating substances are formed, so that this method of preparation is not without danger, and exposes the fruit of one's labour to loss . . . . . . It is unreliable (*trop peu sûr*), and furnishes mixtures, of which the separation presents enormous difficulties." For these reasons, they sought for a simpler and more certain process. This they found in the action of zinc ethers on terchloride of phosphorus, which gives a compound of chloride of zinc and the tertiary phosphine, from which potash separates the latter in a state of purity.

By means of this reaction, Hofmann and Cahours prepared the tertiary phosphines of methyl, ethyl, and amyl. They determined some of their most

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[*] Comptes Rendus, vols. xxi. and xxv.

[†] Comptes Rendus, xli.

important properties, and showed that in many respects they resemble the tertiary amines, especially in the readiness with which they combine with iodides of hydrocarbon radicals to give quaternary compounds. They found, however, that, unlike amines, tertiary phosphines are capable of directly combining with oxygen.

HOFMANN continued the study of the tertiary phosphines, and communicated the results of his experiments to the Royal Society[*] in 1860. He confined his experiments chiefly to triethyl-phosphine, and, in his lengthy memoir, describes accurately its properties and reactions. He prepared and analysed oxide of triethyl-phosphine and the characteristic red compound which bisulphide of carbon forms with the phosphine itself, and he investigated the action of the latter on a considerable number of organic compounds.

BERLÈ[†] attempted to obtain triethyl-phosphine by the action of phosphide of sodium on iodide of ethyl. The phosphide of sodium he prepared by the heating sodium and phosphorus together in rock oil. Iodide of ethyl only acted upon this at a high temperature, and he obtained only very small quantities of the tertiary phosphine. BERLÈ[‡] next attempted to prepare the tertiary phosphine by heating sodium, phosphorus, and iodide of ethyl together in a sealed tube; but although the bodies reacted, he does not seem to have obtained any very satisfactory results.

CAHOURS, in 1859, prepared iodide of tetrethyl-phosphonium by the action of iodide of ethyl, on crystallised phosphide of zinc (prepared by heating the metal in phosphorus vapour) at 180° C. The next experiments on the preparation of phosphines are very interesting and important.

Previous to these only tertiary and quaternary compounds had been obtained, but HOFMANN[§] showed in an elegant manner that the primary and secondary bases may be formed by the action of phosphuretted hydrogen on the iodides of hydrocarbon radicals—a process exactly analogous to that employed by him for preparing the corresponding amines. Phosphuretted hydrogen, however, does not behave in exactly the same manner as ammonia in this reaction, for HOFMANN found that the replacement of hydrogen does not proceed further than the second atom; whereas with ammonia all the hydrogen is replaced step by step, and even quaternary compounds are formed.

Moreover, ammonia acts on the iodides of hydrocarbon radicals much more readily than phosphuretted hydrogen, and at lower temperatures.

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[*] Transactions Royal Society, London, vol. cl. p. 409.

[†] Journ. für. prac. Chem., lxvi. p. 73.

[‡] Comptes Rendus, xlix.

[§] Berichte der. deutsch. chem. Ges., iv. pp. 205, 372; v. p. 100.

HOFMANN's process for obtaining primary and secondary phosphines—which he employed successfully in the methyl, ethyl, and benzyl series—consists in heating a mixture of phosphonium iodide, zinc white, and the hydrocarbon iodide, in sealed tubes for some hours at a temperature of 160°–180°. The tubes are then found to contain a white crystalline mass, consisting of compounds of the hydriodates of the primary and secondary bases with zinc iodide.

The reactions which occur are represented by the equations,

$$2C_2H_5I + 2PH_4I + ZnO = 2[(C_2H_5)H_2P,HI], ZnI_2 + H_2O\,.$$
$$2C_2H_5I + PH_4I \;\; + ZnO = (C_2H_5)_2HP, HI, ZnI_2 + H_2O\,.$$

The separation of the primary from the secondary compound is accomplished with the greatest ease. It is only necessary to add water to the con tents of the sealed tubes when the compound of the primary base is decomposed and the base itself set at liberty. When it has been distilled off, the addition of potash to the residue separates the secondary base.

HOFMANN also studied the action of phosphuretted hydrogen on the alcohols at a high temperature, and with a singularly interesting result.

Not only does phosphuretted hydrogen act on the alcohol, but the bodies produced consist entirely of tertiary and quaternary compounds, no primary or secondary compounds being formed at all. Thus the action of phosphuretted hydrogen on an iodide of a hydrocarbon radical is exactly complementary to its action on an alcohol.

In employing the action of phosphuretted hydrogen on ordinary alcohol for the preparation of the tertiary and quaternary phosphines, HOFMANN places iodide of phosphonium at the bottom of a sealed tube, and above it the alcohol in a smaller tube. The vapour of the phosphonium iodide thus comes in contact gradually with the alcohol. The reaction is complete after six to eight hours digestion at 180°. The tubes are then found to be full of a white crystalline mass, from which caustic potash liberates the tertiary phosphine, whilst the iodide of the phosphonium remains in solution.

The reactions which occur are represented by the equations

$$3(C_2H_5OH) + PH_4I = P(C_2H_5)_3HI + 3H_2O\,.$$
$$4(C_2H_5OH) + PH_4I = P(C_2H_5)_4I \quad + 4H_2O\,.$$

MICHAELIS[*] has comparatively recently added to our knowledge of the phosphines, and to the methods of preparing them.

By passing the mixed vapours of terchloride of phosphorus and benzol through a red hot tube he obtained *phosphenyl-chloride*,

$$PCl_3 + C_6H_6 = (C_6H_5)PCl_2 + HCl\,.$$

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[*] Liebig's Annalen, 181, p. 280.

a substance which he also prepared by the action of terchloride of phosphorus on mercury di-phenyl,

$$PCl_3 + Hg(C_6H_5)_2 = (C_6H_5)PCl_2 + HgCl(C_6H_5) .$$

By the action of water on this body, *phosphenylous acid* is produced,

$$(C_6H_5)PCl_2 + 2H_2O = (C_6H_5)PO_2H_2 + 2HCl ,$$

and this when destructively distilled yields phenyl-phosphine—the phosphorus analogue of aniline,

$$3\{(C_6H)_5PO_2H_2\} = (C_6H_5)PH_2 + 2C_6H_6 + 2HPO_3 .$$

The same body results when hydriodate of phosphenyl-iodide (obtained by the action of hydriodic acid on phosphenyl-chloride) is decomposed with alcohol.

We were led in the first instance to the experiments to be presently described by the difficulty which one of us had experienced in preparing triethyl-phosphine on the large scale. Hofmann's later method had been at first resorted to, but in spite of numerous experiments, it had led to no satisfactory results. The pressure produced when alcohol and iodide of phosphonium are heated together is enormous, especially at the high temperature (180° C.) at which they react, and in almost nine cases out of ten it was found that the sealed tubes burst.

Nor is the other process for preparing triethyl-phosphine, viz., by treating zinc-ethyl with terchloride of phosphorus, a simple operation. The preparation of zinc-ethyl is expensive and troublesome, and although it reacts readily with the terchloride, the reaction is not so simple as might be expected. Scarcely 50 per cent. of the theoretical quantity of crude phosphine can be obtained, and this crude product contains impurities in considerable quantities, which are very difficult to remove. The preparation of triethyl-phosphine is in fact an expensive, uncertain, and troublesome operation.

Such being the case, and one of us requiring large quantities of it, the question naturally presented itself—Is there no simpler and less expensive process for preparing a tertiary phosphine? It seemed to us that one of the processes—and in fact the earliest—for preparing these bodies ought to be an extremely good one, if the difficulties attending its general application could be removed. The process to which we allude depends upon the ease with which metallic phosphides can be formed, and the readiness with which haloid ethers act on them. As before stated, Thenard, Berlè, Cahours, Hofmann and others, have worked with this process, but it has not met with great favour, and was abandoned by Hofmann (who employed phosphide of sodium) on account of the uncertainty of the reaction, the frequent explosions, and the great difficulties in separating the resulting phosphines from each other,—"not to speak of the difficulty of obtaining the phosphide of sodium fit for the reaction."

It seemed to us, however, that in phosphide of sodium an admirable reagent was at hand for the preparation of tertiary phosphines—provided only, to quote again HOFMANN'S words, that it can be obtained in a state "fit for the reaction."

This conclusion has been borne out by our experiments. With proper precaution, phosphide of sodium may be obtained in any quantity, and in a perfectly safe condition. It reacts with haloid ethers in a perfectly smooth manner, nor have we ever had an explosion, nor remarked the production of explosive bodies.

Our first experiments were made with iodide of ethyl. The reaction occurs *at ordinary temperatures with ease,* the iodide of ethyl boils violently, and the chief product of the reaction appears to be the iodide of tetrethyl-phosphonium. We have not as yet, however, brought these experiments to a conclusion, because of the difficulties which we experienced in separating the phosphines and phosphonium salt from the iodide of sodium produced along with them in the reaction.

Our next experiments were made in the benzyl series, which we chose partly because neither tribenzyl-phosphine nor tetrabenzyl-phosphonium salts have hitherto been obtained, and partly because no deliquescent or volatile bodies were likely to be formed, thus rendering the investigation free from those difficulties which cause experiments in the methyl and ethyl series to be so troublesome and laborious. To these reasons for our choice of benzyl must be added its similarity to fatty radicals and the well-known ease with which its compounds react.

Before proceeding to describe our experiments on the preparation of phosphide of sodium, and on its action on chloride of benzyl, we consider it necessary to give a short account of HOFMANN'S researches on monobenzyl- and dibenzyl-phosphine, which we believe to be the only ones that have been made on benzyl-phosphines.

Benzyl-Phosphines.

The following is an abstract of HOFMANN'S paper on "Aromatic Phosphines":*—

He was induced to experiment on the aromatic series, in consequence of the readiness with which, by the use of iodide of phosphonium, he had obtained

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* HOFMANN, Ber. d. deutsch. chem. Ges., iv. p. 100.

methyl- and ethyl-phosphines. His first attempts were made with the view of obtaining a phenyl-phosphine analogous to aniline, a substance highly interesting from a theoretical point of view.

To obtain this body he heated, under varying conditions, phenyl-chloride and iodide of phosphonium; but the experiments did not lead to a successful result, the phenyl-chloride becoming reduced to benzol, which even at high temperatures was not further acted upon. That the reaction did not proceed in the desired manner was, as he says, not surprising, considering the inertness of chloride of phenyl and the fact that aniline cannot be obtained by acting on it with ammonia.

Equally unsuccessful were his efforts to obtain the tertiary phosphine and the quaternary compound by the action of phenol upon iodide of phosphonium, though phosphorised bodies resulted, the nature of which he did not ascertain.

Experiments to obtain a phosphorised toluidine led to no successful issue; but, on the other hand, the preparation of a phosphorus analogue of benzylamine presented no difficulty, as indeed he did not doubt, considering the readiness with which chloride of benzyl reacts with ammonia.

Benzyl Phosphine, $C_7H_7PH_2$.—This body is formed when chloride of benzyl (which may be employed in the crude condition) is heated for six hours at a temperature of 160° with a mixture of phosphonium iodide and zinc oxide. The substances are taken in the proportions of 2 molecules benzyl chloride, 2 of phosphonium iodide, and 1 of zinc oxide.

When complete reaction has occurred the sealed tubes in which the mixture has been heated contain a white crystalline mass. On opening them a large quantity of phosphuretted hydrogen is evolved. On distilling the product of the reaction with water a heavy, oily liquid passes over of highly characteristic odour. This is separated, dried with caustic potash, and distilled in hydrogen. The thermometer rises to 180°, and then remains stationary, whilst a considerable quantity of a colourless, highly refractive liquid distils. This is monobenzyl-phosphine, whilst the lower boiling fraction consists mainly of toluol, and the residue in the retort contains dibenzyl-phosphine and other products. A simple distillation of the crude benzyl-phosphine thus obtained gives the pure body boiling at 180° C. In its properties it resembles in the main other primary phosphines. It oxidises in contact with the air, its temperature rising to 100° C., thick white vapours being formed. It is insoluble in water, but easily soluble in alcohol and ether. It forms a colourless crystalline hydriodate, only slightly soluble in fuming hydriodic acid, and which, like other salts of primary phosphines, decomposes in contact with water into hydriodic acid and the free base. Monobenzyl-phosphine also combines with hydrochloric acid, and gives a yellow insoluble chloro-platinate.

Benzyl-phosphine is formed, according to the reaction,

$$2C_7H_7Cl + 2(H_3PHI) + ZnO = 2[(C_7H_7)H_2PHI], ZnCl_2 + H_2O.$$

This equation, however, only expresses one phase of the reaction, in which simultaneously with monobenzyl-phosphine other products are formed. Of these HOFMANN could only succeed in isolating—

Dibenzyl-Phosphine.—This compound is contained in the residues after the benzyl-phosphine has been distilled off. On long standing in contact with solid potash, these solidify to a soft crystalline mass, which is collected on a linen filter, well squeezed, dissolved in alcohol, and the solution decolorised with animal charcoal. It then deposits, on cooling, beautiful white crystals of the dibenzyl-phosphine, which only require to be recrystallised from alcohol to obtain them in a state of purity.

Dibenzyl-phosphine thus obtained forms glistening white needles of large size, which are tasteless and colourless. They are insoluble in water, sparingly soluble in cold alcohol, readily in hot alcohol. The crystals melt at 205°, and sublime at higher temperatures, but not without partial decomposition.

With the introduction of the second benzyl group the alkaline characters, which are perfectly apparent in monobenzyl-phosphine, disappear.

Dibenzyl-phosphine dissolves in no acid, nor could HOFMANN obtain its chloro-platinate. Its composition could, therefore, only be determined by an analysis of the purified substance. The formation of dibenzyl-phosphine may be expressed by the equation,

$$2C_7H_7Cl + H_3PHI + ZnO = [(C_7H_7)_2HP,HI], ZnCl_2 + H_2O.$$

The mother liquors of the dibenzyl-phosphine contain another phosphorised body, which HOFMANN suspected to be tribenzyl-phosphine, but in spite of many efforts he was not able to prepare that body.

Phosphide of Sodium.

The success attending the use of this reagent for the preparation of phosphines depends entirely on the observance of certain conditions in its manufacture, which we have carefully determined by experiment.

The most essential of these are, the manner in which the sodium and phosphorus are allowed to combine, and the nature and quantity of the reagent employed to prevent the temperature from rising too high during their combination, and to protect the resulting phosphide from subsequent oxidation by the air.

If proper attention be paid to these precautions, phosphide of sodium may be prepared in a perfectly safe manner in large quantities and of uniform composition. Whatever this latter may be, the bulk of the phosphide behaves as Na_3P, as is evident from the nature of the products obtained from it.

We prepare the phosphide by melting sodium under xylol and adding ordinary phosphorus in small pieces,—shaking the vessel in which the mixture is made after each addition of the latter substance in order to bring it thoroughly into contact with the sodium. As regards the proportions of sodium and phosphorus, the theoretical quantities for the formation of the compound Na_3P, are, in round numbers, 7 of sodium and 3 of phosphorus; but our experiments show that with these proportions very bad results are obtained, as regards phosphine compounds. It appears to be necessary to employ a large excess of phosphorus —the proportions which we have found to be most suitable being 19 of that body to 20 of sodium—very nearly twice the theoretical quantity.

Considering that large quantities of phosphorus are converted into the amorphous modification, which does not apparently combine with sodium at those temperatures at which we operate, a simple explanation is afforded of the necessity for employing an excess of phosphorus; for, otherwise, unchanged sodium remains in the product, and, as we shall presently explain, this readily decomposes the chief phosphine compound produced when phosphide of sodium acts on chloride of benzyl. But, on the other hand, an excess of phosphorus over the proportions we have indicated also exercises a prejudicial influence on the quantity of phosphine compounds produced, and at present we can only explain this on the assumption that higher phosphides of sodium are formed, which are inactive.

The xylol necessary to prevent the reaction of the phosphorus and sodium from being too violent must be free from water and high boiling impurities. A single distillation of ordinary xylol is sufficient to purify it for this purpose. The proportion of xylol employed is also an important condition. This, however, we shall best consider when we describe our experiments on the action of the phosphide on chloride of benzyl.

The following is a description of the exact method we employ for preparing a batch of phosphide of sodium containing 78 grms. of sodium and phosphorus:—

40 grms. of freshly scraped sodium are placed in a flask of 500 cc. capacity,—fitted with a cork and wide glass tube placed vertically, and about 4 feet in height, to serve as a reversed condenser—and to it 200 grms. of xylol are added. The mixture is then warmed on a sand-bath until the sodium has melted. 38 grms. of phosphorus are cut into pieces the size of a pea, and these are placed in an evaporating basin containing xylol. They are then added gradually to the melted sodium. The first addition of the phosphorus causes a very violent reaction, so that care is necessary to prevent the xylol from boiling over. As soon as the xylol boils, the cork with its tube to serve as condenser is fitted into the flask, and the reaction allowed to proceed until the boiling ceases. More phosphorus is then added, and the flask well shaken after each addition. It is not necessary to heat the mixture, as the temperature remains sufficiently high to keep the reaction in progress to the end. The resulting product is a granular black powder, which is completely prevented from change by the xylol which surrounds it. We have kept a loosely corked flask containing it for upwards of six months without noticing that it had suffered change. But the slightest trace of moisture at once acts upon it, liberating spontaneously inflammable phosphuretted hydrogen.

Action of Chloride of Benzyl on Phosphide of Sodium.

Chloride of benzyl when boiled with the phosphide of sodium—prepared in the manner we have described—readily acts on it with the formation of common salt and compounds of benzyl and phosphorus. The main phosphine product is the chloride of tetrabenzyl-phosphonium, which may be obtained in large quantities by this method, and is easily isolated from the products of the reaction. Other phosphorised bodies are, however, formed in considerable quantity, the nature of which we shall discuss later.

As we have before stated, careful attention must be paid to the preparation of the phosphide of sodium, otherwise, as we have often observed, no chloride of the phosphonium results, although the whole of the phosphide of sodium may be acted on. On the other hand, the phosphide sometimes remains unacted on, or the reaction takes five or six times longer than is necessary in a properly conducted experiment. A very important condition of success is the right proportion of xylol employed in the preparation of the phosphide of sodium. We have found it advisable to take an excess of this substance in the first place, but to distil off this excess before adding the benzyl chloride.

With the quantities of sodium, phosphorus, and xylol mentioned already we distil off (in an oil bath) 170 grms., that is to say, a sufficient quantity to leave the phosphide of sodium almost dry, but in such a condition that the addition of a small quantity of benzyl-chloride may thoroughly wet the mass and permit of its being boiled without becoming superheated at the bottom. The chloride of benzyl is placed in a tap funnel, and allowed to drop down the wide tube used as a reversed condenser in the preparation of the phosphide of sodium. The tap is turned so that the benzyl-chloride may drip fast on to the phosphide of sodium contained in the flask (in which it has been made), which is heated in an oil bath. Care must be taken, however, lest the benzyl-chloride run in too rapidly, as in that case the ebullition (caused by the reaction) may be so violent that liquid collects in the condensing tube and is blown out by the vapour.

That reaction is occurring in the proper manner may be known by the change of colour of the phosphide of sodium from black to orange. It is advisable after the reaction has proceeded for some time, to remove the flask from the oil bath and to shake it vigorously; but as the lower portions of the phosphide are apt to become superheated, the shaking must be done cautiously.

PREPARATION OF TETRABENZYL-PHOSPHONIUM CHLORIDE.

	1	2	3	4	5	6	7	8	9	10	11	12
Benzyl-Chloride............	Grms. 100	Grms. 160	Grms. 200	Grms. 115	Grms. 220	Grms. 220	Grms. 100	Grms. 100	Grms. 100	Grms. 200	Grms. 100	Grms. 100
Xylol *........................	100	160	Toluol	Toluol	500	500	100–40	100–60	100–55	100–75	100–55	100–60
Sodium	14	22·5	28	17	31	31	14	14	18	28	21	20
Phosphorus..................	6	21	26	15	28	28	9	8	17	26	19	19
Unacted on benzyl-chloride and xylol...	...	...	...	...	...	...	...	...	...	...	...	...
Yield of $(C_7H_7)_4PCl$†.....	12	23	7	7	12		Flask broke	4	23	38	17	38
Theoretical yield	88	141	176	101	193	193	88	88	88	176	88	88

	13	14	15	16	17	18	19	20	21	22	23
Benzyl-Chloride.........	Grms. 100	Grms. 100	Grms. 100	Grms. 200	Grms. 100	Grms. 200	Grms. 200	Grms. 200	Grms. 200	Grms. 200	Grms. 200
Xylol *.....................	100–25	100–25	100–25	245–200	120–100	200–170	200–180	230–205	220–175	220–178	220–176
Sodium	20	20	20	35	20	40	40	40	40	40	40
Phosphorus................	19	19	19	33	19	38	38	38	38	38	38
Unacted on benzyl-chloride and xylol	80	90	90	78	35	40	60	30	52	58	75
Yield of $(C_7H_7)_4PCl$ †..	18	7	5	20	43	70	70	40	65	137	137
Theoretical yield	88	88	88	176	88	176	176	176	176	176	176

* In 7 and subsequent experiments a quantity of the xylol was distilled off after the preparation of the phosphide of sodium, and before the chloride of benzyl was allowed to act on it. The numbers after the sign – show how much of the xylol was thus distilled off.

† The chloride was squeezed in a cloth filter until it was as dry as possible and then weighed.

When the reaction is at an end only a few black particles are visible—the solid portions of the product appearing of a dirty orange colour.

The preceding table shows the results of our experiments on the influence of the conditions which affect the yield of chloride of tetrabenzyl-phosphonium, which no doubt will be serviceable in experiments on the phosphines of other radicals.

Extraction of Chloride of Tetrabenzyl-Phosphonium from the Product.

The product of the reaction we have just described consists of a mixture of common salt, a small quantity of phosphide of sodium which remains unacted on, xylol, chloride of benzyl, and phosphorised bodies, of which the chief is the chloride of tetrabenzyl-phosphonium.

To extract the latter we have tried several different processes, the simplest and best of which is the following :—

The flask containing the product of the reaction is connected with a condenser, and heated in an oil bath at a temperature of 180°–200° C.* as long as liquid distils. The mass remaining in the flask is then detached by a glass rod, and added by small portions at a time to cold water acidulated with hydrochloric acid; but as spontaneously inflammable phosphuretted hydrogen is evolved, the operation must be conducted cautiously. When this gas ceases to come off, the solution is filtered and the residue boiled with a considerable quantity of water (2 or 3 litres). The aqueous extract is then filtered (through a cloth filter), more water is added to the residue, and the two boiled together as before, the solution filtered, and this treatment repeated until a portion of the extract gives no crystalline precipitate when cooled and mixed with hydrochloric acid. The united aqueous extracts are then mixed with about 10 per cent. of their volume of strong hydrochloric acid and allowed to cool. Almost every trace of chloride of tetrabenzyl-phosphonium is then precipitated in the form of minute needles. The compound is collected on a linen filter, well squeezed to free it from mother liquor, and recrystallised from boiling water, from which it separates on cooling in beautiful needles often an inch and a half long, and almost perfectly white and pure. The residue which remains after extracting the phosphonium compound forms a reddish-brown insoluble solid mass. It contains phosphorised bodies, the nature of which we shall consider later.

Chloride of Tetrabenzyl-Phosphonium.—As this body forms the starting point from which the other salts of the phosphonium are obtained, we have examined its properties very carefully. It is sparingly soluble in cold water. (In a rough experiment 100 cc. of water at ordinary temperatures dissolved 0·35 grm.) It is much more soluble in boiling water, and crystallises from

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* A higher temperature must be avoided, as we find that it materially diminishes the yield of phosphonium salt.

it on cooling in long needles, which are somewhat thick and are perfectly colourless. The addition of common salt, and especially of hydrochloric acid, to its aqueous solution reduces its solubility in a remarkable manner: in fact, it is practically insoluble in the dilute acid, and traces may be detected in solution by this means. Chloride of tetrabenzyl-phosphonium crystallises from an aqueous solution with two molecules of water of crystallisation. The dried salt is readily soluble in alcohol, and the solution on slow evaporation yields very beautiful, colourless, rhombic crystals of considerable size and perfect symmetry. These consist of the anhydrous compound. The dried salt is also easily dissolved by chloroform, and on evaporation, the solution yields large colourless crystals, which lose chloroform on exposure to the air, and appear to have effloresced. A determination of the loss which a specimen of the salt crystallised from chloroform suffered when heated to 100° C. showed that the chloride had crystallised with 1 molecule of chloroform. We are not aware that "chloroform of crystallisation" has been noticed before in any substance.

Chloride of tetrabenzyl-phosphonium fuses at 224° C., and volatilises slowly at that temperature apparently unchanged. Heated more strongly it decomposes, yielding solid and liquid products, amongst the former being free phosphorus. Boiled with a solution of potash it suffers a change, which we shall refer to later (see p. 204).

The composition of the chloride was determined by estimations of carbon, hydrogen, chlorine, phosphorus, and water. The combustion was made with chromate of lead and oxide of copper. The chlorine was determined gravimetrically by precipitation as chloride of silver, and the phosphorus by titration with uranium solution after the salt had been fused with a mixture of caustic potash and nitrate of potassium.

Analysis of Chloride of Tetrabenzyl-Phosphonium.

Dried Salt.

* { ·294 grm. gave ·837 carbonic anhydride = 77·7 per cent. carbon.
{ ·294 ,, ,, ·188 water = 7·1 ,, hydrogen.
·6943 ,, ,, ·2298 chloride of silver = 8·2 ,, chlorine.
·6625 ,, ,, by titration = 6·6 ,, phosphorus.

	Obtained.	Calculated for $(C_7H_7)_4PCl$.
Carbon,	77·7	78·0
Hydrogen,	7·1	6·5
Chlorine,	8·2	8·2
Phosphorus,	6·6	7·2
	99·6	99·9

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* The hydrogen in this experiment is too high and the carbon too low, probably because the salt had not been completely dried.

Crystallised Salt.

(1) 26·055 grms. lost at 110° 2·03 grms. water = 7·7 per cent.
2)[*] 3·2392 „ „ ·258 = 8·0 „

	Obtained.		Calculated for $(C_7H_7)_4PCl,2H_2O$.
	I.	II.	
Water,	7·7	8·0	7·7

Crystallised from Chloroform.

4·2015 grms. lost at 110° ·8938 grm. chloroform = 21·2 per cent.

	Obtained.	Calculated for $(C_7H_7)_4PCl,CHCl_3$.
Chloroform,	21·2	21·7

Chloroplatinate of Tetrabenzyl-Phosphonium.—This compound is easily formed on mixing aqueous or alcoholic solutions of chloride of platinum and chloride of tetrabenzyl-phosphonium. In the former case a light orange precipitate is produced, which appears to be amorphous to the naked eye. In the latter, if the two solutions are boiling and dilute, a distinctly crystalline precipitate is produced of a darker colour.

The chloroplatinate is very insoluble, almost absolutely so in water, and is only very slightly soluble in alcohol.

The composition of the salt was determined by a combustion with chromate of lead and oxide of copper—as in all chloroplatinates of phosphines and phosphoniums the determination of chlorine and platinum is very tedious and uncertain.

If attempts are made to determine platinum by the weight of the residue left on ignition, the results are often as much as 2 per cent. too high, owing to the formation of phosphide of platinum. Precipitation by sulphuretted hydrogen we have found to be always incomplete with chloroplatinates of benzyl-phosphines

HOFMANN's method[†] gave us results which were too low. We could, in fact, discover no process for estimating the platinum in this salt, or the chlorine, and were in consequence obliged to fix its composition by an organic analysis. The results of this are as follows:—

·348 grm. gave ·711 of carbonic anhydride = 55·7 per cent. carbon.
·348 „ „ ·1508 of water = 4·8 per cent. hydrogen.

	Obtained.	Calculated for $\{(C_7H_7)_4PCl\}_2PtCl_4$.
Carbon . . .	55·7	56·0
Hydrogen . . .	4·8	4·7

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[*] In this experiment the salt was heated for a whole day, and probably some of it volatilised.

[†] Trans. Roy. Soc. Lond., vol. cxlvii. p. 575.

Sulphate of Tetrabenzyl-Phosphonium.—Nine grms. of the phosphonium chloride were dissolved in about a pint of hot water, the solution was then cooled somewhat, and sulphate of silver added until it ceased to be converted into chloride. The solution was then filtered and concentrated, and yielded a crop of very beautiful colourless rhombic plates of considerable size.* A determination of water of crystallisation and of sulphuric acid showed that these consisted of the normal sulphate crystallising with six molecules of water.

Salt dried at 120°.

Sulphuric Acid (1 and 2 volumetrically by the chromate method, 3 gravimetrically).

(1) 0·5745 grm. required 2·6 cc. ¼ normal $BaCl_2$ = 0·0520 SO_3 = 9·0 per cent.
(2) 0·4203 „ „ 3·8 „ ⅛ „ „ = 0·038 „ = 9·0 „
(3) 0·5053 „ gave 0·131 grm. $BaSO_4$ = 0·045 „ = 8·9 „

Air-dried Salt.

Sulphuric Acid.

0·6865 grm. required 5·6 cc. ⅛ normal BaCl = 0·056 SO_3 = 8·2 per cent.

Water (by heating to 125° C.).

0·5704 lost 0·0574 H_2O = 10·0 per cent.

	Obtained.			
	Dry Salt.			Undried.
	I.	II.	III.	Salt.
Sulphuric anhydride, .	9·0	9·0	8·9	8·2
Water, ...	—	—	—	10·0

	Calculated.	
	$\{(C_7H_7)_4P\}_2SO_4$.	$\{(C_7H_7)_4P\}_2SO_4, 6H_2O$.
Sulphuric anhydride, . .	9·0	8·1
Water, ...	—	10·8

The normal sulphate is one of the most soluble salts of the phosphonium. It has no definite melting point. It grows pasty at 195°, but is not completely fused until 220°.

Action of Sulphuric Acid on Chloride of Tetrabenzyl-Phosphonium.—When

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* In our notice of these experiments in the "Proceedings," we stated that the action of sulphate of silver on the phosphonium chloride yields the *acid* sulphate, and not the *normal* sulphate of the phosphonium. There can be but little doubt that we did obtain and analyse the acid salt, but its formation was probably due to the fact that we acted on a *boiling* solution of the chloride with sulphate of silver, and the filtered solution therefore contained a considerable quantity of the latter salt which we decomposed by sulphuretted hydrogen, thus setting free sulphuric acid which combined with the normal sulphate; and as the acid sulphate thus formed is much less soluble than the normal sulphate, it is probable, as we analysed the first crop of crystals, that they consisted entirely of the acid sulphate. We have verified the correctness of this explanation by an experiment conducted in a similar manner.

oil of vitriol is poured on to the chloride, an immediate effervescence occurs and clouds of hydrochloric acid are produced. Heated on the water bath, the mixture grows dark and eventually becomes completely liquid, provided that an excess of sulphuric acid has been taken. As soon as the whole of the hydrochloric acid has been driven off, the mixture is poured into a small quantity of cold water. A solid substance of a grey colour is precipitated, which by washing with a little cold water becomes free from sulphuric acid. It is then boiled with a tolerably large quantity of water, when it almost completely dissolves, leaving, however, a slight residue containing most of the black colouring matter. On cooling, almost colourless crystals are deposited, which are apparently rhombohedral plates united into spear-shaped forms.

A single recrystallisation gives the new compound in a state of purity.

Its analysis shows it to be the--

Acid Sulphate of Tetrabenzyl-Phosphonium.—The chloride has therefore been acted on by sulphuric acid in the same manner as common salt. Its analysis gave the following numbers :—

·397 grm. gave ·9907 CO_2 = 68·1 per cent. carbon.
·397 „ „ ·2176 H_2O = 6·1 „ hydrogen.
·5252 „ „ ·2445 $BaSO_4$ = 16·0 „ sulphuric anhydride.

	Obtained.	Calculated for $(C_7H_7)_4PHSO_4$.
Carbon, . . .	68·1	68·3
Hydrogen, . . .	6·1	5·9
Sulphuric anhydride, .	16·0	16·2

Acid sulphate of tetrabenzyl-phosphonium is rather more soluble in water than the chloride, and very much less so than the normal sulphate; it readily crystallises from hot water. The addition of hydrochloric acid to its solution causes the precipitation of the chloride. It has a sour taste, and its solution reddens litmus paper.

It does not suffer any loss when heated to 100° C., and therefore contains no water of crystallisation.

It fuses at 217° C., suddenly effervesces at higher temperatures, and suffers decomposition (see p. 214).

Action of Hydrate of Barium on the Acid Sulphate.—The action which occurs when solutions of these two bodies are mixed varies in a remarkable manner with the conditions of the experiment.

We naturally supposed that the hydrate of tetrabenzyl-phosphonium would be produced. Thus—

$$(C_7H_7)_4PHSO_4 + Ba(OH)_2 = (C_7H_7)_4P(OH) + BaSO_4 + H_2O .$$

In our first attempts to prepare the base by this method 3 grms. of the acid sulphate were dissolved in about half a litre of water, and a solution of caustic baryta (in boiling water) was added until no more sulphate of barium was precipitated. The solution was then filtered and a stream of carbonic acid passed through it until all excess of baryta was converted into carbonate. It was then boiled and filtered, and the filtered solution concentrated until it amounted to about 50 cc. in volume. Tufts of needles separated out, though in small quantity ; but on allowing the solution to stand for a couple of days, large rhombohedral plates appeared, which were colourless and of striking refractive power—resembling, in fact, iodide of phosphonium. They were washed with a little water and their mother liquor evaporated down, when a second crop of tabular crystals separated. The two crops were mixed and recrystallised from water. The resulting crystals were analysed.

Heated in a drying oven to 110° C. they became opaque, and lost in weight, thus showing that they contained water of crystallisation. As, however, during drying they developed a smell, recalling that of bitter almonds, we cannot place much reliance on the water determination, as the compound no doubt volatilised slightly. It was, however, necessary to dry it for organic analysis, and we therefore heated it quickly in a small beaker placed in an oil bath until it had partially fused. As this only occurred at a temperature above 200° C., there can be no doubt that we obtained a dry product.

Its combustion thus dried gave numbers agreeing with those required for the base.

0·2065 grm. gave 0·620 CO_2 = 81·8 per cent. carbon.
0·2065 „ „ 0·1256 H_2O = 6·8 „ hydrogen.

	Obtained.	Calculated for $(C_7H_7)_4P(OH)$.
Carbon, . . .	81·8 . . .	81·5
Hydrogen, . . .	6·8 . . .	7·0

Wishing to prepare another quantity of the base, we proceeded in a similar manner, using however more concentrated solutions ; but on filtering and evaporating (after getting rid of excess of baryta), no base could be obtained. This curious result induced us to examine the precipitated sulphate of barium, which we found to contain a substance readily soluble in alcohol, though quite insoluble in water. It separated from its alcoholic solution in white needles. These were recrystallised until of constant melting point, viz., 210–212° C.

They were then dried at 120°, but did not lose weight, so they were at once submitted to an elementary analysis.

0·4234 gave 1·230 CO_2 = 79·2 per cent. carbon.
0·4234 „ 0·2589 H_2O = 6·8 „ hydrogen.

These results, so different from those required by the hydrate, we could not explain, and therefore again repeated the experiment with the acid·sulphate and caustic baryta as far as possible under the same conditions as before—with larger quantities, however—but with exactly the same result. No body soluble in water was produced, but an insoluble body was precipitated with the sulphate of barium, soluble, however, as we had before noticed, in alcohol, and having on recrystallisation the same melting point (210–212° C.). Its analysis gave numbers agreeing with those we had previously obtained.

0·5958 gave 1·7221 CO_2 = 78·8 per cent. carbon.
0·5958 „ 0·3636 H_2O = 6·8 „ hydrogen.

Obviously then two distinct substances are formed by the action of caustic baryta on the acid sulphate, under conditions which vary only slightly from each other.

On consideration, but one explanation appeared probable, viz., that the base suffered decomposition; and the only change which appeared at all likely for it to undergo was a loss of hydrogen and benzyl, and, consequently, the formation of oxide of tribenzyl-phosphine. This change would be analogous to the decomposition which HOFMANN observed on heating the hydrate of tetrethyl-phosphonium, which he found to decompose with formation of ethane and oxide of triethyl-phosphine,

$$(C_2H_5)_4P(OH) = (C_2H_5)_3PO + C_2H_6\,.$$

Similarly, hydrate of tetrabenzyl-phosphonium might split up into toluol and the phosphine oxide,

$$(C_7H_7)_4P(OH) = (C_7H_7)_3PO + C_7H_8\,.$$

On comparing the percentages of hydrogen and carbon required for the oxide of tribenzyl-phosphine, with the results of our analyses of the body soluble in alcohol, we found that they corresponded.

	Obtained.		Calculated for
	I.	II.	$(C_7H_7)_3PO$.
Carbon,	79·2	78·8	78·75
Hydrogen,	6·8	6·8	6·56

It only remained to ascertain whether toluol was produced in the reaction. 7 grms. of the acid sulphate were placed in a distilling flask, and about the same proportion of water as we employed in our two previous experiments. The two were then boiled until the sulphate had dissolved, and a boiling and concentrated solution of caustic baryta was added in excess. The distilling flask was then connected with a condenser, and its contents heated. An oily liquid passed over with the water, which had the odour of toluol, and a boiling point of 112°—exactly that of toluol. Moreover, its weight amounted to 1·0 grm., whereas the quantity we ought to have obtained was 1·2 grm.

There can be no doubt then that the base very easily decomposes into toluol and tribenzyl-phosphine oxide.

That this decomposition is effected by the temperature we must doubt, as we concentrated the solution of the base by boiling, and it suffered no change. But, on the other hand, there can be no doubt that if *weak* solutions of the acid sulphate and baryta are employed, the base is almost—if not altogether the sole product—whilst with *strong* solutions only the oxide is formed.

Action of Carbonate of Barium on the Acid Sulphate.—Carbonate of barium, when added to a solution of the acid sulphate, at once effervesces, and sulphate of barium is formed, whilst the base remains in solution, from which it is easily obtained by evaporation and subsequent cooling.

The reaction occurs according to the equation,

$$(C_7H_7)_4PHSO_4+BaCO_3=CO_2+BaSO_4+(C_7H_7)_4P(OH).$$

We have not observed the production of any oxide of tribenzyl-phosphine in this reaction, even when a very concentrated solution of the acid sulphate is employed, and we therefore recommend it as the simplest and most certain method for obtaining the base, for the acid sulphate is very easily formed from the chloride.

This reaction also shows that no carbonate of tetrabenzyl-phosphonium can exist; nor ought we to be surprised at this, considering that the alkaline power of aromatic phosphines, like that of corresponding amines, is very markedly less than it is in the case of ethyl or methyl phosphines or amines.

Hydrate of Tetrabenzyl-Phosphonium.—This body is one of the most beautiful of all the compounds of tetrabenzyl-phosphonium. It is very soluble even in cold water, and crystallises in very beautiful rhombohedral plates, which we have on one occasion obtained nearly ½ an inch long and ¼ inch broad. The crystals have a very striking refractive power, so that they resemble in appearance the large crystals of phosphonium iodide, which may be formed by slow sublimation.

The hydrate is readily soluble in alcohol; and the crystals obtained from the solution contain alcohol.

0·8746 heated to 110° lost 0·1076 grm. alcohol = 12·3 per cent.

	Obtained.	Calculated for $(C_7H_7)_4P(OH),C_2H_5OH$.
Alcohol,	12·3	12·8

Solutions of the base have an alkaline reaction, and they neutralise acids—salts of the phosphonium resulting.

When the anhydrous base is heated, it begins to fuse at 190°, but a portion remains unfused to 211°. It is probable, therefore, that the base cannot be melted without decomposition. Heated to higher temperatures it decomposes, and gives solid and liquid products, the nature of which we shall discuss later.

Bromide of Tetrabenzyl-Phosphonium.—This compound was obtained by mixing aqueous solutions of bromide of barium and the acid sulphate. The precipitated sulphate of barium contains the greater quantity of the bromide, which is sparingly soluble. It was extracted with alcohol, and the filtered solution mixed with water. On cooling, long silky needles were deposited. Their composition was verified by a bromine determination.

·303 grm. required 6·3 cc. decinormal $AgNO_3$ soln. = 0·0504 Br = 16·6 per cent.

	Obtained.	Calculated for $(C_7H_7)_4PBr$.
Bromine,	16·6	16·8

The bromide is less soluble in water than the chloride. It melts at 216° to 217°C.

Iodide of Tetrabenzyl-Phosphonium was prepared by a similar process. It is almost insoluble in water, but is soluble in a mixture of water and alcohol, and crystallises from the solution in needles resembling the chloride.

For its analysis, a quantity was fused, weighed, dissolved, and titrated with decinormal silver solution.

·2103 grm. required 4 cc. $AgNO_3$ soln. = 0·0508 I = 24·2 per cent.

	Obtained.	Theory for $(C_7H_7)_4PI$.
Iodine,	24·2	24·3

Nitrate of Tetrabenzyl-Phosphonium.—A solution of the base was saturated with a dilute solution of nitric acid; long silky needles separated. They were not analysed.

Chromate of Tetrabenzyl-Phosphonium.—This salt was obtained by acting on a solution of the chloride with chromate of silver. On extracting the precipitate with boiling alcohol, and adding water to the filtered solution, small lemon-yellow plates separated as the solution cooled. They were not analysed.

Oxalate of Tetrabenzyl-Phosphonium.—On adding excess of oxalic acid to a dilute and hot solution of the base, and then allowing the mixture to cool, long needles separated. The salt was analysed by drying at 100° C., and determining oxalic acid in the dried compound by precipitation with chloride of calcium, the oxalate of calcium being eventually ignited and converted into quicklime.

0·741 gave 0·088 CaO=0·1383 C_2O_4=17·9 per cent.
0·770 lost 0·029 H_2O= 3·7 „

	Obtained.	Calculated for $(C_7H_7)_4PHC_2O_4$.
C_2O_4	17·9	18·1
		$\{(C_7H_7)_4PHC_2O_4\},H_2O$.
H_2O	3·7	3·6

Acetate of Tetrabenzyl-Phosphonium.—This salt is the most soluble of any of the compounds of tetrabenzyl-phosphonium which we have examined. It is obtained by the action of the chloride on acetate of silver, and crystallises from alcohol with difficulty. It was not analysed.

Chlorate of Tetrabenzyl-Phosphonium.—This salt was prepared by the action of chlorate of barium on the acid sulphate. It crystallises in long needles from a moderately concentrated solution. Heated above its melting point, it puffs.

Examination of the Residues from the Preparation of Chloride of Tetrabenzyl-Phosphonium.

After extracting the chloride of the phosphonium from the product of action of chloride of benzyl on phosphide of sodium (by boiling the latter repeatedly with water) a solid orange-coloured mass remains, which contains large quantities of amorphous phosphorus, and also organic phosphorus compounds.

We thought it possible, if not indeed probable, that these would contain tribenzyl-phosphine, for it is only natural to suppose that that body is first formed in the reaction, and is only converted into the phosphonium compound by the continued action of the chloride of benzyl. If this were the case some of the phosphine might, we considered, remain unacted upon, and would be found in the residues.

Moreover, we thought that phosphides of sodium of a different composition from the tri-sodium phosphide might be formed along with that body by the action of phosphorus on sodium; for instance, a phosphide analogous in composition to the liquid phosphide of hydrogen, viz., Na_4P_2, or even to the solid phosphide, viz., Na_2P_4. If these bodies were indeed formed, they might give by their action on chloride of benzyl analogous benzyl compounds, and of these the phosphorised cacodyl of benzyl, *i.e.* $(C_7H_7)_4P_2$, would possess a great interest.

We therefore determined to submit the residues to a very careful examination, the result of which we have now to communicate.

On boiling them with chloroform, the whole of the organic ingredients appeared to be dissolved, and the residue consisted apparently of amorphous phosphorus only. The chloroform extract was distilled to dryness, and there remained a solid gummy, slightly crystalline mass. This was boiled with alcohol, when the greater part dissolved, leaving about one-third undissolved in the form of a brown amorphous solid. The brown alcoholic extract was filtered and mixed with about one and a half times its volume of boiling water; the mixture was then boiled and filtered from a brown resinous substance which had been precipitated. The filtered solution deposited on cooling a considerable quantity of a crystalline substance, though in a very impure condition.

We thus split up the residues into three portions—

1. *Soluble in chloroform only.*
2. *Soluble in chloroform and alcohol.*
3. *Soluble in chloroform, alcohol, and a mixture of alcohol and water.*

We may here observe that as the portion of the residues No. 1 was not very inviting, in later experiments the residues were at once extracted with alcohol, so as to obtain only portions 2 and 3.

Examination of Residue soluble in Chloroform, Alcohol, and Alcohol and Water.—This portion of the residue was distinctly crystalline, but highly charged with a brown resinous substance, which threatened at first to render its purification difficult.

At first we attempted to recrystallise it from alcohol, but although well-defined crystals were easily obtained, the colouring matter adhered persistently; animal charcoal was then boiled with the alcoholic solution of some of the crystals which were only slightly coloured, and eventually by this process a colourless, crystalline, and highly refractive substance was obtained.

But we soon found that the crude and strongly coloured residue could be purified in a far easier and simpler manner. On treating it with ether or bisulphide of carbon, the colouring matter was at once dissolved, but the crystalline substance was quite insoluble, so that by simple washing with either of these liquids, an almost colourless residue was obtained, which only required to be recrystallised once or twice from hot alcohol. The crystals thus obtained consisted of brilliant needles of considerable length and thickness, and were apparently quadratic prisms. They fused at 212° C., and appeared to volatilise at higher temperatures almost unchanged. They were analysed by combustion with chromate of lead and oxide of copper.

0·468 gave 1·360 CO_2 = 79·2 per cent. carbon.
0·468 „ 0·2895 H_2O = 6·8 „ hydrogen.

Carbon, ...	79·2
Hydrogen, . . .	6·8

That they contained phosphorus was at once shown by the livid green colour which they imparted to the flame of a Bunsen's burner when heated on a platinum wire.

The numbers required for tribenzyl-phosphine do not agree with those obtained with this substance; but, on the other hand, those calculated for a phosphorised cacodyl are almost identical with them.

Thus—

	Obtained.	Calculated for $(C_7H_7)_4P_2$.	Calculated for $(C_7H_7)_3P$.
Carbon, . . .	79·2	78·9	82·9
Hydrogen, . .	6·8	6·6	6·9

As for the reasons we have given above, we almost expected to find the cacodyl in the residues, we assumed that we really had obtained such a body. But the experiments which we tried to confirm this supposition did not lead to the results which we anticipated.

A phosphorised cacodyl, even of an aromatic radical, ought to possess a strong tendency to absorb oxygen, and therefore would, even if it did not take up oxygen from the air, at least act as a powerful reducing agent. But the body in question showed no reducing tendencies whatever. A solution of nitrate of silver was not altered when boiled with its solution. Chloride of platinum at once produced a crystalline precipitate, which was not changed by boiling. This want of reducing power we considered a stong argument against the supposition that the substance was a phosphorised cacodyl. Moreover, we noticed that it showed an indifference towards those reagents which react energetically with cacodyl. It is true that we obtained a compound with bromine, and also one with sulphur; but the result of their analyses could not be reconciled with the supposition that they were derivatives of a phosphorised cacodyl.

On looking over our notes, we were struck with the fact that, so far as carbon and hydrogen are concerned, both oxide of tribenzyl-phosphine and a phosphorised benzyl-cacodyl have an almost identical composition; and we also noticed that dibenzyl-phosphine would require similar numbers.

Thus—

	Calculated for		
	$(C_7H_7)_4P_2$.	$(C_7H_7)_3PO$.	$(C_7H_7)_2HP$.
Carbon,	78·9	79·7	78·9
Hydrogen,	6·6	6·6	6·6

We did not think it likely that dibenzyl-phosphine had been formed in the reaction, as we could not account for the hydrogen atom which it requires; but bearing in mind the results of our experiments on the action of baryta on the acid sulphate of tetrabenzyl-phosphonium, it did not appear impossible that oxide of tribenzyl-phosphine had been formed; for, by the action of phosphide of sodium on water, caustic soda is produced: this might react on chloride of tetrabenzyl-phosphonium, and give rise to oxide of tribenzyl-phosphine and toluol.

At first sight, such a supposition may not appear probable, as haloid salts of methyl- and ethyl-phosphonium are not changed by caustic alkalies; but we have shown that corresponding salts of benzyl-phosphonium possess very different properties from these bodies. On treating the product of the action of phosphide of sodium on chloride of benzyl with water, abundance of phosphuretted-hydrogen was evolved, showing that a considerable quantity of phosphide of sodium had remained unacted on. The solution was boiled; and thus, if alkalies really act on chloride of tetrabenzyl-phosphonium in the manner we have indicated, we have the necessary conditions for the production of oxide of tribenzyl phosphine.*

As a further argument for supposing that the oxide had really been obtained, and not the cacodyl, it will be noticed that, although the percentage of carbon calculated for the two bodies varies by only 0·8 per cent., the results of our analyses are more favourable to the supposition that the body is the oxide, and not the cacodyl. For we obtained 0·3 per cent. too much carbon for the cacodyl, and therefore 0·5 per cent. too little for the oxide; and in carefully conducted organic analyses the carbon is often too low, but seldom too high.

We had noticed that oxide of tribenzyl-phosphine (obtained as described at p. 198) combines with iodide of zinc to form a compound (analogous to HOFMANN'S zinc iodide compound of triethyl-phosphine oxide) of characteristic crystalline form. If, then, the substance were the phosphine oxide, the

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* We have since proved that alkalies act very readily on chloride of tetrabenzyl-phosphonium. On boiling a solution of the chloride in alcohol with potash or soda for a few minutes, decomposition occurs, chloride of the alkaline metal is precipitated and the solution contains oxide of tribenzyl-phosphine, which is easily identified by its insolubility in water and other characteristic properties.

production of this salt would be an almost crucial test. We therefore proceeded with the supposed cacodyl as we had done with the oxide of tribenzyl-phosphine, and operating under exactly the same conditions, obtained a double salt with zinc iodide, which could not be distinguished from that of the oxide, either in crystalline form or in composition.

We have further verified the identity of the supposed cacodyl with oxide of tribenzyl-phosphine, by processes which we may consider along with the properties of that substance.

Since writing the above, we have noticed that oxide of tribenzyl-phosphine has been obtained by F. Fleissner,* by the action of benzal chloride on iodide of phosphonium. The results of Fleissner's investigations on the properties of the oxide, so far as they go, are in accordance with our own.

Oxide of Tribenzyl-Phosphine.—Subjoined are the results of the analysis of the oxide prepared by three different methods :—

I. *Obtained as just described from the residues.*

II. and III. *Obtained by the action of caustic baryta on chloride of tetrabenzyl-phosphonium.*

IV. *Obtained during experiments on the action of sodium on chloride of tetrabenzyl-phosphonium* (see p. 211).

	Obtained.				Calculated for $P(C_7H_7)_3O$
	I.	II.	III.	IV.	
Carbon, ...	79·2	79·2	78·8	78·3	78·75
Hydrogen, ...	6·8	6·8	6·8	6·7	6·56
Phosphorus, ...	8·5 8·8	—	—	8·4	9·68
Oxygen, ...	—	—	—	—	5·01
					100·00

The three specimens were quite different in appearance.

I. Crystallised in thick needles of great refractive power, and quite transparent.

II. and III. In opaque plates of indefinite form.

IV. In very bulky, silky needles.

We could not at first reconcile ourselves to the belief that they were one and the same body.

The following carefully conducted experiments, however, appear to prove beyond doubt that they were so :—

Melting Point.—This was determined in the ordinary manner, by heating the carefully dried and pulverised substance in a capillary tube tied to a thermo-

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* Ber. d. deutsch. chem. Ges., xiii., 1665.

meter, both thermometer* and capillary tube being placed in a beaker containing sulphuric acid.

	I.	II. and III.	IV.
(*a*)	212° C.	212°	212°
(*b*)	212°	212°	210–212°

The temperature is uncorrected.

Double Salt with Zinc Iodide.—This compound was formed easily with any of the three specimens, by adding to its alcoholic solution an alcoholic solution of zinc iodide, and evaporating to small bulk. The double compound separates in thin transparent plates of characteristic form.

Examined under the microscope *no difference could be detected in the crystalline form of the double salt prepared with any of the three specimens of the oxide.*

The salt was analysed by volumetric determination† of iodine in specimens of Nos. I. and of II. and III.—

I. 0·606 grm. required 12·4 cc. decinormal $AgNO_3$ = 0·15748 = 26·0 per cent. iodine.
II. and III. 0·232 „ „ 4·7 „ „ „ = 0·05969 = 25·9 „ „

Calculated for $\{P(C_7H_7)_3O\}_2ZnI_2$ . . . . 26·4 „ „

Chloroplatinate.—This salt is characteristic, and is formed with ease on mixing dilute alcoholic solutions of the oxide and chloride of platinum. It separates almost immediately as a light orange-coloured granular powder—which, under the microscope, is seen to consist of groups of needles, thick, four-sided, and with blunt ends. Very commonly two needles form a cross, at other times several radiate from a common centre. *No difference could be detected in the crystalline form of the chloroplatinate prepared with any of the specimens.*

The salt was analysed by determination of carbon, hydrogen, and in one specimen of chlorine also :—

I.

Chlorine.

0·4356 grm. required 15·3 cc. decinormal $AgNO_3$ = ·054315 Cl = 12·4 per cent.‡
0·4605 „ „ 16·4 cc. „ „ = 05822 „ = 12·6 per cent.§

IV.

Carbon and Hydrogen.

(A) 0·3932 grm. gave 0·8497 CO_2 = 0·25491 C = 58·9 per cent.
0·3932 „ „ 0·1874 H_2O = 0·02082 H = 5·3 „
(B) 0·2738 „ „ 0·5975 CO_2 = 0·16295 C = 59·4 „
0·2738 „ „ 0·1350 H_2O = 0·015 H = 5·4 „

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* One of CASELLA'S.

† VOLHARDT'S method.

‡ HOFMANN'S method.

§ By precipitating the platinum with sulphuretted hydrogen and titrating the filtered solution.

	I.		IV.	
Carbon,			58·9	59·4
Hydrogen,			5·3	5·4
Chlorine,	12·4	12·6	——	——
Platinum,	———		——	——

The formula which Hofmann[*] gives for the chloroplatinate of the oxide of triethyl-phosphine is $3(Et_3PO)$, Et_3PCl_2, $PtCl_4$; but this formula does not appear to be a very probable one. It seems to us to be more likely that the chloroplatinate is a compound of the phosphine oxide with hydrochloric acid and chloride of platinum, and we find that the numbers calculated for such a formula, viz., $4(Et_3PO)$, $2HCl$, $PtCl_4$, agree as closely with those obtained by Hofmann in the analysis of the chloroplatinate, as do those calculated from his formula, thus—

		Calculated for	
	Obtained.	$3(Et_3PO),(Et_3PCl_2),PtCl_4$.	$4(Et_3PO),2HCl, PtCl_4$.
Carbon,	30·17	30·9	30·4
Hydrogen,	6·75	6·4	6·3
Platinum,	21·06	21·2	20·8
Chlorine,	22·93	22·9	22·5

It will be seen that the only difference between these two formulæ is that the one on the right hand contains an atom more oxygen and two atoms more hydrogen than the one on the left; that is to say, a difference of 18 as regards molecular weight. As the latter amounts to 930 in Hofmann's formula, the difference in the calculated percentage of each element is very slight, and this is still more the case with the chloroplatinate of the benzyl compound—the molecular weight of which with Hofmann's formula is 1674, and with our formula 1692.

But, on the other hand, the proportion of carbon is so large that the percentage of that element is perceptibly different with the two formulæ, and it will be seen that this difference is decidedly in favour of the formula which we propose.

We may add that it appears to us to be highly improbable that O should be replaced by Cl_2, by simply mixing at ordinary temperatures chloride of platinum and the phosphine oxide.[†]

The results of our analysis, compared with the numbers calculated for the two formulæ are—

		Calculated for	Calculated for
	Obtained.	$3\{(C_7H_7)_3PO\}, \{(C_7H_7)_3PCl_2\}, PtCl_4$.	$4\{(C_7H_7)_3PO\}2HCl,PtCl_4$.
Carbon,	59·2	60·2	59·5
Hydrogen,	5·3	5·0	5·0
Platinum,	——	11·7	11·7
Chlorine,	12·5	12·7	12·5

[*] Trans. Roy. Soc. Lond., 1860, p. 418.

[†] The experiments of Crafts and Silva (*loc. cit.*) show that this replacement does not occur.

Brominated Compound.—This is a very characteristic substance, and its production, with all of the specimens of the supposed oxide, we considered to be a strong proof of their identity.

It is formed by dissolving the phosphine oxide in glacial acetic acid (boiling), and adding bromine in excess. No visible reaction occurs, except that the bromine is at first decolorised. On cooling, the compound is precipitated as a granular crystalline powder of bright yellow colour. Sometimes needles are observed; but these are found, when examined under the microscope, to consist of cubical or rhombohedral crystals united; the crystalline powder consisting of the same forms isolated.

For analysis, the compound was simply dried *in vacuo* for some time, and was not recrystallised.

Carbon and Hydrogen.*

0·4746 grm. gave 0·9915 CO_2 = 0·2704C = 56·9 per cent.
0·4746 „ „ 0·2117 H_2O = 0·0235H = 4·9 „

Phosphorus.†

0·6777 required 16·1 cc. uranium solution = 0·0368 P = 5·2 per cent.

Bromine.‡

0·1685 required 6·0 cc. silver solution = 0·048 Br = 28·4 per cent.
0·2128 „ 7·55 cc. „ „ = 0·060 Br = 28·3 „
0·3498 „ 12·37 cc. „ „ = 0·099 Br = 28·3 „

These numbers agree closely with the rather curious formula,

$$4\{(C_7H_7)_3POBr_2\},(C_7H_7)_3PO, \text{ or } 5\{(C_7H_7)_3PO\}, 4Br_2,$$

but with no other that appeared probable.

	Obtained.			Calculated.
	I.	II.	III.	
Carbon,	56·9	—	—	56·3
Hydrogen,	4·9	—	—	4·7
Phosphorus,	5·2	—	—	6·9
Bromine,	28·4	28·3	28·3	28·5

The bromine compound when treated with acetic acid loses bromine. It cannot, therefore, be readily recrystallised. Heated by itself it fuses, but at no definite temperature, to a deep yellow liquid. Hydrobromic acid is then given off, and later bromide of benzyl (?) distills. Heated with alcohol it dissolves, and the solution (at first yellow) gradually becomes colourless, and the odour of bromide of benzyl is apparent; but a considerable quantity of bromine may be precipitated by nitrate of silver from the alcoholic solution. When boiled with water it decomposes, and bromine is evolved.

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* By combustion with oxide of copper and chromate of lead.

† Fused in a silver dish with caustic potash and nitrate of potash, and subsequently titrated with uranium solution.

‡ Fused in a silver dish with caustic potash, and subsequently titrated by VOLHARDT's method.

Sulphuretted Compound.—When the phosphine oxide is fused with sulphur a reaction occurs, which apparently varies with the temperature and with the quantity of sulphur employed. If much sulphur is taken and the mixture heated to a high temperature, sulphuretted hydrogen is evolved, the mass becomes dark coloured, and resinous products are formed.

But if the proportion of sulphur is low ($P(C_7H_7)_3O : S_2$) and the temperature is kept at the melting point of the oxide or rather higher (240°), the sulphur dissolves, no gas is evolved, and the product dissolves completely in a large quantity of boiling alcohol. The solution on cooling deposits beautiful silky needles of a light buff colour, which do not readily change in appearance (nor alter in their melting point) by recrystallisation. That the new substance contains sulphur is shown by burning it on platinum foil, when a strong odour of sulphurous anhydride is at once observed.

The substance fuses at 211°–212° (uncorrected). It is insoluble in water, and sparingly soluble in alcohol. The only determinations made were of the carbon and hydrogen which it contains.

0·2103 gave 0·597 CO_2 = 0·16254 C = 77·3 per cent.
0·2103 „ 0·132 H_2O = 0·01466 H = 6·9 „

These numbers do not agree with any simple addition product. The only probable formula which agrees with the numbers obtained is,

$$4\{(C_7H_7)_3PO\}, (C_7H_7)_3POS = 5\{(C_7H_7)_3PO\}, S.$$

Thus—

	Obtained.	Calculated.
Carbon, ...	77·3	77·3
Hydrogen, ...	6·9	6·4

Examination of Residue, soluble in Chloroform and Alcohol only.

This portion of the residue was contained in the dark brown mother liquors of the crystalline substance, which the preceding experiments have shown was oxide of tribenzyl-phosphine.

On evaporating off the alcohol a dark brown syrupy mass remained, which solidified on cooling to a resin. This contained some crystalline matter, which we could not succeed in separating. We have subjected the resin to many experiments with the view of obtaining definite products, only, however, with partial success.

In one of our earlier experiments we subjected it to the action of heat. 55 grms. were heated in a distilling flask. The thermometer rose rapidly to 380°, and a small quantity of a solid substance distilled. The temperature then fell suddenly, and a liquid distillate was obtained. After some time the temperature again rose above the boiling point of mercury, and the residue began to char. The products of this distillation were collected together and redistilled. They began to boil a little above 100° C. The distillate was divided into two fractions, viz., from 100°–200° C., and from 200°–320° C.

The first of these was liquid, and on redistillation passed almost entirely between 110°–114° C. (chiefly at 112° C.), and had all the properties of toluol. The second was solid, and contained a *large quantity of free phosphorus.* As its fractional distillation did not give satisfactory results it was dissolved in boiling alcohol. Free phosphorus in some quantity remained undissolved, and on filtering and cooling the solution, colourless crystals separated. They were collected and recrystallised until their melting point was constant, viz., 118° C.

This is the melting point given by LAURENT for stilbene, and the crystalline habit which is so characteristic was exactly the same as that of the substance under examination. On combustion we obtained numbers agreeing fairly well with those calculated for that hydrocarbon.

0·3135 gave 1·0815 carbonic anhydride = 0·29495 carbon = 94·1 per cent.
0·3135 „ 0·1965 water = 0·02183 hydrogen = 6·9 „

	Obtained.	Calculated.
Carbon, . . .	94·1 . . .	93·3
Hydrogen, . . .	6·9 . . .	6·6

The mother liquors from which it had been separated were concentrated, and yielded a batch of colourless crystals, which were not examined. The mother liquors from them were considerably concentrated, and yielded another crop of colourless crystals, which, after repeated recrystallisation, ceased to alter in melting point. This was 51° C, which is that of dibenzyl. We have not analysed the substance, as we considered its identity with dibenzyl proved by its melting point and characteristic odour.

We had thus proved that the resin split up on heating into free phosphorus, stilbene, dibenzyl, and toluol—a result which might occur supposing it to have consisted of tribenzyl-phosphine. The equation,

$$2(C_7H_7)_3P = 2P + \overbrace{C_{14}H_{12}}^{\text{Stilbene.}} + \overbrace{C_{14}H_{14}}^{\text{Dibenzyl.}} + \overbrace{2C_7H_8}^{\text{Toluol.}}.$$

shows this.

This supposition is strengthened by the fact that sulphide of benzyl yields stilbene when heated; and one of us has shown that organic compounds of phosphorus and sulphur often behave in a similar manner.

Moreover, subsequent experiments showed that chloride of tetrabenzyl-phosphonium is decomposed by heat into hydrochloric acid, and the same products as we obtained on heating the resin. We also heated the resin with chloride of benzyl in a sealed tube for some time at 180°–190°C. Nothing particular appeared to have occurred, the contents of the tube consisting of a brown viscous mass. But on boiling this with water, and cooling the solution, chloride of tetrabenzyl-phosphonium crystallised out, and was proved to be pure by a determination of chlorine.

0·656 required 13·5 cc. decinormal $AgNO_3$ = 7·3 per cent. Cl.
$(C_7H_7)_4PCl,2H_2O$ requires . . . 7·6 " "

This experiment would have definitely proved the resin to consist of tribenzyl-phosphine, had the phosphonium chloride been produced in large quantity; but such was not the case, for about 20 grms. of resin only gave about 2 grms. of the chloride; still it shows that the resin contained the phosphine.

As Hofmann (*loc. cit.*) has found that dibenzyl-phosphine does not combine with acids, we could scarcely expect to obtain salts of the tertiary-phosphine. We, however, heated the resin with fuming hydrochloric acid, but, as we expected, obtained no salt. We have also tried to obtain the well characterised oxide of tribenzyl-phosphine, by treating the resin with various oxidising agents, but without success. Nor could we obtain any definite compounds on treating the resin with bromine, chloride of platinum, or iodide of zinc. We therefore abandoned its further investigation.

Attempts to prepare Tribenzyl-Phosphine.

So far as we are aware, no method has been discovered for converting the oxide of a tertiary-phosphine or a salt of a compound phosphonium into a tertiary-phosphine itself.

Considering the remarkable stability of the former class of bodies, and the tenacity with which the oxygen adheres to the phosphorus, we scarcely expected to effect the reduction of the oxide of tribenzyl-phosphine. We, however, subjected it to the action of potassium, of sodium, and of zinc dust, but, as we expected, it either remained unchanged, or suffered complete decomposition.

We hoped, however, to meet with better success in attempting to obtain tribenzyl-phosphine from chloride of tetrabenzyl-phosphonium. Two methods suggested themselves to us, the first being to act on the chloride with sodium, which we anticipated would give chloride of sodium, dibenzyl, and the phosphine,

$$2[(C_7H_7)_4PCl]+Na_2=2NaCl+C_{14}H_{14}+2(C_7H_7)_3P.$$

A preliminary experiment showed that when chloride of tetrabenzyl-phosphonium is boiled for some hours with xylol and sodium, chloride of sodium is produced.

We therefore made a carefully conducted experiment as follows:—

24 grms. of the pure chloride were carefully dried and introduced into a

flask connected with a reversed condenser. 100 grms. of redistilled xylol (boiling point 135°–137° C.) were then added together with 1·3 grm. of sodium. A current of hydrogen was then passed through the apparatus, and the mixture kept gently boiling. When most of the sodium had been acted on (which required some days' digestion), the xylol was poured off and filtered. On cooling, it deposited an abundance of crystalline matter. This was collected on a cloth filter, well squeezed to free it from adhering xylol, and dissolved in boiling alcohol. On cooling, crystals separated having the appearance of oxide of tribenzyl-phosphine, and which were proved to consist of that body. The xylol from which this oxide had separated was distilled to dryness, and the residue taken up with boiling alcohol. The solution on cooling deposited beautiful silky needles, which were recrystallised twice from alcohol. In spite of their very different appearance from other specimens of oxide of tribenzyl-phosphine, a most careful examination showed that they consisted of that body (see p. 205). We are completely unable to account for the difference in appearance of the two quantities of the oxide obtained in this experiment. No one would imagine that they were the same body. We could not obtain any other definite products from this experiment.

Now the production of the oxide may be accounted for in two ways—(1) the chloride of tetrabenzyl phosphonium was not perfectly dry, and caustic soda was formed, which then acted upon it (as we have already shown), to give toluol, common salt, and the oxide; (2) tribenzyl-phosphine was formed, and absorbed oxygen from the air during the subsequent processes to which the product of the reaction was submitted. We have repeated the experiment several times, using every precaution to prevent water or oxygen from coming in contact with the mixture of sodium, xylol, and the phosphonium chloride, but always with the same result—viz., production of large quantities of the oxide. At present we do not know which of the two explanations we have given of its production is the correct one.

We may mention that finely divided silver acts on the chloride of tetrabenzyl-phosphonium when the two are heated together; the action, however, only occurs to a slight extent, and we were not successful in obtaining any definite product.

The other method that occurred to us for obtaining tribenzyl-phosphine from the chloride of tetrabenzyl-phosphonium was to treat the latter with phosphide of sodium, which we hoped would react so as to give tribenzyl phosphine and chloride of sodium,

$$3(C_7H_7)_4PCl + Na_3P = 3NaCl + 4(C_7H_7)_3P.$$

The following experiment was made:—3 grms. of phosphide of sodium and a little xylol were heated in a sealed tube, with 13 grms. of chloride of tetrabenzyl-phosphonium. After three days' heating at a temperature of 180°–190° most of the phosphide was acted on. The tube was then opened and repeatedly extracted with dry chloroform. The extract was distilled to dryness, and the residue treated with ether, which dissolved most of it, but left a small quantity of the oxide of tribenzyl-phosphine. The ethereal extract was evaporated to dryness, and left a light-coloured soft resin, which partly crystallised. A phosphorus determination showed that this contained the quantity of that element calculated for tribenzyl phosphine,

0·651 required* 29·1 cc. uranium solution =	9·9 per cent. P
$(C_7H_7)_3P$ requires	10·2 „

The quantity, however, of the resin at our disposal was so small that we could not make a thorough investigation of it. But we are inclined to the belief that both it and the resin obtained as a bye product in the preparation of the chloride of tetrabenzyl-phosphonium consisted mainly of tribenzyl-phosphine (see p. 209).

Action of Heat on the Salts of Tetrabenzyl-Phosphonium.

During the experiments we have described, we obtained on heating several of the salts of tetrabenzyl-phosphonium, results which invited a closer investigation. Partly on this account, and partly from the interesting results which Drs Crum Brown and Blaikie† have obtained by the action of heat on the salts of trimethyl-sulphine, we determined to study the behaviour of one or two of the compounds of tetrabenzyl-phosphonium when heated.

Action of Heat on Chloride of Tetrabenzyl-Phosphonium.—We hoped that the salt would dissociate when submitted to the action of heat into chloride of benzyl and tribenzyl-phosphine.

A considerable quantity of the chloride previously dried and fused was placed in a small distilling flask and heated in an air bath. Nothing particular occurred until the temperature had risen to about 300° C., when the fused salt began to grow brown, and a colourless liquid distilled. When a considerable quantity of this had passed over, hydrochloric acid was evolved, and later the distillate was yellow, and contained an abundance of free phosphorus. The heating was continued until nothing further distilled. There remained a considerable residue, consisting chiefly of charcoal.

The whole of the distillate was fractionated. Hydrochloric acid was evolved in abundance; the thermometer then rose to 109°, and by far the larger quantity of the product passed over between that temperature and 115°. This fraction on redistillation boiled constantly at 110°–113°, and had the odour of toluol. It was not further examined, and was considered to be that substance.

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* After fusion with a mixture of nitrate of potash and caustic potash.

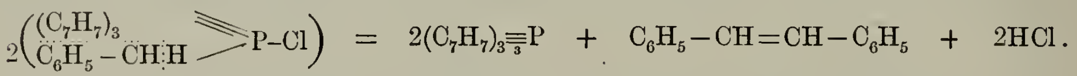
† Proceedings Roy. Soc., Edin.

The higher boiling residue passed between 280°–300°, and solidified in the condenser. It was dissolved in alcohol, and recrystallised several times. The recrystallised substance had the characteristic form and melting point (118° C.) of stilbene.

In the mother liquors there remained a solid of lower melting point, and having the odour of dibenzyl; but its quantity was too small to enable us to identify it absolutely. We think that there can be but little doubt that it consisted of that body.

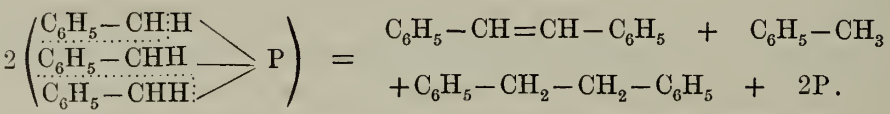
No chloride of benzyl could be found, although the liquid product certainly smelt of it. Its quantity was therefore insignificant.

This experiment shows that the phosphonium chloride is not dissociated by heat, but splits up in a somewhat complicated manner. Very possibly the first action of heat is to give stilbene, hydrochloric acid, and tribenzyl-phosphine.



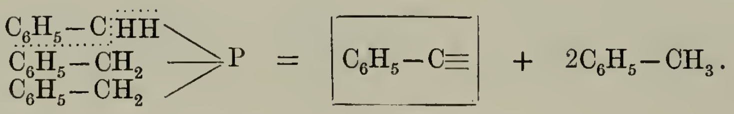
$$2\left(\begin{matrix}(C_7H_7)_3 \\ C_6H_5-CH\vdots H\end{matrix} > P-Cl\right) = 2(C_7H_7)_3\equiv P + C_6H_5-CH=CH-C_6H_5 + 2HCl.$$

The phosphine splitting up later into toluol, stilbene, and dibenzyl.



$$2\left(\begin{matrix}C_6H_5-CH\vdots H \\ C_6H_5-CHH \\ C_6H_5-CHH\vdots\end{matrix} > P\right) = \begin{matrix}C_6H_5-CH=CH-C_6H_5 + C_6H_5-CH_3 \\ +C_6H_5-CH_2-CH_2-C_6H_5 + 2P.\end{matrix}$$

It is however quite possible, considering the large quantity of toluol which is formed in proportion to the stilbene, and also considering the considerable amount of charred matter which remains, that the tribenzyl-phosphine splits up into toluol, and the residue $\boxed{C_6H_5-C,}$ only, the latter becoming carbonised.



$$\begin{matrix}C_6H_5-C\vdots HH \\ C_6H_5-CH_2 \\ C_6H_5-CH_2\end{matrix} > P = \boxed{C_6H_5-C\equiv} + 2C_6H_5-CH_3.$$

Action of Heat on the Acid Sulphate.—8 grms. of the acid sulphate were carefully dried, and heated in a small retort connected with a wide condensing tube. The salt fused, then effervesced violently, and a colourless liquid distilled which solidified in the condenser. Sulphurous anhydride was given off at the end of the operation, and a slight residue of syrupy consistency and of a dark brown colour remained in the retort. The crystalline product was washed with alcohol until quite colourless, and then recrystallised several times from the same liquid, in which it was not very soluble. It crystallised in very thin needles of considerable length. These melted at 205°–206° C. It did not precipitate chloride of barium, but contained sulphur, as it gave the sulphuric acid reaction after it had been oxidised with a mixture of nitric acid and chlorate of potash; and molybdate of ammonia showed that phosphoric acid was also present in the substance thus oxidised. No chloroplatinate could be obtained, but on mixing alcoholic solutions of the substance and of chloride of platinum a black precipitate was produced, consisting either of reduced platinum or of its sulphide.

The substance was burnt with chromate of lead and oxide of copper, and gave numbers agreeing with those required for the sulphide of tribenzyl-phosphine.

0·3567 gave 1·0097 CO_2 = 0·27587 C = 74·4 per cent.
0·3567 „ 0·2114 H_2O = 0·02348 H = 6·6 „

	Obtained.	Calculated for $(C_7H_7)_3$ PS.
Carbon,	74·4	75·0
Hydrogen,	6·6	6·2

The compound was not further examined.

Action of Heat on the Hydrate.—From the experiments described at p. 196 on the action of caustic baryta on the acid sulphate, we were led to think that the latter would easily split up into toluol and oxide of tribenzyl-phosphine, and we therefore determined to ascertain if this supposition were correct.

A quantity of the hydrate crystallised from alcohol was placed in a distilling flask and heated in an oil bath. The alcohol of crystallisation first passed off, and at 250° C. the compound melted, and immediately a colourless liquid began to distil, which ceased to pass over at 260° C. The liquid was redistilled and boiled constantly at 111°–112° C. It consisted therefore of toluol.

The residue in the distilling flask crystallised on cooling, was insoluble in water (whereas the hydrate readily dissolves), but was soluble in alcohol, and crystallised in the characteristic form of the oxide. Its melting point was found to be 212° C., and it gave the characteristic brominated compound and chloroplatinate of the oxide.

The decomposition which the hydrate suffers when heated may therefore be expressed by the equation—

$$(C_7H_7)_4P(OH) = (C_7H_7)_3PO + C_7H_8 .$$

Action of Heat on Oxide of Tribenzyl-Phosphine.—The oxide partly volatilises unchanged when it is heated, and partly decomposes into toluol, free phosphorus, charred matters, and other substances obtained in too small quantity to be investigated.

IX.—*On the Geology of the Færöe Islands.* By JAMES GEIKIE, LL.D., F.R.S. L. & E. (Plates XIII., XIV., XV., XVI.)

(Read March 15, 1880.)

CONTENTS.

II. PHYSICAL FEATURES OF THE ISLANDS.

III. GEOLOGICAL STRUCTURE OF THE ISLANDS.

IV. THICKNESS OF THE STRATA: CONDITIONS UNDER WHICH THEY WERE AMASSED.

V. GLACIAL PHENOMENA OF THE ISLANDS.

VI. ORIGIN OF THE VALLEYS AND FIORDS: SUBAERIAL AND GLACIAL EROSION.

I. INTRODUCTION.

In this paper I give an account of observations made during a visit in 1879 to the Færöe Islands in company with my friend Mr AMUND HELLAND of Christiania. The principal object of our journey was to examine the glacial phenomena of the islands, but we studied so far as we could the various rock-masses of which the group is composed, and constructed a geological sketch-map to show the line of outcrop of coal, the disposition of the strata, the direction of dykes, and the trend of the glaciation. I have only to add, that all the observations recorded in the following pages were made in concert with my friend, and I am glad to say that we were quite at one in our general conclusions.*

The earliest references to the geology of the Færöe Islands are met with in a general description of the group by LUCAS JACOBSON DEBES† (1673), but, as might have been expected, they are of no scientific value. He makes brief reference to the occurrence of coal in Suderöe, stating that it is found in only one place "to which one can with difficulty come;" from which it is probable that he had in view some of the outcrops in the precipitous sea-cliffs.

In 1800 appeared a general account of the islands by JORGEN LANDT, a resident Danish clergyman, in which the physical features of the islands are well described.‡ The author was no geologist, but he notes some of the more characteristic aspects of the rocks, and was clearly of opinion that some of these at least had been in a state of fusion. He also gives some account of the many large angular perched blocks which are so plentifully sprinkled over the islands. It was LANDT's description of the igneous rocks which induced Sir GEORGE MACKENZIE to visit the islands. Sir GEORGE was accompanied by Mr THOMAS ALLAN, and each subsequently gave an account of his own observations; the papers appearing in an early volume of the Transactions of this Society.§

Sir GEORGE MACKENZIE limits his remarks on the "trap" of the Færöes to such characters as seemed to him to demonstrate the igneous origin of that class of rocks. He distinguishes between the "tuff" or "tuffa" and the "trap;" shows how they are interbedded; and gives the general inclination of

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* Mr HELLAND's paper has been published since the present memoir was read. See "Om Færoernes Geologi," in the Danish Geografisk Tidskrift, 1881.

† Færoæ et Færoa Reserata, &c., Kiobenhafn, 1673.

‡ Forsog til en Beskrivelse over Færoerne, Kiobenhavn, 1800. An English translation of LANDT's work appeared in 1810.

§ "An Account of some Geological Facts observed in the Faröe Islands" (MACKENZIE), Trans. Roy. Soc. Edin., vol. vii. p. 213; and "An Account of the Mineralogy of the Faröe Islands" (ALLAN), *op. cit.* p. 229.

the strata as towards south-east at an angle of about 4° or 5°. He was of opinion that the bedded traps had been ejected from submarine volcanoes.

Mr ALLAN's paper is chiefly mineralogical, but he also gives some geological details. Both he and MACKENZIE noticed the dykes that here and there intersect the strata, but only Mr ALLAN describes the irregular masses of "greenstone" which are unconformable to the regular bedded trappean rocks among which they occur. He also insists upon the igneous formation of all the traps, but does not commit himself to MACKENZIE's submarine-volcano theory. The circumstances under which the traps were formed seem to him as inexplicable as ever, but he evidently leans to the view of their subaerial origin. He describes the smoothed appearance of the sides of the mountains, and particularly refers to a place at Eide in Österöe where "the rock is scooped and scratched in a very wonderful degree, not only on the horizontal surface, but also on a vertical one of 30 to 40 feet high, which had been opposed to the current, and presented the same scooped and polished appearance with the rest of the rock, both above and below." These phenomena he recognises to be the same as the smoothed and dressed rocks near Edinburgh.

MACKENZIE's and ALLAN's papers were supplemented by Mr W. C. TREVELYAN, who, in a letter to Dr BREWSTER,* gives descriptions of the geology of Myggenæs and Suderöe—two of the islands which MACKENZIE and ALLAN were unable to visit. His short description of the coal-beds of Suderöe is correct so far as it goes, but, curiously enough, he says the beds dip south-east, while the section given by him shows them dipping to the north. The letter is accompanied by some excellent sketch-sections, exhibiting the appearances presented by certain irregular masses of basalt.

A few years later Dr FORCHHAMMER, who does not appear to have known of MACKENZIE's and ALLAN's papers, visited the islands at the instance of the Danish Government, and afterwards published a very able description of their geognosy,† accompanied by an admirable geological map. His observations and views, however, I shall refer to more particularly in the sequel. He makes no reference to the phenomena of smoothed rocks which so impressed ALLAN.

The next geological notice of the Færöe Islands occurs in a series of articles by ROBERT CHAMBERS, entitled "Tracings in Iceland and the Færöe Islands."‡ He spent only some two or three days among the group, but recognised marks of glaciation at various places, as I shall afterwards point out.

Since the date of his visit, the islands have frequently been referred to in books of travel, but none of these has added anything to what was already

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* "On the Mineralogy of the Faröe Islands" Trans. Roy. Soc. Edin., vol. ix. p. 461.

† "Om Færöernes geognostiske Beskaffenhed," Det kongl. danske Vidensk. Selsk. Skrifter, 1824. See also KARSTEN's Archiv. für Mineralogie; vol. ii. p. 197.

‡ Chambers's Edinburgh Journal, 1855.

known. In 1873, however, appeared an excellent paper by Professor JOHNSTRUP, in which he gives a detailed account of the coal-beds of Suderöe.[*] This, I believe, is the most recent addition to our knowledge of the geology of the Færöe Islands. It is referred to in my description of Suderöe.[†]

II. PHYSICAL FEATURES OF THE ISLANDS.

1. *Extent, Form, and Trend of the Islands and Fiords.*—The Færöe Islands[‡] are upwards of twenty in number, and nearly all are inhabited. They extend over an area of about seventy miles in length from north to south, and nearly fifty miles in breadth from west to east. The two largest islands are Stromöe and Österöe, which closely adjoin and contain together upwards of 250 square miles, an area which is nearly equal to that of all the other members of the group. The extent of land in this little archipelago may therefore be roughly estimated at about 500 square miles. Nearly all the islands have an elongated form, and are drawn out in a N.N.W. and S.S.E. direction. This is the direction also of the more or less narrow sounds or open fiords that separate the islands in the northern part of the archipelago; and the wider belts of water in the south, such as Suderöe Fiord, Skuöe Fiord, and Skaapen Fiord, have the same general trend. A glance at the accompanying map (Plate XVI.) will show that many of the closed fiords which penetrate the islands extend in a similar direction throughout the whole or a large part of their course. There are no great depths in the immediate vicinity of the islands. None of the *closed* fiords is so deep as many of the Scottish and Norwegian sea-lochs, the deepest soundings indicated upon the charts never exceeding 65 fathoms. The soundings, however, are few in number, and we were told by the fishermen of considerably greater depths in some places than are shown on the chart. Thus we were assured that Skaalefiord is 40 or 50 fathoms deep. Immediately outside of the islands the sea-bottom appears to slope away somewhat gradually in all directions until a depth of upwards of 100 fathoms is reached at a distance of 15 or 20 miles, more or less, from the nearest coast-line.

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[*] "Om Kullagene paa Færöerne samt Analyser af de i Danmark og de nordiske Bilande forekommende Kul," K. D. Vidsk. Selsk. Oversigt, 1873, p. 147.

[†] Since the above was written, I have met with another paper referring to Suderöe, by A. H. STOKES, H.M. Inspector of Mines, in "Trans. Chesterfield and Derbyshire Institute of Mining, Civil, and Mechanical Engineers," vol. ii. p. 320. The author seems to have examined only the mines and outcrops in the Trangjisvaag district, and he gives the average thickness of the coal seen by him, together with the heights above the sea-level of the various points at which the seam crops. He gives also analyses of the coal. He upholds the submarine origin of the volcanic rocks, and thinks the coal may be the remains of driftwood floated from America.

[‡] For the spelling of place-names, I have followed the Danish Chart, although the orthography differs from that used in other Danish works. Some of the places I refer to are not given on the chart, and for the spelling of these I am indebted to my colleague Mr HELLAND. A number of the place-names in Suderöe, I have taken from the map accompanying Professor JOHNSTRUP's paper.

2. *Configuration and Height of the Land.*—The islands are for the most part high and steep, many of them being mere narrow mountain-ridges that sink abruptly on one or both sides into the sea. The larger ones, such as Stromöe, Österöe, and Suderöe, show more diversity of surface, but they possess very little level land. All the islands have a mountainous character—the hills, owing to the similarity of their geological structure, exhibiting little variety of feature. These high grounds form as a rule straggling, irregular, flat-topped masses, and sharper ridges which are notched or broken here and there into a series of more or less isolated peaks and truncated pyramids. Sometimes the mountains rise in gentle acclivities, but more generally they show steep and abrupt slopes, which in several instances are found to have inclinations of 25° to 27°, and even 30°. In many places they are still steeper, their upper portions especially becoming quite precipitous. They everywhere exhibit the well-known terraced character which is so common a feature of trappean masses. Precipices and long cliffs or walls of bare rock rise one above another, like the tiers of some cyclopean masonry, and are separated by usually short intervening slopes, which are sparsely clothed with grass and moss, and sprinkled with tumbled blocks and débris. The greatest elevations are reached in the two largest islands, Österöe and Stromöe, Slattaretind in the former attaining an elevation of 2852 feet, and Skiellinge Field in the latter of 2502 feet.* Many other hills in these two islands are over 2000 feet in height, and some approach within 200 or 300 feet of the dominating point. Indeed, the average elevation of Österöe and Stromöe can hardly be less, and is probably more than 1000 feet. The other islands are equally steep and mountainous, but in none do the hills seem to attain a greater elevation than 2000 feet. Thus Stoiatind in Waagöe is probably not over 2000 feet in height; Kalsöe in the north-east is 1817 English feet, Kunöe 2000 feet, and Naalsöe opposite Thorshavn 1276 feet. In Suderöe some of the hills are more than 1700 feet high—one of them, Kvannafield, we found to be 539 mètres = 1786 feet. The mean elevation of all the islands (exclusive of Stromöe and Österöe) must exceed 800 feet, and is probably not less than 900 feet.

The coasts are usually precipitous, many of the islands having only a very few places where a landing can be effected. Store Dimon, for example, possesses but one landing-place, and even that is accessible only in calm weather. The west coasts that face the open sea are as a rule the most precipitous—the

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* The height of Slattaretind is given in some Danish geographies which I consulted in the islands, as 2710 feet (Danish) = 2789 feet English; Forchhammer makes it 2816 French feet; and another authority gives it at 882 metres = 2894 English feet. The height adopted in the text is that obtained by Mackenzie and Allan. There is a similar uncertainty as to the exact height of Skiellinge Field; some Danish geographies and gazetteers giving it as 2350 feet = 2418 English feet. The height mentioned above is taken from the Danish Chart, which in Danish feet is 2431 feet or 2502 English feet. This corresponds with the height of 763 mètres given by some writers.

finest mural cliffs occurring in Stromöe, between Westmannshavn Fiord and Stakken. These cliffs range in height between 900 and 2000 feet, and at Mÿling the nearly vertical walls of rock are even 2277 feet high. Österöe and the north-east islands show sea-cliffs which exceed 1000 feet in height, and similar lofty cliffs occur in Waagöe, Sandöe, Suderöe, and all the other islets.

3. *Character of Valleys.*—The best defined valleys are often comparatively broad in proportion to their length. Followed upwards from the head of a fiord, they rise sometimes with a gentle slope until in the distance of two or three miles they suddenly terminate in a broad amphitheatre-like cirque. In many cases, however, they ascend to the water-parting in successive broad steps or terraces (Plate XIII. figs. 2 and 3),—each terrace being cirque-shaped, and framed in by a wall of rock, the upper surface of which stretches back to form the next cirque-like terrace, and so on in succession until the series abruptly terminates at the base, it may be, of some precipitous mountain. Occasionally the *col* between two valleys is so low and level that it is with some difficulty that the actual water-parting can be fixed. Such is the case with Kolfaredal between Höi and Leinum-mjavatn in Stromöe, where a well-defined hollow passes right through the hills, leading from the head of Kollefiord to the sea at Leinum. The height of the flattened *col* in this hollow is only 259 feet, yet it is overlooked by hills that exceed 2000 feet in elevation. A similar long hollow crosses the same island between Saxen and Qvalvig. In Österöe, likewise, a long low-level pass serves to connect the head of Fundingsfiord with that of Skaalefiord. In Sandöe and Suderöe, similar appearances may be noted. Besides these more or less well-defined valleys, the mountains frequently show isolated amphitheatric cirques. Sometimes these cirques open directly upon the sea, and may possibly represent the upper terminations of valleys, the lower portions of which have been removed by marine erosion. As examples, I may refer to the wide cirque (half mile in breadth and same in length) in Österöe, which is cut across by the sea-cliffs between Andafiord and Fuglefiord, and to the narrower but equally well-marked cirque-valley (one mile long by about $\frac{1}{5}$th mile broad) which is abruptly truncated by the steep cliffs of Tiödnenaes in Suderöe. Other isolated cirques, much smaller than these, but yet sometimes of considerable size, may often be noted on the mountain-slopes at heights of several hundred feet or even yards above the bottoms of the valleys into which they discharge their drainage. Good examples occur amongst the high grounds above Saxen, where the small upper cirques must be 1200 or 1400 feet above the broad valley into which their waters tumble down a series of cliffs and precipices.

4. *Lakes and Streams.*—There are numerous lakes in the islands, but they are mostly of small size. The two largest occur in Waagöe—one of them being

about 4 miles long, by half a mile in breadth. These, however, we did not visit. None of those we saw exceeded half a square mile in extent, and most were much smaller. At Sand in Sandöe, there is a narrow lake-like expanse of water about 1½ mile in length, which appears to be almost on the level of the sea, from which it is separated by low flats and sand dunes. But nearly all the lakes occupy rock-basins.

Streams are very abundant, but none is of much importance. Owing to the excessive rainfall,* however, they must occasionally discharge very considerable bodies of water, and as we shall see in the sequel they are potent agents of geological change.

III. Geological Structure of the Islands.

1. *General Dip of the Strata.*—The geological structure of the islands is very simple. The principal rocks are bedded basalts, with intercalated partings and layers of tuff, and in Myggenæs and Suderöe of clay, shale, and coal. The prevalent dip of the strata in the northern islands is south-easterly, at a low angle, as was first pointed out by Mackenzie. In the north part of Österöe, however, the dip is towards north-east, according to Forchhammer, whose observations we were able to confirm, and the same geologist states that the dip in Myggenæs is easterly. In Suderöe, again, the strata incline uniformly to N.N.E. Nowhere is there any trace of a westerly inclination, and the steepest dips are found in Myggenæs, Waagöe, and Suderöe. In the former, Trevelyan says it is near 45°, while Forchhammer, who is probably nearest the truth, gives it as 10°. Judging from the view we had of the cliffs of Waagöe, the dip appeared to be 10° or 12° in the west of that island, but it decreased towards the east. In Suderöe the dip varies from 2° or 3° to 15° or thereabout. The south-easterly dip of the strata in the northern islands is certainly less than Mackenzie makes it, and cannot be greater than 2° or 3° on the average. Forchhammer is unquestionably correct in his view, that the rocks of Suderöe and Myggenæs are the oldest of the series, and it will be most convenient therefore to treat of these rocks first.

2. *Contemporaneous or Bedded Basalt-rocks of Suderöe.*—The basalt-rocks of Suderöe do not show much variety. The most common rock is a dark blue, almost black, and sometimes brown, fine-grained crypto-crystalline anamesite, which is usually scoriaceous and slaggy above and below, and not infrequently

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* On an average of several years, there are only forty days in the year on which it does not rain. The annual fall is 78 inches. It is a common belief out of Færöe that the islands are shrouded in fogs during the greater part of the year. This, it seems, is a mistake. We were told by Danes who had resided for some years in the islands, that they had not experienced more mist and fog than in Denmark; and the meteorological records which are kept show that fogs occur on only thirty-nine days in the year. They are worst in the beginning of summer. The best time to visit the islands is from about the end of July to the end of August or middle of September.

contains irregular layers of amygdaloidal cavities, ranged along the central or middle zone of the bed. It is composed of plagioclase, augite, magnetite, and olivine, the last being often more or less altered into serpentine. Such is the average character of the rocks which immediately overlie the coal-bearing strata, and anamesites of similar appearance predominate in the island. They generally decompose with a rusty brown crust, and are frequently much broken up, weathering into irregular spheroids. On slightly weathered faces, the rock has often a dull greenish colour and somewhat earthy appearance. The most distinctly amygdaloidal portions of a rock, are usually of a paler shade, and more close-grained texture than the darker less porous areas by which they are surrounded, and, viewed from a little distance, the various parts of one and the same flow resemble a series of separate beds. This peculiarity, which is sufficiently striking, was noted by FORCHHAMMER, who remarks that "the amygdaloidal rock alternates with the basalt, but these alternations shade into each other, and are not at all well-defined, but are very distinctly seen when the rock is looked at from a distance of some hundred feet. Then the different layers are seen with their different colours, and one finds that the junction line is parallel to the plane which the principal mass of the dolerite forms with the claystone (*i.e.*, tuff), and therefore parallel to the stratification."

The dark anamesite frequently becomes more coarsely crystalline, so as to assume the character of a typical dolerite, which is often rendered more or less porphyritic with plagioclase. This porphyritic character, however, is certainly much less common and less distinctly marked in the basalt-rocks of Suderöe than in those of the northern islands. FORCHHAMMER, indeed, maintains that the traps above the coals are markedly porphyritic with "glassy felspar," while those underlying the coals are not porphyritic. Accordingly, he has in his map coloured all the northern islands and certain parts of Suderöe and Myggenæs as "dolerite-porphyry"—the remaining portions of Myggenæs and the southern island, which are below the horizon of the coal, being distinguished as "dolerite without glassy felspar." We could not, however, trace any difference in Suderöe between the basalt-rocks below and those immediately above the coals. At the same time, well-marked porphyritic and coarsely crystalline dolerites do occur in Suderöe at some distance above the coal. In the mountain called Nakin, for example, there is a highly crystalline and porphyritic dolerite quite like many which occur in Stromöe and Osteröe. No hard and fast line, however, like that suggested by FORCHHAMMER, can be drawn between the beds above and those below the coal. The most that can be said is simply this, that while highly porphyritic dolerites prevail above the horizon of the coal, and therefore throughout the northern and smaller part of Suderöe, and over all the northern islands, dark non-porphyritic and fine-grained rocks are the most common varieties met with below that horizon, so that anamesites predominate in Suderöe, and dolerites in the northern islands.

The anamesites of Suderöe are, upon the whole, less strikingly amygdaloidal than the basalt-rocks of the northern islands, and the cavities seldom or never attain the large size that is frequently to be seen in the rocks of Stromöe and Österöe. They are generally, but by no means always, drawn out in the plane of the bedding, and have thus often a flattened appearance; frequently, however, they are almost circular, but more commonly still, perhaps, their shape is ragged and irregular. I have mentioned the fact that amygdaloidal areas often traverse the face of the rock in the plane of bedding, so as to form more or less well-defined lines. They also occasionally show a kind of curled, coiled, or involved arrangement, as if the rock had been rolled over upon itself while in a plastic or viscous state. Some of the largest amygdaloidal cavities we saw were in the rocks of Nakin and on the sea-coast at Waag, where they contain very beautiful zeolites. I noticed here stilbite, chabasite, quartz, and calcedony. Heulandite is said also to occur in amygdaloidal cavities in Suderöe, and chlorophæite is found at Qvalböe. Probably other minerals are to be met with, for I made no special search. According to Trevelyan, native copper is very frequent, though not abundant. Near Famarasund he found it in thin plates in a bed of "claystone;" some of it, he says, contains gold, which is "also, but rarely, found separate." The place referred to by him is near the base of a sea-cliff which the boatmen pointed out to us as we sailed past, but we could not stop to visit it.

The upper and under surfaces of the anamesites form an interesting study. Sometimes the upper portion for several feet in thickness appears to be composed of a jumbled mass of irregular-shaped fragments of scoriaceous rock, which gradually shades, as it were, into the denser, non-porous crystalline mass of which it forms the crust. In other cases, however, the slaggy part appeared somewhat distinctly marked off from the denser rock on which it seemed to rest. Here and there the beds show a wrinkled and crumpled surface like that assumed by viscous bodies in motion. Some anamesites, again, appeared to have little or no scoriform crust, but were only somewhat amygdaloidal and vesicular atop,—the rock then having a tendency to weather into spheroidal masses. This latter character, however, was more frequently characteristic of the lower or under surfaces of the beds. These basal portions, so far as I had opportunity in Suderöe of observing them, appeared to be less scoriaceous than the upper surfaces, and they were often much less amygdaloidal and vesicular than the central part of the same flow. Sometimes one might detect bits of red tuff and shale caught up in the under surface of an anamesite, and very often the beds showed strong red discolorations below, when they came into contact with a pavement of tuff. Now and again, too, the under part of a basalt-rock would present a highly broken and jumbled appearance—crystalline, compact, and non-amygdaloidal rock being commingled with highly vesicular and honeycombed fragments, but all welded together so as to form one solid mass.

Many of the anamesites are more or less distinctly columnar. Good examples of such are seen in the Trangjisvaag district, in the valley above Howe and along the sea-coasts. In Kvannafield these columnar rocks break up into fantastic walls and isolated peaks and tors not unlike ruined masonry. Even when true prismatic and columnar structure is wanting, the rocks are yet traversed by well-marked vertical joints, which, as will be pointed out more fully afterwards, greatly assist the denuding agents in their work of destruction.

The beds appear to vary much individually in thickness, but I think 40 to 70 feet would be a good average. Some, however, were certainly not over 30 feet thick, while others may have reached and even exceeded 100 feet. We did not trace out any one particular bed to see how far it would extend, but could quite well follow the lines of bedding along the slopes of the hills, and could thus carry the outcrop of a particular anamesite for a distance of several miles. The rocks, however, have so much in common that I doubt whether in most cases one could surely identify the same bed in different valleys, unless the outcrop itself were actually followed. The anamesite overlying the coal-beds appeared to be one and the same flow, for wherever we examined it the rock showed a very similar character—the only differences being merely such as frequently can be traced in closely adjoining portions of one and the same rock-mass. And this is equally true of the anamesite upon which the coal-bearing strata repose. The separate flows, however, thicken and thin out, and although I nowhere in Suderöe chanced to come across the terminal portion of a sheet, yet I have no doubt that those beds which did not measure more than 12 or 15 feet in thickness were merely the attenuated terminal portions of much thicker flows.

3. *Bedded Tuffs.*—The anamesites are usually separated from each other by tuff which varies in thickness from mere thin layers of a few inches up to beds 30 or 50 feet in thickness; in some places the tuffs are even thicker. These tuffs are generally fine-grained, like indurated mud, but occasionally they pass into a kind of tufaceous grit. They are generally of a bright brick-red colour, but sometimes they are grey, blue, green, and yellow. In some good sections they are seen to consist of alternate ribbons and bands of fine-grained tuff, with shattery, crumbling, fissile, shaly clays. Often, however, a bed of tuff will show no lines of bedding, and looks like an amorphous structureless mudstone. Even in such beds, however, it will often be found that the tuff splits most readily along the plane of bedding, and a close inspec-

tion will sometimes reveal several lines of coarser granules alternating with the finer-grained sediment. Under the microscope, the red tuffs are seen to be made up essentially of so-called "palagonite."

In the numerous exposures we visited I never was able to find any true lapilli. In a coarse-grained tuff that crops out on the eastern slope of Kvannafield a few small stones were detected, but none of these exceeded half-an-inch in diameter. Only in one place did we come upon what seemed to be a true agglomerate. On the shore at Qvalböe, the low cliffs, 10 to 12 feet high, are formed of an agglomeratic tuff resting upon anamesite. The matrix of comminuted gritty débris is crammed with angular and subangular stones and lapilli of all shapes and sizes, from mere grit up to blocks more than one foot in diameter. The included fragments were all of basalt-rock, and the mass showed no trace of bedding. It is just possible, therefore, that it may be only the scoriform brecciated upper surface of an anamesite.

4. *Coal and Coal-bearing Beds.*—The strata immediately associated with the coals of Suderöe may be described as dark carbonaceous shales and clays, which frequently have a tufaceous aspect. But their general appearance will be gathered from the sections given in Plates XIII. and XIV. figs. 5–9, and described in the Explanation. The coal occurs as more or less lenticular layers in beds of dark indurated clay and shale. The seams, therefore, are very inconstant, and thicken and thin out in the most irregular manner. They appear mainly along one horizon, occupying a position about midway between the top and bottom of the trappean rocks of Suderöe. This is the only horizon along which they have been worked to advantage, and it is doubtful whether they occur anywhere else in a workable condition. About 1100 feet lower down, however, another outcrop of coal occurs, but it appears to be very local. The section seen is shown in the illustration (Plate XIII. fig. 7). The whole thickness of the coal-bearing beds at this place was 10 to 15 feet. They consisted of fine-grained greenish mudstone and tufaceous shales, with some nodules of coarse ironstone. Forchhammer says that a layer of glance coal, 3 inches thick, was got here, but we saw only fragments of it lying about. This appears to be the lowest horizon at which coal has been met with.

It is in the central and northern part of the island where coal has been principally worked, and there can be no doubt that all the workings are upon one and the same horizon (see Plate XIII. figs. 1 and 4). Trevelyan knew this, and the section which accompanies his paper gives a correct generalised view of the geological structure of Suderöe.

The coal is of two kinds: one a bright lustrous coal, which does not soil the fingers, having a glassy fracture, and closely resembling in general appearance some of the glossy parrot coals of the Scottish coal-fields—the other, a dull lustreless coal, which soils the fingers, and in which one may readily detect a vegetable structure. These two kinds of coal alternate in one and the same seam (Plate XIII. figs. 5 and 6)—sometimes a bed of glance coal being streaked with laminæ of dull slaty coal, at other times a seam of slaty coal showing many thin lines of glance coal. This last, indeed, appears to be most usually the case, as the slaty coal is the commoner variety of the two. Johnstrup states that every lenticular mass of glance coal represents the flattened trunk of a tree, in which can be seen the annual rings of growth. This, I do not doubt, may be true of the thicker layers, but it does not seem to be the case with the finer streaks and threads; at all events I could see no trace in these of flattened stems. But our examination was necessarily imperfect and incomplete. It seemed to me, however, that the alternating layers of bright and dull coal spoke to the gradual accumulation in water of different kinds of vegetable matter or of different parts of the same plants, and that the coal was analogous to what is sometimes seen in our Scottish coal-fields, where thin layers of gas-coal, black-band ironstone, and common coal alternate and interosculate in one and the same seam.

The comparative composition of the two kinds of coal is shown in the following analyses, which are taken from Johnstrup's paper :—

Glance Coal.

	I.	II.
Organic,	85·3	83·1
Inorganic (Ash),	2·5	2·5
Hygroscopic Water,	12·2	14·4

Common or Slate Coal.

	Good Coal.		Bad Coal.	
	I.	II.	I.	II.
Organic,	78·0	73·4	65·0	60·6
Inorganic (Ash),	10·7	9·2	16·2	29·3
Hygroscopic Water,	11·3	17·4	18·8	10·1

Johnstrup tells us that some of the coals are extremely ashy, containing as much as 51 and even 74 per cent. of inorganic material. This latter, however, is rather a carbonaceous clay than a coal. In open-air sections it is not difficult to trace the passage from coal into shale—an appearance which, taken in connection with the general aspect of the beds, is strongly suggestive of the aqueous formation of the coal-seams. I saw no trace of a true underclay, and nothing resembling rootlets. Indeed I was rather surprised at the apparent scarcity of plant-remains in the shales. Dark vegetable impressions were observed, but there was nothing among these which could have been specifically determined. The shales and clays associated with the coals generally contain thin lines and layers of glance coal and dull common coal, and now and then small nodules of coarse grey clay-ironstone make their appearance. The mode of occurrence of these thin lines and streaks of coal in the shale seems clearly to indicate deposition in water of vegetable débris and muddy sediment. The shales and clays are generally dark dull grey, but sometimes they are rusty brown; in close contact with the thicker coals they are usually very dark or black. In some places, as at Syd i Hauge (see Plate XIII. fig. 8), they have quite a tufaceous aspect, are dull green in colour, and do not differ from the green tufaceous shales which are sometimes met with between separate beds of anamesite.

The outcrop of the coal-beds is shown upon the accompanying map, and does not differ much from that given by FORCHHAMMER. JOHNSTRUP's map only indicates the areas over which, according to his opinion, the coals extend. He has also left uncoloured those parts of the coal-beds that are at a lower level than the sea, and consequently considerable tracts in the north and north-east of Suderöe are ignored as coal-bearing. In the mountainous tracts of Borgaknappen and Kvannafield the coal-bearing strata seemed to us likewise to have a wider extension than JOHNSTRUP's map allows. The line of bedding could be quite well followed from Kvannafield round to Borgaknappen, and the same beds occupy a considerable area in Tuanahelgafield. Of course, I do not maintain that workable coal will be found everywhere along the outcrop given upon the map. The seams, as I have said, thicken and thin out irregularly, and in no part of the coal-field probably will they be found to preserve for any distance an equable thickness or even to be continuously present. The line of outcrop simply indicates the geological horizon of the coal—the outcrop of the shales and clays in which the coals are found.

The dip of the strata in Suderöe is uniformly N.N.E. Between Waag and Kvannafield the inclination probably does not average over 2° or 3°. It increases slightly north, and at Frodböenÿpen (see Plate XIV. fig. 9), it is as much as 11°; at Kvanhauge the rocks dip at 10° to 14°. Owing to the lowness of the dip, it will be seen that the coal-strata occur as isolated cappings on the crests of the high grounds in the middle of the island (see Plate XIII. figs. 1 and 4).

5. *Coal, &c. of Myggenæs and Tindholm.*—The only other islands in which coal occurs are Myggenæs and Tindholm,* in Sörwaagsfiord. We did not visit these, but I may mention what FORCHHAMMER says about them. The coal of Myggenæs, according to this authority, occurs as a thin layer, from ¼ of an inch to 5 inches thick, embedded in a brownish clay or clunch. Associated with this clunch is a black schistose clay which now and then contains reed-like impressions, like those which occur in the black shales or schistose clays of Suderöe. The whole thickness of the coal-bearing beds is from 3 to 6 feet. They occur at an elevation of 1000 feet.

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* According to an old writer (HENSCHEL), whose MSS. are in the Royal Danish Archives, coal is said to occur in Gaasholm and in Waagöe. But it seems this is doubtful (JOHNSTRUP).

In Tindholm coal and clay are found irregularly associated with basalt. Forchhammer's description, which is not very clear, would lead one to suppose that the beds are much disturbed, interrupted, caught up, and enclosed in the basalt. He gives a section in which basalt is seen terminating abruptly against clay, and in the latter he says there are sporadic lumps of basalt. Perhaps these "lumps" may be only veins seen in cross-section.* Many of the basalt-dykes which intersect the sea-cliffs of the northern islands are accompanied by what seem to be irregular lumps of black basalt completely isolated and embedded in the surrounding dolerite and tuff—but these are clearly only the sectional faces of smaller veins proceeding from the main dyke (see Plates XIV. and XV. figs. 14 and 15).

According to Forchhammer, the coal-beds of Tindholm are perhaps on a different horizon from those of Myggenæs.

6. *Subsequent or Intrusive Basalts of Suderöe.*—Basalt occurs intrusively in Suderöe both in the form of sheets and veins or dykes. Very fine exposures of a sheet of prismatic basalt 30 to 50 feet thick are seen on the shore at Frodböe, where the rock is fine-grained and of a dark blue colour. It shows a few small round vesicles, which are usually filled with calcspar. The columns of this basalt vary in diameter from a few inches up to 1 foot 6 inches and 2 feet. They are often extremely regular, and sometimes show beautiful radiating forms. Similar prismatic basalt occurs at Kvannabotnir. There and at Kvanhauge irregular dykes, veins, and sheets are intruded among the anamesites, tuffs, and shales. All these dykes and sheets are evidently part and parcel of one and the same irruptive sheet, which may be traced in the cliffs round into Qvalböefiord as far as Tiödnenæs, and a similar irregular mass occurs on relatively the same horizon on the opposite side of the fiord at Qvalböe, from which place it continues along the coast for some distance down the fiord. At one place to the north-east of Qvalböe the veins and dykes proceeding from this mass are beautifully displayed in the cliffs as they traverse a bright red rock, which is probably tuff (Plate XIV. fig. 10). Close to Qvalböe the basalt is quite prismatic. It is most probable that all these intrusive basalts belong to one and the same intrusive sheet. At Frodböe the rock occurs a little below the horizon of the coal-beds (see Plate XIII. fig. 1), while at Kvanhauge the latter are highly confused and disturbed by it; and it continues at the same level all round the coast to Tiödnenæs. On the opposite shore of the fiord it reappears at Qvalböe, where it seems to occupy the position of the coal—the coal never having been observed at this place. These phenomena are quite in keeping with what we know of the intrusive basalt-rocks of the Scottish coal-fields, which are peculiarly prone to occupy the position of coal-seams. Not unusually our miners find some particular coal destroyed over a wide district by

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* Trevelyan says that the coal and clay of Tindholm are "apparently enclosed in the trap."

the intrusion of a sheet of dolerite. Occasionally such a sheet will leave its usual horizon, and, after rising through a considerable thickness of sandstone and shale, will push itself laterally into an upper seam, and continue along that line for some distance until it may ascend to a yet higher coal which it will "burn" in the same manner as the others. The coal-beds in the Carboniferous series of Scotland would thus appear to have been "lines of weakness." In like manner, the coal-bearing beds of Suderöe would seem to have yielded more readily to the assaults of the intrusive basalt than the harder and less easily divided anamesites with which they are associated. It is remarkable, at all events, that nowhere else in the island do such intrusive sheets occur. We could hardly have missed seeing them had they been present, for each cliff and mountain-slope is a magnificent geological diagram, in which every detail of structure is graphically exhibited.

Dykes and veins of basalt, however, were noted in the cliffs between Famarasund and Famöyë. These seemed to trend N.W. by N., nearly in the same direction as the coast. They sent out numerous small veins and threads in all directions, and appeared to be of the same character as the similar dykes which we observed in great abundance throughout the northern islands.

7. *Contemporaneous or Bedded Dolerites of the Northern Islands.*—As I have already indicated, the basalt-rocks of the northern islands (Stromöe, Österöe, Sandöe, &c.) are upon the whole more coarsely crystalline than those of Suderöe, and rather dolerites than anamesites. But, just as in Suderöe we occasionally come upon sheets of coarse dolerite interstratified with anamesites, so in the northern islands anamesites are now and again encountered among dolerites. The prevailing colour of the dolerites of the northern islands is some shade of blue, but there are many black, grey, red, and purple varieties. All are composed essentially of augite, plagioclase, and magnetite, and most contain olivine, which is often abundant. Some of them are extremely coarse in texture—the crystals of plagioclase with which the rocks are invariably porphyritic, sometimes reaching half an inch or more in length,* and being often developed in great abundance, so much so indeed as occasionally almost to obscure the matrix in which they are embedded. It is this markedly porphyritic character which serves to distinguish the basalt-rock of the northern islands from those which in Suderöe underlie and immediately overlie the coals. Among the most beautiful porphyritic dolerites which we saw were those of Skaapen in Sandöe, of Höÿviig near Thorshavn, and of the hills at Storevatn near Leinum. The weathering of the augite, when the crystals are distinguishable, often imparts a reddish-brown tint to the rock on slightly weathered

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* FORCHHAMMER says they sometimes reach an inch in length. This able geologist's geognostic descriptions are in general singularly lucid, and he has given in small compass what seemed to us a perfectly accurate account, so far as it goes, of the principal features presented by the dolerites of these islands.

faces. The olivine occurs either as dark or pale green rounded and amorphous granules or imperfect crystals, but very frequently it is more or less altered into serpentine. So abundant is the magnetite that it often strongly affected the compass, and one had to be on one's guard while taking the direction of dips and glacial striæ. Some of the rocks at Eide in Österöe were particularly magnetic. The fracture of the dolerite varies of course according to the character of the rock; sometimes it is smoothly conchoidal, but more generally it is somewhat irregular, more particularly in the case of the highly crystalline and more coarsely porphyritic varieties, some of which have quite a hackly fracture.

I selected for microscopic examination a number of specimens which might be taken as fairly representative of the rocks of Suderöe and of the northern islands. Like the anamesites, the dolerites of the northern islands differ chiefly in texture and the varying proportion of their component minerals. In some cases, as at Skaapen, the base of the rock is quite compact like that of a basalt; in many others it is crypto-crystalline, like that of the anamesites of Suderöe; while in yet others the texture is coarse and granular, and between these varieties there is every gradation. Again, some of the dolerites are much more abundantly and coarsely porphyritic than others. Occasionally the disseminated crystals of plagioclase are small and few in number, while in some rocks, as already mentioned, they are large and thickly interlaced. The crystals of olivine also occasionally attain a large size. Owing partly to these differences and partly to structural peculiarities, the dolerites are variously acted upon by the weather, as will be afterwards pointed out more particularly. I found that as a rule the more highly amygdaloidal portions of a rock succumbed most readily to the denuding forces—the denser or less amygdaloidal areas often projecting beyond these latter for several feet.

Amygdaloidal and non-amygdaloidal areas frequently alternate in more or less regular bands which are parallel to the plane of bedding, and several of these alternations might be observed in one and the same bed, the line of separation between the bands appearing at the distance of a few yards to be often well-defined (see Plate XIV. fig. 11). The matrix of the amygdaloidal areas was frequently finer grained than the other parts of the rock; it varied also in colour, and was often dull and earthy, becoming soft, wacké-like, and crumbling. The non-amygdaloidal bands, on the other hand, were generally coarser grained, crystalline, and hard. The more crystalline parts of a dolerite might thus be black or blue, while the amygdaloidal portions were pale red or brown, grey, yellow, or dirty green. Small amygdaloidal cavities often occurred more or less numerously in the harder crystalline bands, along the line of junction with the wacké-like areas; but, so far as my observations went, they quickly disappeared at the distance of a few feet from the junction-line, although a few might now and again be detected through the body of the rock; and even occasionally a sporadic area, more or less vesicular and honeycombed, might be seen completely enclosed in crystalline non-amygdaloidal rock. Such alternating and variously coloured layers, although the individual zones are frequently of very irregular thickness, have yet all the appearance of true bedding when viewed from a little distance.

The amygdaloidal cavities vary in size from mere points up to hollows more than 2 feet in diameter. Many of them are round, others are more or less flattened and drawn out in the plane of bedding, while yet others are quite irregular, and seem to have been formed by the confluence of several vesicles. In some places the cavities are very abundant—the rocks being literally honeycombed with them. When such is the case they are generally small—the larger cavities being perhaps most common when the rock is least porous. Some of the largest we saw were on the east coast of Skaalefiord. Very frequently the cavities occur in more or less continuous lines or layers, parallel to the plane of bedding (see Plate XIV. fig. 12), a feature which may be noted again and again in the sea-coast sections, particularly along the north-west shores of Stromöe. Now and again also may be observed that involved appearance of the cavities which has already been described as occasionally visible in the anamesites of Suderöe. The prevailing amygdaloidal minerals are chabasite, stilbite, mesotype, apophyllite, analcime, quartz, chalcedony, calcspar, and green earth. It is not uncommon to find two, three, or even four different zeolites in one and the same drusy cavity.

I have said that more highly amygdaloidal parts often alternate with harder non-amygdaloidal zones in one and the same bed. This, however, is far from being always the case. Sometimes the vesicular areas appear to be as durable as the other portions of a rock, and do not differ from these either in colour or texture. Frequently the dolerites seem to be tolerably homogeneous throughout—there being no trace of that alternation of zones just referred to. The under and upper surfaces, however, wherever they came under my observation, were always more or less vesicular, and often highly slaggy and scoriaceous. These scoriaceous portions are very striking in appearance. They appear to be made up of jumbled and broken fragments of highly vesicular dolerite—varying in diameter from a few inches up to several feet, enclosed in a less vesicular matrix of the same material. At other times the matrix appears to be amorphous, earthy-like, and highly discoloured, generally becoming bright red, and showing occasional yellow and parti-coloured areas. These red discoloured areas so closely resemble the tuffs upon which the dolerites repose that it is sometimes hard to say where dolerite ends and true tuff begins. When the rock is highly porphyritic, however, the presence of the large crystals of plagioclase in the reddened portions usually enables one to detect the line of junction between the two rocks, which is frequently very irregular. This discoloration is probably due to the decomposition of the augite and olivine, and the production of sesquioxide of iron, and the resultant rock thus resembles the "palagonite" of petrologists. It seemed to me, however, that in some cases the tuff over which the old lava flowed had been caught up and commingled with the latter, as I have frequently observed to be the case with the porphyrites of Carboniferous and Old Red Sandstone tracts in Scotland, as in the Cheviots, the trappean hills of Ayrshire, the Ochils, the Sidlaws, and other Lowland ranges. In these Scottish areas the under portions of the porphyrites often contain quantities of baked sandstone and mudstone, which have evidently been caught up while in the condition of soft sand and mud, and become inter-coiled and involved with the once molten rock. Some of the dolerites of the islands now under review appeared to be much more scoriaceous above and below than others. Occasionally the slaggy under surface did not measure more than a foot or two, while in other cases it would reach as many yards. The upper surfaces were likewise often scoriaceous, but, owing perhaps to the comparative absence of red palagonitic matter, they were as a rule less conspicuous than the under surfaces. Some superficial crusts which I saw might readily have been mistaken for volcanic agglomerate. On the shore at Klaksvig, for example, a fine reddish brown vesicular dolerite is seen with a highly scoriaceous upper surface. This crust is made up of fragments chiefly vesicular, of all shapes and sizes, from mere grit up to pieces 6 inches and 1 foot in diameter. Some of the fragments were not unlike bombs, and had only the crust itself been visible it would have been difficult to distinguish the rock from a true volcanic breccia or agglomerate. Another appearance presented by the upper surface of some of the dolerites has been described by Sir G. Mackenzie as "not unlike coils of rope or crumpled cloth, an appearance which we should expect to be assumed by any viscid matter in motion."

The beds of dolerite vary much in thickness, and it is not easy to give any average. Some were less than 20 feet thick, while others exceeded 100 feet. But as they do not preserve the same thickness throughout, it would only be possible to give a reliable average after a large number of individual beds had been followed along their entire extent, which has not yet been done. It may be that the thinner beds seen in a section attain a greater thickness in some other part of their course, and that no single bed has a maximum thickness so inconsiderable as 20 feet. It is remarkable, however, for what a distance a bed will retain an uniform thickness. One could follow some well-marked sheets often along the whole course of a fiord, throughout which they seemed to retain very much the same thickness. As giving some notion of the number of beds, I may mention that in the hill-slopes and cliffs between Kollefiord and Kalbaksfiord we counted some twenty sheets of dolerite, separated by lines and layers of tuff—the highest bed visible being perhaps some 1500 feet or so above the sea-level. Again, in the fine mural cliffs and bare rugged slopes of Skiellinge Field, as viewed from Höi at the head of Kollefiord, some thirty beds of basalt-rock and tuff-partings were visible, which would give an average of about 80 feet for each bed. Some of the beds, however, were considerably under that thickness, while others could hardly have been less than 120 feet or even more.

None of the bedded dolerites that we saw was so markedly columnar as the more typical of the anamesites of Suderöe. Now and again, however, we observed a rude approximation to columnar structure, and the rocks were very generally traversed by strong master-joints at right angles to the plane of bedding.

8. *Bedded Tuffs of the Northern Islands.*—The tuffs of the northern islands are precisely similar to those of Suderöe, and they need not therefore be specially described. I may merely state that we never chanced to come across any clunch or clay similar to that with which the coals of Suderöe are interbedded, and no trace of coal has ever been met with in the islands at present under review. The thickness of the tuff beds is very variable ; sometimes they consist of mere lines, while in other cases I saw in the cliffs beds which may have exceeded 100 feet in thickness. It is just possible, however, that these tuff-like beds, which were merely observed as we boated past, may have been earthy decomposing dolerites. Now and again I saw a tuff thin out as in the sea-cliffs near Gritenaes in Stromöe (see Plate XIV. fig. 13). But upon the whole the tuffs are less conspicuous than the dolerites, for while the latter form cliffs and steep faces, the latter usually give rise to slopes and ledges which are covered over with débris and vegetation. Some of these slopes indicated a thickness of 200 or even 300 feet of soft rock underneath, but whether this thickness was all tuff or partly tuff and rotten dolerite, I cannot say. In other places again, particularly in the sea-cliffs in the north-west of Stromöe, the tuff seems to occur as mere thin lines and partings. Some very instructive sections showing the rapid alternation of tuff and basalt-rock are seen along the southern shores of Fundingsfiord. Here beds of red tuff, varying from a foot or less up to several yards, are interbedded with irregularly weathering dolerite, and show well the undulating surface over which the old lavas occasionally flowed (Plate XIV. fig. 12).

9. *Subsequent or Intrusive Basalts of the Northern Islands.*—Two sheets of intrusive basalt have been described as occurring—the one in Stromöe and the other in Österöe ; but neither of these was visited by us. They are mentioned by every writer who has treated of the geognosy of the northern islands. The more striking of the two masses is that which is seen exposed along the western face of Skiellinge Field. It is a columnar basalt of an average thickness of 100 feet, which traverses the beds obliquely, and is represented by

Trevelyan in a section as extending from Norderdahl to Leinum. Its general features are well described by Allan. Another and thicker basaltic mass is figured by Trevelyan as occurring near Zellatrae (Selletrod) in Österöe. These, so far as I know, are the only intrusive sheets which have been observed in the northern islands. Vertical or approximately vertical dykes and veins, however, are exceedingly numerous. We saw many in the cliffs, and these are indicated upon the map, and there are probably many more in those regions which we did not visit. We also came upon fragments of close-grained blue basalt in many places upon the hill slopes, which had doubtless been derived from dykes and veins exposed to denudation on the steep precipices above us. All the dykes seem to consist of the same kind of rock—a hard, fine-grained compact blue basalt (of the same composition as the bedded basalts), abundantly jointed at right angles to its direction, with several more or less continuous joints running parallel to its trend. The cross-joints give the rock quite a prismatic structure, the prisms being confined between the parallel joints, or between these and the walls of the dyke. Thus in one and the same dyke there may be several series of prisms; but as both the dykes themselves and their parallel jointing are very irregular, the prisms are irregular also. Each dyke sends out numerous small veins which ramify in all directions, and are invariably minutely jointed across. The connection between these veins and the main dyke is often clearly exposed; but very frequently this is not the case, and the small threads and veins then appear quite isolated, the connection with the dyke having either been removed by denudation, or being still concealed behind the visible surface of dolerite through which the veins are squirted. Owing to their highly jointed character, these dykes fall rapidly before the action of the weather and the denuding agents. Thus in the sea-cliffs they almost invariably give origin to caves. Nothing can well be more striking than the appearance presented by many of these curious dykes. In the sea-cliffs they generally appear superficially black or dark green, and contrast very strongly with the ruddy coloured dolerites and tuff across which they break. I give sketches of a few of the more remarkable ones I saw (Plates XIV. and XV. figs. 14–17). Fig. 14 represents a set of dykes which are probably part and parcel of one and the same intrusive mass. All the appearances connected with this and other similar dykes gave one the impression that the basalt at the moment of intrusion must have been in a condition of extreme fluidity. Nowhere that we saw did the dykes disturb the bedding—they seemed to have cut the dolerites very much as a knife cuts cheese. Another very remarkable dyke is shown in fig. 16 *a*, *b*, Plate XV. The decomposition and erosion of this dyke have given rise to a curious cave which forms a kind of natural arcade with a double entrance, as shown upon the plan (fig. 16 *a*). The dyke is in the form of a cross, and the two limbs meet in the roof of the arcade where the beknotted mass projects downwards, reminding one of the groined ceiling of some Gothic structure. But the eccentricities of these dykes are endless, and no two are ever alike. They strongly reminded me of the irregular basalt-dykes and veins which occur so numerously in the Outer Hebrides.*

There appear to be two systems of dykes, but they probably belong to the same age. One series trends from a little east of north to west of south, and the other from north of west to south of east; but the precise direction of some of those which we saw is not quite certain. When a dyke is only seen in one vertical sea-cliff section, and has not been traced inland, its true direction may easily be mistaken, and such may quite well be the case with some which are indicated upon the map. Many of them, however, were so placed as to show their trend conspicuously enough, and these certainly gave evidence of a double series, one set running at approximately right angles to the other. But until the dykes in all the islands have been carefully mapped out this point will not be definitely settled. I may remark in passing, that they are never so regular as the Miocene dykes in Scotland; these latter, as is well known, traverse the country in great wall-like sheets, from which often few or no subsidiary veins proceed; but the dykes of the Færöes divide and subdivide again and again, and send out veins and threads innumerable.

There is no evidence to show whether or not there is any connection between the dykes and the larger intrusive masses of prismatic basalt. It is quite possible, however, and even probable, that both belong to the same period of volcanic activity, and that they may have been injected from below at a time when sheets of basalt still continued to be poured out at the surface.

IV. Thickness of the Strata: Conditions under which they were amassed.

1. *Thickness of the Strata.*—The dip of the basalt-rocks and tuffs in the northern islands, exclusive of Myggenæs, is somewhat persistently towards south-east, at an angle which hardly ever reaches 5°, and is usually much less. Sometimes, indeed, the dip is barely appreciable, and the beds appear to be quite horizontal. The average inclination certainly does not exceed 3°, but is probably greater than 2°. We have thus a thickness of 9000 or 10,000 feet for the rocks in the northern islands. To this must be added the thickness of the lower series (the beds under the coal) as developed in Myggenæs, Suderöe, and Munken, which cannot be less than 4000 feet.

2. *Igneous Rocks of Subaerial Origin.*—Sir George Mackenzie was of opinion that the "traps" of the Færöe Islands were the products of submarine volcanic

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* Quart. Journ. Geol. Soc., vol. xxxiv. p. 854.

action, and this view has been generally accepted by geologists. Indeed, the Færöe Islands are sometimes referred to as "a typical example of an upheaved submarine volcano." The greater lateral extension of the basalt-beds as compared to their thickness is supposed to indicate a flow under heavier pressure than that of the atmosphere alone. The phenomena presented by the old basaltic plateaux of Færöe, Iceland, and other countries, are contrasted with the appearances which are known to characterise the eruptive products of Hecla, Etna, Vesuvius, and other modern subaerial volcanic cones, and since these latter rarely or never form such vast successions of parallel and widely extended sheets of lava, the older basalts I refer to are believed to have been spread out upon the bed of the sea. But if we put aside the fact of their greater horizontal dimensions, we find that the basalt-rocks of the Færöe Islands present most of the features which are commonly supposed to be characteristic of subaerial lava-flows. They are generally vesicular, and often scoriform above and below; they exhibit layers and lines of pores and larger cavities, often flattened out in the plane of bedding; now and again their upper surfaces have that slaggy, wrinkled, and crumpled appearance which is so typical of certain modern lavas; while their middle parts are not more vesicular than are the central portions of undoubtedly subaerial flows. The absence of fragmental accumulations, such as volcanic breccias and agglomerates, is really no proof of the submarine origin of the basalt-rocks of Færöe and other similar trappean plateaux. Such coarse accumulations are generally distributed round the immediate neighbourhood of the orifice from which they are ejected. The basalt beds of the Færöes may quite well have been ejected from one or more central orifices, in which case the absence of fragmental materials would only serve to indicate that the focus or foci of eruption must have been at a considerable distance from the present islands. Or it may be that the whole series of basalt-rocks are the products of vast fissure-eruptions. But if this be their origin I certainly met with no direct evidence in its favour. None of the numerous dykes which we saw could possibly be the feeders that supplied the bedded basalts. Most of the dykes died out upwards—often wedging out in the middle of a basalt-bed or tuff—and the rock of the dyke could always be clearly distinguished from that in which it terminated. The dykes, in short, are only thin, irregular veins that ramify and split up into mere threads, and have no resemblance to those great wall-like basalt-dykes of supposed Miocene age, which are so common in Scotland. Veins exactly similar to those of the Færöes, however, are very common in the Outer Hebrides.

But whatever the particular origin of the bedded basalts of the Færöe Islands may have been—whether they flowed from one or more foci like the lavas of modern volcanoes, or welled up from below along the lines of great fissures—all the evidence is against the view that they were erupted upon the bed of the sea. If this had been their origin, we should be at a loss to account for the total absence of marine organic remains in the interstratified tuffs. Nothing at all resembling the fossiliferous tuffs of the Campagna di Roma and the Terra di Lavoro is to be found. Instead of these we have the coal-beds of Suderöe; and hitherto the only fossils which the Miocene volcanic rocks of northern regions have yielded are land-plants, which would be inexplicable enough if these igneous masses had invariably been the products of submarine volcanoes.* The equable thickness and wide extension of the bedded basalts, which have been thought by some to indicate that the old lavas have been spread out under the weight of a superincumbent ocean, are equalled and even surpassed by the great lava-flow from Skaptur Jokul in 1783, which covers an area as extensive as that of all the Færöes, and which in the open country does not average more than 100 feet in thickness. It may be admitted that the lavas of some modern volcanoes have "a more rugged and porous aspect" than many of the basalt-sheets of the Færöes—amongst which we look in vain for those great "clinker-fields" and cinder-like masses which are often met with in the products of recent eruptions. But all modern lavas are not equally scoriaceous, and many have no thicker cinder-like crust than the old basalts of the region under review.

While not disputing that the Færöe basalt-beds may have been poured out from fissures, it seems to me that the phenomena are not inexplicable on the view that they have proceeded from one or more foci in the manner of modern lavas. But if this has been the case, then it is obvious that the centre or centres of eruption must have been far removed from the site of the present islands. This, as I have already remarked, would explain the absence of breccias and agglomerates, of lapilli and bombs. It would also account for the uniform character of the ancient lavas. It is well known that in modern volcanoes lavas and tuffs of very different character issue at different times from one and the same orifice, or from craters which are contiguous. Thus a volcanic mountain may be built up of a great succession of basalt-rocks, trachytes, trachy-dolerites, obsidian, agglomerate, fine tuff, &c. And the basalts of modern formation do not differ essentially from those of older tertiary, secondary or primary age—such differences as do occur being sufficiently accounted for by long-continued chemical action. It is likewise true that trachytic rocks are not confined to modern volcanoes, but occur also interstratified with tertiary and secondary strata. We may reasonably infer, then, that if the Færöe basalts came from volcanic foci, and consolidated in proximity to these, they ought to have been associated not only with coarse agglo-

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* Marine fossils are said to occur in the *Surtarbrandr* or lignite-beds of the sea-coast, near Húsavík in Iceland; but this appears to be exceptional—the palagonite-tuffs of that island being otherwise as destitute of any trace of marine life as those of the Færöes.

merates but with other varieties of lava. But as this is not the case, it may be supposed that the whole vast series of basalt-beds and tuffs (13,000 feet or 14,000 feet in thickness) accumulated upon the outskirts of an old volcanic area. They would, in this view, represent the heavier and more fluid lavas, derived from foci which may also have ejected agglomerates and many lavas of lighter specific gravity—these last having been unable to reach the great distances attained by the basalts. This would only be upon a larger scale than what we know has taken place in regions like Auvergne, where, as "in the Mont Dore, the trachytic currents," according to SCROPE, "have in no instance flowed more than from 4 or 5 miles from the central heights of the volcanoes; the basaltic currents, on the contrary, have reached a distance of 15 miles or more."

3. *Miocene Age of the Strata: Physical Conditions under which they were amassed.*—Although, as I have said, the plant-remains of Suderöe have not been specifically determined, there is no reason to doubt that geologists are right in referring the igneous rocks of the Færöe Islands to the Miocene period. They almost certainly belong to the same great series of which the basalt-plateaux of Iceland, Greenland, Spitzbergen, and our own islands form separate portions. Such being the case, it may be allowable to offer a few remarks on the physical conditions under which the rocks of the Færöe Islands would seem to have been accumulated.

We know that during the Miocene period there existed a very wide extent of land in northern regions. It is even highly probable that America and Europe were at that time connected, so that plants could migrate freely across broad areas which now lie drowned beneath the waters of the Arctic Ocean. It is not unlikely that during Miocene times land may have stretched continuously westward from what are now the Færöe Islands to Iceland and Greenland. This belt of land must have been the scene of great volcanic activity, and we may conceive how after many successive sheets of lava had been poured out from one or more vents, or from long fissures, all the hollows of the old land-surface would be filled up for as great a distance as the molten rock flowed. If the lavas flowed from orifices like those of ordinary volcanoes, there may have been one or more central cones, rising probably to a considerable elevation, and surrounded by vast plains that sloped outwards with a diminishing inclination in all directions. The cones themselves would be built up of irregular masses of different kinds of lava and heaps of more or less loose scoriæ, lapilli, bombs, and tuff. The same materials would also enter largely into the composition of the immediately adjacent low grounds. But the further one travelled from the centre of dispersion, the less abundant would lapilli and other loose ejecta become. Highly porous and scoriaceous lavas and clinkers would in like manner abound in the vicinity of the volcanic centre, but they would become less conspicuous as the outskirts of the igneous area were approached. The lavas would still continue to show scoriform crusts, but many of them would begin to exhibit a somewhat smoother or less rugged surface, showing, in place of great fields of cinder heaps, a wrinkled and crumpled appearance, such as is assumed by any viscid substance in motion. In short, the outlying parts of the igneous region would be invaded only by the more fluid and specifically heavier lavas, the lighter and more porous lavas and agglomerates would in great measure be restricted to the cone or cones and their vicinity. Tufaceous deposits, however, would not be wanting in any part of the land to which the lavas might flow, and they might well extend even much further. The tuffs of the outlying regions, however, would generally be fine-grained, consisting of the volcanic dust which the winds had power to carry to considerable distances; of volcanic mud or tuff; and of the materials derived from the subaerial disintegration of the exposed lavas. Such fine-grained detritus, whether washed down the gentler slopes by rain or swept forward as mud, would tend to accumulate in the hollows of the ground. Moreover, since the inclination of the surface in the outer zone of the volcanic area must have been as a rule very gentle, there would be no rapid flow of water, and therefore comparatively little aqueous erosion; and thus coarse gravel and shingle would be generally absent. But, just because the slope of the land was gentle and tolerably equable, fine tufaceous alluvia would tend to be widely distributed—gathering thickly in the hollows, and thinning off where the ground rose in swells and undulations. In short, they would form rather sporadic patches and layers of variable depth, than widespread continuous sheets of equable thickness. These assumptions, as we have seen, are confirmed by direct observation; the tuffs are much less continuous and of less uniform thickness than the basalt-rocks with which they are interstratified.

Now let us suppose that, after many sheets of lava had been poured out and spread above the site of the future Suderöe, a pause in the volcanic activity ensued, and the region referred to ceased for a time to be overflowed. We can readily believe that, under the climatic conditions prevailing in Miocene times, vegetation would sooner or later creep over the surface of the cooled basalts. Rain-water would gather in the depressions of the ground, and so give rise to swamps and pools and shallow straggling lakes, in which mineral and vegetable matter would gradually accumulate. It is not improbable that the basalt-plateaux might even be densely wooded. Such conditions might obtain for a prolonged period, so as to allow of the accumulation in swamps, bogs, and lakes of very considerable depths of vegetable matter, mixed with mud and clay and fine sand, and now and again with small stones or pebbly grit. At other times the suspension of volcanic activity might not be so prolonged, and a renewed incursion of lava might take place before the last current had sufficiently cooled to permit of vegetation spreading over its surface, or indeed before the plants themselves had time to occupy the ground. Again, it might occasionally happen that, owing to the nature of the volcanic surface, there could be little or no accumulation of vegetable matter in swamps and pools, and the mere "carpet of greenery" which may have covered the ground in whole or in part, might well be destroyed upon the advance of another lava-flow.

The appearances which have just been described as the most likely to occur under the circumstances I have supposed, are precisely those which are found associated with the coal-beds of Suderöe. The character of the clays and tufaceous shales with which these coals are interbedded, and the manner in which mineral and vegetable layers interosculate, all point to quiet deposition in shallow lakes, and the slow accumulation of plant-remains in swamps, marshes, and bogs. The thin layer of coal at Dalbofos may indicate a comparatively short period of rest, while the thicker coals at the higher level seem to bespeak a pause of much longer duration. In like manner, many of the tufaceous shales which appear to be unfossiliferous, may yet have been accumulated in precisely the same manner as the shales which accompany the coal layers, and which in some places they closely resemble. The mere absence from these shales of coal or plant-remains does not necessarily prove that no vegetation covered the plateaux at the time the shales in question were accumulated. The presence of the little patch of coal at Dalbofos, which is quite local—none ever having been seen elsewhere on the same horizon—shows us how easily all trace of a vegetable layer might be obliterated. But while it may be true that some of the darker tufaceous shales may thus be of the nature of "surface-wash," and owe their origin directly to the action of the weather, there can be little doubt that by much the greater proportion of the red and particoloured tuffs are due more or less directly to igneous action. They consist of the finer dust and grit blown out during eruptions, and spread by the winds over vast areas, and partly no doubt of the same material carried down by rain and swept from higher to lower levels by running water—sometimes, perhaps, the tuffs may represent former currents and streams of volcanic mud.

4. *Position of old Volcanic Centre of Eruption.*—It would be interesting to ascertain the locality of the volcanic centre from which the old lavas of the Færöe Islands were ejected. I am inclined to think that it lay somewhere to the westward, partly for the reason that the rocks have an average easterly dip, and partly because the sea between the Færöe Islands and Iceland is not so deep as it is in the direction of Scotland. The dip, although it may have experienced subsequent modification, may yet indicate the original inclination of the ground, while the lesser depth of the sea to the west does not imply such extreme depression and denudation as must have taken place if the site of the ancient volcano lay far to the east of the present islands. At the same

time, there is something to be said for the view that the old volcanic centre may after all have occurred in that direction, and that owing to the sinking down of the central region, the dip of the great basalt plateaux has been reversed. Such enormous denudation and so many great movements of the earth's crust have taken place since Miocene times, that too much stress may easily be laid upon the configuration of the sea-bottom, and the present dip of the strata. In whatever direction the centre of eruption lay the fact remains, that in the basalt-masses of Færöe we see only a few shreds of what must at one time have been a continuous plateau, occupying a much wider superficial area. The lofty cone or cones, if from such rather than fissures the basalts were erupted, have entirely disappeared—perhaps the looser and less consolidated materials of which they would probably be composed, having, we may suppose, contributed to their overthrow. This, I may remark, is the fate which has overtaken all the great volcanic centres of our own islands. Thus the volcanic products of the Old Red Sandstone, Carboniferous, and Permian formations are now represented chiefly by sheets of igneous rock, many of which have consolidated at a greater or less distance from the points of eruption. Such cones of scoriæ and lava as may formerly have existed have been entirely demolished—their sites being now indicated by the hard plugs of rock that occupy the pipes or necks through which ashes and molten rock found a passage to the surface.

V. Glacial Phenomena of the Islands.

1. *Early Notices of Glacial Phenomena.*—The earliest notice of the abraded and striated rocks of the Færöe Islands occurs as already mentioned in Mr Allan's paper. His description does not tell us in what direction the abrading agency moved; but Robert Chambers, who visited the islands forty-three years afterwards, and saw the *roches moutonnées* and striæ described by Allan, was clearly of opinion that the ice had come from the north. He says, "They (the striæ) presented themselves in abundance in several places, most strikingly of all within sea-mark on the shore of the quiet bay, being all directed from the north," &c. Again he describes similar striæ observed by him in Iceland, which had the same trend with those at Eide, and concludes that these facts, taken in connection with observations of a like kind in the north of Europe and America, indicate "that there has been one universal sweeping of the surface by ice, down to some point in latitude which remains to be determined. The parallel channels between the Færöe Islands, all lying between north-west and south-east, I regard as excavations made by this wide-spreading arctic ice-sheet." Mr Chambers likewise noticed the glaciated rocks at Thorshavn, but failed to see the striæ which many of them present. Again,

he chronicles the occurrence of striæ at Westmannshavn, "directed from N. 80° E. (when 30° were allowed for variation)." Since CHAMBERS' visit no geologist, so far as I know, has published any account of the glaciation of the islands. Professor JOHNSTRUP'S interesting paper makes no reference to the "superficial geology" of Suderöe, and this paper, as I have said, is the latest contribution to our knowledge of the geology of the Færöe Islands.

I shall describe the glacial phenomena under the following heads:—*Glaciation; Till or Boulder Clay; Erratics and Morainic Débris;* and *Lake-Basins.* Some further remarks on the subject will also be given when I come to discuss the origin of the valleys and fiords.

2. *Glaciation of the Islands.*—Every island visited by us showed conspicuous marks of glacial abrasion. Sometimes the striæ were finely preserved, at other times they were faint, and only the deeper ruts were conspicuous upon the smoothed faces, while in very many cases all the more delicate ice-markings had disappeared, and only the characteristic rounded and dome-shaped outlines remained. Frequently, too, the *roches moutonnées* have been broken and shattered by the action of frost to such an extent that the glacial form is best seen from a little distance. Some of the most perfect examples of striated rock-surfaces occur in Stromöe. Thus at Thorshavn we detected a number of well-smoothed faces, the direction of the striæ varying from E. 40° S. to E. 45° S., the abrading agent having clearly come from north-west. Some of these striated faces occur in the little town itself; as, for example, upon rounded rocks on the side of a street or road not far from the church. They are visible also upon *roches moutonnées* at various places along the shores of the little promontory, upon which a considerable part of the town is built. But perhaps the best example is seen upon the side of the path that leads to the fort. Here, at the distance of 90 or 100 yards from the latter, there is a wide surface of basalt planed down to a level and traversed by long parallel striæ and ruts which trend E. 35°–45° S. In the immediate outskirts of Thorshavn several other striated faces were observed showing a similar direction; but on one face the direction was more easterly—E. 10° S. Some good examples were also noted in the neighbourhood of Höÿviig, a mile or two to the north of Thorshavn. At this place fine *roches moutonnées* may be seen, and well-marked striæ pointing E. 40° S., which occur both on horizontal, sloping, and vertical surfaces. The hills immediately to the west of the town show marks of glacial abrasion up to and over their summits (1048 feet), and the high ground between Arge and Kirkeböe appear in like manner to have been smothered in ice, the basalt-cliffs and terraces have been bevelled and rounded off, and the hill-slopes generally show a well-marked glaciated contour or outline.

All the steep seaward slopes between Thorshavn and Kalbaksfiord are highly glaciated, fine *roches moutonnées* being seen on the shore at Qvitenæs, where the tops of the columns of basalt are finely smoothed off. Although we only saw these rocks from the boat as we passed along the shore, we were yet near enough to distinguish the coarser striæ, which appeared to have the same direction as those at Höÿviig and Thorshavn. The appearance of the glaciation on the hill-slopes in Kalbaksfiord is very impressive. Here one can see at a glance in which direction the ice has flowed; it has clearly crossed the lower reaches of the fiord from north-west to south-east, a direction which corresponds with the trend of the upper part of the fiord. On the south side (the *Stoss-seite*) the hill-face exhibits the strongest marks of glaciation, while on the north side (the *Lee-seite*) the dolerites are rough and rugged, and show little or no trace of abrasion. The seaward slopes between Kalbaksfiord and Kollefiord also exhibit marks of glacial abrasion.

We crossed Stromöe from Öreringe to Westmannshavn. The lower parts of the mountains that overlook Kolfaredal are smoothed and abraded in a south-east direction, and we estimated the height reached by the glaciated outline to be some 1500 or 1600 feet. Above that level all is rough and rugged, and destitute of the slightest trace of glacial abrasion. At the Storevatn of Leinum we found the *roches moutonnées* at the exit of the lake gave evidence of an ice-flow towards the south-west into Westmannshavnfiord. The pass across the dividing ridge between Kolfaredal and the valley that leads down to Westmannshavn we found to be 1243 feet (379 mètres). At this level are *roches moutonnées*, but we saw no striæ. The glaciated outline was continued up the mountain-slopes above us for not less than 400 feet.

At Westmannshavn many well glaciated surfaces occur, but the striæ have in most cases disappeared. In one or two places, however, upon the steep hill-slopes to the west of the large waterfall, faint striæ and ruts were observed with a trend of W. 30° S., while close to the waterfall itself we got them pointing S. 5° W. Again, upon a point that juts into the sea E.S.E. from the church, ruts and striæ, directed to S. 40° W. and S.W., occur upon the surface of *roches moutonnées*. All the hill-slopes surrounding the bay are highly abraded, the basalt-cliffs and terraces being rounded and smoothed off in a striking manner (Plate XV. fig. 18).

The valley that opens upon Saxenfiord is likewise well glaciated, and exhibits smoothed and striated rocks in several places. On the plateau near the church many smoothed surfaces appear, but the striæ have in most cases vanished. We got several good examples, however, all of which pointed in the same direction, namely, W. 25° N. or down the valley. Between the church and the lake we met with other instances, but the *roches moutonnées* were, as a rule, much broken up, and to a large extent masked by their own ruins. We traced the glacial outline in the district between Saxen and

Tiörnevig up to within 100 feet or so of the *col* or water-parting, immediately above which the rocks give no evidence of having been subjected to glacial abrasion. The *col* we found to be 1693 feet (516 mètres) above the sea, and the glaciation came close up to this level; the rocks upon the *col*, however, were much broken up by frost, but abraded rocks with the characteristic glaciated contour certainly reached 1600 feet. We saw no striæ at Tiörnevig, but the sea-ward slopes of Stromöe opposite Österöe show well-marked *roches moutonnées* between Tiörnevig and Haldervig, and much further south, as we could see very plainly from the high grounds of Österöe.

Perhaps the best preserved *roches moutonnées* we anywhere observed were in Österöe and Sandöe. It was with considerable interest that we visited the northern portion of the former island, for we felt that the evidence to be gathered there would go a long way to settle the question which we had come to solve. No difficulty was experienced in finding the locality described so long ago by ALLAN, and subsequently visited by CHAMBERS, but the striæ, instead of being "directed from the north," had clearly been graved by ice coming from quite the opposite point of the compass. The Kodlen peninsula we found glaciated all over, the *roches moutonnées* on both sides of the isthmus being beautifully perfect, and showing *Stoss-* and *Lee-seiten* in the most admirable manner. In many places the striæ are well seen, and long ruts and channelings or grooves and trenches, well smoothed and ice-worn, traverse the rock-surface. The direction of the striæ, ruts, and grooves varied a little from N. 10° W. to N. 10° E.—the variation being evidently due to the form of the ground.

We traced the glaciated contour up to a height of 1302 feet (397 mètres), which was the summit level of the pass leading from Eide to Funding, but the slopes facing the sound between Österöe and Stromöe seemed to be glaciated to a somewhat greater height. The direction of glaciation upon those slopes, so far as we could observe them, seemed to be in a direction corresponding with the trend of the sound, namely from S.S.E. to N.N.W. Crossing the ridge to Funding, we found that the glaciation pointed east into Fundingsfiord, and that ice had evidently gone down the valley. The rugged mountains overlooking the upper reaches of Fundingsfiord from the east appeared conspicuously glaciated in the direction of the fiord, but the upper parts of the rough hills between that and Andafiord were above the limits of glaciation. At Andafiord we got striæ upon a surface of basalt under boulder-clay. The striæ pointed down the fiord or E. 40° N.

The rugged promontory between Leervigsfiord and Giötheviig shows strong marks of glacial abrasion in the direction of those fiords, but the higher parts of the ridge project above the glaciated area. The southern shores of Giötheviig are well rubbed in the same direction. Between Giöthe and Skaalefiord the *roches moutonnées* are well defined, and show striæ, ruts, and grooves, which point E. 35°–40° N., evidently the work of ice which overflowed from Skaalefiord. The dividing-ridge between Skaalefiord and Giötheviig, at the place we crossed, was 410 feet high, but the glaciation swept up to within a short distance of the hill-tops. Skaalefiord itself has brimmed with glacier-ice, the great body of which flowed down the fiord, as the highly abraded seaward slopes on both sides clearly attest. The glaciation is particularly well seen at Tofte Naes—the whole of that peninsula exhibiting every evidence of severe glaciation. The direction of ice-flow, as shown by the *roches moutonnées*, was towards S.S.E. The west coast of Österöe, opposite Kollefiord, also gives evidence of having been abraded in a south-east direction.

I have no doubt that glacial striæ might be found in other parts of Stromöe and Österöe which we did not visit. In the neighbourhood of Qvalvig, for example, glacial phenomena are probably well developed. But the localities we examined sufficed for our purpose, and supplied abundant evidence to show that these islands had been glaciated by a local ice-sheet. We found not the slightest indication that they had ever been impinged upon by ice flowing from the north.

The evidence obtained in the smaller islands served further to establish this conclusion. We visited Boröe and found that Boröevigfiord was abraded in a S.S.E. direction—in other words, the ice had flowed down the fiord. We boated along a portion of the coast-line of Kalsöe and Kunöe, but the other islands, Wideröe, Svinöe, and Fuglöe, we did not approach. We could see, however, that the higher parts were extremely rugged and quite destitute of any appearance of glaciation; and from the analogy supplied by Boröe, I have no doubt that their lower portions will give evidence of a local ice-flow.

Naalsöe, opposite Thorshavn, appears smoothed off to its summit; and the seaward slopes of Waagöe opposite Westmannshavn are glaciated in the direction of Westmannshavnfiord. But I could not be sure whether the ice in this fiord had moved to north-west or south-east. It is most probable, however, that the ice-flow was in both directions—in the northern reach going towards north-west, and in the southern section to east and south-east. The rugged mountain of Stoiatind in Waagöe soars above the limit of glaciation.

The direction of glaciation in Hestöe we did not determine, but it will doubtless be found to agree with that of the hill-slopes on the Stromöe side of Hestöe-fiord, which, so far as I could make out, was towards S.S.E. Unfortunately, thick fog prevailed when we traversed the district between Thorshavn and Kirkeboe, and we were not fortunate enough to find any striæ at the latter place.

At Skaapen, in the north of Sandöe, the ground is highly glaciated, but owing to the absence of any well-defined *Lee-seite,* and the disappearance of the striæ, we could not be certain as to the direction followed by the ice. On the opposite side of the island, however, we found strongly marked *roches moutonnées,* and very fine examples of striation. As these are perhaps the best preserved specimens to be found in the Færöe Islands, it may be well to indicate the precise locality. We met with them at the point which forms the south-west limits of Sandsbugt. Close to this point there is a deep ragged cleft in the rocks into which the sea has access by a subterranean passage. The dolerite at this place shows fine striæ pointing to S. 40° W., but the best example occurs on the headland at the point itself. Here the *roches moutonnées* indicate very clearly the direction of the ice-flow, and the striæ (S. 40° W.) are particularly sharp and fresh. Nearer the village of Sand, we found striæ with a more southerly trend—S. 15° W. Of the interior part of Sandöe I can say very little—for we traversed it in a dense drizzling fog. We could only see that *roches moutonnées* and ice-worn rocks accompanied us across the hills.

The higher parts of Skuöe, as seen from our boat, appeared to be smoothed off from the north or north-east; but Store Dimon and Lille Dimon, when we passed them the first time, were shrouded in mist, and on our return from Suderöe rough weather prevented us approaching them.

Suderöe has supported a considerable mass of ice, for we traced the glaciated outline up to a height of 1400 feet. Above that level all is rough, angular, and serrated. The low ground that extends from the head of Qvalböefiord to the west coast is highly moutonnée, the position of the *Stoss-* and *Lee-seiten* indicating an ice-flow from east to west. Here also the striæ point E. and W. In Trangjisvaag valley, the direction of glaciation is towards south-east, as shown both by *roches moutonnées* and striæ. Both sides of the fiord into which this valley opens are highly glaciated in the same direction. At Ördevig, the striæ point E. 30° N., and correspond in direction with the trend of the valley in which they occur. The fine cirque-like valley of Howe affords admirable examples of glaciation. The whole broad amphitheatric space has been filled with ice, like a great reservoir; the flat bottom being thickly set with *roches moutonnées,* and the smoothed and rounded glacial contour rising on the hill-slopes to a height of 1400 feet. The upper part of the valley is sprinkled with many lakelets, which rest in true rock-basins. Striæ are not abundant, but we noticed them in several places, and they all pointed to the east, or down the valley. Another finely glaciated cirque valley descends from Kvannafield and Borgaknappen to the cliffs on the west coast, north of Famarasund. The ice that filled Howe valley must have brimmed over and become confluent, not only with the Trangjisvaag ice, but also with the glacier masses that descended the Dalbofos valley and Waagsfiord, for the hills above Porkerji and Naes are strongly glaciated all over. The trend of the abraded rocks on both sides of Waagsfiord is towards the south-east, but at Waag there is a hollow which runs from the head of the fiord south-west to the open sea coast, along which a stream of ice has flowed, as is shown by *roches moutonnées* and striæ pointing S.W. At Famöÿe, likewise, we got evidence of an ice-flow to the west —striæ and *roches moutonnées* on the south side of the bay pointing distinctly in that direction.

I have some additional remarks to make upon the subject of glaciation, but these I shall defer to a subsequent paragraph.

3. *Till or Boulder-clay.*—The till or boulder-clay of the Færöe Islands closely resembles the similar deposit which occurs in the hilly and mountainous districts of Scotland. We found it in a great many places, generally as little local patches, sheltering in the lee of *roches moutonnées* and projecting rocks; at other times spreading more continuously over low ground, and covering the beds of gently-sloping and wide valleys. Not infrequently it occurs along the margins of fiords, where the hills retire, and the coast-land is low. It varies much in thickness, but seldom exceeds 15 feet, and generally it is much thinner. In the neighbourhood of Thorshavn, it is a hard, tough, dark brown deposit, stuck full of blunted stones and boulders, some of which were well-striated. This was the case especially with some of the bigger stones. The same deposit of till showed here and there an irregular layer of earthy gravel of the usual character. The clay ranged in thickness from a few feet up to six yards; and here and there contained blocks of basalt that measured 10 and 12 feet across. Along the shores of the bay it rests upon a glaciated surface, and the same is the case with the till at Höÿviig, which is of a dark brownish blue colour. I noticed till also in Kolfaredal and at Westmannshavn and Saxen. Thin sprinklings were observed at various places between Eide and the foot of Slattaretind; and at Andafiord the low cliffs along the shore are formed of a very hard, dark greyish blue till with angular and blunted stones—some of the larger ones showing striæ. This till rests on a striated surface of dolerite.

Another good exposure of till occurs on the shores of Boröevig fiord, close to Klaksvig. It contains intercalated lenticular beds of fine tough brown stoneless, laminated clay and sand, as shown in Plate XV. fig. 19. The till is of the usual character, but very few of the included stones show faint striæ; they are of the common blunted subangular shape. At Giöthe there is a good deal of till, and irregular sheets of it appear here and there along the course of Skaalefiord, as at Siov, Strendre, and Glibre. Again in Sandöe considerable depths of till fill the bottom of the valley that opens into the sea at Sand. The deposit in this valley is more than 20 feet thick, and is well exposed along the course of the stream. We noticed till in Suderöe in many places, but more particularly in Trangjisvaag valley, and at Ordevig. In the former it occupies the whole bottom of the valley, and it also shows in various places along the northern shores of the fiord. Intercalated lenticular beds of gravel, clay, and sand occur here and there.

The distribution of the till and the mode of its occurrence harmonised completely with the appearance presented by the glaciated rocks; it lay either upon low undulating grounds, or was closely packed together behind rocks, whose abraded and ice-worn faces were quite destitute of any such covering. All the stones and boulders in the till were of local origin, and in the many exposures which we examined we never saw a single fragment which might not have been derived from the islands themselves—all consisting of basalt-rocks and tuff, and chiefly of the former. This till, we had no doubt whatever, represents the ground-moraine, or *moraine de fond* of the old ice-sheet that covered the islands. On steep slopes and in situations which must have been exposed to the full force of the ice-flow not a scrap of till appeared.

4. *Erratics and Morainic Débris.*—Large angular blocks of basalt-rock are of common occurrence throughout the islands, but in some districts they are more conspicuous than in others. In the vicinity of Thorshavn they are specially numerous, and many of them attain a large size, measuring occasionally upwards of 20 feet across. They occupy positions which preclude the possibility of their having fallen or rolled down from the hills, and as they are now and again associated with coarse morainic débris, I do not doubt that they have been deposited in their present positions during the melting of the ice-sheet. An excellent exposure of morainic débris, consisting of earth and angular fragments of all shapes and sizes up to large blocks, may be seen on the road that leads out of Thorshavn on the way to Kirkeböe. Large blocks are frequently seen dotting the hill-slopes in greater or lesser numbers throughout all the islands, and not a few may have had a glacial origin, but in many cases such isolated blocks and morainic débris can hardly be distinguished from the loose fragments which are disengaged even now by the action of frost, and rolled down from the upper parts of the hills. It is noticeable, however, that while perched blocks are quite absent from hill-tops which give no evidence of glaciation, they are yet often scattered abundantly over the surface of high ground which has been glacially abraded. This is well seen upon the ridge between Giöthe and Skaalefiord, where isolated erratics are sprinkled about upon the moutonnée surface. But even in the valleys I found true morainic débris less plentiful than might have been expected. In Kolfaredal, for example, only a slight sprinkling occurred, and in many cases this débris might quite well have resulted from the shattering by frost of the rocks *in situ*. This was particularly well seen in Saxen valley, where immediately below the lake the bottom of the valley is filled with what appear at a first glance to be hummocks of morainic matter. I found, however, that many of those hummocks were mere knobs and bosses of basalt-rock screened and masked by their own ruins. Whether some of the

débris and loose blocks that were scattered about might not have had a true morainic origin, it was impossible to say, but from the presence of some blunted and evidently glaciated stones, this seemed highly probable. True terminal moraines, however, were noticed in the valley that leads down to Westmannshavn, on the way over from the head of Kolfaredal. At Andafiord in Österöe, I found the till overlaid by true morainic débris and shingle, and all the low ground was sprinkled with large erratics which could not have rolled to their present positions, but are of unquestionably glacial origin (see Plate XV. fig. 20). At Klaksvig also may be seen erratics and morainic gravel and sand overlying till (see fig. 19). In Suderöe, as in the northern islands, numerous loose erratics appear, but morainic débris seems to occur in mere superficial sprinklings, and never, so far as I saw, formed definite mounds. So far as my observations went, well-marked terminal moraines appeared to be quite exceptional, but much of the loose angular débris and earth which are scattered over the bottoms of the valleys and the lower grounds are doubtless of morainic origin. It is needless to add that not a single erratic or loose fragment of rock foreign to the islands was observed.

5. *Lake-Basins.*—All the lakes, with one or two exceptions, occupy true rock-basins. None, as I have already mentioned, attains a large size. They are somewhat numerous, and were formerly more abundant, for not a few appear to have been silted up, and are now represented by little sheets of alluvium and cakes of peat. As all the lake-basins we visited present the same kind of features, a few only need be specially referred to.

The *col* between Kolfaredal and the valley that takes down to Leinum is only 259 feet (79 mètres) above the sea. In the Leinum valley, a short distance below the water-parting, occurs a little lake (Mjavatn), and about half a mile or so further down is a second and larger lake (Storevatn). Mjavatn is divided by a *cône de déjection* of detritus brought down into the valley by a torrent escaping from the hills on the north side. The surface of the lake is only 12 or 13 feet lower than the water-parting—the height over the sea being 75 mètres. The lake is about quarter of a mile or so in length, and it appears to be shallow. Yet it is a true rock-basin, since the stream at its lower end flows over rock.

Storevatn is three-quarters of a mile or more in length, and half a mile or so in breadth, and seems to be deeper than Mjavatn. At its lower end it is hemmed in by rock, over which the stream flows. The height of this lake we found to be 63 mètres, or 207 feet. *Roches moutonnées* occur at the foot of both lakes, but only a thin sprinkling of angular débris is scattered over the valley. There are no true moraine mounds. Storevatn lies at the base of tolerably steep hills—the one on its north-west side being glaciated all over. The lake originally extended up the valley to the north-west, and must at one time have been nearly two miles in length.

Storevatn evidently owes its origin to the grinding action of the ice that flowed from the heights between Qvalvig and Leinum. This ice was deflected by the mass of the hill called Saaten, and would necessarily erode a hollow where the opposition to its flow was greatest. I think it is also highly probable that in late glacial times this hollow, which had been excavated at a period when the ice was thickest, would be occupied by a local glacier. Mjavatn appears to be likewise due primarily to the excavating action of the ice-sheet. It lies quite close to the low *col* or water-parting at the head of Kolfaredal, which, when the ice first began to stream down the slopes of the island, was probably a more marked feature than it is now. The water-parting may then have formed a rocky barrier against which the ice that flowed across into Kolfaredal would press with great force. Here then another rock-basin would be formed, which, however, would tend to become obliterated as the rock-barrier continued to be lowered by the grinding of the strong ice-current that passed across it. In late glacial times the hollow may have been to some extent modified by the action of a small local glacier.

Another interesting rock-basin is that in the valley of Saxen. The surface of this lake is 22 mètres or 74 feet above the sea. The valley in which it lies is wide, and comparatively flat-bottomed—the position of the lake being shown in Plate XV. fig. 21, which is a diagrammatic longitudinal section of the valley. The present stream has cut deeply into the old valley-bottom, and now flows some 140 feet or so below its general level. The lake-basin appears to have been excavated in the bed of the old valley which rises some 60 feet or so above the surface of the water. I saw no trace of old water-levels, which would indicate a former greater height for the lake. But its borders are strewed with so much débris fallen from the heights above, that any such traces might well be obliterated. I think it most probable, however, that the lake-surface was never much higher than it is, but that the deepening of the outlet went on contemporaneously with the excavation of the rock-basin, and consequently that the deep gully in which the stream now flows is not entirely of post-glacial origin. It is worthy of note that the water-parting of the valley in which the Saxen lake-basin occurs is a mere flat *col* like that of Kolfaredal. The glacier to which it owes its origin did not therefore head in lofty, steeply-inclined valleys and corries, but was rather a thick flattened mass of ice that gathered deeply over the low-lying *col*, and seems to have flowed both to north-west and south-east.

Besides these larger lakes, which occupy nearly the whole breadth of the valleys in which they occur, very many lakelets lie in cirques. The great cirque of Howe, for example, is studded with lakelets. I counted upwards of twenty, varying in breadth from 50 or 60 feet up to several hundred yards. They are all true rock-basins—the bed of the great cirque in which they lie being also abundantly covered with well-marked *roches moutonnées*. In the numerous smaller cirques that occur in Suderöe and the northern islands, lakes are of almost invariable occurrence. Now and again, however, such lakes have become silted up, and are replaced either by flats of alluvial detritus and peat-moss, or by quantities of rough débris which have tumbled from the surrounding precipices. All these cirque-lakes are unquestionably of glacial origin—the cirques themselves having been originally formed by the action of springs and frost, and subsequently deepened and excavated by small local glaciers and *glaciers remaniés*, as I shall describe more fully in the sequel.

The rock-basins visible in the islands themselves have thus been excavated under varying conditions. Some, as we have seen, have been hollowed out when the ice was at its thickest. They belong to the period of general glaciation, while many are due to local glacial action, which has likewise in some cases modified the results produced by the erosion of the ice-sheet. In the great amphitheatric cirque of Howe, we see how innumerable small rock-hollows may be scooped out by the action of one and the same ice-flow. Doubtless, most of these little basins owe their origin to some accidental circumstance. In some cases, perhaps, the rock has yielded unequally, owing to more abundant jointing or to differences in mineralogical composition and petrological structure. In other cases the basins may simply indicate localities where the ice, owing to the form of the ground, was enabled to exercise greater intensity of erosion.

VI. Origin of the Valleys and Fiords: Subaerial and Glacial Erosion.

1. *Forms of Valleys.*—I have already made brief reference to the various forms assumed by the valleys, and must now describe these a little more fully. For this purpose I shall select one or two examples which may be taken as typical of all the others.

The great cirque-valley of Howe in Suderöe is one of the finest to be met with in any of the islands. It opens upon Howe Bay on the east coast of Suderöe with a breadth of nearly one mile. Its bottom is gently undulating, being studded with clustering *roches moutonnées*. Following the stream upwards we are suddenly brought to a cliff or wall of rock at a distance of rather more than a mile from the sea. This wall circles round the valley, and appears to form its head. But when it is surmounted we find a second broad cirque-like valley bounded in like manner by steep cliffs, above which other cliffs rapidly succeed, rising tier above tier to the summits of the bare rugged mountains. This upper cirque-valley is wider than the lower one, and its bottom is covered with *roches moutonnées*, in the hollows amongst which occur the numerous lakelets of which I have already spoken. What chiefly impresses one is the great width of the valley relative to its length. From the sea to the head of the upper cirque is just some three miles; yet the width of the valley at its upper termination, at the base of Borgaknappan, is nearly one mile and a half (see Plate XIII. fig. 1).

The geologist, crossing from Saxen to Tiörnevig in Stromöe, will traverse two very characteristic valleys. The stream which comes from the north falls into Saxenfiord down a succession of steep cliffs. When we ascend these cliffs, which are perhaps 400 or 500 feet high, we find ourselves in a flat-bottomed valley bounded by encircling cliffs of dolerite, above and beyond which another similar but shorter cirque-valley appears. Between this upper plateau and the valley of Tiörnevig the water-parting is reached at a height of 1693 feet (516 mètres). From this point the ground descends rapidly towards the north-east into another cirque-shaped valley, the sides of which consist of a succession of narrow plateaux, so that the stream descends by leaps from one stage to another till it reaches the sea at Tiörnevig (see Plate XIII. fig. 2).

Similar features characterise nearly all the valleys. They descend in a series of platforms, which vary in number, breadth, and relative height, but invariably present the same features. Those I have now described agree in this respect that they all have well-defined water-partings; to get from one valley over into the other we must ascend and descend several hundred feet. But there are other valleys, the heads of which coalesce, as it were, so that we pass from the one into the other over a low flattened *col* or water-parting. Such valleys form the great hollows which I described in a previous section as crossing some of the islands from sea to sea. The lofty rock-barriers which must at one time have separated the heads of these valleys have been demolished. The measurements we obtained in Kolfaredal will illustrate the general character of those remarkable hollows. From Kollefiord we found that the valley rose to the water-parting (259 feet) with a mean inclination of 13° or 14°. The water-parting itself is low and flat, and it was hard to distinguish any culminating point. The descent on the other side of the water-parting is very gentle, the fall being only some 50 feet or so for the first two miles. After this the sea is reached at Leinum in less than a mile—the fall being of course more than 200 feet in this short distance.

2. *Fiords.*—The soundings upon the chart prove that the long fiord which separates Stromöe from Österöe, occupies the bed of two submerged valleys with a low separating *col*, over which there is shallow water. This *col* occurs in the narrow part of the sound between Nordskaale and Öre, and the soundings show that from this point the water deepens both towards north-west and south-east. The fiord is shallower at its mouth near Eide, where there are 5½ and 9 fathoms of water, than it is at and above Haldervig, where we get depths of 18 to 30 fathoms. The southern part of the fiord has not been sounded, but it is probably the deeper of the two sections. Many of the other sounds between the islands are apparently of the same nature as that just described—

such as Qvanna Sund, Svinöefiord, Harald Sund, Kalsöefiord, Leervigsfiord, Westmannsfiord, &c. An elevation of 200 or 300 feet would probably suffice to run the sea out of all these fiords and sounds and convert them into valleys, communicating with each other across low level *cols.* They would, in short, resemble the long hollows that have already been described as crossing the islands from shore to shore. Conversely, were the islands to be submerged for 200 or 300 feet, new sounds and fiords would make their appearance, and Stromöe would be cut up into three separate islands, Österöe into two, Boröe into two, and Suderöe into three, while the present fiords would then cover all the low grounds at their origin, stretching back into those broad amphitheatric cirques which are so prominent a feature in the configuration of the Færöe Islands.

Although the fiords are never very deep, they yet, as we have seen, resemble those of Scotland and Norway in this respect, that they are shallower at or near their mouths than somewhat further up. Unfortunately, the soundings indicated upon the chart are not numerous, and reliable details are thus wanting. But the fishermen assured us that it was certainly true that the fiords were deeper above than below their entrances. The soundings between Österöe and Stromöe show that Sundene at least has this character; and it is interesting to observe that the deepest portion of that fiord occurs just where it should if the depression owed its origin to the grinding action of the ice that flowed towards the north. There appears also to be a deep excavation in the sea-bottom to the north of Naalsöe, comparable to the deep hollows that are met with along the inner margin of the Outer Hebrides and many other islands off the Scottish coast—hollows which I have elsewhere shown must be attributed to the erosive action of glacier-ice.*

3. *Trend of Valleys and Fiords: Main Water-parting.*—One sees at a glance that the Færöe Islands are only the more mountainous parts of a region which has been submerged within comparatively recent geological times. And it is not difficult to account for the north-west and south-east trend of so many of the valleys and fiords. If we draw a somewhat undulating line from north-east to south-west between Svinöe and Waagöe, we traverse in so doing the main water-shed of the islands, and what must likewise have been the chief water-shed when the land stood several hundred feet higher. Now, if we suppose the original surface of the land to have been gently undulating, there can be little difficulty in accounting for the trend of the valleys and fiords. What is now the main water-parting will represent the low undulating water-shed of the old table-land—the ground to north or north-west of the line having a gentle fall in that direction, while to the south of the line the inclination would be to

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* The Great Ice Age, p. 289; Quart. Journ. Geol. Soc., vol. xxxiv. p. 861; Trans. Geol. Soc. Glasg., vol. vi. p. 161.

south and south-east. In addition to that main line of drainage, there would of course be subsidiary water-partings, such as that which runs down through Stromöe between Saaten and the heights that lie to the south of Thorshavn. From this water-shed streams would flow east in the direction of Kollefiord and Kalbaksfiord, and west into what is now Hestöefiord.

4. *Origin of Main Water-parting, &c.*—To what the original superficial undulations of the old table-land were due it is not so easy to say. Evidence is not wanting, however, which seems to show that in some cases the direction of a valley may have been determined by the dip of the strata. Thus in Fundingsfiord the dolerites dip approximately in the same direction as the fiord or E.N.E., and similar appearances were noted in Andafiord, where the beds incline to north-east. Again, on the south side of the main water-parting nearly all the fiords and valleys run towards the south-east, or approximately in the same direction as the dip. On the other hand, it will be noted that some of the valleys and fiords trend at right angles to the dip, particularly in Österöe and Suderöe, while others run in a direction exactly opposite to the inclination of the strata. It is possible, therefore, that the coincidence of the dip with the trend of certain valleys and fiords may be to some extent at least accidental, and that the configuration of the original surface may have been determined only in part by the inclination of the bedding. It seems not unlikely, indeed, that mere irregularities in the deposition and accumulation of the youngest or latest of the trappean strata may have had much to do in producing the primeval water-sheds of the old table-land; so that, while the original streams would in many cases flow with the dip of the rock, they might in other cases frequently be compelled to run in some different direction. It is even quite possible that the strata may have been slightly tilted since the streams first began to carve out the hollows which are now land-valleys and sea-lochs. For example, the dolerites in the north of Österöe and Stromöe may have been approximately horizontal or even had a slight dip towards the north-west when running water commenced to carve out the now submerged valley between Nordskaale and Eide. If the subsequent tilting were slowly effected, the erosion of the valley might have kept pace with the elevatory movement; the direction of the drainage need not have been reversed. But we see now such a very small portion of the ancient volcanic plateau that it is almost useless to speculate upon the various causes, for there may have been many not now apparent, which determined the principal water-sheds of the now fragmentary table-land. MACKENZIE was of opinion that the narrow channels that separate the islands might have originated in the destruction of large basalt-veins, removed by denudation in the same manner as those smaller veins and dykes which are seen giving rise to caves and hollows along the shore-line. The fiords, however, are as we have seen simply submerged valleys, and there is nothing to show that the valleys

of the land have been hollowed out along the course of large dykes. Many of the small veins which are now exposed to the action of the weather certainly crumble rapidly away, and so give rise to more or less deep gullies. We have no reason to believe, however, that any dykes actually reached to the original surface of the old plateau. And if they did break through that surface they must have overflowed, and cooled under circumstances which would necessarily produce a rock differing considerably in character from that of the dykes which we now see, but probably approaching to that of the dolerites which they intersect.

5. *Atmospheric Erosion.*—From the appearances presented by the land-valleys there can be no doubt that these hollows owe their origin to the action of the usual atmospheric agents, aided by the subsequent erosive powers of glacier-ice. To make this clear, a few notes on the nature of the subaerial denudation now going on seem desirable, and these I shall supplement with some remarks on the effects that have been produced by former glacial action.

Although the basalt-rocks of the Færöe Islands, when freshly exposed, are hard and tough under the hammer, yet their composition and structure render them peculiarly liable to more or less rapid denudation. Not only are they frequently decomposed by the chemical action of the atmospheric forces, but their abundant jointing enables frost to act most effectively upon them, while the work of demolition is still further aided by the horizontality of their bedding. I have already mentioned the fact that some of the basalts weather more readily than others, and that even in one and the same bed there are often great differences in this respect. Thus certain basalts show rough irregular surfaces —the wacké-like portions crumbling to earth and sand—while the harder parts weather less rapidly, and thus amorphous hollows, and ruts, and shapeless humps, knobs, and ridges come to diversify the faces of the rocks in many localities. These appearances, however, are best seen in the sea-cliffs. In the inland valleys the hollows in the rock are often masked by the fall of débris from the ledges above, and are only conspicuous upon very steep cliffs where the loose material finds no angle of repose. As some basalts weather more rapidly than others, their demolition often leads to the destruction of the harder masses that overlie them. The latter are undercut, and by and by large segments split off and fall away. But the undermining of the rocks is carried on in the most marked manner by springs which frequently issue in abundance all along the outcrops of certain beds, particularly when more or less impermeable tuffs alternate with the basalts. This action results in a more or less steep cliff, broken by little sloping ledges which are often thickly carpeted with bright green mosses, in striking contrast to the bare walls of brown rock above and below them (see Plate XV. fig. 23). Not only are the basalt-rocks undermined by the mechanical action of the springs, but they are of course abundantly subject to the action of frost, and immense quantities of débris are thus showered down the precipices. One can see that the denudation is going on rapidly in many places, and thus gradually destroying the glaciated aspect of the ground.

The low dip of the bedding greatly aids the frost and springs in their work of destruction, and now and again considerable landslips take place in consequence. At Tiörnevig in Stromöe we saw the cultivated grounds to a large extent buried under masses of débris and large blocks which had fallen suddenly only a year or so before our visit, and the evidence of similar landslips having occurred in many of the higher valleys of the islands was abundant and conspicuous. So rapid, indeed, is the destruction of the mountains that one is apt to wonder that the valleys are not more plentifully covered with débris ; for the streams are insignificant, and hardly able to carry seaward any large proportion of the débris showered down the slopes by springs and frosts. Nevertheless, some of the streams during floods would seem to overflow wide areas, and probably carry seaward no inconsiderable amount of material. They are fast silting up the lakes, and many of these have already been obliterated. And the same silting-up process is going on in the fiords. Thus Saxen Fiord, which was once a good harbour, and could be entered by sloops and other vessels, will now hardly admit a small boat. It was not quite low tide when we entered, and yet our boat grounded several times, and was only brought to shore by dint of vigorous pushing. I have little doubt that could the quantity of material carried down by the streams be fairly estimated, we should find it considerably in excess of what might have been supposed.

It is evident that springs and frosts have been among the chief agents in widening the valleys. When the streams first cut down into the basalt-rocks, they doubtless flowed in more or less deep trenches—the walls of which, undermined by springs and riven by frost, would gradually recede. Moreover, owing to the regularity of the bedding, and the low dip of the strata, the retreat of the opposing cliffs would be tolerably uniform, so that each valley would tend to retain a somewhat equable breadth throughout. But as the streams in their course traversed a series of beds—some of which would yield to denudation much more readily than others—the waters would descend in a succession of runs and leaps. Each hard bed of trap, which happened to be underlaid by a more or less thick band of soft tuff or decomposing earthy amygdaloid, would give rise to a waterfall, the crest of which would gradually retreat up the valley as the trap continued to be undermined by the rapid wasting-away of its pavement. It would rarely or never happen, however, that all the waterfalls in a valley would retreat at the same rate, and thus one would in the course of time overtake another, with which it would coalesce, as it were, to form a higher fall.

This heightened cascade would in like manner gradually retreat up the valley, and perhaps would merge with others before it finally reached the steeper slopes in which the stream originated. The retrocession of the rock-walls however, would not be entirely due to the action of the stream—for the undermining process would be carried on at the same time across the whole breadth of the valley by the action of springs and frost. In short, the rock-face would recede up the valley in the very same manner as the loftier lateral cliffs, between which the water flowed. The Færöe Islands afford numerous examples of every stage in this kind of valley-formation. In Kolfaredal we find the valley-bottom rising from the sea-level with a gentle acclivity to the watershed —the rock-walls and cascades have disappeared. In other valleys, again, we have the bed rising with the same low inclination until it is hemmed in, as it were, by a rock-wall over which the water pours from an upper platform. This latter in like manner slopes gently upwards until it is suddenly cut off by a similar rock-wall, above which a third flat-bottomed course succeeds, terminated by another steep face of rock, and so on. The steeper the gradient of a valley the more numerous do the transverse cliffs and waterfalls become, which of course is only what might be expected from the comparative horizontality of the strata.

Valleys, excavated in the manner described, are necessarily more or less cirque-shaped at the head, and similar but usually smaller lateral cirques open upon them at various levels throughout their course. These lateral cirques have been formed by the locally rapid recession of the valley-cliffs. Here and there some particular bed, perhaps pretty high up in the cliff, is more quickly undermined than the strata below it, and the upper section of the cliff therefore tends to recede more rapidly than the under. In this way small lateral cirques are formed which collect the tribute of the springs and send down their cascades to the main stream.

6. *Former Greater Rainfall.*—Now the recession of all those rock-walls and cliffs results in the production of enormous quantities of débris, the accumulation of which, if it be permitted, must in the course of time bank-up the precipices and retard their waste. And this is precisely what is taking place. The streams are unable to carry away all the loose material which is brought down the slopes by the action of springs and frost. It is evident, therefore, that the time must arrive when these slopes will become more or less masked or concealed under their own ruins. Even now one may see the process far advanced in many mountain-valleys —great curtains of débris hanging from the higher parts of the hills, and sweeping in long trains down to the low grounds, where they gather upon the bottoms of the valleys, and are often left undisturbed by the streams, confined as so many of these are to narrow post-glacial trenches. It is clear, then, that there must have been a time when the rainfall in the Færöe Islands was more considerable

than now—a time when the streams flowed in sufficient body to flood their valleys, and to prevent the undisturbed accumulation of débris-banks at the base of their cliffs. It is quite impossible that the valleys could have been excavated to their present breadth by the small streams of to-day—even with all the aid of springs and frost. These streams are now busied in digging narrow trenches in the flat bottoms (as shown in Plate XV. fig. 22), forming as it were valleys within valleys.

7. *Glacial Erosion of Valleys, &c.*—There are many appearances, however, which cannot be explained by aqueous erosion even on the supposition that the rainfall was formerly more excessive. The width of many of the cirques, the form of the valley-bottoms, the presence of rock-basins, and other phenomena all testify to powerful glacial erosion. The rounded and somewhat undulating contour of the valley-bottoms, and the smoothed and bevelled appearance of the cliffs are conspicuously glacial. The valleys have been glacially deepened and widened, and the harsher features which the cliffs must have presented in preglacial times have thus been softened down. The demolition of the rocky *cols* between two valleys is also unmistakably the work of the ice. As with the valleys so with the amphitheatric cirques, large and small alike, and whether forming the head of a valley or opening abruptly upon a valley from a mountain-slope—all have been considerably modified by glacial action—many containing rock-margined lakelets. When local glaciers occupied these cirques, the recession of the cliffs by which they are surrounded would proceed at a rapid rate—the débris, instead of gathering at their base and forming a protecting mantle, being carried outwards and drifted over the rock-ledges to some lower glacier, or *glacier remanié,* upon the surface of which they might be carried down to sea.

8. *Weathering of Glaciated Surface.*—But throughout all the islands the features impressed by former intense glacial erosion are now, as I have said, being more or less rapidly effaced. *Roches moutonnées* are breaking up and disappearing; ice-worn cliffs are being chipped and shattered by frost; great taluses of débris are accumulating at the foot of scaur and precipice; rock-basins are being tapped and silted up; streams are digging deep gullies in the flat glaciated bottoms of cirques and valleys; and thus erelong the characteristic ice-worn outlines will vanish, and those features which must have characterised the islands in early preglacial times will come more and more prominently into view.

9. *Limited accumulation of Till upon Land.*—When the islands were enveloped in their ice-sheet, the action of frost would be confined to such ridges and hill-tops as projected above the *mer de glace*, while severe glacial abrasion would go on below. This abrasion, carried on doubtless during a prolonged period, resulted in the more or less complete removal of all great banks of débris

that cloaked the valley-slopes,—in the bevelling and rounding-off of basalt-cliffs and ledges,—in the deepening and widening of cirques and valleys, the levelling of valley-bottoms, the reduction of low-lying water-partings or *cols*, and the excavation of rock-basins. It is in accordance with all that we know of the glacial phenomena of Scotland, Norway, and Switzerland, that the material produced by glacial abrasion should not have collected in any great quantity under the ice. The gradients, as a rule, are too steep, and comparatively little till, therefore, was accumulated in the valleys, the great mass having doubtless been rolled out to sea, and spread over the sea-bottom—part of it probably being carried away by the icebergs that broke off from the terminal front of the ice-sheet.

10. *Direction of Ice-flow and Extent of Ice-sheet.*—The undulating lines which I have described as indicating the primeval water-shed of the old table-land also mark out the centres from which the *mer de glace* flowed. The long sound that separates Österöe from Stromöe brimmed with ice which flowed in two directions. North of Nordskaale the movement was northerly, while south of the shallow part of that sound the ice held on a southerly course. So thick was the *mer de glace* that its upper strata flowed across Kollefiord and Kalbaksfiord, and even overwhelmed Naalsöe. All Stromöe south of Kalbaksfiord appears to have been smothered in ice flowing to south-east, and I believe that the direction of the flow in Hestöefiord was the same. Sandöe was also overwhelmed, nor can there be any doubt that the ice which covered it was continuous with that which cloaked all the islands to the north. Of these last it is enough to say that so far as our observations went, they appear to have been glaciated invariably in the direction of the principal fiords. A glance at the map, indeed, will show that the ice streamed outwards everywhere from the dominant high grounds.

The appearances in Suderöe are extremely interesting, inasmuch as they prove that the ice of that island, although for the most part strictly local, and flowing east and west from the chief heights, was yet connected with the *mer de glace* of the northern islands. This is shown by the fact that glacier-ice has passed up Qvalböefiord across the island to the west coast. That ice could not have come from Suderöe itself, but from a thick glacier-mass occupying the bed of the sea between Suderöe and Sandöe. In other words, the ice-sheet of the northern islands must have coalesced with that which covered Suderöe. This is not astonishing when we remember that the *mer de glace* of Stromöe must have reached a thickness, at what is now the sea-level, of 1500 or 1600 feet. So thick a mass could not have floated off in the shallow water (20 to 40 fathoms) that separates Suderöe from the northern islands. But the ice that streamed south from Stromöe and Österöe was thicker even than these depths imply. To the north of Naalsöe we get a depth of 120 fathoms which must have been filled up of course before the ice could overflow that island. This indicates a mass of ice not less than 2200 or 2300 feet in thickness. In Suderöe, again, the upper surface of the ice attained a height of 1400 feet, which we may take as the thickness of the stream that flowed out of Trangjisvaagfiord and Howebugt. We cannot wonder then that the shallow seas which separate the Færöe Islands were completely filled up, nor that the outflow of ice from Suderöe should have been controlled by that coming towards it from the north. The direction of the striæ and *roches moutonnées* at the head of Qvalböefiord agrees with that of the glaciation in the west of Sandöe, and seems to point to a general movement of the *mer de glace* towards the south-west. Probably all the ice that lay to the west of Skuöe and the two Dimons flowed in this direction, while that which lay to the east of these islands participated in the south-easterly movement.

How far out to sea the ice-sheet extended can only be conjectured, but judging from the thickness it attained upon the islands, and in the sounds and fiords, it may well have reached what is now the 100-fathoms line, where it would break away in bergs. Like the greater *mers de glace* of Europe and North America, it tells a tale of excessive evaporation and precipitation, and one ceases to marvel at the thickness attained by the ice-sheets of those vast continental regions when one sees the indisputable evidence of a very considerable sheet of glacier-ice having covered even so limited an area as that of the Færöe Islands.

11. *Origin of Erratics and Morainic Débris.*—The large erratics which are scattered over hill-tops and hill-sides were doubtless deposited by the *mer de glace* during its final dissolution; and the erratics and loose morainic débris that occur in the valleys mark out, in like manner, the gradual disappearance of those local glaciers that still occupied the hollows of the islands after the higher grounds had been relieved of their icy coverings. I have mentioned the fact that valley-moraines are much less numerous than one might have expected, when the shattery character of the igneous rocks is kept in mind. It is true that considerable quantities of loose morainic-like débris are frequently scattered over the bottoms of the valleys, but well-marked mounds of morainic origin appear to be of rare occurrence. We saw some in the valley leading down to Westmannshavn, and some of the mounds in the Saxen valley may be moraines, but such of them as were exposed in section proved to be *roches moutonnées* buried under their own ruins. It is difficult to account satisfactorily for this scarcity of moraine mounds, more especially when we remember that in other countries, such as Scotland, North of England, Wales, Ireland, Norway, Switzerland, &c., where the rocks as a rule are less easily acted upon by the weather, distinct valley-moraines are yet more or less abundantly met with. The following considerations, however, may help to explain the apparent anomaly.

1*st.* Long after the general *mer de glace* had become reduced to a series of small isolated glaciers, it is probable that snow and névé may have continued to cover the land so as to protect the rocks from the excessive waste which they now experience. The superficial moraines, therefore, need not have been very extensive.

2*d.* Again, we must remember that the conformation of the ground, unlike that of the Alps, would not favour the preservation of large valley-glaciers after the snow-fall had become less, and the snow-line had retreated to a higher level. The ice which formerly occupied all the valleys of the Færöes could only have been sustained by the copious precipitation of snow over the whole land-surface. But when the line of perennial snow had risen to 1000 feet or thereabout, only a few local glaciers would probably exist at the heads of the valleys, while *glaciers remaniés* would be distributed along the flanks of the valleys at all those points where torrents and cascades presently appear. There would be no large trunk glaciers formed by the union of considerable lateral glaciers, as in the valleys of the Alps. Thus there would be a general absence of terminal moraines in the middle of a wide valley, for the superficial débris would be distributed chiefly along the flanks of the glaciers and in front of the small *glaciers remaniés.* Moreover, the moraines thus formed would tend to become obscured by the gradual accumulation upon them in post-glacial and recent times of rock-rubbish detached by the weather from the cliffs above.

3*d.* But the principal reason for the apparent scarcity of valley-moraines was probably the continuous and comparatively rapid dissolution of the ice after the snow-line had retreated several hundred feet above the sea level. The ice would appear to have made no long pauses in the valleys, as the ancient valley-glaciers of Britain did, but melted gradually and continuously away. The distribution of the morainic material in sheets over the beds of the valleys seems to point to the destructive action of water escaping from the dissolving glaciers. The detritus thus formed has much the character of that loose aggregation of coarse shingle, earthy grit, and boulders, which is known in Switzerland as "Alpine diluvium."

VII. Marine Erosion.

The erosive action of the sea is admirably exhibited along the shores of the islands, and more especially upon those parts of the coast-line that face the open ocean. Everywhere the cliffs are undermined and eaten back, the rate of erosion varying according to the character of the rocks at the sea-level. The rapid recession of the cliffs is aided not only by the soft and decomposing character of so many of the basalt-rocks and tuffs, but also by the abundant jointing of the rocks; and springs and frost are evidently as actively engaged along the sea-cliffs as they are upon the steep slopes that overlook the valleys. But the influence of jointing upon denudation is certainly most marked in the sea-cliffs. Nowhere can this be seen to better advantage than along the magnificent shore-line of Stromöe between Westmannshavnfiord and Mýling. The cliffs there are nearly vertical, and show broad, bare, plane faces, that look often as if they had been only freshly fractured or sliced. Towards the top they are more rugged, and grass grows on all the little ledges, giving the appearance to the cliffs of having been sprinkled with green tufts. The upper parts of the cliffs are often riven by the frost into peaks, spikes, and spires. This great rock-wall, I may add, ranges in height from 1200 feet or so up to 2277 feet. Between Muulen and Saxen occur some splendid stacks called the "Drangar" (isolated or lonely ones). Some of these are not less than 400 feet in height. They taper upwards to sharp pinnacles, and one of them, called "Toskuradrangar," which forms a long wall running parallel to the cliff, is pierced by a lofty portal. Long vertical master-joints are conspicuous in the cliffs at irregular intervals, and give rise to hollows and caves. All the caves we saw between Muulen and Saxen were worked out either along the lines of such joints or in vertical dykes of basalt. They occur in all stages. Here one sees the process just beginning,—a little cleft only a foot or two in width, and a few feet in height. There again one observes another which shows a somewhat greater breadth and height, the height almost invariably exceeding the breadth. Sometimes as many as twenty caves can be counted in the space of a quarter of a mile or less, varying in extent from a few feet in height and breadth to large caverns 20 to 50 feet in height, and somewhat less in breadth, which penetrate the cliff for some considerable distance. The master-joints just referred to seem to cut the cliffs at right angles to their trend, and they are crossed by another set of great joints which have the same direction as the coast-line. Thus when the sea has undermined the cliff to a certain extent, the strata eventually give way and great segments are sliced off along the lines of jointing that run parallel to the shore. These joints are, of course, not so conspicuously visible as those which cut them at right angles. Nevertheless, they were seen again and again on the sides of projecting headlands, and the clean fracture presented by the faces of the cliffs themselves clearly indicate their presence. The large sea-stacks or "drangar" seemed to me to owe their origin to the destruction of caves which had been hollowed out along both lines of jointing, the long wall-like sea-stack called "Toskuradrangar" being evidently defined by joint-planes. This well-marked cross jointing has also given rise to the remarkable indentation in the cliffs which occurs a little south of the "drangar," where the cliffs retire so as to form a kind of marine amphitheatre about 60 or 70 yards in diameter, and surrounded by nearly vertical precipices rising to some 1200 or 1400 feet.

Similar joints are well seen along the coast of most of the other islands.

They are finely displayed in those of Waagöe, Österöe, Sandöe, Skuöe, and Suderöe, and I have no doubt that they have played a most important part in determining the trend of the coast-line where that faces the open ocean. In the quieter fiords the action of the sea, although frequently well-marked, is of course not so conspicuous.

Basalt-dykes almost invariably give rise to caves. This is due not so much to the decomposition of the basalt (which is generally a harder and less easily decomposed rock than the bulk of the bedded strata) as to the minutely fissured or jointed character of the intruded rock. The dykes are traversed by many long joints parallel to their direction, and by innumerable cross joints, so that they fall an easy prey to frost and the battering of the waves (see Plate XIV. section fig. 14) One of the most beautiful dyke-caves is that to which I have already referred, the " Hole under Kjetle " (Plate XV. fig. 16).

From the fact that caves occur solely at the sea-level and are nowhere seen inland, we gather not only that they are of purely marine origin, but also that no part of the Færöe Islands has been submerged within any late geological period. We searched everywhere for evidence of the former presence of the sea, but failed to find the slightest proof that the islands were ever smaller than they are now. This is in keeping with what my brother and Messrs Horne and Peach have observed in Orkney and Shetland, and with what I have noticed in the Outer Hebrides. The belief amongst the inhabitants, indeed, is that the land is sinking, but the facts mentioned by them in support of this view do not appear to be satisfactory. Thus the shallowing of Saxen Fiord might be entirely due to the action of the Saxen stream, aided by the tide itself. There are several considerations, however, which lead me to believe that the islanders are probably right in their conjecture. The present coast-line does not appear to me to be very old. Had it been of long standing I should have looked for more evidence of excessive marine erosion. We know that along the present coast-line of Scotland a terrace of marine erosion is frequently visible. Our land has stood so long at its present level, that the waves have cut back the cliffs for some distance, so that at low tide a platform or terrace of rock is more or less exposed at their base. Now the rocks of the Færöe Islands are being denuded much more rapidly than those parts of the Scottish coast-line to which I refer ; and had the land remained at its present level for any prolonged period, we might certainly have expected to meet with such rock-platforms in the Færöe Islands more or less abundantly. But the cliffs seem generally to shoot down at once into deep water, and only in a few places were sea-stacks in any number. A submerged rock-platform diversified with numerous stacks, some of which peer above the sea-level, occurs along the west coast of Suderöe, but this is apparently the only island which is thus reef-fringed. And even these reefs are perhaps too deeply submerged to have been cut down by the waves at their present level. I should infer that, if the islands are not now sinking, they have within recent times experienced some degree of depression.

VIII. Peat and Buried Trees.

The low grounds and gentler slopes in the islands are often coated with thick turf or peat, which is extensively dug for fuel. It varies in thickness from two to six or eight feet; and here and there, in what appear to be the bottoms of old lakes, it may possibly be thicker. So far as my observations went, the *Sphagnaceæ* appeared to form a smaller proportion of the peat than is the case in Scotland. At the bottom, roots and twigs of brushwood are frequently present, and in some places they are quite abundant. The largest pieces we saw were not more than an inch thick, but we were informed by the people, who were digging the turf in Österöe, Stromöe, Sandöe, Suderöe, and other islands that sticks as thick as one's wrist were common; and at Eide in Österöe, the merchant there told me he had seen them taken from the peat near Eide Vatn as thick as his leg. I could not determine the species of wood with any certainty, but the pieces I saw were probably juniper and birch. No brushwood now exists anywhere in the islands, except in the private gardens and enclosures at Thorshavn, yet the evidence supplied by the peat makes it certain that the lower parts of the Færöes must formerly have been pretty well clothed with brushwood and small trees. This was of course in post-glacial times, when the islands were probably of considerably greater extent, and enjoyed a climate more suited than the present to the growth of arboreal vegetation.*

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* I have elsewhere endeavoured to show that the Færöe Islands were connected with Scotland in post-glacial times. See Prehistoric Europe, p. 518.

IX. EXPLANATION OF PLATES.

Plate XIII.

Fig. 1. Represents a horizontal section, drawn along the line A.B., upon the map, across the Island of Suderöe. The horizontal and vertical scales are the same. The horizon of the thin coal got at Dalbofos is shown by a thick line; but it must be understood that the coal itself has been found only at one place. The beautiful columnar basalt of Frodböe is shown at *b*.

Fig. 2. This is a diagrammatic representation of the form of the ground between Saxen and Tiörnevig in Stromöe.

Fig. 3. Is a similar diagrammatic section across Österöe, between the sea at Eide and the head of Fundingsfiord. These sections illustrate a very common feature in the valleys of the Færöe Islands, many of which descend in successive platforms.

Fig. 4. Is a horizontal section, drawn to same scale as fig. 1, across the north end of Suderöe along the line C.D.

Fig. 5. Sketch-section of an exposure of strata at the coal-workings of the Præstefield (Suderöe), at a height of 147 mètres above the sea. The coal occurs in two layers, and is separated by 4 to 6 inches of shaly clay. The shales overlying the coals are interlaminated with lines and thin seams of glance coal, which are sometimes as much as 3 or 4 inches thick. There is a good deal of iron pyrites in the shales and coal-lines above the coal. The reference letters are as follows:—

d. Tumbled blocks and superficial débris.
t. Till or boulder-clay.
i. Nodules of coarse grey arenaceous clay-ironstone; 1 to 3 inches in diameter.
s. Dark shales and clays with lines and layers of glance coal and common coal; about 8 feet thick.
c^1. Glance coal; 8 inches.
d. Dark shaly clay or clunch; 2 to 8 inches.
c^2. Coal; 2 feet.
g. Space covered with grass and débris; tufaceous shales.
a. Dark anamesite.

The dip is north-east at 5°.

Fig. 6. Sketch-section of strata at Præstefield (Suderöe), near the place shown in fig. 5. The spot is 161 mètres above sea-level; the dip of the strata is towards north-east at 3°. The reference letters are as follows:—

t. Till or boulder-clay.
s. Shales and clays, about 12 feet thick, with layers and seams of coal, as in section fig. 5. The coal-lines are lenticular, and are most abundant in the shales immediately overlying the thick coals; towards the top of the section they are less plentiful.
i. Ironstone nodules in shales.
c^1. Coal; 8 inches.
d. Shale or clay; 4 inches.
c^2. Coal; 1 foot 2 inches.

Fig. 7. Sketch-section of strata at Dalbofos (Suderöe); 607 feet above sea-level:—

a. Anamesite; earthy and decomposing into rude spheroids below.
s. Fine grained greenish tufaceous shales, with fine mudstones.
s i. Nodules of coarse ironstone in greenish tufaceous shales.
b. Tufaceous, agglomeratic, scoriform upper surface of anamesite.
c. Probable position of thin coal seam (3 inches) described by Forchhammer; not now seen in place.

Fig. 8. Section of upper part of sea-cliff at Syd i Hauge, on west side of the Præstefield (Suderöe). Height of coal about 440 feet above the sea. From mouth of mine to top of overlying anamesite 50 or 60 feet.

a^1. Dull, dark blue, fine-grained anamesite; showing amygdaloidal band towards middle of the bed; decomposing spheroidally below.
s. Shattery dull green tufaceous shales with streaks and lines of coal.
c. Coal, about 3 feet; seamed with layers and streaks of clay or shale.
a^2. a^3. Anamesites of same character as a^1.
t. Line of red palagonitic tuff.

PLATE XIV.

Fig. 9. Diagrammatic sketch-section of part of sea-cliff at Frodböenÿpen (Suderöe).

a^1. Bed of anamesite, 50 or 60 feet thick, showing lines of amygdaloidal cavities.
s. Brown shales and clay; 15 or 20 feet thick.
e. Coal, about 1 foot 6 inches; with parting of shale or clay.
s i. Shattery brown mudstones resting on brown ferruginous shales, with some nodules of ironstone; 20 to 30 feet thick.
a^2. Anamesite, decomposing spheroidally.

Fig. 10. Sketch-section of basalt-veins; northern shore of Qvalböefiord, near Qvalböe.

d d. Basalt-veins.
t. Red tuff.

Fig. 11. Sketch-section, sea-cliff, Stromöe, near the Drangar.

a. Red tuff.
b b b. Amygdaloidal bands or zones in dolerite.
c c. Non-amygdaloidal dolerite.
d. Overlying bed of dolerite.

Fig. 12. Sketch-section; sea-cliff near Eidevig, Fundingsfiord.

d^1 d^2 d^3. Beds of dolerite.
a. Zone of wacké-like amygdaloidal rock, forming part of bed d^2.
t t. Beds of red tuff.

Fig. 13. Sketch-section; sea-coast near Qvitenæs, Stromöe, showing thinning out of red tuff *t*, between beds of dolerite *d*.

Fig. 14. Sketch-section; sea-cliffs west coast of Stromöe, a little south of entrance to Saxen Fiord. *b b* Dykes and veins of basalt traversing beds of dolerite, with separating layers of red tuff. Dykes are much jointed both longitudinally and transversely. Their thickness varies from a mere thread up to 12 or 14 feet. *j j* are joints traversing the cliffs and giving origin to caves c^1. c^2 shows a cave excavated in the line of a dyke.

PLATE XV.

Fig. 15. Ground-plan of a dyke with veins, near Saxen, Stromöe.

Fig. 16. *a.* Diagrammatic ground-plan of cave ("Hole under Kjetle") at southern entrance to Saxen Fiord. *c a* shows the south opening into the cave, and *c b* the north entrance. The arcade is excavated along the lines of cross dykes which are represented in the engraving by the cross hatching.

Fig. 16. *b.* shows the appearance of the dyke as seen in the roof of the cave.

Fig. 17. Sketch-section of dyke; sea-cliff, west coast of Skuöe. The cliff shown in the sketch is about 600 feet high.

Fig. 18. Hill-slope near Westmannshavn, to show glaciated contour—the sharp edges of the basalt-beds being smoothed off.

Fig. 19. Sketch-section, sea-shore, near Klaksvig, Boröe.
- *p.* Peat.
- *m.* Boulders, shingle, gravel, and sand.
- *t.* Tough hard dark blue till, with subangular glaciated stones.
- *c.* Tough brown laminated clay and sand, with no stones.

Fig. 20. Sketch-section; sea-coast, Andafiord, Österöe.
- *a.* Coarse unstratified shingle, and rough earthy grit with large boulders. Morainic débris.
- *b.* Very hard, dark greyish blue till, with subangular, angular, and blunted stones and boulders—some of the larger ones showing striæ. The deposit rests on a striated pavement of blue dolerite; the striæ point out to sea or E. 40° S.

Fig. 21. Diagrammatic longitudinal section of Saxen Valley. *l* lake; *v* bottom of old glacial valley; *s s* level of present stream (Giogværaa); *F* level of fiord.

Fig. 22. Diagrammatic section across Saxen Valley; *v* bottom of glacial valley; *s* bed of present stream; *d* débris from subaerial waste of cliffs.

Fig. 23. Diagrammatic section to show denudation of basalt-rocks, *d*, caused by springs creeping between these and intercalated layers of tuff, *t*. Talus of débris forming at base of cliff shown at *r*.

PLATE XVI.

Geological Map of Færöe Islands. The general features of the geology of the Færöe Islands are correctly indicated upon the map which accompanies Dr FORCHHAMMER's paper ("Om Færoernes geognostiske Beskaffenhed," *Kongl. danske Vidensk. Selsk. Skrifter*, 1824), of which the present is almost a reproduction so far as the delineation of the coal-crops is concerned. The dips of the strata, the dykes and veins, and the direction of striæ and *roches moutonnées* are from my own observations. The coal-crops also differ somewhat from the lines given by FORCHHAMMER, and from those on the more recent map of Suderöe by Professor JOHNSTRUP.

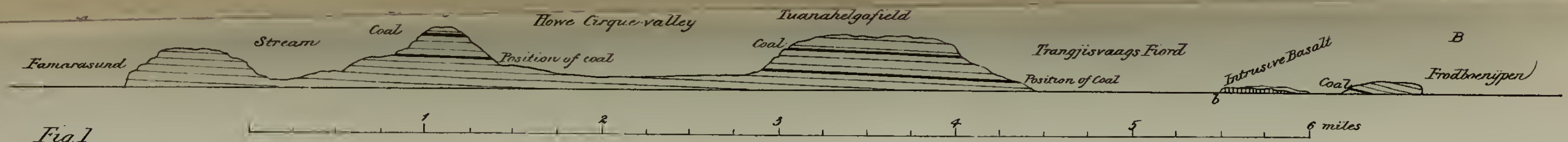
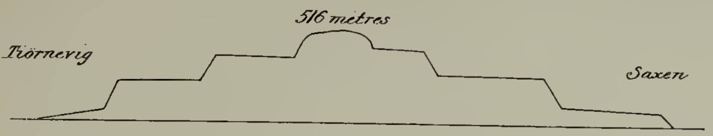


Fig. 1



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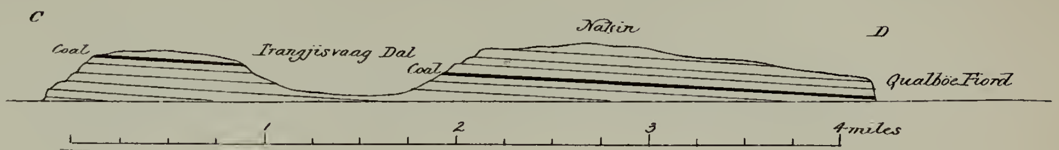

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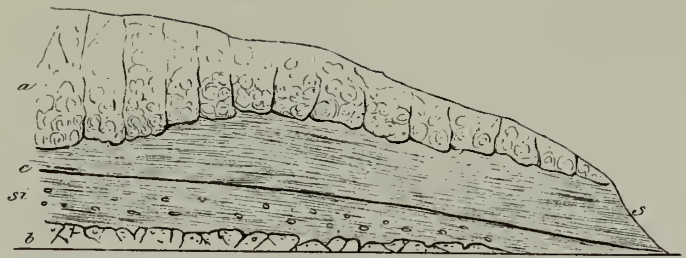

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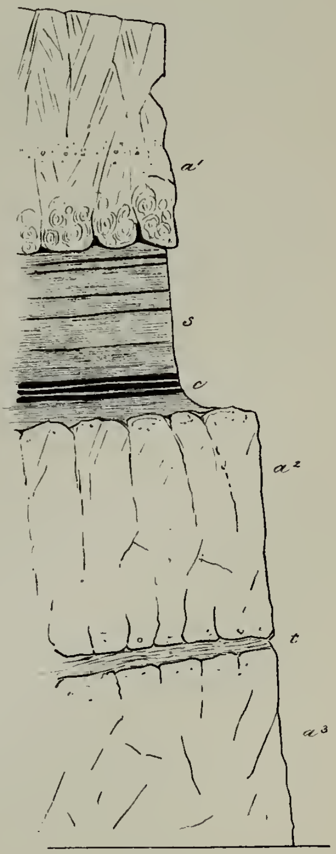

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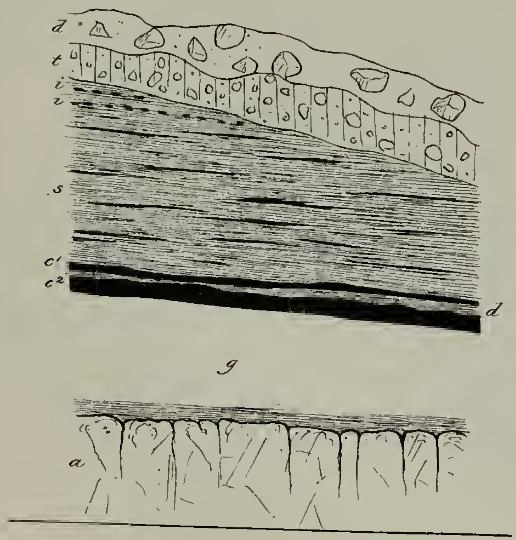

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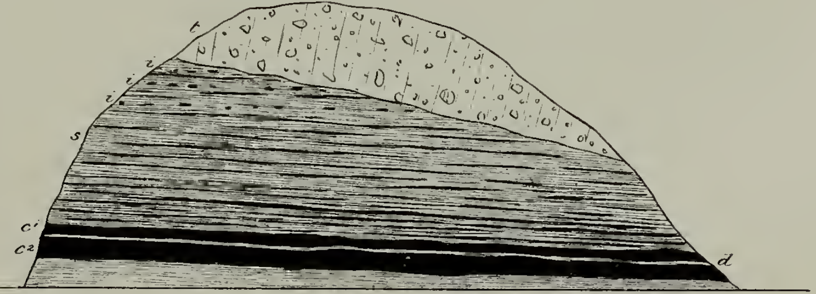

Fig. 6.

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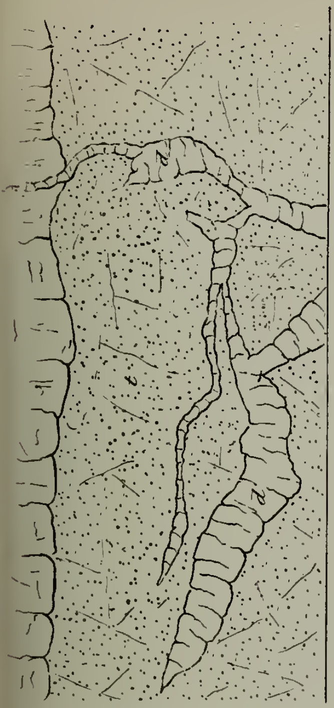

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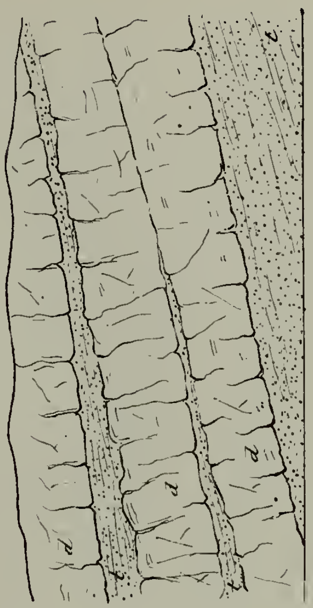

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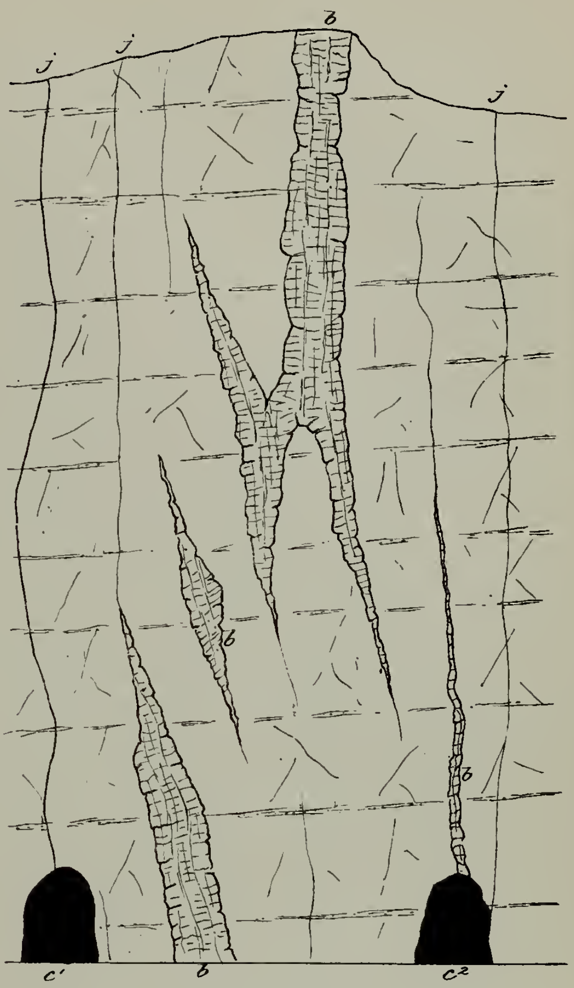
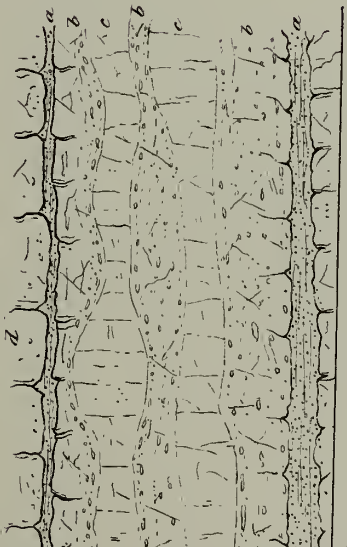


Fig. 14.

Fig. 9.



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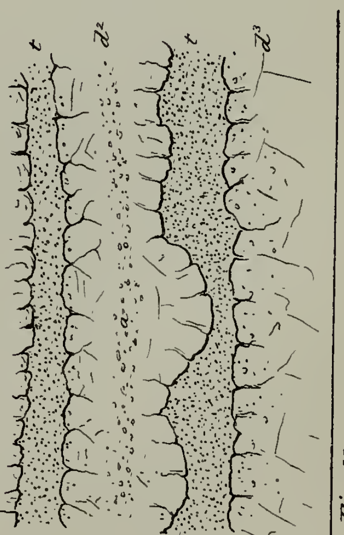

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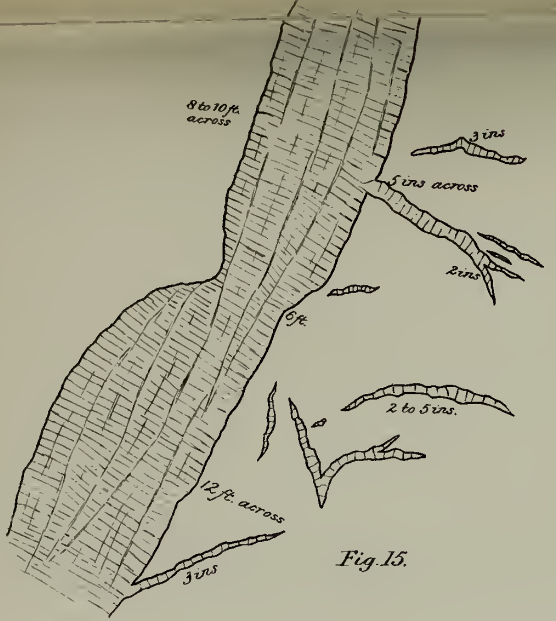

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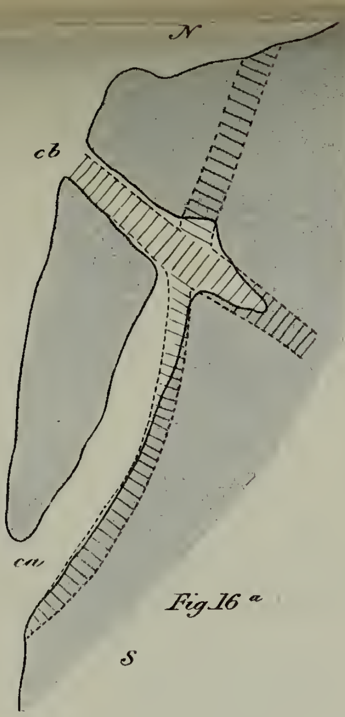
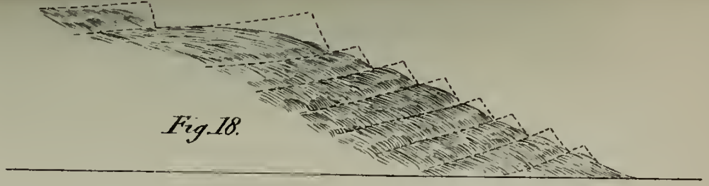


Fig. 16 a



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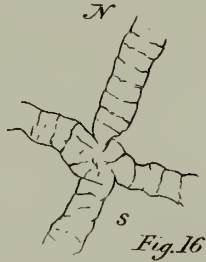
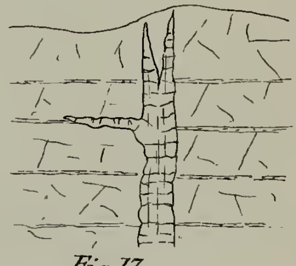


Fig. 16 b



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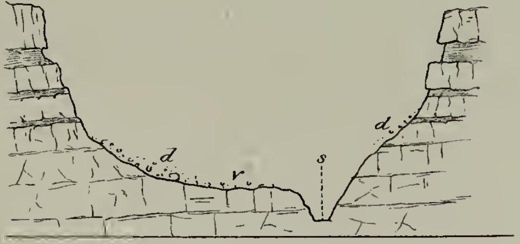

Fig. 22.

Fig. 21.

Fig. 23.

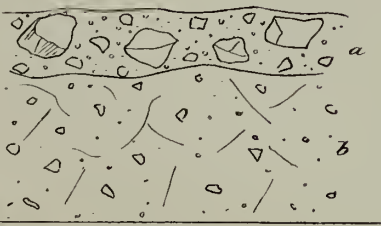

Fig. 20.

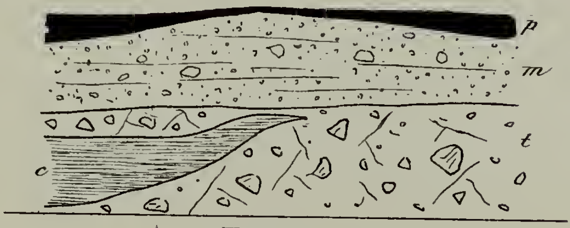

Fig. 19.

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MAP OF THE
FÆRÖE ISLANDS
Reduced from the
KAART
over
FÆRÖERNE
TRIGONOMETR^{SK} OPMAALET AF CAPITAINE BORN
udgivet fra
Det Kongelige Söe Kaarte Archiv
1806

INDEX
To Geological Colours and Signs.

- ▭ Basalt-rocks & Tuffs above Coal.
- ▭ Basalt-rocks & Tuffs below Coal
- / Intrusive Basalt
- ↙ Dip of Strata
- — Crop of Coal
- → Direction of Glacial Striæ
- ⤑ Direction of Roches moutonnées.

X.—*Researches in Contact Electricity: Thesis for the Degree of Doctor of Science.* By Cargill G. Knott, D.Sc. Communicated by Professor Tait. (Plate XVII.)

(Received July 23d ; revised October 27th, 1879).

At the surface of separation of any two different substances in contact, there exists in general an electromotive force tending to maintain a certain difference of potential between them. This principle, established for metals by Volta in 1796, has been extended by later investigators to other substances, including liquids and gases. From these early researches of Volta,[*] and the later more elaborate inquiries of Kohlrausch,[†] Hankel,[‡] and Gerland,[§] there have been deduced certain fundamental laws, which have been fully corroborated by the recent work of Clifton,[||] and Ayrton and Perry.[¶] If, of a number of conductors set serially in contact, the difference of potential between each successive pair is quantitatively estimated and reckoned positive or negative, according as the first member of the pair is at a higher or lower potential than its successor, then the difference of potential between the first and last members of the chain is equal to the algebraic sum of the potential differences between the successive contiguous pairs. Should the series be made up of simple conductors, the potential difference between the extremities is quite independent of the nature, number, and order of the intervening components, and is, indeed, equal to the difference obtained by direct contact of these extreme members. Hence, in a circuit composed of such substances (metals for example) and kept at a uniform temperature throughout, the sum of the differences of potential existing at the various surfaces of contact taken in order all round the circuit is zero. The resultant electromotive force is therefore also *nil*, and no current can exist. This result of experiment is in full accordance with the recognised principle of the conservation of energy, there being in these circumstances no source from which the current could derive its energy. Should the contact-chain, however, consist partly of compound or chemically decomposable conductors, the potential difference between the

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[*] Annales de Chimie, vol. xl. p. 225 (1801); also Wiedemann's "Galvanismus," vol. i. §§ 1-7 and 14.

[†] Poggendorff's Annalen, vol. lxxxii. p. 1 (1851), and vol. lxxxviii. p. 465 (1853).

[‡] *Ibid.*, vol. cxv. p. 57 (1862), and vol. cxxvi. p. 286 (1865).

[§] *Ibid.*, vol. cxxxiii. p. 513 (1868).

[||] Proceedings of the Royal Society (London), vol. xxvi. (1877).

[¶] *Ibid.*, vols. xxvii. (1878), and xxviii. (1879).

extremities may, and frequently does, become a function of the intermediate structure, and is then no longer equal to the direct contact-difference between the extreme members.* With a circuit including such materials in its composition, the resultant total electromotive force does not in general vanish, so that the existence of a current is possible and necessary; and the energy of this current is derived from the energy of chemical combination, which is the one aspect of the accompanying action, whose other aspect is the decomposition of the compound conductor. Except such chemical action were possible no current could be generated; so that, probably, the possibility of chemical action, and the non-vanishing character of the resultant electromotive force in the circuit, are necessarily co-existent phenomena. Such, at present, seems to be the most complete theory of the voltaic cell.

Although no current exists in a circuit of simple conductors maintained at a uniform temperature because of the mutual balancing of the contact forces, it is possible to cause a current to flow by heating or cooling one of the junctions, and thereby destroying the equilibrium of the contact forces. The energy of the thermo-electric current so obtained is a partial transformation of the energy which was originally expended in unequalizing the temperature of the system. Apparently, then, the contact-difference of potential between two metals or other simple conductors depends upon the temperature—a conclusion verified in a very remarkable way by consideration of the *Peltier effect*, or reversible thermal effect, produced by the passage of a current across the junction of two different metals. By an application of the dynamical theory of heat, Sir WILLIAM THOMSON† proved that this evolution or absorption of heat at the junction, according as the current flowed in one or other direction, indicated an electromotive contact force, acting against the current when heat was evolved, with the current when heat was absorbed. In other words, because of the difference of potential at the junction, the current has to do work when passing in one direction, and has work done upon it when passing in the other—giving rise respectively to an evolution and absorption of heat. From consideration of the principle of dissipation of energy, Professor TAIT‡ has developed a formula for this electromotive contact force, expressing it as a parabolic function of the temperature; and this theory has been indirectly verified by a long series of experiments upon the thermo-electric properties of metals.

With a view of testing by direct contact experiments the variation with temperature of the contact-difference of potential between dissimilar metals, I undertook the experiments whose results form the subject of this thesis. It must be premised, however, that any positive result cannot be regarded as due

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* See the papers of KOHLRAUSCH, HANKEL, CLIFTON, and AYRTON and PERRY, cited above.

† Transactions of the Royal Society of Edinburgh (1851).

‡ *Ibid.* (1870–71).

only to the metals; for, as pointed out by Professor CLERK MAXWELL,* VOLTA's electromotive force of contact is in general greater than that indicated by the Peltier effect, and sometimes of opposite sign—a discrepancy to be accounted for by the fact that in direct contact experiments there is always a film of condensed air or other gas between the metals when they are in so-called contact, and that possibly the chief effect "must be sought for, not at the junction of the two metals, but at one or both of the surfaces which separate the metals from the air or other medium which forms the third element of the circuit." After a few preliminary experiments I concluded that *direct* contact of the surfaces under investigation was a sufficiently accurate and constant method for indicating any appreciable change which might occur. It was found necessary, however, to keep the surfaces continually polished in a particular manner, since they gradually altered their surface condition when exposed to the action of the air—a fact formerly established by HANKEL.† Previous to any discussion of the results obtained, it is advisable first to give a description of the apparatus and method of experiment.

Of the two metallic surfaces which were the subject of experiment the lower was the upper surface of a flat cylindrical flask-shaped vessel, which rested on an insulated stand in electric connection with one pair of opposite quadrants of a THOMSON Quadrant Electrometer. The temperature of this surface was determined by the temperature of the water contained in the flask. Three such flasks were used—one of iron, one of zinc, and the third with the one flat surface copper and the other tin. The diameters of the plane faces, the thicknesses of the flasks, and their volume capacities, are as follows:—

Flask.	Diameter in Millimetres.	Thickness in Millimetres.	Volume in Cubic Millimetres.
Iron, . . .	128	17	198,000
Zinc, . . .	131	16	168,000
Copper and Tin, .	129	16	196,000

The upper plate of the condenser was a disk of approximately the same area as the lower, on which it pressed during contact by its own weight. It could be readily adjusted by screws to a practically accurate parallelism with the lower plate, and had only one degree of freedom—an up-and-down motion directed by a pin and guiding slot. It depended from the brass top of a cylindrical glass case which surrounded the insulated stand and flask on all sides, if we except the small aperture through which the internal arrangement was put in connection with the electrometer. Great care was necessary in dry

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* Electricity and Magnetism, vol. i. § 249.

† Pogg. Ann., vol. cxxvi. p. 286 (1865).

weather to avoid rubbing, and thereby electrifying this glass case, which during the experiments had to be repeatedly removed, so that the temperature inside might be observed and the surfaces repolished. The upper and movable plate of the condenser was connected with the other pair of electrometer quadrants, which were put to earth and kept constantly at zero potential. In all cases the plates were brought into direct surface contact, and the deflection on the electrometer scale caused by the charge left on the insulated flask and the connected quadrants, when the upper plate was withdrawn to a height of five inches, was taken as the quantitative estimate of the difference of potential due to the contact of the surfaces. These opposed surfaces were polished with emery paper, and dusted with dry chamois skin. The polishing was effected manually, the surface to be polished being held for the time in one hand, and the emery paper in the other, and the two rubbed vigorously together for a quarter of a minute or so. After being thus polished the surfaces were dusted and reset in as short a time as possible, an interval of about fifteen seconds elapsing between the polishing of the second surface and the first contact of the two plates.

In the first series of experiments the condenser-plates remained almost always in contact, being separated only when a reading was to be taken, or when the surfaces had to be repolished and the temperature of the water in the flask observed. The upper disk was then virtually at the same temperature as the lower. Readings were taken in groups of five at a time, the interval between each reading being conditioned by the swing of the electrometer mirror, which, under the action of the bifilar suspension, had of course to come to rest, or nearly so, before its indications could be of any value. After each group of readings the surrounding glass case was removed, the temperature of the cooling water observed, the surfaces repolished, and the whole arrangement re-adjusted precisely as before. On the whole, the five consecutive readings of any group were very consistent considering the difficulties besetting electrometer measurements of contact forces, and were sufficiently so in all but a few very exceptional cases to warrant the belief that, during the two or three minutes necessary to make the complete set of readings, comparatively little change took place on the surfaces. From theoretical considerations I was led to try iron and copper as likely metals to give positive results. In this I was not disappointed; but the difficulty of drawing any sure conclusion from the indications so obtained, or in any way deciding between the claims of the various possible explanations which might be given to account for the facts, induced me, after four months experimenting, to conduct the inquiry on a different, and what turned out to be an improved, principle. In these earlier experiments it is to be particularly observed that the two surfaces were at any instant both at the same temperature; in the later experiments the temperature of the lower surface only was made to vary, so that the surfaces were generally at different temperatures. By the former method it was found that the difference of potential between polished iron and polished copper fell off by at least $\frac{1}{130}$th of its original value for a rise in temperature of 1° C. Many series of experiments were made with these two metals, and each day's results gave the same general indication; although, as might have been expected from the nature of the inquiry, it is hardly possible to deduce from them any definite quantitative law.

The general results of eleven series of experiments are given in the following table. The first column represents the lowest temperature for which readings were taken; the second gives the electrometer deflection for that temperature due to the electrification by contact of the lower surface; the third indicates the like deflection for the higher temperature; the fourth registers that higher temperature; and the fifth notes the percentage average decrease of the deflection for unit increase of temperature.

Lower Temperature.	Deflection.	Deflection.	Higher Temperature.	Percentage Decrease.
7°C.	70	50	30°C.	1·32
14	60	35	40	1·60
13	78	58	45	·83
10	77	56	45	·78
18	110	80	50	·85
20	93	76	41	·87
23	110	85	50	·84
16	110	60	48	1·42
16	110	85	35	1·22
20	112	91	38	1·04
16	112	90	36	·98

The first four experiments give smaller readings than the last seven—a discrepancy easily accounted for by the change of circumstances occasioned by removal to another room, and a refitting of the surfaces. Yet, that in such altered circumstances the average percentage temperature-variation of the deflection should be so consistent throughout, argues strongly in favour of the reality of such a variation. A like series of experiments was commenced with a zinc surface substituted for the copper or under surface; but, though there were indications of a somewhat similar variation, these were too vague to admit of any definite deductions being made. The same was true of the aluminium-zinc pair. In this mode of experimenting, however, it was impossible to determine how much of the resultant variation of a given pair was due to the action of a particular component, or how far this variation depended directly upon the change of temperature, or indirectly through consequent material alteration of the surfaces—through oxidation, for example.

These considerations led me to abandon my first method of experimenting; and in the modified method finally adopted, the temperature of the upper plate of the condenser was kept constant, while the temperature of the lower was made to vary. This required the contact to be instantaneous, so that only one reading could be taken between each preparation of the surfaces and observation of the variable temperature. During this interval the upper plate was laid upon an iron slab, and thus kept at the temperature of the room; and just before the apparatus was reset for observation the temperature of the lower surface was noted, and both surfaces were polished and dusted as usual. The first experiments were made with two iron surfaces, which, after sufficient polishing at the ordinary temperature of the air, gave no deflection on separation after contact. The lower surface was then heated up to 70° or 80° C. in the manner formerly described, and then allowed to cool, while at rapid intervals instantaneous contacts were made with the upper surface, each contact being made as soon after polishing as possible. In this way I found that iron hot was strongly negative to iron cold, and apparently more negative the higher its temperature—in other words, the difference of potential between iron and iron increases with the difference of temperature, being zero when the temperature difference is zero. A glance at the representative curve (Diagram, fig. 2) shows the nature of this change. The six different symbols represent six different curves, five of which give the results of as many independent experiments, while the sixth (represented by the circle and dot) is the average curve formed by the combination of the others. Each point on any one of the five primary curves, is, as far as possible, the mean of five consecutive readings—a method of reduction which recommended itself as giving the most probable value for the mean contact. Each point of the final mean curve is obtained by taking the average of all such points as lie in the same temperature decade. Subjoined are the tabulated results of these experiments, the upper row of each of which gives the temperature of the lower condenser plate, and the lower the corresponding deflection on the electrometer scale.

EXPERIMENT I. (*February* 27, 1879).

(Curve symbol .).

Temperature (in degrees C.), . . .	53·8	49·4	45·4	31	23·1
Deflection, ...	21·8	21	17·4	10·8	7·2

EXPERIMENT II. (*February* 28).

(Curve symbol +).

Temperature, ...	61·9	40·7	31·6	22·4
Deflection, ...	31·7	25·2	14·7	7·7

Experiment III. (*March* 5).

(Curve symbol ×).

Temperature, ...	64·6	47·3	31	22·2
Deflection, ...	37·7	26	15·2	12

Experiment IV. (*March* 6).

(Curve symbol ∨).

Temperature, ...	66·5	36·7	34·2	25
Deflection, ...	47·5	17	16	3

Experiment V. (*March* 13).

(Curve symbol ∧).

Temperature, ...	60·4	55·5	38	30	23·2
Deflection, . . .	37	36	20	9·3	6

The reduced means for curve VI. (symbol ⊙) are as follows:—

Temperature, ...	63·1	54·6	45·7	33·4	23·2
Deflection, . . .	38·5	28·9	22·4	14·9	7·2

The temperature of the room, and therefore of the upper surface, was 12°C., at which point then the curve should meet the line of temperatures. The mean curve is obviously best represented by a straight line, whose tangent of inclination to the temperature line is — ·76, expressed in diagram units.

In seeking for an explanation of the results of these experiments, we must not neglect the possible effects due to surface oxidation, or to the change in density of the gas condensed upon the metallic surface. If the negative character of heated iron to cold iron disappeared on the cooling of the former, then the effect must be the result of some temporary change accompanying the heating—such for example as the mere change of temperature, or the driving off of the condensed gases at the higher temperature, or of both causes combined. Experiment, however, clearly proved that the originally heated surface, when cooled to the temperature of the colder surface, retained its strong negative characteristics with no appreciable diminution; from which it would appear that the observed phenomena are to be attributed mainly to a *permanent* change of surface condition depending upon the temperature to which that surface has for a brief period been subjected—probably to oxidation. It was also found by trial that no appreciable increase in the deflection corresponding to a given temperature resulted when a considerable interval of time was suffered to elapse between the polishing of the heated surface and the making of contact between it and the upper and colder surface. Whether the instantaneous contact was made fifteen minutes (the usual interval) forty minutes, or sixty minutes after polishing, the electrometer deflection was, as far as the method admitted of judging, the same. Probably after a longer lapse of time than that here specified, a change might become manifest—such a change as HANKEL long ago established for iron and other metals at the ordinary temperature of the air. In order to compare this *time-variation* of surface condition with the *temperature-variation* established above, I made a series of observations, at sufficiently distant intervals of time, of the deflections produced by contact and separation of two iron surfaces, one of which was kept constant by polishing, while the other was permitted to vary, by being simply left to itself. Both were initially polished to be the same electrically—a state of affairs evidenced by the absence of any effect on the electrometer when the two plates were separated after contact. Readings were first taken at intervals of five minutes, then at intervals of ten minutes, fifteen minutes, and finally at half hour intervals. Each number in the following table is the mean of five readings taken in rapid succession within the lapse of one minute.

EXPERIMENT X. (*May* 20).
(Fig. 1, *b*).

Time (in minutes).	Deflection (iron against iron).
0	0
5	−11
10	−14
15	−15
20	−16
30	−18
45	−19·4
75	−20

The curve corresponding to these numbers is given in the diagram (fig. 1, *b*). In its main characteristics it is very similar to an ordinary curve of cooling, and is markedly dissimilar to the curve which represents the temperature-variation of surface condition. Curves *a* and *c* on the same diagram indicate the corresponding variations for copper and aluminium respectively. The copper was electrified by contact with iron, both surfaces being allowed to vary; and the real time-variation of the copper was obtained by properly introducing the *known* time-variation of the iron. The aluminium was electrified by contact with polished zinc, to which it was originally positive, but in the course of half an hour became as strongly negative. The contacts were instantaneous, and except immediately before the taking of a reading the surfaces were kept far apart. The tabulated values for these metals are given below, the chemical symbol for each metal being employed to represent the corresponding surface, and the suffix *p* signifying that the surface to which it is suffixed was kept polished and therefore constant.

Experiment XI. (*May* 21).

(Fig. 1, *a*).

Time (in minutes).	Cu | Fe	Cu | Fe_p (=Cu | Fe+Fe | Fe_p).	Cu | Cu_p
0	−63	−63	0
2	−61	−67	− 4
7	−58	−70	− 7
17	−57	−73·7	−10·7
47	−55	−75·5	−12·5

Experiment XII. (*May* 9).

(Fig. 1, *c*).

Time (in minutes).	Al | Zn_p	Al | Al_p
0	+18	0
10	− 7·4	−25·4
20	−14·6	−32·6
30	−16·2	−34·2
45	−24·2	−42·2
60	−24	−42
90	−36	−54
1350 (observed next morning)	−47	−65

In experiment XI., the second column contains the observed values; the third is calculated from it by adding to each number the corresponding number from the iron curve; and the numbers of the fourth column are obtained from those of the third by subtracting from each the first number, which gives the deflection due to polished copper and polished iron. In experiment XII. there is no column corresponding to the second column of experiment XI., since the zinc surface employed for comparison was kept constant throughout the experiment. The corresponding curves for zinc and tin are not represented on the diagram because of their great proximity to the iron curve. In the course of an hour the change on the zinc was only 6 per cent. greater than the corresponding change on the iron; while in forty minutes there was no appreciable difference in the changes on the tin and iron surfaces.

The gradual character of the change here indicated is of special value in the present inquiry, as I hope to bring out in the final conclusions to which I have been led. Meanwhile it is advisable to give the results of the experiments on the temperature-variation of the other metals which I investigated. Though not so full and satisfactory as the results for iron, these later researches all indicate the same general facts—as may be gathered from the following tables for copper hot against iron cold, both surfaces being polished with emery paper immediately before contact.

Experiment VI. (*March* 24).

(Fig. 3; symbol .).

Temperature.	Deflection (Cu_p | Fe_p)
62° C.	−66·6
57	−68·2
52	−64·5
48	−61·5
44	−57·3
32	−54
24	−52
12	−50

Experiment VII. (*March* 25).

(Fig. 3; symbol ×).

Temperature.	Deflection (Cu_p | Fe_p)
70° C.	−69
55	−65
43	−62
30	−52
23	−47
12	−47

The conditions under which these experiments were made were the very same as those under which the temperature-variation of the iron was investigated. The representative curve is shown in fig. 3, all the points clustering approximately round a straight line whose tangent of inclination to the temperature axis is − ·39, measured in diagram units. Hence it appears that the temperature-variation of copper is smaller than that of iron, and that consequently, since the iron is the more positive metal, the difference of potential between iron and copper falls off as the temperature of both is raised—a result already obtained in the earlier experiments (see page 275).

Zinc was the next metal which came under investigation. At first it was electrified by contact with aluminium, kept polished at a constant temperature. This latter metal, however, is not very suitable, on account of its proneness to rapid change in time as evidenced by its curve on the diagram (fig. 1, *c*). Nevertheless the same negative growth of the heated metal was indicated, and more self-consistent results were obtained by contact of zinc hot with zinc cold, both polished as usual. The numbers are as follows:—

Experiment VIII. (*March* 28).

(Fig. 4; symbol ·).

Temperature.	Deflection (Zn_p | Al_p)
63°·8 C.	−78
46·5	−66
34	−64
21·8	−56·3
10	−40

EXPERIMENT IX. (*April* 4).
(Fig. 4; symbol ×).

Temperature.	Deflection (Zn_p | Zn_p)
65° C.	−42
45	−22·5
42·7	−19·2
40·6	−17·7
38·8	−18·5
28·6	−8

In the diagram (fig. 4), two lines are drawn, each representing one of the above experiments. The dotted line is that which best agrees with the readings of experiment VIII., the points on the curve of which are represented on the diagram as "dots." The curve-points of experiment IX. are entered as crosses, and they all lie very near the continuous line drawn on the diagram. The tangent of inclination of this line is − ·9, expressed in diagram units.

Apparently, then, zinc varies more rapidly with temperature than iron; and hence, since zinc is the more positive, the contact difference of potential between zinc and iron falls off, as both are simultaneously raised in temperature; a result in accordance with the indications of the earlier experiments with zinc and iron when both were made to vary similarly in temperature. This suggested the possibility that the more positive metal might be subject to the greater temperature-variation. According to this hypothesis, tin, which occupies in the electromotive series a position intermediate to zinc and iron, should give a correspondingly intermediate line for its temperature-variation. It was impossible, however, with the means I had at my disposal, to arrive at anything like a quantitative result for tin. Not having at the time another tin surface, I was compelled to make use of either zinc or iron as the other condenser plate; and, as both of these gave large deflections with tin, the readings were wild and unsatisfactory. No experiment gave even self-consistent results; and no two of them had much in common—except the undoubted characteristic which indicated a similar "negative growth" with rise of temperature of the tin surface.

As already noticed, the *permanency* of this negative-growth with temperature increase after the surface is cooled—a characteristic which was established by direct experiment in every case—proves conclusively that whatever change in the electromotive force of contact of any two of the metals, iron, zinc, copper, and tin, may be due directly to change of temperature; such a possible change is quite inappreciable by ordinary contact methods, and is altogether masked by changes due to other and secondary causes. In seeking for such causes, we must consider the probable alteration with temperature in the density of the gaseous film condensed over the metal surface, which alteration, however, is not permanent on restoration to the original temperature, provided the surface has remained the same chemically. Any permanent alteration in the density of the condensed gases presupposes, then, a chemical change on the surface; and if there be no such permanent alteration, or if it be insufficient to account for the observed phenomena, the last resource still seems to be chemical change, to which accordingly we look as the only efficient cause, whether directly or indirectly, of the changes observed in the mutual electrical relations of metals. This hypothesis is also supported by the known phenomena of time-variation of metal surfaces in both their chemical and electrical relations. The electrically negative character of unpolished iron, copper, zinc, tin, aluminium, &c., to polished iron, copper, zinc, tin, aluminium, &c., is generally attributed to surface oxidation; probably, then, the electrically negative character of polished and heated iron, copper, zinc, and tin, to polished but unheated iron, copper, zinc, and tin, is to be referred to a similar cause. If so, then the above experiments lead to the result that for these metals at least, there is for every temperature a definite surface condition which no amount of polishing can alter—a surface condition produced most probably by a film of oxide or other similar compound over the metallic surface by the action of atmospheric air; and that, further, the surface change due to change of temperature is a direct function of that temperature-change. This surface state forms within the first few seconds after polishing, perhaps instantaneously, and thereafter no appreciable change ensues till several minutes have elapsed, when the inevitable time-variation of the surface, as depicted in the curves of fig. 1, begins to show itself. Hence it would appear that at ordinary temperatures a chemically pure surface of these four metals in air is an impossibility; and that the same holds true for other metals, even for the so-called non-oxidisable, is a not improbable surmise. In this connection it should be remarked that to the eye there was no appreciable alteration of surface, no dimming of the bright metallic polish, even after the lapse of several minutes.

The experiments which form the subject of this thesis were made in the Physical Laboratory of Edinburgh, during the summer session of 1878, and the winter session 1878–79. The apparatus was, for the most part, lent me by Professor Tait, whom I here thank for the kindly interest he has evinced in my work, and the ever ready advice with which he has aided me.

Added, May 1881.—As it was just possible in the above experiments that the variations of potential observed might be affected by changes in the capacity of the condenser, further experiments were made in which any such alteration in capacity might be effectively eliminated. The two opposed surfaces of the condenser, brought to within a millimetre distance of each other, were put into metallic contact by means of external wires. In this way, after the method o

Kohlrausch, any change in the difference of potential could be measured in terms of a Daniell cell. The results obtained fully corroborated the former conclusions, as a glance at the following table will show. The first column, headed δ V, gives the variation of potential for a rise of temperature of 1° C. expressed in terms of a Daniell cell; and the second column, headed *p*, indicates the range of probable error in the estimate which was deduced as the mean of several distinct experiments.

	δ V	*p*
Zinc,	−·0028	±·0003
Iron,	−·002	±·0004
Copper,	−·001	±·0002
Tin,	−·001	±·0002

It may be noticed that of these zinc gave the most regular results. In deducing these numbers it was assumed that the variation varied directly with the temperature throughout the range of 60° C. Thus, polished zinc at 20° C. gives with polished zinc at 80° C. a difference of potential equal to ·168 of a Daniell cell—the hotter surface being, of course, the negative surface.

Many definite results were also obtained for the time-variation for aluminium, zinc, iron, and copper. The representative curves were in all cases similar to those shown in fig. 1. This being understood, the following numbers indicate the difference of potential between the polished metal surface and the same surface after twenty-four hours' standing.

Aluminium,	·3	(in terms of 1 Daniell cell.)
Zinc,	·14	
Iron,	·114	
Copper,	·086	

It was found, however, that different days' experiments gave somewhat varying results—the atmospheric conditions as to temperature, humidity, &c., having probably some effect. Indications were also obtained in the course of experiment that this time-variation depended upon the more arbitrary conditions under which the varying surface was allowed to vary; whether, for example, it was freely exposed to the air, or was left close to the opposed surface; whether it was the negative or positive element in the condenser, and such like. Where so many possible factors enter, however, it is extremely difficult to draw any sure conclusions.

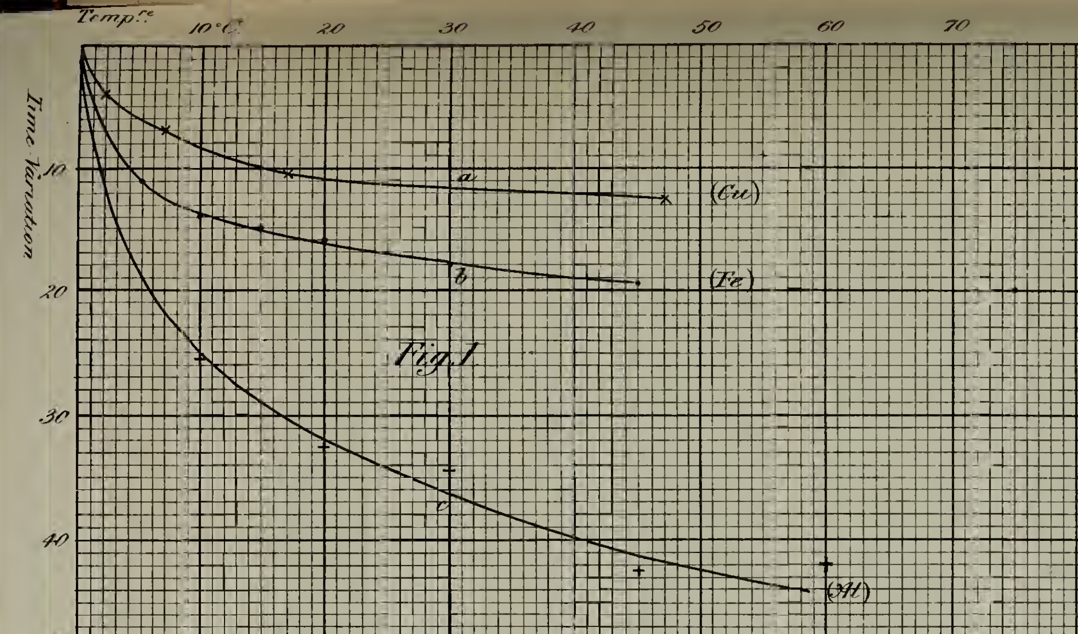

Fig. I

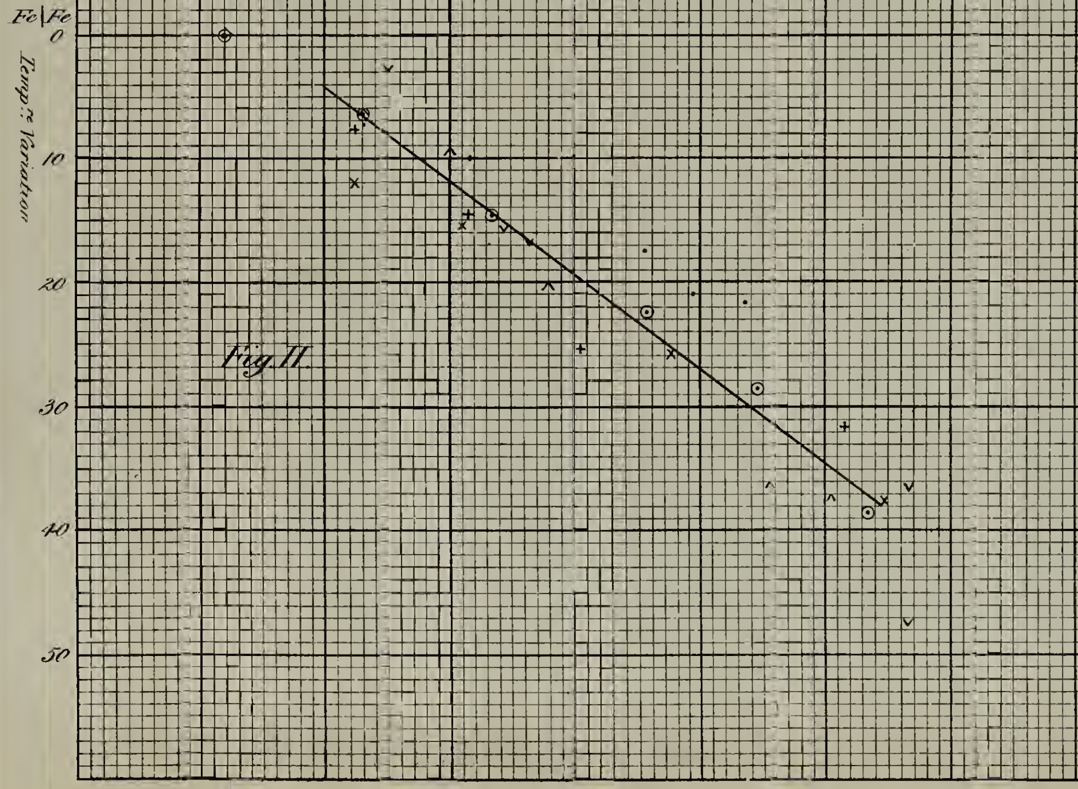

Fig. II

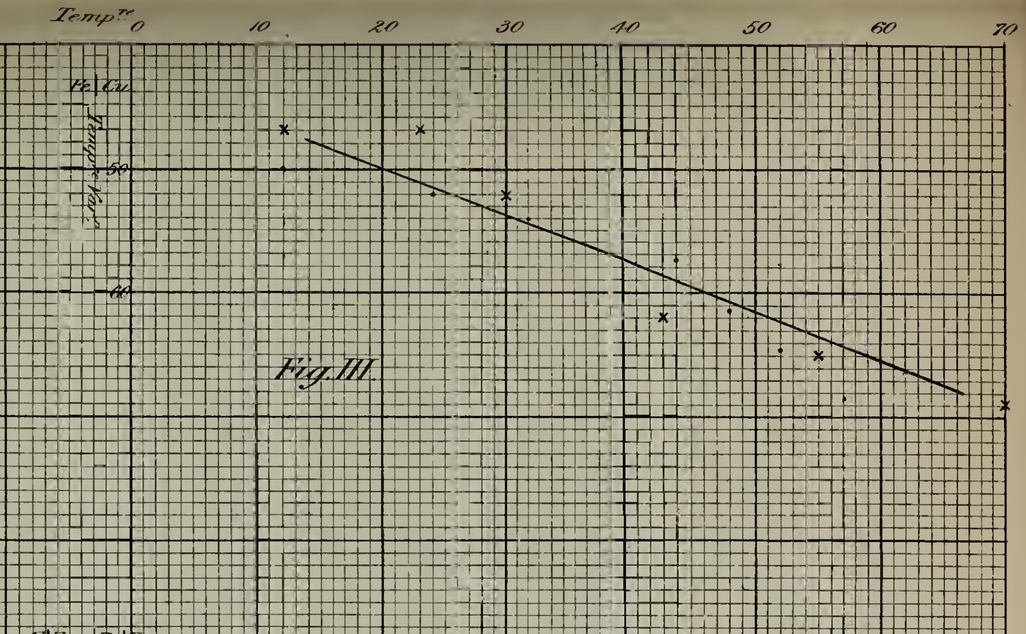

Fig. III

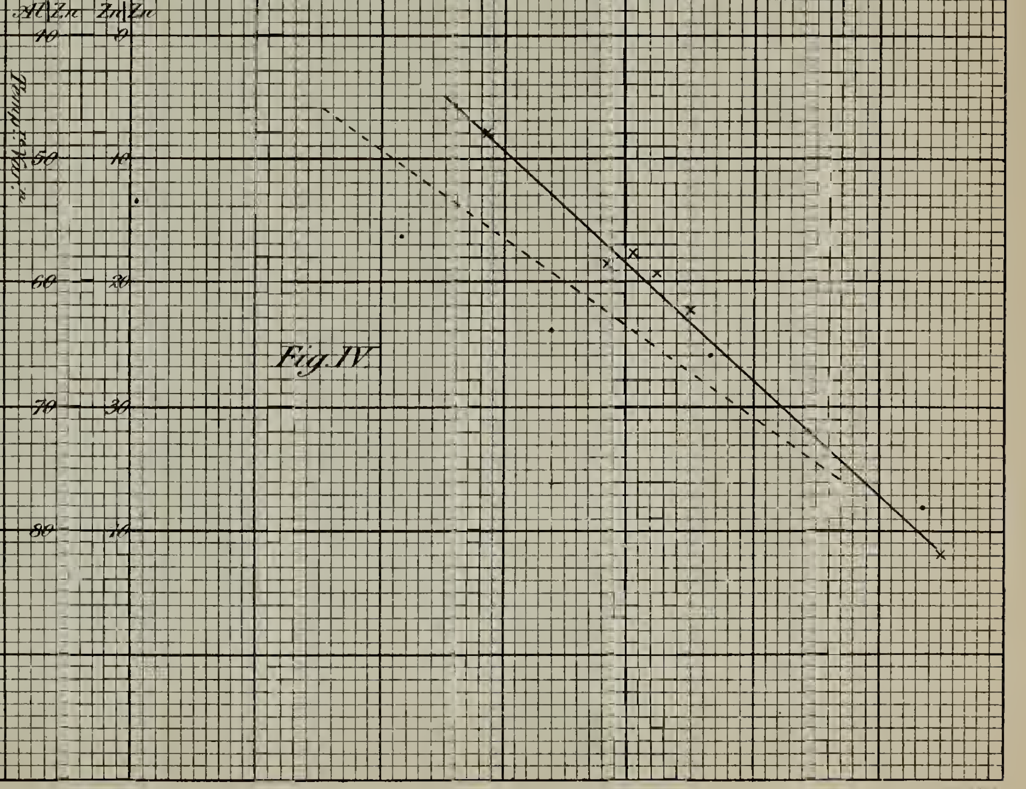

Fig. IV

XI.—*On Phosphorus-Betaines.* By Professor Letts. (Plate XVIII.)

(Read January 3, 1881.)

In a paper by Professor Crum Brown and the author on *Dimethyl-Thetine and its Derivatives,** attention was drawn to the analogies which frequently exist between elements which have different atomicities, and which are usually considered as belonging to different families. The most striking examples of such elements are boron and carbon, gold and platinum, and phosphorus and sulphur.

Since the publication of that paper, the author has pursued the subject, and his experiments, which have been made with the object of comparing the properties of analogous compounds of nitrogen, phosphorus, and sulphur, have confirmed the view that the two latter elements are very closely related, and that in many cases at least, phosphorus is more nearly allied to sulphur than it is to nitrogen.

In the course of these experiments many facts and considerations relative to the three elements have occurred to the author, which he believes have not hitherto been presented in a clear and concise form. No doubt, some of them have been noticed by other chemists, but he believes that such has not been the case with all, and he is therefore induced to give a slight sketch of the analogies and differences which the three elements exhibit, before proceeding to describe his experiments.

A Comparison of the Properties of Nitrogen, Phosphorus, and Sulphur.

If we compare the three elements in the free state, we cannot but be struck with the very close analogies existing between phosphorus and sulphur, and the great dissimilarity of nitrogen to either.

Phosphorus and sulphur are solid bodies; both exist in allotropic modifications which are produced by the action of heat on a particular form of each element. Nitrogen is gaseous, and so far as is known does not exist in more than one condition.

Again, both sulphur and phosphorus have what is usually termed "abnormal" vapour densities; that is to say, in the gaseous state their molecules contain more than two atoms. At a sufficiently high temperature, however, the molecules of sulphur are dissociated into simpler ones containing two atoms,

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* These Transactions, vol. xxviii.

and this fact, considering the similarity of the two elements, renders it probable that at a sufficiently high temperature the molecules of phosphorus would behave in a similar manner.*

Regarding other physical properties of the three elements, such as specific gravity, atomic volume, &c., it is not necessary to say much, as nitrogen, on account of its gaseous nature, does not admit of a ready comparison with the other two. It may be mentioned, however, that both the atomic weight and specific gravity of phosphorus and sulphur are very close to each other, and consequently their atomic volumes are nearly identical.†

Turning now to the chemical properties of the three elements (in the free state), we again find a close similarity between phosphorus and sulphur, whereas nitrogen possesses scarcely a point of resemblance to either; for whilst the former are characterised by their energetic attraction for other elements, nitrogen is strikingly inert, and displays scarcely any tendency to enter into combination.

The great affinity of phosphorus for oxygen needs no comment; that of sulphur for the same element is considerably less, but is still well marked; whilst nitrogen possesses so slight an attraction for oxygen, that its oxides are powerful oxidising agents. We have then in phosphorus, sulphur, and nitrogen a group of elements which show a regular gradation in affinity for oxygen; and, as we might expect, the affinity of these elements for hydrogen is in exactly the reverse order, ammonia being the most stable of their hydrides, and phosphuretted hydrogen the least, whilst sulphuretted hydrogen stands midway between them. We might perhaps expect from these facts that, as ammonia is the most alkaline of all the hydrides, sulphuretted hydrogen would be more alkaline than phosphuretted hydrogen; but this is not the case, for the latter has a neutral reaction, and combines directly with hydriodic and hydrobromic acids, whereas sulphuretted hydrogen has a slight, but still a distinct acid reaction, and does not, so far as we know, combine with any hydracid.

The difference observed in the affinity of phosphorus, sulphur, and nitrogen, for oxygen and hydrogen, exercises, as we might expect, an important influence on the properties of their compounds. Thus most compounds of phosphorus, with electro-positive elements or compound radicals, oxidise spontaneously, as in the case of phosphuretted hydrogen, many metallic phosphides, and the

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* The author has communicated with Professor Victor Meyer on this subject, who stated that he had already made experiments in this direction, and that they indicated a diminution in the vapour density of phosphorus at a high temperature. Professor Meyer having thus established his priority to any experiments on the vapour density of phosphorus at high temperatures, the author has left the matter in his hands.

† According to Ramsay (Journ. Chem. Soc., 1879), the sp. gr. of sulphur at its boiling-point is 1·4799, and its atomic volume (in the sense in which Kopp employs the term) 21·6. The same author, in conjunction with Masson (Journ. Chem. Soc., 1880), gives the sp. gr. of phosphorus at its boiling-points as 1·4850, and its atomic volume as 20·91.

phosphines; and even partly oxidised compounds of phosphorus often greedily absorb oxygen, and are, as a consequence, powerful reducing agents.

Similar compounds of sulphur do not as a rule oxidise spontaneously, or if they do so the oxidation occurs slowly, as with solutions of sulphuretted hydrogen and metallic sulphides. But oxidising agents easily attack them and convert them into oxidised products. Thus sulphuretted hydrogen, by simple contact with sulphuric acid, is oxidised to water and sulphur. Organic sulphides (R'_2S) are converted by treatment with nitric acid into sulphanes (R'_2SO), and sulphones (R'_2SO_2); mercaptans ($R'HS$) into sulphonic acids ($R'HSO_3$).

Corresponding compounds of nitrogen show much less tendency to oxidise, and only in a very few cases are they capable of directly fixing oxygen; thus in the case of the compound ammonias although oxidised products are known ($R'NO$, $R'NO_2$, &c.) they are not produced by direct oxidation.

These considerations help us to understand the action of reducing agents on oxidised compounds of the three elements, and also explain why completely different methods must be employed for obtaining their organic compounds. A nitro-body is an oxidised compound of nitrogen; in it the oxygen is only weakly held, consequently a reducing agent easily removes it, and usually causes the addition of hydrogen.* Consequently an amine is readily obtained by the reduction of a nitro-body. Oxidised compounds of sulphur are also easily reduced. Thus nascent hydrogen de-oxidises sulphuric, sulphurous, and hyposulphurous acids, and converts them into sulphuretted hydrogen, and is also capable of converting (certain at least of the) sulphanes and sulphones into sulphides. But it is more difficult to reduce an oxidised sulphur compound than an oxidised nitrogen compound. For instance, nitrate of potash is easily reduced to nitrite, and eventually to oxide of potassium by heat alone; whereas sulphate of potassium suffers no change when heated unless a reducing agent such as carbon is present; in which case, however, the oxygen is removed.

But if we attempt to remove oxygen from an oxidised compound of phosphorus by ordinary reducing agents, we experience as a rule much greater difficulty. It is stated that both phosphorous and hypophosphorous acids may be reduced by nascent hydrogen,† but phosphoric acid is not affected by that reagent, nor is the oxide of a tertiary phosphine. A powerful reducing agent acting at a high temperature must generally be employed for the reduction of an oxidised compound of phosphorus.

We can therefore readily understand why phosphines cannot be prepared by the reduction of oxidised organic compounds of phosphorus, whilst amines are produced by such a process with the greatest ease, and even sulphides are formed from sulphines, sulphones, &c., without much difficulty.

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* Not however in all cases, as we see in the preparation of azo-bodies.

† This statement requires confirmation.

Respecting compounds of oxygen and of hydrogen with the three elements, it may not be superfluous to point out some of the more important and interesting points of resemblance and difference which exist between them.

As regards their compounds with hydrogen, nitrogen forms a single hydride; sulphur, two; phosphorus, three. In all three cases the hydride containing the maximum of hydrogen is gaseous, and possesses a powerful and characteristic odour and energetic properties. All three of these gaseous hydrides are decomposed by the spark, and phosphuretted and sulphuretted hydrogen are decomposed by heat. Ammonia, however, is more stable.

As we might expect from the readiness with which both sulphur and phosphorus are oxidised, their compounds with hydrogen are very inflammable, whilst ammonia can only be burnt under special conditions.

The strongest point of analogy between ammonia and phosphuretted hydrogen is, that both are alkaline substances, in which respect they are unique amongst the hydrides of elements. But the alkaline properties of phosphuretted hydrogen are very weak, as it combines under ordinary atmospheric pressure with only two acids, viz., hydriodic and hydrobromic acids, and its compounds with these are so unstable that they dissociate at ordinary temperatures, and cannot exist in solution.

As before pointed out, phosphuretted hydrogen, in respect of its alkaline properties, is intermediate between the strong base ammonia and the faint acid sulphuretted hydrogen. In other respects, phosphuretted hydrogen is more allied to sulphuretted hydrogen than it is to ammonia. This is especially noticeable in its action on solutions of the heavy metals, where it acts either as a reducing agent (gold, &c.) or precipitates a metallic phosphide (cadmium and copper), or precipitates a mixture of the metal and metallic phosphide (mercury).

Both sulphur and phosphorus form only two well-marked compounds with oxygen; whilst nitrogen, in spite of its slight affinity for that element, forms no less than five oxides.

Phosphorus, as we might expect from its powerful affinity for oxygen, combines directly with the maximum quantity of that element; whilst sulphur, when burnt, only forms its lower oxide; and free nitrogen is not capable of direct oxidation, except under special conditions.

The highest oxides of the three elements resemble each other in being volatile solids, and in having a strong affinity for water. Nitric anhydride is the least stable, and frequently decomposes spontaneously. Sulphuric anhydride is decomposed at a high temperature, whilst phosphoric anhydride displays a much higher degree of stability.

If we consider the oxy-acids of the three elements, we see that an undoubted analogy exists between sulphuric and phosphoric acids. Both are very powerful acids. Their salts are stable at a high temperature, and in a great many cases their solubility is similar.

Nitric acid cannot be said to resemble either sulphuric or phosphoric acid, nor can its salts be compared with sulphates or phosphates.

There is a distinct analogy between hypophosphorous and hydrosulphurous acids, and between phosphorous and sulphurous acids. The first two are extremely powerful reducing agents, and to the best of the author's belief they are the only substances which precipitate cuprous hydride from a solution of a copper salt. Sulphurous and phosphorous acids are also reducing agents, but by no means such powerful ones.

It is rather curious that in this series of acids, so far as their formulæ are concerned, the only difference between corresponding terms is that all the members of the sulphur series contain *two* atoms of hydrogen, whilst those of the phosphorus series contain *three.*

H_2SO_2	H_3PO_2
H_2SO_3	H_3PO_3
H_2SO_4	H_3PO_4

There is one point in which sulphur does not resemble either phosphorus or nitrogen, viz., in the large number of oxy-acids which it forms. No oxy-acids of phosphorus or nitrogen have been obtained corresponding with hyposulphurous acid or with the polythionic acids.

Phosphorus and sulphur also agree in their strong affinity for the halogens, especially for chlorine, whilst nitrogen has almost no attraction for them. The chlorides of sulphur and of phosphorus resemble each other in certain of their properties. Thus the higher chlorides of both readily dissociate into chlorine and the lower chlorides, and this is especially the case with the chloride of sulphur, SCl_4 which dissociates even at ordinary temperature into SCl_2, or S_2Cl_2 and free chlorine. Again, these higher chlorides act upon the hydrates of organic radicals, giving their oxychlorides, chloride of the organic radical, and hydrochloric acid.

The two following equations will illustrate this—

$$C_6H_5-COOH + SCl_4 = HCl + SOCl_2 + C_6H_5-COCl$$
$$C_6H_5-COOH + PCl_5 = HCl + POCl_3 + C_6H_5-COCl$$

The lower chloride of sulphur is decomposed by water, with formation of hydrochloric and sulphurous acids (and free sulphur); and the lower chloride of phosphorus is decomposed in a similar manner, with formation of hydrochloric and phosphorous acids.

There is a very striking difference between the three elements in their affinity for carbon—a difference that explains several facts which at first sight appear anomalous. It is difficult to say whether nitrogen or sulphur has the strongest affinity for carbon; for although, undoubtedly, bisulphide of carbon is obtained with greater ease than cyanogen—the compound ammonias (bodies in which carbon is directly united to nitrogen)—are so numerous, stable, and so easily obtained, that we must accord to nitrogen a very high degree of affinity for carbon. Phosphorus, on the other hand, has but a slight attraction for carbon. The two elements do not combine directly (so far as we know) to form a compound analogous to cyanogen, and even the compounds which phosphorus forms with hydrocarbon radicals (phosphines) are only obtained with difficulty.

This striking difference between the three elements explains, in the author's opinion (in some measure at least), the curious fact, that whereas both nitric and sulphuric acid readily act on a large number of aromatic bodies in such a manner that the nitrogen or sulphur becomes directly united to the carbon which they contain, phosphoric acid or anhydride is without action on them. Considering the analogies which certainly exist, and are always insisted upon, between nitrogen and phosphorus, and also those which exist (but are not so commonly insisted upon) between sulphur and phosphorus—we should certainly be strongly inclined to predict, if we did not know to the contrary, that "phospho" bodies ought to be easily produced by the action of phosphoric acid or anhydride on aromatic hydrocarbons. It is almost unnecessary to say that these bodies are known. We are acquainted with phosphinic and phosphonic acids ($R'PO(OH)_2$ and $R'_2PO(OH)$), and with phosphine oxides (R_3PO), substances which are strictly analogous to sulphonic acids ($RSO_2(OH)$) and sulphones (R_2SO_2), and which are produced by a similar process, viz., by the oxidation of phosphines, but their preparation from phosphoric acid or phosphoric anhydride cannot be accomplished.

Organic Compounds of the three Elements.—Nitrogen is remarkable for the ease with which it combines with carbon partly saturated with other elements, and consequently the number of organic compounds containing nitrogen is very large. The number of these is increased by the fact that nitrogen easily combines not only with hydrocarbon radicals, but also with radicals containing carbon, hydrogen, and oxygen. Thus the amides are among the most numerous of the organic compounds of nitrogen.

Compounds of sulphur and hydrocarbons are readily obtained, and the mercaptans (compounds which may be considered as analogous to primary or secondary amines) are also numerous. But compounds of sulphur with oxidised organic radicals are scarce. However, we know of thi-acetic acid ($(CH_3-CO)SH$) and sulphide of acetyle ($(CH_3-CO)_2S$), which may be considered as analogous to primary (or secondary) and tertiary amides respectively.

Primary, secondary, and tertiary phosphines are known, and are analogous in composition and in many of their properties to amines, but the author is not aware that any phosphorus compound analogous to an amide has been obtained. Phosphorus indeed displays but little tendency to combine with oxidised hydrocarbon radicals.

If we compare the phosphines with mercaptans and hydrocarbon sulphides, on the one hand, and with the amines, on the other, we find (as might indeed be expected) very much the same difference between them as we notice between phosphuretted hydrogen, sulphuretted hydrogen, and ammonia.

Thus compounds of primary phosphines with the hydracids are decomposed by water, just as phosphonium iodide is decomposed by water, and the phosphines oxidise with the greatest ease, and even spontaneously. The products of their oxidation are analogous to those which the mercaptans and hydrocarbon sulphides yield. Thus—

$$\begin{array}{lcl} \mathrm{R'SH} & \text{gives} & \mathrm{R'SO_2(OH)} \\ \mathrm{R'_2S} & ,, & \mathrm{R'_2SO_2}, \\ & & \\ \left\{\begin{array}{l} \mathrm{R'PH_2} \\ \mathrm{R'_2PH} \end{array}\right. & \begin{array}{c} ,, \\ ,, \end{array} & \begin{array}{l} \mathrm{R'PO(OH)_2} \\ \mathrm{R'_2PO(OH)}, \end{array} \\ \mathrm{R'_3P} & ,, & \mathrm{R'_3PO}, \end{array}$$

as the final products of oxidation.

The most characteristic property of a mercaptan is the readiness with which it exchanges its hydrogen for metals. The author is not aware that any attempts have been made to obtain analogous metallic derivatives of primary and secondary phosphines, but it is highly probable that such bodies may exist and could be easily obtained.

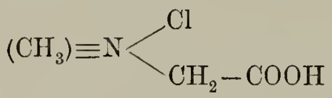
The organic compounds of the three elements which best admit of comparison are the tertiary amines and phosphines and the sulphides of hydrocarbon radicals. These bodies have been well studied, and all of their most important properties are known. Let us compare the properties of $(CH_3)_3N$ with those of $(CH_3)_3P$ and $(CH_3)_2S$. They are all volatile liquids of peculiar and characteristic odour, and all possess alkaline properties. These are most strongly marked in trimethyl-amine, least so in sulphide of methyl.

Perhaps the most characteristic property of a tertiary amine is the readiness with which it combines with the iodide of a hydrocarbon radical to form the iodide of a compound ammonium, the hydrate of which is a very powerful base. A tertiary phosphine is perfectly similar in this respect, as it combines with great readiness with an iodide of a hydrocarbon radical, and from the product of union, salts of the compound phosphonium are easily obtained, analogous in a great many respects to those of the compound ammonium. A sulphide of a hydrocarbon radical also combines readily with the iodide of a hydrocarbon radical. Thus on simply mixing sulphide and iodide of methyl, a reaction at once occurs, and so much heat is developed by their combination that it is necessary to cool the vessel containing the mixture in order to prevent loss. The resulting sulphine iodide is very similar to the iodide of a compound ammonium or phosphonium. Its hydrate is a powerful base which absorbs carbonic anhydride from the air, and precipitates the hydrates of metals from solutions of their salts.

But there is one important particular in which a tertiary amine is utterly unlike a tertiary phosphine, or the sulphide of a hydrocarbon radical. A tertiary amine is not capable of directly fixing oxygen, nor indeed of yielding any simple oxidised derivative. But both a tertiary phosphine and the sulphide of a hydrocarbon radical are oxidised with ease (indeed the former absorbs oxygen from the air with avidity), and simple products of oxidation are formed. Trimethyl-phosphine oxidises to $(CH_3)_3PO$, and sulphide of methyl to $(CH_3)_2SO$ and $(CH_3)_2SO_2$.

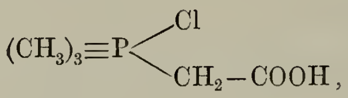
Dimethyl-sulphone $(CH_3)_2SO_2$ and oxide of trimethyl-phosphine closely resemble each other. They are solid neutral substances which distil without decomposition. They resist the action of oxidising agents in a remarkable manner, being unchanged by boiling with nitric acid.*

Dr Crum Brown and the author found that just as trimethyl-amine and trimethyl-phosphine combine with chloracetic acid to give the hydrochlorate of betaine, and of phosphorus-betaine respectively,



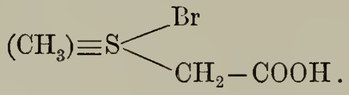
$$(CH_3)\equiv N\left\langle\begin{matrix}Cl\\ CH_2-COOH\end{matrix}\right.$$

and



$$(CH_3)_3\equiv P\left\langle\begin{matrix}Cl\\ CH_2-COOH,\end{matrix}\right.$$

sulphide of methyl combines with bromacetic acid to give the hydrobromate of a body which they called *thetine,* or rather *dimethyl-thetine,*



$$(CH_3)\equiv S\left\langle\begin{matrix}Br\\ CH_2-COOH.\end{matrix}\right.$$

Thetine is, in certain respects, analogous to betaine. Both are deliquescent bodies, possessing a neutral reaction, and only weak alkaline properties, and both yield similar salts, which are readily obtained by the action of silver salts on their hydrochlorates or hydrobromates.

But the author has shown that both the base thetine and also its salts, are decomposed by heat in a simple and characteristic manner, whilst Brühl has investigated the action of heat on salts of betaine, and has found that they decompose in a completely different way.

These results of Brühl's, coupled with the author's experiments, led to the question, How will the salts of phosphorus betaine behave when heated? and

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* The author has seen their vapour pass almost unchanged over a layer of mixed carbonate and nitrate of potash, heated to incipient fusion.

in what respects do they resemble and differ from corresponding compounds of betaine and thetine?

Dr CRUM BROWN and the author had expressed the opinion that phosphorus-betaine would probably more closely resemble thetine than betaine; and as the former had been only subjected to a cursory examination, the author determined to carefully examine it, and to study its properties.

Before, however, proceeding to describe his experiments, it is necessary to state the results of HOFMANN and MEYER'S work on phosphorus-betaines. HOFMANN was the first to surmise and to prove their existence, and so far as the author can ascertain, he and his pupil MEYER are the only chemists who have investigated them.

"*Action of Chloracetic Ether on Triethyl-Phosphine.*[*]

. . . . . "Triethyl-phosphine and chloracetic ether combine with evolution of heat, and formation of a brownish liquid of considerable consistency. If somewhat large quantities are to be mixed, it is desirable to moderate the action by the presence of a volume of anhydrous ether equal to or greater than the aggregate bulk of the two liquids. Dissolved in water, separated by filtration or distillation from the excess of chloracetic ether employed, and mixed with dichloride of platinum, the new chloride furnishes a beautifully crystallised platinum salt, which after several recrystallisations from boiling water has the composition,

$$C_{10}H_{22}PO_2,PtCl_2=\left[(C_2H_5)_3\left(\begin{matrix}C_2H_2O_2\\C_2H_5\end{matrix}\right)P\right]Cl,PtCl.$$

submitted to the action of oxide of silver, the chloride undergoes the same change which was observed in the corresponding nitrogen compound,

$$\left[(C_2H_3)_5\left(\begin{matrix}C_2H_2O_2\\C_2H_5\end{matrix}\right)P\right]Cl+\left.\begin{matrix}Ag\\H\end{matrix}\right\}O+\left.\begin{matrix}H\\H\end{matrix}\right\}O=\left[(C_2H_5)_3\left(\begin{matrix}C_2H_2O_2\\C_2H_5\end{matrix}\right)\left.\begin{matrix}P\\H\end{matrix}\right\}\right]O+\left.\begin{matrix}C_2H_5\\H\end{matrix}\right\}O.$$

It is scarcely necessary to point out the perfect analogy of the new phosphuretted compounds with the corresponding bodies in the nitrogen series. Whatever view be entertained of the latter must also be taken regarding the former. Conceived in the anhydrous condition, the product obtained by the action of oxide of silver upon the chloride may be considered as phosphuretted glycocoll, with three equivalents of ethyl in the place of three of hydrogen,

$$C_8H_{17}PO_2 = C_2H_2(C_2H_5)_3PO_2.$$

"The phosphuretted compound resembles in its properties the substance

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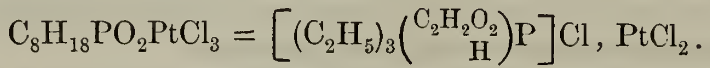
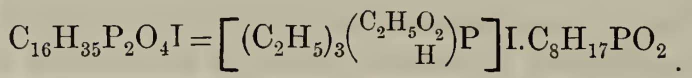
[*] HOFMANN, Proceedings Royal Society, vol. xi. p. 530.

derived from triethyl-amine. The aqueous solution when evaporated *in vacuo* solidifies into a radiated crystalline mass. I have been satisfied to fix the composition of this body by the analysis of the well crystallised platinum salt which was found to contain



$$C_8H_{18}PO_2PtCl_3 = \left[(C_2H_5)_3\binom{C_2H_2O_2}{H}P\right]Cl\,,\ PtCl_2\,.$$

and by that of the iodide. The latter was formed by precipitating the platinum salt by sulphuretted hydrogen, decomposing the chloride formed in this manner by oxide of silver, and dissolving the triethylated compound in hydriodic acid. The solution was evaporated to dryness, the residue washed with absolute alcohol, and recrystallised from the same liquid. This iodide is more soluble and less beautiful than the corresponding compound in the nitrogen series. Analysis showed, however, that it has an analogous composition, viz.,



$$C_{16}H_{35}P_2O_4I = \left[(C_2H_5)_3\binom{C_2H_5O_2}{H}P\right]I.C_8H_{17}PO_2\,.$$

. . . . "

" *The Betaine of the Phosphorus Series.* *

" In general the study of phosphorised organic compounds has been preceded by the knowledge of the corresponding members of the nitrogen series. There are, however, some cases known in which the phosphorised bodies have been investigated before the analogous nitrogen compounds. Among these are the compounds derived from glycocoll by replacement of hydrogen by alcohol radicals.

" During his great research on phosphorus bases, Professor HOFMANN also studied the action of monochloracetic acid on triethyl-phosphine, and obtained in this reaction the chloride of a base which possesses the composition,

$$(C_2H_5)_3(C_2H_3O_2)P,Cl\,.$$

" When he removed the chlorine from this body by oxide of silver, there was not produced as might have been expected the hydroxyl compound,

$$(C_2H_5)_3(C_2H_3O_2)P(OH)\,,$$

but by the splitting off of hydrochloric acid,

$$(C_2H_5)_3(C_2H_2O_2)P = C_2H_2(C_2H_5)_3PO_2\,,$$

which may be regarded as triethylated glycocoll, the nitrogen of which is

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* MEYER, Ber. d. deutsch. chem. Ges. iv.

replaced by phosphorus. At the same time, Professor HOFMANN also examined the action of triethyl-amine on chloracetic acid, and found, as was to be expected, that a corresponding nitrogen body, the triethylated glycocoll, was produced,

$$C_2H_2\,(C_2H_5)_3NO_2\,.$$

"This last compound received an increased interest when the homologous compound in the methyl series, the trimethylated glycocoll, was met with under very remarkable conditions.

"LIEBREICH showed that the chloride of neurine (a body formed as a decomposition product of protagon), and which so far as its composition is concerned may be regarded as oxethyl-trimethyl-ammonium chloride,

$$(CH_3)_3(C_2H_5O)NCl\,.$$

is converted by the action of oxidising agents by replacement in the ordinary manner of two atoms of hydrogen by one atom of oxyen into the chloride,

$$(CH_3)_3(C_2H_3O_2)NCl\,,$$

which, exactly like the homologous ethylated body, by dechlorination loses hydrochloric acid, and is converted into the body,

$$(CH_3)_3(C_2H_3O_2)N = C_2H_2(CH_3)_3NO_2\,.$$

that is to say, passes into trimethylated glycocoll.

"LIEBREICH obtained the same body, which from its mode of production from neurine, may be called oxy-neurine, by a reaction analogous to that which HOFMANN has given, by acting on trichloracetic acid with trimethyl-amine. Some time previously SCHEIBLER, during his researches on the chemical com position of the sugar beet, obtained from its juice a splendid crystallised base, for which he proposed the name Betaine (from *Beta vulgaris*). Later researches carried out by SCHEIBLER showed that betaine is actually identical with the very base obtained from neurine, *i.e.*, with oxy-neurine or trimethylated glycocoll.

"It remained to perfect this group of bodies by the study of the methylated phosphorus base. The preparation of the trimethyl-phosphine required for this reaction was attended with difficulties, so long as it had to be obtained by the former troublesome methods.

"The reaction discovered by HOFMANN and CAHOURS between trichloride of phosphorus and zinc-methyl leaves, it is true, nothing to be desired in sharpness, but unfortunately all the methods hitherto given for the preparation of zinc methyl are in the highest degree uncertain, and give under the most favourable circumstances only a very limited yield. On the other hand, the new process which Hofmann has lately communicated, allows of the preparation of trimethyl-phosphine in any quantity and of perfect purity. The trimethyl-phosphine employed in the research which follows was prepared exclusively by the action of phosphonium iodide on methyl alcohol.

" *Action of Monochloracetic Acid on Trimethyl-Phosphine.*

" If the two bodies are mixed in equimolecular quantities a reaction is noticed, even at ordinary temperatures. If the mixture has been heated for five to six hours in a sealed tube at 100° C., a product is formed which consists of a deliquescent viscous syrup, throughout which crystals are interspersed. This mass always contains small quantities of hydrochlorate of trimethyl-phosphine but consists for the greater part of a compound in which one molecule of trimethyl-phosphine and one molecule of chloracetic acid are united together. It was not difficult to demonstrate by means of experiment the composition foreseen theoretically of this body. The directly-formed chloride, on account of its hygroscopic properties, and also, as already observed, from its contamination with small quantities of hydrochlorate of trimethyl-phosphine, seemed to be but little suited for analysis. The simplest way for examining it was clearly the analysis of its platinum salt.

" On dissolving the crude product in water, and adding to the solution a slightly diluted solution of chloride of platinum, the platinum salt is precipitated immediately as an orange-yellow crystalline mass. This is easily soluble without decomposition in boiling water, and separates on cooling from this solution in splendid crystals of rhombic form. The carbon and platinum determinations in this salt showed that it is composed according to the formula,

$$C_{10}H_{24}P_2O_4Cl_2PtCl_4=2[C_2H_2(CH_3)_3PO_2,HCl],PtCl_4,$$

" On treating the aqueous solution of the platinum salt with sulphuretted hydrogen the pure chloride is obtained. I concentrated the solution at first on the water bath, and then allowed it to stand for some time under the receiver of the air-pump: in this manner the chloride is obtained as a crystalline deliquescent mass. On treating the solution with chloride of gold, a beautiful gold salt is obtained, which crystallises in long yellow needles, easily soluble in water. In order to obtain the free base corresponding with the salts just described, the chloride was converted into sulphate by means of sulphuric acid. This was treated with baryta, and the excess of baryta removed by means of a current of carbonic acid. The solution thus obtained gradually solidified *in vacuo* to a splendid radiating crystalline mass. The solution of the base does not affect vegetable colouring matters. If hydrochloric acid is added to it, the original chloride is reformed, which was identified by preparation and analysis of the platinum salt.

"The base forms with hydriodic and nitric acids well crystallised salts. The iodide is easily obtained by dissolving the free base in hydriodic acid, evaporating the solution to dryness, washing the dry substance with a little absolute alcohol to remove free iodine, and then crystallising the decolorised salt from hot alcohol.

"The iodide is easily soluble in water, and crystallises in beautiful leaflets. An estimation of iodine shows that the composition of the salt is,

$$C_2H_2(CH_3)_3PO_2.HI.$$

"Thus the normal iodide had been obtained, a fact which is somewhat remarkable, as, according to Hofmann's researches on the corresponding ethyl compound, both of the phosphorus and nitrogen series, a molecule of the base is found associated with the iodide.

"The nitrate is very soluble in water; the solution crystallised, but less easily than that of the iodide. I have not analysed the salt.

"This also was the case with the free base, which is so hygroscopic that the analysis could only have been performed with difficulty.

"But in the face of so many analogies, it cannot be doubted that in this case also, by the action of oxide of silver on the chloride, an exchange of chlorine for hydroxyl does not occur, but in its stead a separation of hydrochloric acid, in consequence of which the compound would be,

$$(CH_3)_3C_2H_2O_2P = C_2H_2(CH_3)_3PO_2,$$

i.e., trimethylated phosphorised glycocoll, or the betaine of the phosphorus series."

*The Materials necessary for the Research.**

The materials necessary for the research which the author determined to undertake were chloracetic and bromacetic acids, and trimethyl-phosphine or triethyl-phosphine. The former were purchased from Messrs Kahlbaum & Co. of Berlin, whose preparations the author has always found may be relied on. But the trimethyl- and triethyl-phosphine are substances not readily purchased, and it was considered better for many reasons to prepare them.

No difficulties were expected in accomplishing this, as Hofmann has recently published a method which is stated by him to give excellent results,

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* Owing to the expensive nature of the materials necessary for these experiments the author applied in 1879 (when they were commenced) for a sum of money from the Government Research Fund, which was granted him. He takes this opportunity to acknowledge the assistance thus received, without which he would probably have abandoned the research long before its conclusion.

and to be capable of yielding the bodies in any quantity that may be desired. This method consists in heating methyl or ethyl alcohol with iodide of phosphonium for some hours in a sealed tube at 180° C., when a mixture of hydriodate of triethyl-phosphine and iodide of tetrethyl-phosphonium results, from which caustic potash separates triethyl-phosphine in the pure state.

The author has been unsuccessful in his attempts to prepare trimethyl- and triethyl-phosphine in quantity by this process, although he has repeated the experiment between thirty and forty times with every precaution. The sealed tubes almost always exploded, and only in two or three cases did this not occur. He was therefore compelled to abandon this method, and to resort to the earlier process for preparing a tertiary phosphine. This was discovered by HOFMANN and CAHOURS,[*] and consists in treating a zinc ether with terchloride of phosphorus. The method is at least certain, although tedious and troublesome; and as zinc methyl is difficult to obtain on a large scale, it was necessary for the author to confine his experiments to the ethyl series.

As he has made very large quantities of triethyl-phosphine by this process, and his experience may be of use to others who may have occasion to prepare it, he thinks it better to describe the exact method of procedure which he adopted.

Zinc-Ethyl.—This was prepared by means of the zinc copper couple, which GLADSTONE and TRIBE[†] have shown to give very good results on the small scale. The author has made a very large number of experiments with this method, and always with complete success. The process is simple and easily carried out, and the yield of zinc-ethyl is very good. The author can strongly recommend it for the preparation of large quantities of that substance.

The zinc for the couple was always prepared by pouring the molten metal into an almost red hot iron mortar, stirring and pounding as rapidly as possible. With a little practice, it is easy to manipulate almost 16 kilogrammes of zinc in a couple of hours, and to obtain it as a very fine powder.

This fine powder is sifted from the coarser particles by means of a wire-gauze sieve—the gauze being of the usual size employed as a support when heating beakers, &c.

The copper was obtained by the reduction of the ordinary powdered oxide of commerce in a stream of hydrogen. It was sifted through the same sieve as was employed for the zinc.

The couple was prepared as GLADSTONE and TRIBE recommend.

One part of powdered copper and nine parts of zinc powder are placed in a flask and heated over a large Bunsen's burner with constant shaking until the particles begin to accumulate in small lumps. Great care is necessary to obtain

[*] Trans. Roy. Soc. Lond., 1857.

[†] GLADSTONE and TRIBE, Journ. Chem. Soc., 1879.

an active couple, and only practice can insure success. The slightest overheating causes the metals to agglomerate into a solid semi-fused mass, which is quite inactive.

The iodide of ethyl was prepared by the usual process, washed thoroughly with water, distilled, dried with phosphoric anhydride, and rectified.

The apparatus employed in the preparation of the zinc-ethyl is shown in Plate XVIII. figs. 1 and 2. The iodide of ethyl having been added to the couple placed in the flask A, the latter is heated in a water bath B until the action is at an end (*i.e.*, until the iodide of ethyl ceases to distil). The condenser C is then shifted from the position shown in fig. 1 to the position shown in fig. 2, and is connected with the balloon D which contains dry ether, and is provided with two tubes and a tap funnel.* The flask A containing the ethyl-iodide of zinc is transferred to a bath of melted paraffin B (fig. 2). A stream of carbonic acid is passed through the apparatus, and the paraffin heated so long as zinc ethyl distils.

To arrive at the weight of the zinc ethyl produced, the flask containing the dry ether (its two tubes stopped with indiarubber and glass rods) is weighed before and after the distillation of the zinc ethyl. This flask is then connected with the condenser, which in its turn is connected by a cork and bent tube with a large tap funnel E (fig. 3), the cork in the tap funnel being provided with a small exit tube. A stream of carbonic acid is then passed through the apparatus, and when the latter is filled with it, the current is stopped by a pinchcock G. The calculated weight of terchloride of phosphorus is now placed in the tap funnel F, and the flask D is placed in a water bath, through which a stream of cold water is circulating. The tap of the funnel is then opened, and the terchloride run in very slowly. The action is violent—the ether boils (in spite of the cold water surrounding the flask), and flows over into the tap funnel E. When all the terchloride has been added, the water bath is heated, and the remainder of the ether distilled off. The tap of the funnel E is now opened, and the ether run off. The tap is then closed, and water slowly added through F. This usually occasions a violent action, so that it is advisable to add the water slowly at first. A large excess of a strong caustic soda solution is now added through F, and a layer of the phosphine rises to the surface, a white powder (oxychloride of zinc ?) separating also in large quantity.

The carbonic acid apparatus is disconnected, the water bath removed, and a strong current of steam blown through the tube H (fig. 4), which is pushed further through the cork, so that its end is almost at the bottom of the flask. The phosphine distils over, and forms an oily layer floating on the water, which has passed over with it. When no more oily drops distil, the water is

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* The iodide of ethyl ought to be perfectly dry, otherwise a great deal of gas is evolved by its action on the couple. The author has found phosphoric anhydride to be the only reliable dehydrating agent.

drawn off and the phosphine collected in a separate vessel. The subjoined table gives statistics of the method.

PREPARATION OF ZINC-ETHYL AND TRIETHYL-PHOSPHINE.

Weight of Couple.	Weight of Iodide of Ethyl.	Action began in—	Action finished in—	Zinc Ethyl produced	Phosphine produced
(1) 300 grms.	300 grms.	50 mins.	15 mins. later.	95 grms.	75 grms.
(2) 400 „	350 „	40 „	10 „	100 „	
(3) 300 „	300 „	15 „	20 „	78 „	25 „
(4) 200 „	200 „	240 „	240 „	62 „	55 „
(5) 200 „	200 „	150 „	65 „	60 „	
(6) 200 „	190 „	35 „	10 „	60 „	
(7) 200 „	200 „	120 „	120 „	60 „	63 „
(8) 200 „	200 „	2 days.	... „		
(9) 400 „	400 „	30 mins.	15 „	115 „	
(10) 200 „	200 „	40 „	15 „	... „	
(11) 100 „	100 „	20 „	20 „	... „	
(12) 400 „	400 „	35 „	25 „	... „	(10) and (12) gave 47 grms.
(13) 400 „	400 „	25 „	... „	... „	
(14) 400 „	400 „	10 „	60 „	115 „	40 „
(15) 800 „	800 „	15 „	90 „	250 „	34 „
(16) 300 „	330 „	10 „	120 „	85 „	53 „
(17) 300 „	330 „	20 „	120 „	85 „	
(18) 500 „	600 „	5 „	240 „	160 „	85 „
(19) 350 „	470 „	7 „	90 „	117 „	
				1442	477

It should be added, that although this method is undoubtedly the best we possess at present for preparing triethyl-phosphine, the yield of the latter is not very satisfactory, as it amounts to only about 50 per cent. of the calculated quantity. Moreover, the crude phosphine is by no means pure, and requires to be fractionally distilled many times before a product boiling at the right temperature is obtained. The higher boiling portions resulting from this fractionation consist mainly of oxide of triethyl-phosphine, but the nature of the lower boiling fractions (which amount to a considerable quantity) the author has not at present been able to ascertain.

It ought also to be mentioned that triethyl-phosphine is a very disagreeable substance to work with for any length of time, as the constant inhalation of the small quantities of its vapour produces (as HOFMANN has remarked) sleeplessness, which may continue for a considerable time.

Although triethyl-phosphine oxidises at ordinary temperatures, it does not do so to any considerable extent so long as it is not heated. The author has always kept it in ordinary stoppered bottles, and has not adopted any special precautions while working with it.

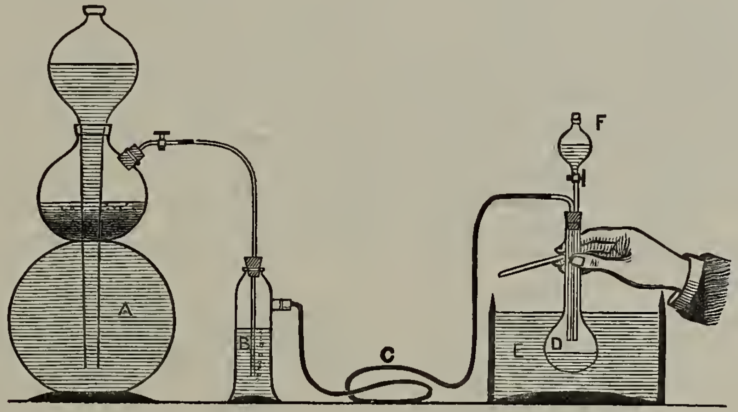
The author's first experiments were made on the action of triethyl-phosphine on *bromacetic acid,* as he had employed the latter reagent in his experiments on the thetines. Instead, however, of obtaining the hydrobromate of triethyl-phosphorus betaine by this reaction, other bodies were formed, the investigation of which was extremely troublesome, and lasted over a considerable time.

It was only when he substituted chloracetic for bromacetic acid that he obtained betaine compounds, and then the investigation was much simplified.

The author thinks it best to describe these latter experiments first, and then to consider the nature of the substances formed by the action of bromacetic acid on triethyl-phosphine.

Action of Chloracetic Acid on Triethyl-Phosphine.

The apparatus employed in these experiments is shown in the figure. It consists of a distilling flask D, which can be immersed when necessary in the vessel E, containing cold water and shaken by the hand, the long indiarubber tube C permitting this, whilst a stream of hydrogen from the generator A is passing through the apparatus.



A—Hydrogen generator.	D—Small distilling flask.
B—Sulphuric acid drying bottle.	E—Vessel full of cold water.
C—Long indiarubber tube.	F—Tap funnel.

4·7 grms. of chloracetic acid (molecular weight = 94·5) were placed in the distilling flask. The cork through which the tube C (connected with the hydrogen generator) and the tube of the tap funnel F pass was then fitted in, and hydrogen allowed to stream through the apparatus for some time.

5·9 grms. of triethyl-phosphine were then placed in the tap funnel F, and allowed to drop slowly on to the chloracetic acid.

The latter dissolved with considerable difficulty in the phosphine, and at first no action was apparent, but on shaking the mixture well, a dense syrupy liquid began to separate, and after some time most of the mixture had assumed this form, but a small quantity of a lighter liquid floated on its surface. The mixture grew very hot whilst this was occurring, and had to be cooled repeatedly by immersing the distilling flask containing it in cold water. In about an hour and a half's time the whole solidified to a solid crystalline mass, which was perfectly white and very hard.

This was washed several times with dry ether to remove any phosphine or chloracetic acid that had not been acted on. As chloroform had been found to be very suitable for dissolving organic phosphorised compounds, an attempt was made to get the product into solution by its means, but it did not appear to dissolve it perceptibly. Alcohol, however, dissolved it with tolerable ease, and on cautiously adding dry ether to the warm solution until the mixture became turbid, and then allowing it to stand, beautiful glittering crystals separated, which at first appeared to be needles, but afterwards grew into rhombohedral plates about 2 mm. in length.

Nearly the whole of the product was thus recrystallised, then dried in the desiccator *in vacuo*, and submitted to analysis.

Chlorine.—By precipitation with nitrate of silver.

(1) 0·4485 gave 0·282 AgCl = 0·07025 Cl = 15·6 per cent. Cl
(2) 0·6385 „ 0·3995 „ = 0·09952 „ = 15·6 „ „

Carbon and Hydrogen.—By combustion with chromate of lead: the front of the tube containing a mixture of the chromate and oxide of copper.*

(1) 1·296 gave 0·7722 H_2O = 0·0858 H = 6·6 per cent. H
1·296 „ 2·4013 CO_2 = 0·6549 C = 50·5 „ C
(2) 0·5165 „ 0·3705 H_2O = 0·04116 H = 8·0 „ H
0·5155 „ 0·9451 CO_2 = 0·25775 C = 50·0 „ C

	Obtained.		Calculated for	
	I.	II.	$(C_2H_5)_3P{<}\substack{Cl \\ CH_2-COOH}$	$(C_2H_5)_3P{<}\substack{Cl \\ CH_2-COOC_2H_5}$
Chlorine, . .	15·6	15·6	. . 16·7	. . 14·8
Carbon, . .	50·5	50·0	. . 45·1	. . 49·9
Hydrogen, .	6·6	8·0	. . 8·5	. . 9·1

These results indicated that the product was not a pure substance.

The action of chloracetic acid on triethyl-phosphine was repeated with larger quantities, exactly the same phenomena being observed as before.

The product, however, was twice recrystallised from alcohol and ether, and was obtained in beautiful colourless needles more than half an inch long. These were analysed, and were found to have the composition required for the product of union of a molecule of chloracetic acid with one of triethyl-phosphine.

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* Neither of these combustions can be relied on as the compound in both cases decomposed with unexpected rapidity, and the sulphuric acid in the drying tube blackened, showing that the oxidation had not been complete.

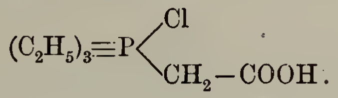
Chlorine.—Volumetrically, by VOLHARDT'S method.

(1) 0·5905 required 27·9 cc. decinormal $AgNO_3$ = 16·7 per cent. Cl
(2) 0·1930 „ 9·7 „ „ „ = 16·8 „ „
(3) 0·4302 „ 20·2 „ „ „ = 16·6 „ „

Carbon and Hydrogen.

0·1497 gave 0·1193 H_2O = 0·013255 H = 8·5 per cent. H
0·1497 „ 0·2485 CO_2 = 0·06777 C = 45·3 „ C

The composition of the body was further verified by that of its chloroplatinate, which will be described presently. Its reactions indicated that it was the hydrochlorate of triethyl-phosphorus-betaine,



$$(C_2H_5)_3{\equiv}P\begin{cases}Cl\\ CH_2-COOH.\end{cases}$$

The experiment of preparing the hydrochlorate was repeated again and again, the same phenomena being observed in each case.

If large quantities are to be operated with (22 grms. of the phosphine and the equivalent quantity of chloracetic acid were the largest the author ever employed), care must be taken to reduce the acid to a fine powder, otherwise it will not dissolve in the phosphine. In any case vigorous shaking of the mixture must be resorted to, to accomplish the solution of the acid, and also to bring the phosphine thoroughly into contact with it. This is very difficult when once the oily layer has begun to form, and only very violent shaking will insure the whole of the acid being acted on. In a well-conducted experiment scarcely a trace of phosphine remains in excess, but if the shaking has not been thorough much remains. Care must also be taken to cool the distilling flask; but, on the other hand, if the temperature is kept too low, the reaction is not complete. Some hours were always allowed to elapse before the product was recrystallised. The recrystallisation is easily effected by dissolving the product in a considerable quantity of hot alcohol, and then adding ether cautiously with constant stirring. The addition of ether is stopped as soon as the mixture becomes permanently turbid; on setting it aside for some time almost the whole of the hydrochlorate separates in beautiful colourless needles. The hydrochlorate thus purified is not perceptibly deliquescent, some of the crystals remaining for twenty-four hours exposed to the air without liquefying. This is surprising, as MEYER (*loc. cit.*) found the corresponding compound of trimethyl-phosphorus-betaine to be highly deliquescent.

It has a sour taste, and an acid reaction. Its other properties will be considered later.

Chloroplatinate of Triethyl-Phosphorus-Betaine.—On mixing dilute aqueous solutions of chloride of platinum and of the hydrochlorate, no precipitate is produced; but if concentrated and hot solutions of the two are mixed, the chloroplatinate separates on cooling in groups of thick needles of a light orange colour. The compound is a very beautiful one, and frequently the crystals attain the length of half an inch.

(1) 0·5763 lost 0·0143 = 2·3 per cent. H_2O
0·5763 gave 0·1461 Pt = 25·3 „ Pt
0·5763 „ 0·629 AgCl = 27·0 „ Cl
(2) 1·0086 „ 0·257 Pt = 25·4 „ Pt
1·0086 „ 0·27335 Cl = 27·1 „ Cl

	Obtained.		Calculated for $2\left\{(C_2H_5)_3P{<}^{Cl}_{CH_2COOH}\right\}, PtCl_4, H_2O$
Water,	2·3	...	2·3
Platinum,	25·3	25·4	25·2
Chlorine,	27·0	27·1	27·2

Hydrobromate of Triethyl-Phosphorus-Betaine.—9 grms. of the pure hydrochlorate were dissolved in water and converted into hydrate by the action of oxide of silver. From the filtered solution the small quantity of silver dissolved was precipitated by hydrobromic acid, and to the solution filtered from bromide of silver an excess of hydrobromic acid of constant boiling point was added. The mixture was then evaporated in the water bath until a syrup remained. This was maintained at a gentle heat to drive off excess of hydrobromic acid. When this had been accomplished the syrup (which was slightly brown in colour) was left to itself for a short time, and solidified to a radiating crystalline mass. It was dissolved in hot alcohol, and ether was then added cautiously to the solution until an oily liquid began to precipitate. The mixture was now allowed to stand, and soon began to crystallise.

The crystals which formed consisted of colourless and very thin quadratic plates, which were in many cases half an inch across.

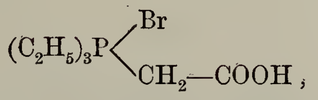
Some of the crystals were dried *in vacuo* over sulphuric acid, and a determination of bromine made by VOLHARDT'S volumetric process.

0·0880 required 34 cc. centinormal $AgNO_3$=0·0272 Br=30·9 per cent. Br

	Obtained.	Calculated for $(C_2H_5)_3P{<}^{Br}_{CH_2-COOH}$.
Bromine,	30·9	31·1

The hydrobromate is somewhat deliquescent, but resembles in other properties the hydrochlorate.

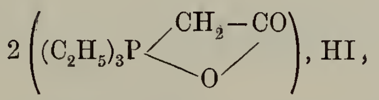
In order to be quite certain that it was really a betaine derivative, some of it was reconverted into hydrochlorate by the action of oxide of silver and then of hydrochloric acid. This solution yielded the characteristic chloroplatinate when it was mixed with chloride of platinum. The necessity for proving that the body in question was a betaine derivative, and had the constitution expressed by the formula,



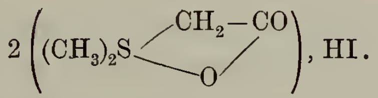
$$(C_2H_5)_3P\begin{cases}Br\\CH_2-COOH\end{cases}$$

will be apparent from the experiments on the action of bromacetic acid on triethyl-phosphine (see p. 321), for the author was at first led by them to believe that no hydrobromate of the phosphorised betaine could exist. However, the experiments just described are sufficient to establish the constitution of the body in question, which was further proved by the manner in which it decomposed when heated (see p. 316).

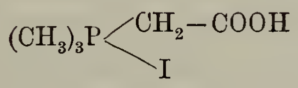
Hydriodate of Triethyl-Phosphorus-Betaine.—Hofmann, in the paper already mentioned, obtained a hemi-hydriodate of the betaine,



on treating the free base with hydriodic acid, and Dr Crum Brown and the author have shown that dimethyl-thetine, when treated in the same manner, yields a similar compound,



But Meyer (*loc. cit.*) obtained the normal hydriodate with trimethyl-phosphorus-betaine, viz.,



$$(CH_3)_3P\begin{cases}CH_2-COOH\\I\end{cases}$$

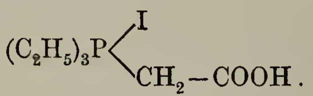
and could not succeed in obtaining a body analogous to Hofmann's hemi-hydriodate.

The author repeated Hofmann's experiment (though in a somewhat modified way).

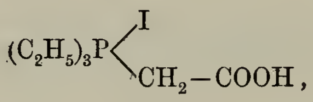
5 grms. of the pure hydrochlorate were converted into hydrate by the action of oxide of silver, and to the filtered solution hydriodic acid of constant boiling point was added in slight excess over the quantity required for the production of the normal hydriodate. The solution was evaporated to dryness on the water bath, and when most of the water had been driven off, yielded a syrupy liquid which crystallised on cooling. The solid mass was dissolved in alcohol and ether added.

The hydriodate was precipitated in small granular crystals about as large as pins' heads. After some time these were collected and washed repeatedly with dry ether. The colourless crystals thus obtained were then placed in the desiccator, and after some time the iodine which they contained was determined volumetrically by VOLHARDT's method.

0·3615 required 11·5 cc. decinormal $AgNO_3$ = 0·146051 Ag = 40·5 per cent.
1·165 „ 37·5 „ „ = 0·476250 „ = 40·8 „

	Obtained.		Calculated for  $(C_2H_5)_3P{<}\genfrac{}{}{0pt}{}{I}{CH_2-COOH}$.
	I.	II.	
Iodine,	40·5	40·8	41·8

Although these results do not exactly agree with the theoretical quantity, it must be remembered that the substance was not recrystallised, and was very deliquescent. The author considers that they prove the existence of the normal hydriodate,



$$(C_2H_5)_3P{<}\genfrac{}{}{0pt}{}{I}{CH_2-COOH},$$

but also believes that the hemihydriodate described by HOFMANN exists, and probably also an analogous compound of the methylated phosphorus-betaine.

Hydrate of Triethyl-Phosphorus-Betaine.—14 grms. of the carefully purified hydrochlorate were dissolved in water and mixed with an excess of moist oxide of silver. Chloride of silver was at once formed, and the solution grew warm. The mixture was thrown on to a cloth filter, and the solution separated from the chloride and oxide of silver by squeezing. A few drops of hydrochloric acid were then added to precipitate the silver which had passed into solution, and the latter was then filtered. The solution was now placed *in vacuo* over sulphuric acid, and after some days yielded a colourless syrup, which eventually solidified to a radiating crystalline mass.

Some of this crystalline mass was exposed for many weeks in the desiccator (but not *in vacuo*), until it appeared to be perfectly dry.*

It was then placed in a weighed tube, and exposed *in vacuo* at first over sulphuric acid, and afterwards over phosphoric anhydride.

The vacuum was not perfect during the five or six months that the compound was thus exposed, but was renewed from time to time.

At the end of this period the hydrate had ceased to lose weight. Altogether 0·45925 lost ·0405 H_2O = 8·82 per cent.

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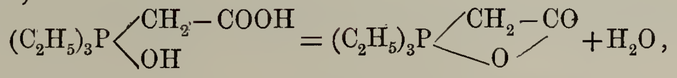
* It was reduced to powder as soon as it was partly dry, so that any water enclosed in the crystals might evaporate.

The equation,

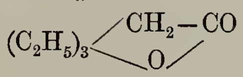


$$(C_2H_5)_3P\left<\begin{array}{l}CH_2-COOH\\ OH\end{array}\right. = (C_2H_5)_3P\left<\begin{array}{l}CH_2-CO\\ O\end{array}\right> + H_2O,$$

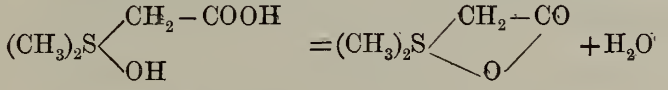
requires a loss of 9·27.

The compound which had thus been dried was then burnt with oxide of copper and chromate of lead, taking the greatest possible care to introduce it into the combustion tube in the dry state, a task of some difficulty, owing to its strong attraction for moisture.

0·4160 gave 0·3715 H_2O = 0·0413 H = 9·8 per cent. H
0·4160 „ 0·8380 CO_2 = 0·2285 C = 54·9 „ C

	Obtained.	Calculated for  $(C_2H_5)_3\left<\begin{array}{l}CH_2-CO\\ O\end{array}\right>$
Carbon,	54·9	54·6
Hydrogen,	9·8	9·6

Now this result is of some importance, as the base thetine has been shown to behave in exactly the same manner; that is to say, when dried over sulphuric acid, it has the composition of a hydrate, but *in vacuo* it loses a molecule of water. Thus—

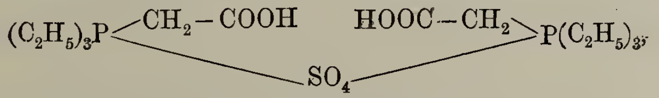


$$(CH_3)_2S\left<\begin{array}{l}CH_2-COOH\\ OH\end{array}\right. = (CH_3)_2S\left<\begin{array}{l}CH_2-CO\\ O\end{array}\right> + H_2O$$

And not only in this respect do the two bases resemble each other, for in their other properties they are closely analogous. Both are highly deliquescent; both crystallise in the same manner, but only when their solutions are highly concentrated; both have a neutral reaction; and as will be shown presently, both behave in a similar manner when heated.

Sulphate of Triethyl-Phosphorus-Betaine.—This compound was prepared by adding sulphate of silver to a solution of the hydrochlorate, filtering from chloride of silver, removing dissolved sulphate of silver by means of hydrochloric acid, and after filtering the solution evaporating it *in vacuo* over sulphuric acid. After a considerable time the syrupy liquid which remained, when most of the water had evaporated, solidified to a highly deliquescent crystalline mass.

There can be no doubt that this consisted of the sulphate,



$$\begin{array}{c}(C_2H_5)_3P<CH_2-COOH \qquad HOOC-CH_2>P(C_2H_5)_3,\\ SO_4\end{array}$$

but owing to its deliquescence it was not analysed.

Ethyl-Chlorate of Triethyl-Phosphorus-Betaine.—This compound was prepared by Hofmann, but was not obtained by him in the crystalline state (see p. 293).

Wishing to obtain some of this body for his experiments, the author proceeded in the manner described by Hofmann, but with somewhat different results.

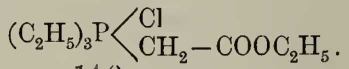
The following experiment will show this :—

6·1 grms. of triethyl-phosphine and 5·9* grms. of chloracetic ether (boiling point 140°–145°) were allowed to react on each other in the apparatus already described for preparing the hydrochlorate, and with the same precautions.

The two liquids simply mixed at first, but on shaking for some time an oily layer was precipitated, and the mixture grew very hot.† By continued shaking the upper layer (triethyl-phosphine ?) gradually disappeared, and eventually the product consisted of a colourless syrupy liquid. In a few minutes very beautiful circular crystals began to appear, and soon the contents of the flask had completely solidified. After an hour's interval the white crystalline mass thus obtained was broken up and treated three times in succession with dry ether. Most of it was then thrown on to blotting paper and placed *in vacuo* over sulphuric acid.

It was considered sufficient to fix the composition of the body by a chlorine determination, and by the analysis of the chloroplatinate.

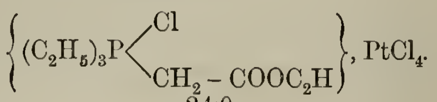
1·231 required 50·0 c.c. decinormal $AgNO_3$=0·1775 Cl =14·4 per cent.

	Obtained.	Calculated for  $(C_2H_5)_3P{<}\begin{matrix}Cl\\CH_2-COOC_2H_5\end{matrix}$.
Chlorine, . .	14·4	14·8

The ethyl-chlorate of triethyl-phosphorus-betaine is very deliquescent, and dissolves with ease in alcohol and chloroform. It cannot, however, be recrystallised from its solution in either of these liquids, even by the addition of ether: the ether precipitating oily drops, which refuse to solidify.

Chloroplatinate of Ethyl-Chlorate of Triethyl-Phosphorus-Betaine.—A solution of the ethyl-chlorate yields a copious precipitate of a light orange colour with chloride of platinum, which dissolves on boiling the solution, and separates on cooling in crystalline scales. The chloroplatinate thus obtained was analysed by dissolving it in water, precipitating the platinum by sulphuretted hydrogen, and determining the chlorine in the filtered solution volumetrically.

0·8245 gave 0·2025 Pt = 24·5 per cent. Pt.
0·8245 „ 0·8643 AgCl = 0·21532 Cl = 26·1 per cent. Cl.

	Obtained.	Calculated for 2  $\left\{(C_2H_5)_3P{<}\begin{matrix}Cl\\CH_2-COOC_2H\end{matrix}\right\}$, $PtCl_4$.
Platinum,	24·5	24·0
Chlorine,	26·1	25·9

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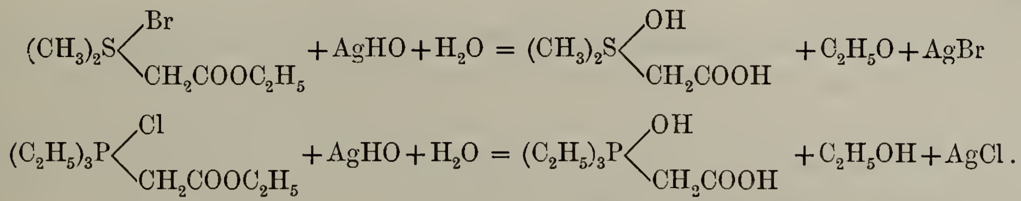
* These quantities are equimolecular.

† From time to time the mixture was cooled by immersing the distilling flask in water.

Action of Oxide of Silver on the Ethyl-Chlorate.—Hofmann states (*loc. cit.*) that the ethyl-chlorate is decomposed by oxide of silver into the base (triethyl-phosphorus-betaine) and alcohol, a reaction exactly similar to that which the author has observed with the ethyl-bromate of dimethyl-thetine. Thus—



$$(CH_3)_2S\left\langle\begin{array}{l}Br\\CH_2COOC_2H_5\end{array}\right. + AgHO + H_2O = (CH_3)_2S\left\langle\begin{array}{l}OH\\CH_2COOH\end{array}\right. + C_2H_5O + AgBr$$

$$(C_2H_5)_3P\left\langle\begin{array}{l}Cl\\CH_2COOC_2H_5\end{array}\right. + AgHO + H_2O = (C_2H_5)_3P\left\langle\begin{array}{l}OH\\CH_2COOH\end{array}\right. + C_2H_5OH + AgCl.$$

The author deemed it of interest to repeat Hofmann's experiment.

On mixing a solution (in water) of the ethyl-chlorate with recently precipitated oxide of silver, chloride of silver was formed, *and a strong smell of acetic ether became manifest.* The filtered solution was distilled, and the distillate was proved to contain alcohol, but it also had a strong odour of acetic ether.

The residue of the distillation was mixed with chloride of platinum, and yielded the characteristic blunt needles of the chloroplatinate of triethyl-phosphorus-betaine. These were dried at 110° C. and analysed.

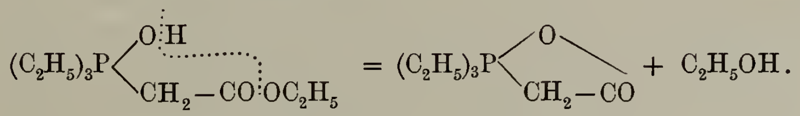
0·562 gave 0·1461 Pt=25·9 per cent. Pt.
0·562 „ 0·1556 Cl=27·7 per cent. Cl.

	Obtained.	Calculated for $2\left\{(C_2H_5)P<^{Cl}_{CH_2COOH}\right\}, PtCl_4$.
Chlorine,	27·7	27·7
Platinum,	25·9	25·7

The smell, however, of acetic ether was so pronounced that the author felt assured that it had indeed been produced in the reaction. Its formation is readily intelligible on the assumption that part of the ethyl-hydrate produced in the first phase of the reaction does not break up into alcohol and the phosphorus-betaine, but suffers a totally different, but no less simple decomposition.

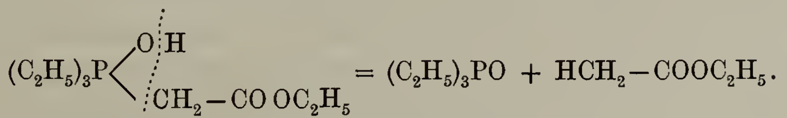
The two reactions may be represented thus—

(1)



$$(C_2H_5)_3P\left\langle\begin{array}{l}O\vdots H\\CH_2-CO\vdots OC_2H_5\end{array}\right. = (C_2H_5)_3P\left\langle\begin{array}{l}O\diagdown\\CH_2-CO\end{array}\right. + C_2H_5OH.$$

(2)

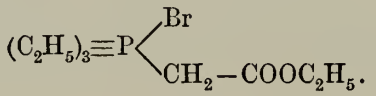


$$(C_2H_5)_3P\left\langle\begin{array}{l}O\vdots H\\ \vdots CH_2-CO\,OC_2H_5\end{array}\right. = (C_2H_5)_3PO + HCH_2-COOC_2H_5.$$

The author has not proceeded further with the investigation of this reaction, as the experiments to be described presently on the behaviour of the compounds of triethyl-phosphorus-betaine with caustic potash fully confirm the above interpretation of it.

Ethyl-Bromate of Triethyl-Phosphorus-Betaine.—Bromacetic ether acts on triethyl-phosphine with even greater energy than chloracetic ether. It is necessary to dilute the bromacetic ether with dry ether before adding the phosphine, otherwise so much heat is disengaged that the compound is partially decomposed.

Each drop of the phosphine occasions a turbidity in the solution, and the ether boils from the heat disengaged unless the vessel in which the experiment is conducted is placed in cold water. A layer of oily liquid soon forms, and after a few minutes this suddenly solidifies to a solid crystalline mass, whilst the supernatant ether also deposits abundance of crystalline matter. Owing to the extreme deliquescence of this body, its analysis was not attempted. Its reactions, however, leave no doubt as to its composition and constitution, which are expressed by the formula,



$$(C_2H_5)_3{\equiv}P\left\langle\begin{matrix}Br\\ CH_2-COOC_2H_5.\end{matrix}\right.$$

This is of some importance, for, as will be shown presently, bromacetic *acid* does not, except under special conditions, give a betaine derivative with triethyl-phosphine.

Ethyl-Iodate of Triethyl-Phosphorus-Betaine.—Iodacetic ether and triethyl-phosphine react on each other with as much energy as bromacetic ether and the phosphine, and dilution with ether is necessary to moderate the action. Exactly the same phenomena are observed as in the preparation of the ethyl-bromate. On mixing the ethereal solution of the iodacetic ether with the phosphine an oily layer is precipitated, which solidifies after a short time. The compound was not analysed.

Action of Heat on the Compounds of Triethyl-Phosphorus-Betaine.

One of the most interesting questions which presented itself in connection with the compounds which have just been described, was the change which they would suffer when submitted to the action of heat. Indeed, the author was chiefly induced to study them from a desire to decide this question. For he had shown some time ago* that the compounds of dimethyl-thetine are decomposed by heat in a very interesting way, and from the analogy of these bodies with corresponding compounds of the phosphorus-betaine, he was strongly inclined to the belief that the latter would behave in a similar manner to the former when heated.

The interest of the question was considerably heightened by the fact that

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* LETTS. These Transactions, vol. xxviii. p. 591.

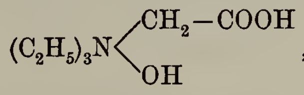
Brühl[*] had investigated the action of heat on ethlyated betaine, but had obtained a totally different class of products from those into which thetine is resolved.

Thus the action of heat on compounds of thetine and of betaine has been studied, with the result that they behave differently.

How will salts of the phosphorised betaine behave when heated? Will they give similar compounds to those which betaine yields, or will they be decomposed in the same way as thetine?

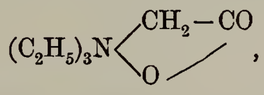
This question the author determined if possible to decide: but before describing the experiments which he performed with this object, it appears to him to be advisable to give a short *resumé* of Brühl's experiments with betaine, and of his own with thetine.

Brühl's experiments were conducted with triethyl betaine (*triethyl-amido-acetic acid*)



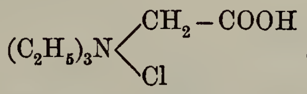
$$(C_2H_5)_3N\left\langle\begin{matrix}CH_2-COOH\\OH\end{matrix}\right.$$

, or



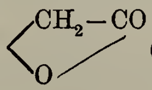
,

and also with its hydrochlorate,



$$(C_2H_5)_3N\left\langle\begin{matrix}CH_2-COOH\\Cl\end{matrix}\right. .$$

The former was heated in a bath of sulphuric acid to 210° C. At this temperature it began to froth and to distil, the distillate consisting of a colourless oil possessing an ammoniacal odour. The temperature rose towards the end of the operation to 230°, and a small quantity of charcoal remained in the retort. The distillate consisted essentially of triethylamine and of the unchanged betaine. These two bodies were the only ones which Brühl could obtain from the betaine by the action of heat, but the temperature at which the distillation is conducted has a considerable influence on their relative quantities. At a temperature of 210°–230°, the quantity of triethylamine is from one-third to one-fourth that of the betaine taken, whilst from one-half to two-thirds of the latter distils unchanged.

The only salt of the betaine with which Brühl appears to have made experiments was the hydrochlorate. Regarding the action of heat on this, he merely says, "I have satisfied myself by experiment that even the chloride (hydrochlorate) distils, but with considerable decomposition." These results appear to show that betaines and their compounds either dissociate into a triamine, and the radical  (or the products of its decomposition), or else distil unchanged.

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[*] Annalen der Chem. u. Pharm., vol. clxxvii. p. 214.

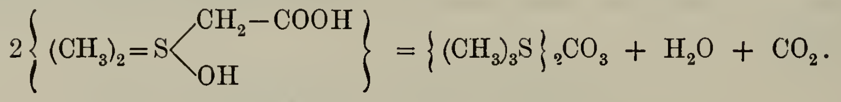
Very different is the behaviour of the thetines and their compounds when heated.

The author's experiments extended to dimethyl-thetine itself and to its salts with oxyacids and with hydracids. It will be sufficient to say that all the former appear to be decomposed in a similar manner, but that the latter suffer a totally different kind of decomposition.

The free base and its oxysalts always yield carbonic anhydride, and a salt of trimethyl-sulphine. Its haloid salts give, it is true, a trimethyl-sulphine compound, but this is accompanied by thio-diglycollic acid and a haloid ether of methyl.

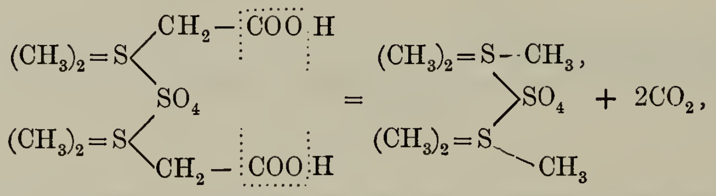
The decomposition which the free base, its sulphate, and its hydrobromate suffer will render this clear.

(1)



$$2\left\{(CH_3)_2=S\left<\begin{array}{l}CH_2-COOH\\OH\end{array}\right.\right\}=\{(CH_3)_3S\}_2CO_3+H_2O+CO_2.$$

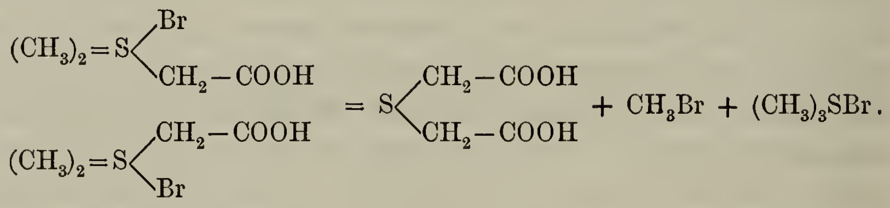
(2)



$$\begin{array}{l}(CH_3)_2=S\left<\begin{array}{l}CH_2-COO\,H\\ \\ \end{array}\right.\\ \qquad\quad SO_4\\ (CH_3)_2=S\left<\begin{array}{l}\\CH_2-COO\,H\end{array}\right.\end{array}=\begin{array}{l}(CH_3)_2=S-CH_3,\\ \qquad\qquad\quad >SO_4\\ (CH_3)_2=S-CH_3\end{array}+2CO_2,$$

and

(3)



$$\begin{array}{l}(CH_3)_2=S\left<\begin{array}{l}Br\\CH_2-COOH\end{array}\right.\\ (CH_3)_2=S\left<\begin{array}{l}CH_2-COOH\\Br\end{array}\right.\end{array}=S\left<\begin{array}{l}CH_2-COOH\\CH_2-COOH\end{array}\right.+CH_3Br+(CH_3)_3SBr.$$

Action of Heat on Ethyl-Bromate of Triethyl-Phosphorus-Betaine.[*]

Several experiments were made on the action of heat on this body (which was always prepared by adding triethyl-phosphine to an ethereal solution of bromacetic ether). The results were similar, but as the products were not in each case completely investigated, it will be more convenient to give a summary of the experiments.

The ethyl-bromate was heated in a distilling flask connected with the

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[*] The first of the author's experiments on the action of heat on the compounds of triethyl-phosphorus-betaine was made with this body. At the time he had only studied the action of bromacetic acid and of bromacetic ether on triethyl-phosphine, and consequently was unacquainted with any salts of the phosphorised betaine (see pp. 300, 301). The experiments with the ethyl-chlorate and hydro-chlorate were made more than a year afterwards.

apparatus which the author employed for catching any permanent gases in his experiments on the action of heat on salts of thetine.*

It fused below 100° C., and effervesced between 140°–150°: after some time it solidified (at about 170°). A very few drops of liquid distilled, but a large quantity of gas was evolved, and of this more than one-third consisted of carbonic anhydride. The solid residue was recrystallised (1) from alcohol, in which it was very soluble, and another crop of crystals (2) was obtained from the mother liquor.

Bromine was determined in each of these.

(1) 0·6051 gave 0·5345 AgBr = 0·2275 Br = 37·59 per cent. Br.
(2) *a* 0·4104 „ 0·3586 „ = 0·1527 „ = 37·2 „
(2) *b* 0·6648 „ 0·580 „ = 0·2468 „ = 37·11 „

These numbers agree with the bromine calculated for bromide of triethyl-methyl-phosphonium.

	Obtained.			Calculated for $(C_2H_5)_3(CH_3)PBr$.
	I.	II.		
		a	*b*	
Bromine, . .	37·6 .	37·2	37·1 . . .	37·5.

Some of the crystallised product which had yielded these numbers was dissolved in water and treated with oxide of silver, hydrochloric acid, and chloride of platinum in succession, when an orange-coloured precipitate was formed. This chloroplatinate was dissolved in boiling water, and separated as the solution cooled in very characteristic crystals, consisting of minute octohedra, usually truncated at their solid angles.

Analysis of these showed them to consist of the chloroplatinate of triethyl-methyl-phosphonium.

Platinum.

(1) 0·600 gave 0·174 Pt = 29·0 per cent. Pt.
(2) 0·8563 „ 0·2504 „ = 29·2 „

Carbon and Hydrogen.

0·6703 gave 0·3253 H_2O = 0·03614 H = 5·4 per cent. H
0·6783 „ 0·6035 CO_2 = 0·1646 C = 24·5 per cent. C

	Obtained.		Calculated for $2\left\{(C_2H_5)_3(CH_3)PCl\right\}, PtCl_4$
	I.	II.	
Platinum, . .	29·0	29·2	29·1
Carbon, . .	—	24·5	24·8
Hydrogen, . .	—	5·4	5·3

These numbers show that the solid product of the action of heat on the

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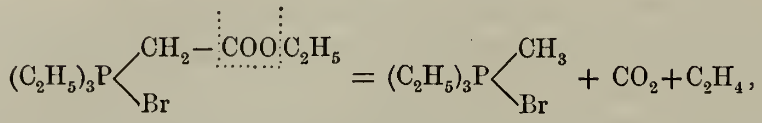
* These Transactions, vol. xxviii. p. 597.

ethyl-bromate is bromide of triethyl-methyl-phosphonium. The formation of this substance is explained by the equation—

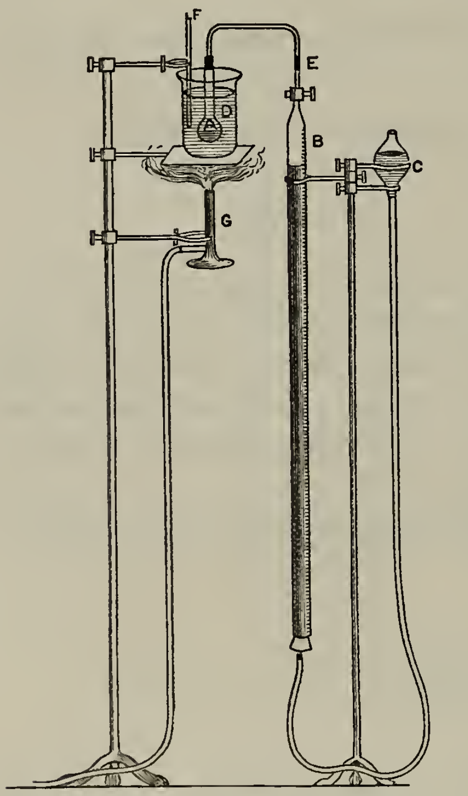


$$(C_2H_5)_3P\left\langle\begin{matrix}CH_2-COO\,C_2H_5\\Br\end{matrix}\right. = (C_2H_5)_3P\left\langle\begin{matrix}CH_3\\Br\end{matrix}\right. + CO_2+C_2H_4,$$

a decomposition very similar to that which the *oxysalts* of thetine suffer when heated.

It must be observed, however, that the author did not detect any ethylene amongst the gaseous products of the reaction, but on the other hand only about one-third of them consisted of carbonic anhydride.

Action of Heat on Ethyl-Chlorate of Triethyl-Phosphorus-Betaine.—The experiments on the action of heat on this body were made chiefly with the apparatus represented in the figure. Either the pure ethyl-chlorate or the product of action of chloracetic ether and triethyl-phosphine was carefully weighed, and placed in the flask A, which was then connected by the tube and indiarubber joint E, with the inverted burette B, previously completely filled with mercury by raising the reservoir C. The oil bath D was then heated by the Bunsen's burner G. As the ethyl-chlorate decomposed, the gaseous products passed into the burette. . Care was taken, by lowering the reservoir C, to keep the mercury both in it and in the burette at the same level. When no further evolution of gas occurred, A was cooled in water, and the volume of the gas which had been generated read off. The proportion of carbonic anhydride which it contained was determined as follows. A small funnel was attached by an indiarubber joint to the tap of the burette, and a quantity of strong potash solution poured into it. The mercury reservoir was then lowered, and the tap of the burette turned on for a few moments until sufficient potash solution had run into it. The tap was then turned off and the gas well agitated with the potash solution, and after some time its volume read off. The residual gas could also be examined.



A—A small flask of about 15 cc. capacity.
B—Inverted burette filled with mercury.
C—Mercury reservoir connected by indiarubber tube with B.
D—Oil bath.
E—Indiarubber junction.
F—Thermometer.

A good many experiments were made; the results being similar in each case. The ethyl-chlorate fused below 100° C., and began to give off gas at about 120°–130°. As the temperature increased, the evolution of gas became more rapid, and eventually the substance solidified, after which no more gas was produced. The solid product was brownish in colour, apparently due to the presence of charred substances. It ought also to be noticed that a very small quantity of liquid distilled during the experiment.

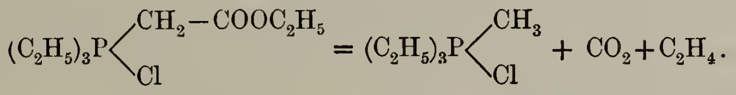
The quantity of gaseous products amounted to about 14–16 cc. for the molecular weight of the ethyl-chlorate in milligrammes, *i.e.* 0·241 grms. The addition of potash caused an absorption of about one-half this amount. The gas which remained burned with a smoky flame, and was absorbed in great measure by bromine,* thus showing that ethylene had been formed.

The solid product was converted into chloroplatinate. This was recrystallised from boiling water, and the crystals had the characteristic form of chloroplatinate of triethyl-methyl-phosphonium. Their identity with that substance was proved by their analysis.

0·4325 grm. gave . . . . 0·1285 Pt = 29·7 per cent.
0·4325 gave 0·5452 AgCl = 0·1348 Cl = 30·9 „

	Obtained.	Calculated for $2\{(C_2H_5)_3(CH_3)PCl\},PtCl_4$.
Platinum,	29·7	29·1
Chlorine,	30·9	31·5

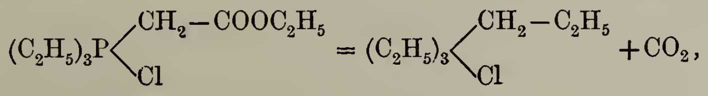
The preceding experiments show that the ethyl-chlorate decomposes in the manner represented by the equation,



$$(C_2H_5)_3P\Big\langle\begin{matrix}CH_2-COOC_2H_5\\ Cl\end{matrix} = (C_2H_5)_3P\Big\langle\begin{matrix}CH_3\\ Cl\end{matrix} + CO_2+C_2H_4.$$

But this equation can only explain the decomposition of part of the ethyl-chlorate; for if the whole of the latter decomposed as it indicates, a molecular weight of the substance in milligrames ought to yield at least 44 cc. of a mixture of ethylene and carbonic anhydride, whereas, roughly speaking, only one-third of that amount of gases were evolved. The author has not, however, ascertained the nature of the other reactions or reaction which occur.

That the ethyl-chlorate should decompose in the manner shown by the above equation, the author considers to be somewhat remarkable. When he first noticed that the ethyl-chlorate yielded carbonic anhydride on heating, he expected that the decomposition had occurred thus—



$$(C_2H_5)_3P\Big\langle\begin{matrix}CH_2-COOC_2H_5\\ Cl\end{matrix} = (C_2H_5)_3\Big\langle\begin{matrix}CH_2-C_2H_5\\ Cl\end{matrix} +CO_2,$$

but such is not the case.

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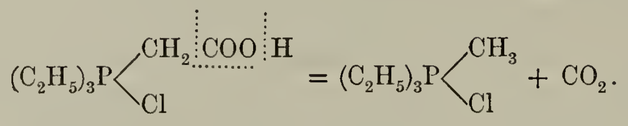
* This was ascertained by transferring some of the gas to an inverted burette full of water. A little bromine was then added, and the mixture shaken.

Action of Heat on Hydrochlorate of Triethyl-Phosphorus-Betaine.—The experiments made with this substance were conducted in the same apparatus as was employed for studying the action of heat on the ethyl-chlorate.

The hydrochlorate had been recrystallised two or three times from alcohol and ether, and was perfectly pure.

It fused at 145°–150°, then violently effervesced, and after a short time solidified to a snow-white mass. The gas evolved consisted of pure carbonic anhydride, and amounted to almost exactly the quantity calculated from the equation,*



$$(C_2H_5)_3P\left\langle\begin{matrix}CH_2\vdots COO\vdots H\\ Cl\end{matrix}\right. = (C_2H_5)_3P\left\langle\begin{matrix}CH_3\\ Cl\end{matrix}\right. + CO_2.$$

The solid product gave the characteristic chloroplatinate of triethyl-methyl-phosphonium, which was analysed.

0·5255 grms. gave 0·1558Pt = 29·4 per cent.
0·5255 „ gave 0·6735 AgCl = 0·1666 Cl = 31·7 „

	Obtained.	Calculated for $2\{(C_2H_5)_3(CH_3)PCl\}PtCl_4$.
Platinum,	29·4	29·1
Chlorine,	31·7	31·5

Action of Heat on the Hydrobromate.—The recrystallised hydrobromate obtained from the hydrochlorate (see p. 304) was also submitted to the action of heat. It fused, effervesced from the escape of carbonic anhydride, and then solidified. The residue yielded the characteristic chloroplatinate of triethyl-methyl-phosphonium.

Action of Heat on the Hydrate.—The change which the hydrate suffers when heated is very interesting, and was discovered quite accidentally. Wishing to concentrate its aqueous solution, the latter was evaporated on the water bath. When most of the water had been driven off, and a syrupy liquid remained, the author noticed a smell of triethyl-phosphine. Fearing decomposition, the heating was stopped, and the syrupy liquid was placed in the receiver of the air-pump over sulphuric acid. On exhausting the air, effervescence occurred, and the syrup solidified. After some time it was removed, and the drying completed on a water bath.

The dried mass effervesced with acids, even the weakest, such as tartaric acid. It at once gave an insoluble precipitate of a light orange colour when its solution was mixed with chloride of platinum, and its solution precipitated

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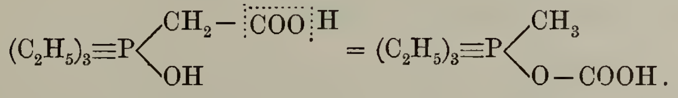
* 78·2 cc. were obtained from 0·762 grms. of the hydrochlorate instead of 80 cc.

carbonate of silver when it was mixed with nitrate of silver. It also had a very faint acid reaction.

Now all these properties are those of a *bicarbonate*, and there can be little doubt that the hydrate is converted by heat into the isomeric bicarbonate of triethyl-methyl-phosphonium.

Thus —



$$(C_2H_5)_3\equiv P\left\langle\begin{array}{l}CH_2-COO\,H\\ OH\end{array}\right. = (C_2H_5)_3\equiv P\left\langle\begin{array}{l}CH_3\\ O-COOH\end{array}\right. .$$

That the phosphonium salt had been formed was proved not only by the characteristic form of its chloroplatinate, but also by an analysis of the latter.

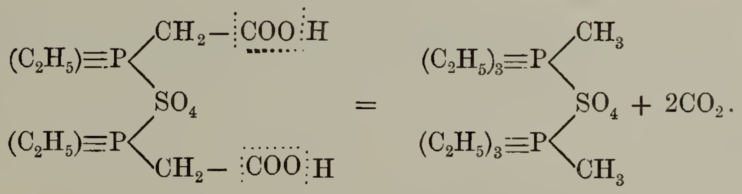
0·5484 grm. gave 0·1610 Pt = 29·4 per cent.

0·5484 gave 0·698 AgCl = 0·1726 Cl = 31·5 „

	Obtained.	Calculated for $2\{(C_2H_5)_3(CH_3)PCl\}, PtCl_4$.
Platinum,	29·4	29·1
Chlorine,	31·5	31·5

Action of Heat on the Sulphate.—The sulphate when heated behaves like the other compounds which have been spoken of. It fuses, effervesces from escape of carbonic anhydride, and then solidifies. The solid residue was converted into chloroplatinate, which crystallised in the characteristic form of the triethyl-methyl-phosphonium compound. It was not considered necessary to analyse it.

The decomposition of the sulphate, there can be no doubt, is expressed by the equation,

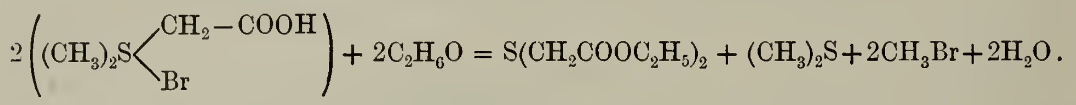


$$\begin{array}{l}(C_2H_5)\equiv P\left\langle CH_2-COO\,H\right.\\ \qquad\qquad SO_4\\ (C_2H_5)\equiv P\left\langle CH_2-COO\,H\right.\end{array} = \begin{array}{l}(C_2H_5)_3\equiv P\left\langle CH_3\right.\\ \qquad\qquad SO_4\\ (C_2H_5)_3\equiv P\left\langle CH_3\right.\end{array} + 2CO_2 .$$

The preceding experiments show that the compounds of triethyl-phosphorus betaine behave in exactly the same manner when heated, as the *oxy*-salts of dimethyl-thetine, and in this respect are utterly unlike the compounds of the true betaine.

Here then we have another of the many examples in which analogous compounds of phosphorus and sulphur display similar properties, whilst the corresponding nitrogen compounds behave differently. It should be remarked, that the author has in vain sought for a compound of phosphorus analogous to thio-diglycollic acid, viz., $P(CH_2COOH)_3$. Neither by the action of heat on any compound of the phosphorised betaine, nor by other reactions which might be expected to give rise to this body, could it be obtained. The author, however, proposes to make other experiments with the view to obtaining it, although he thinks it very possible it is not capable of existence.

Amongst the experiments made in this direction, may be mentioned one in which alcohol was heated for more than a week in a sealed tube with the hydrochlorate of triethyl-phosphorus-betaine at a temperature varying from 90°–100° C. Now the hydrobromate of dimethyl-thetine when heated with alcohol gives thio-diglycollic ether. Thus—



$$2\left(\mathrm{(CH_3)_2S}\begin{array}{l}\diagup\mathrm{CH_2-COOH}\\ \diagdown\mathrm{Br}\end{array}\right) + 2\mathrm{C_2H_6O} = \mathrm{S(CH_2COOC_2H_5)_2} + \mathrm{(CH_3)_2S} + 2\mathrm{CH_3Br} + 2\mathrm{H_2O}.$$

The phosphorised betaine compound was however simply decomposed, even at the temperature mentioned, into carbonic anhydride and chloride of triethyl-methyl-phosphonium.

Action of Caustic Potash on Compounds of Triethyl-Phosphorus-Betaine.

The author was led to these experiments by an observation he had made, that the product of action of bromacetic acid on triethyl-phosphine is readily acted on by caustic potash, with formation of oxide of triethyl-phosphine.

The author was aware that bromacetic acid and triethyl-phosphine do not, except under special conditions, give a betaine derivative; the product formed by their union being of a different nature.

It occurred to him that caustic potash might, however, react with a compound of the phosphorised betaine so as to give oxide of triethyl-phosphine, and he deemed it of importance to decide this point by experiment.

Action of Potash on the Hydrochlorate.—A preliminary experiment showed that an oily layer at once separated when strong potash solution was mixed with the hydrochlorate.

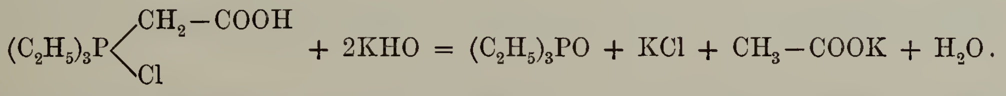
13 gms. of hydrochlorate (once recrystallised) were dissolved in about 25 cc. of water, and solid potash added by degrees. The solution grew very hot, and developed a faint odour of triethyl-phosphine, which the author believes to have been due to impurities present in the hydrochlorate. When 18 grms. of potash had been added, the solution separated into two layers, the lower of which consisted of an aqueous solution of the salts formed by the reaction. The upper layer was of a yellow colour. It was separated in a tap funnel, and fractionally distilled. The thermometer rose rapidly, and remained stationary within a degree or two of 240° C., during which a colourless distillate passed over, which solidified to a crystalline mass on cooling.

The boiling-point, zinc iodide compound, and other properties of this body, at once characterised it as oxide of triethyl-phosphine.

It should have been mentioned, that before all the potash had been added to the hydrochorate, an attempt was made to extract any substances which might have been formed and which were soluble in ether (to which some alcohol had been added). The oily layer from which the oxide of phosphine was obtained was highly charged with ether, alcohol, and a solid salt, which remained in the retort after all the oxide of phosphine had volatilised. This was dissolved in water, then just accidulated with nitric acid, nitrate of silver added, and the boiling solution filtered from the precipitated chloride of silver. The filtered solution was just neutralised with carbonate of ammonia and then allowed to cool, when a considerable quantity of crystals separated having the appearance of *acetate* of silver, and which a determination of silver showed were really that body.

0·2444 gave 0·1565 Ag $= 64·0$ per cent. Ag.
Calculated for $C_2H_3O_2Ag = 64·6$ „

Thus caustic potash acts on the hydrochlorate to give oxide of triethyl phosphine, together with chloride and acetate of potassium. The reaction is expressed by the equation,



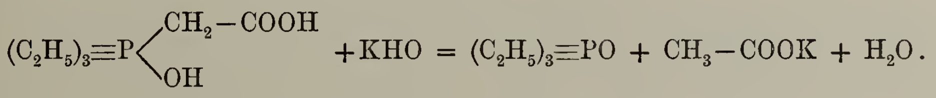
$$(C_2H_5)_3P\begin{cases} CH_2-COOH \\ Cl \end{cases} + 2KHO = (C_2H_5)_3PO + KCl + CH_3-COOK + H_2O.$$

Action of Caustic Potash on the Hydrate.—A quantity of the base which had been dried *in vacuo* was shaken with a strong solution of potash. It dissolved after a short time, the solution grew warm, and an oily liquid rose to the surface. This was separated, and consisted of a strong aqueous solution of oxide of triethyl-phosphine.*

The remaining solution from which the oily layer had been separated was neutralised with nitric acid, the mixture heated, and nitrate of silver added. On cooling, the characteristic crystals of acetate of silver separated. Their composition was verified by a determination of the silver which they contained.†

0·3157 gave 0·2017 Ag $= 63·9$ per cent. Ag.
Calculated for $CH_3-COOAg = 64·6$ „

Potash behaves then with the hydrate in exactly the same manner as with the hydrochlorate, the reaction occurring as follows :—



$$(C_2H_5)_3{\equiv}P\begin{cases} CH_2-COOH \\ OH \end{cases} + KHO = (C_2H_5)_3{\equiv}PO + CH_3-COOK + H_2O.$$

Action of Potash on the Ethyl-Chlorate.—The author has mentioned (p. 309) that, whilst investigating the action of oxide of silver on the ethyl-chlorate, he

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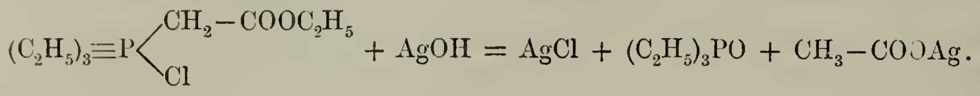
* Oxide of triethyl-phosphine appears to be completely insoluble in strong caustic potash solution.

† The crystals became discoloured by phosphuretted hydrogen accidentally present in the air of the room in which they were dried. The deficiency in silver is probably due to this.

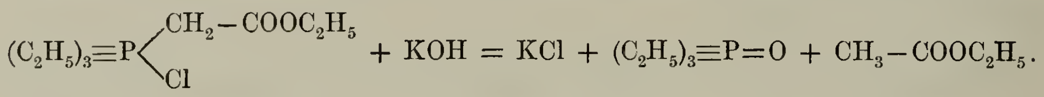
noticed on mixing the two substances a very powerful smell of acetic ether, which led him to suspect that part at least of the ethyl-chlorate had decomposed according to the equation,



$$(C_2H_5)_3{\equiv}P\Big\langle\begin{matrix}CH_2-COOC_2H_5\\ Cl\end{matrix} + AgOH = AgCl + (C_2H_5)_3PO + CH_3-COOAg.$$

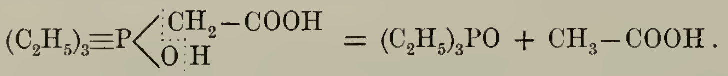
The action of potash on the ethyl-chlorate has confirmed him in this suspicion. On shaking some of the ethyl-chlorate with strong caustic potash solution an oily layer separated, and at once a very powerful odour of acetate of ethyl was developed.

It was not considered necessary to proceed further with the experiment, as the odour of acetic ether is unmistakable, and the production of the oily layer, experience had shown, always indicated the phosphine oxide. There cannot be the slightest doubt that caustic potash acts on the ethyl-chlorate, converting it *entirely* into triethyl-phosphine oxide, chloride of potassium, and acetic ether.



$$(C_2H_5)_3{\equiv}P\Big\langle\begin{matrix}CH_2-COOC_2H_5\\ Cl\end{matrix} + KOH = KCl + (C_2H_5)_3{\equiv}P{=}O + CH_3-COOC_2H_5.$$

Nor can any surprise be felt at this reaction, considering the powerful affinity of triethyl-phosphine for oxygen. It is indeed remarkable that such a body as the hydrate of the phosphorus betaine is capable of existence at all, and still more so that it does not split up into acetic acid and the phosphine oxide when heated—



$$(C_2H_5)_3{\equiv}P\Big\langle\begin{matrix}CH_2-COOH\\ O\;H\end{matrix} = (C_2H_5)_3PO + CH_3-COOH.$$

The author also tried the action of oxidising and reducing agents on the hydrochlorate of triethyl-phosphorus-betaine, but without very interesting results. Nitric acid acted readily on the hydrochlorate when the two were warmed together, abundance of red fumes escaping. When all action was over the nitric acid was distilled off, and a colourless liquid residue remained, which suddenly effervesced at 220° C., red fumes escaping. The heating was stopped and the residue was dissolved in water, and heated with chloride of platinum, when an abundant light orange-coloured precipitate resulted. Analysis showed this to consist of chloroplatinate of triethyl-methyl-phosphonium. Part then of the hydrochlorate had escaped oxidation, and had simply lost carbonic acid.

In the nitric acid which had distilled off a small quantity of oxide of triethyl-phosphine was detected. The author could find no other definite products of oxidation, except a minute quantity of an acid substance which gave a white precipitate with sulphate of copper.

Action of Bromacetic Acid on Triethyl-Phosphine.

A preliminary experiment showed that a very violent action occurs when the two bodies are mixed, so violent indeed that the greater part of the mixture was blown out of the vessel in which it was made.

If, however, the two are mixed in the apparatus employed for preparing the hydrochlorate of triethyl-phosphorus-betaine (see p. 301) and with similar precautions, the reaction is completely under control.

The bromacetic acid is at first dissolved by the phosphine, and the mixture then grows very hot. If the phosphine is added slowly, and the mixture well agitated from time to time, a colourless syrupy liquid results, which does not solidify on standing. If, on the other hand, the phosphine is added rapidly, and the temperature has not been kept down, the product is dark brown in colour, and very often solidifies almost completely on standing. The colourless syrupy product also solidifies on cooling if it be heated for a short time at 100° C., but it grows brown during the operation. The solidified product is extremely deliquescent, liquefying almost immediately when exposed to the air. It is very soluble in alcohol, but is insoluble in ether. The addition of the latter to its alcoholic solution causes the precipitation of an oily liquid which refuses to crystallise. It is also soluble in chloroform, and ether often precipitates it from its solution in that liquid in the form of small rhombic crystals. It is, however, extremely difficult to recrystallise it in this way, and the brown colouring matter adheres to the crystals most obstinately.

The properties of the product either before or after recrystallisation are not those of a salt of the phosphorised betaine. Thus it yields no crystalline compound with chloride of platinum, nor could a crystalline chloroplatinate be obtained after its bromine had been replaced by chlorine (by treating its solution with oxide of silver, filtering and adding hydrochloric acid).

It was found that its solution gave with carbonate or acetate of lead crystalline compounds, and much time was spent in endeavouring to fix their composition.

On adding carbonate of lead to the aqueous solution of the product, effervescence occurs, and if the solution is hot, a crystalline precipitate is soon formed. Also on mixing acetate of lead with a solution of the product, sparingly soluble crystalline compounds are produced. If the solutions are cold a white flocculent precipitate falls, which in tolerably dilute solution dissolves spontaneously. On scratching the sides of the vessel in which the two solutions have been mixed, or on warming the mixture, a colourless salt is precipitated in needles or plates. If the solutions are boiling two salts are often formed—one crystallising in warty masses, the other in plates and needles. On dissolving either of these in boiling water an insoluble residue is left, which appears to be bromide of lead. (It melts to a yellow liquid, and does not char when heated). The filtered solution deposits needles or plates on cooling, and very little of the warty crystals; and on again recrystallising, the salt is obtained almost free from the latter.

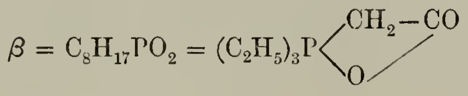
The composition of the lead salt varies, and although a large number of specimens were examined no two of them yielded the same numbers. The crystalline form was often entirely different, and was altered by recrystallisation of the salt. Moreover, a distinct smell of triethyl-phosphine was always noticed when carbonate of lead was employed in its preparation.

The author could arrive at no definite conclusion as to the composition of these sparingly soluble lead compounds. He thinks it advisable, however, to give the numbers obtained—

	I.	II.	III.	IV.	V.	VI.
Lead, . . .	49·4	49·7	44·6	44·5	43·7	68·2
Bromine, . .	37·2	36·6	40·0	40·0	...	26·7

	VII.	VIII.	IX.	X.	XI.
Lead, . . .	67·3	...	...	53·4	39·6
Bromine, . .	25·2	45·2	42·0	42·5	43·0

I. and II. obtained with acetate of lead, and produced from a hot solution.
III., IV., and V. „ „ „ a cold „
VI. and VII. obtained as I. and II.
VIII., IX., X., and XI., obtained with carbonate of lead.



$$\beta = C_8H_{17}PO_2 = (C_2H_5)_3P\left\langle\begin{array}{l}CH_2-CO\\O\end{array}\right.$$

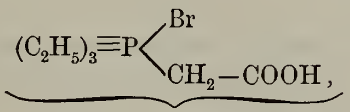
	Lead.	Bromine.
Calculated for $\beta + PbBr_2$ . .	38·1	29·4
„ $\beta + 2PbBr_2$ . .	45·5	35·2
„ $\beta + 3PbBr_2$ . .	48·7	37·6
„ $\beta + 4PbBr_2$ . .	50·4	38·9

The preceding results having failed to establish the composition of the product, other reactions were sought for which would decide this point. In considering how to attack this problem the question presented itself, is it not possible that the action of triethyl-phosphine on bromacetic acid gives rise to an isomer of hydrobromate of triethyl-phosphorus-betaine? Such a phenomenon would not be extraordinary, as chloracetic, bromacetic, and iodacetic acid do not always act in the same manner.

It is quite conceivable that three bodies can exist having the composition of hydrobromate of triethyl-phosphorus-betaine.

The constitution of these three may be represented by the formulæ—

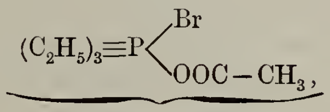
I.



$$(C_2H_5)_3{\equiv}P\left\langle\begin{matrix}Br\\ CH_2-COOH\end{matrix}\right.,$$

Hydrobromate of triethyl-phosphorus-betaine.

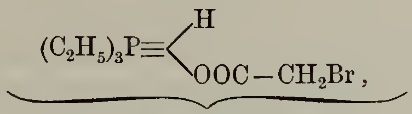
II.



$$(C_2H_5)_3{\equiv}P\left\langle\begin{matrix}Br\\ OOC-CH_3\end{matrix}\right.,$$

Aceto-bromide of triethyl-phosphine.

III.



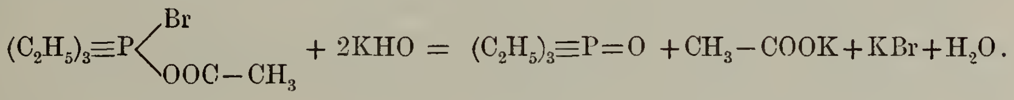
$$(C_2H_5)_3P{\equiv}\left\langle\begin{matrix}H\\ OOC-CH_2Br\end{matrix}\right.,$$

Bromacetate of triethyl-phosphine.

No. II. would probably give no platinum salt, whereas No. III., if it gave any, would give the chloroplatinate of triethyl-phosphine. No. III. would probably give no bromide of silver on treating its solution with nitrate of silver.

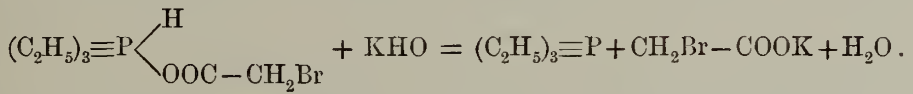
It occurred to the author that the action of caustic potash would decide between II. and III. For if it reacted with them at all, the reaction would probably be as follows:—

(II.)



$$(C_2H_5)_3{\equiv}P\left\langle\begin{matrix}Br\\ OOC-CH_3\end{matrix}\right. + 2KHO = (C_2H_5)_3{\equiv}P{=}O + CH_3-COOK+KBr+H_2O.$$

(III.)



$$(C_2H_5)_3{\equiv}P\left\langle\begin{matrix}H\\ OOC-CH_2Br\end{matrix}\right. + KHO = (C_2H_5)_3{\equiv}P+CH_2Br-COOK+H_2O.$$

With II. potash would react to give oxide of triethyl-phosphine, acetate of potassium, bromide of potassium, and water; whilst III. would give with the same reagent triethyl-phosphine and bromacetate of potassium (or glycollate and bromide of potassium).

It was resolved, therefore, to submit the product of action of bromacetic acid on triethyl-phosphine to treatment with caustic potash.

Action of Caustic Potash.—18 grms. of triethyl-phosphine were dropped slowly into 20 grms. of bromacetic acid in the apparatus already mentioned. The product was heated to 100° for about twenty minutes; it became brown, and a few bubbles of gas were evolved; on standing it solidified. It was then dissolved in chloroform, and a large excess of dry ether added—sufficient to precipitate the product in the crystalline state. The mixture of chloroform and ether was poured off from this, and it was then well washed with dry ether, and the last traces of ether removed by gentle heating.

It was then dissolved in water and the solution warmed. 6 grms. of solid caustic potash were added (dissolved in a little water), and the two solutions mixed. No separation of triethyl-phosphine occurred. Another 6 grms. of potash were then added ; triethyl-phosphine then separated, but so far as could be judged it amounted to only 2 or 3 grms.

The aqueous solution was drawn off from it, and it was found that *the addition of strong caustic potash solution to this caused the separation of an oily liquid which rose to the surface* and collected in a layer.

The mixture was repeatedly extracted with ether (which dissolved the oily layer), and the ethereal extract separated by a tap funnel, and fractionally distilled.

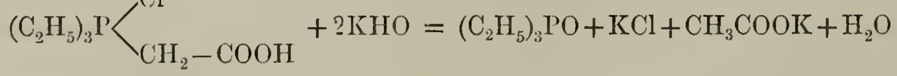
As soon as the ether, water, and triethyl-phosphine had passed over, the thermometer rose to 239°, and remained stationary at that temperature, whilst a colourless liquid passed over, which solidified on cooling.

The boiling-point of this liquid, as well as its properties, left no doubt as to its identity with triethyl-phosphine oxide.

The potash solution from which it had been extracted with ether, precipitated, during the extraction, a colourless crystalline salt. To obtain more of this, a considerable quantity of alcohol mixed with a little ether was added. The insoluble salt was then collected on a filter, and washed repeatedly with alcohol. It weighed 9 grms., and consisted entirely of bromide of potassium.

These experiments indicate that bromacetic acid unites with triethyl-phosphine to give both the isomers, which, for the sake of convenience, we may call II. and III. For although neither acetate nor bromacetate of potassium were specially sought for in the product of action (owing to the difficulty of separating them from the large excess of caustic potash present), the production of *both* triethyl-phosphine and the phosphine oxide may be considered as almost conclusive evidence of the production of both isomers, and from the quantities of these it would appear that II. is formed in far larger quantity than III.

But shortly after these experiments were made, it was found that hydrochlorate of triethyl-phosphorus betaine also reacts with potash to give the phosphine oxide, and both chloride and acetate of potassium, the reaction occurring according to the equation,



$$(C_2H_5)_3P\begin{cases}Cl \\ CH_2-COOH\end{cases} + 2KHO = (C_2H_5)_3PO + KCl + CH_3COOK + H_2O\,.$$

(see p. 319 .

The question therefore arose—is no hydrobromate of triethyl-phosphorus-betaine formed when bromacetic acid acts on triethyl-phosphine ?

The hydrobromate was, therefore, prepared from the hydrochlorate (see

p. 304) and it was found (1) that it readily yielded a sparingly soluble platinum salt; and (2) that it yielded carbonic acid on heating (see p. 316).

Now it has been already mentioned that *no* sparingly soluble platinum salt could be obtained from the product of action of bromacetic acid or triethyl-phosphine, and it had also been found that this product yields only a very small quantity of carbonic acid on heating (see p. 328), both of which results are against the supposition that any of the true hydrobromate is formed.

Fresh experiments were, however, necessary to decide this point. 3·5 grms. of carefully dried and purified bromacetic acid were dissolved in about 20 cc. of perfectly pure and dry ether. 3 grms. of triethyl-phosphine were dissolved in about the same quantity of ether, and the two solutions were simply mixed, without any special precautions. The flask in which the mixture was made was then corked and placed in cold water: oily drops precipitated. The flask was vigorously shaken from time to time, and was then left to itself in the cold water. The contents began to crystallise in a short time, and soon solidified to a solid mass. After a few hours this was broken up and thoroughly extracted with dry ether. It was then placed in *vacuo* for some hours.

Some of the snow-white product thus obtained was titrated with standard nitrate of silver solution, and was found to contain the amount of bromine required for the formula $C_8H_{18}O_2PBr$.

(1) 0·3316 required 13·2 cc. $AgNO_3$=0·1056 Br=31·8 per cent. Br.
(2) 0·4707 „ 18·5 „ „ =0·1480 „ =31·4 „ Br.

	Obtained.		
	I.	II.	Calculated for $C_8H_{18}O_2PBr$.
Bromine, .	31·8 .	31·4 . .	31·1

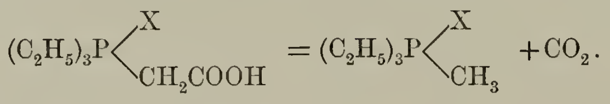
A portion of the product was treated with oxide of silver, and hydrochloric acid was added to the filtered solution. On the addition of chloride of platinum to this, a sparingly soluble orange-coloured salt separated exactly like the chloroplatinate of triethyl-phosphorus betaine.

Moreover, on heating some of the product, carbonic acid was given off in abundance, no charring occurred, and the residue solidified. On treating the latter with oxide of silver, hydrochloric acid, and chloride of platinum in succession, the characteristic chloroplatinate of triethyl-methyl-phosphonium separated.

These results then are quite different from those previously obtained, and indicate that some at least of the body produced by the action of bromacetic acid on triethyl-phosphine is the true hydrobromate of triethyl-phosphorus betaine. There was, however, no doubt whatever in the author's mind, from the numerous and carefully conducted experiments he had made on the action of the two bodies, that under certain conditions *none* of the true hydrobromate is obtained.

In the experiment just described both the bromacetic acid and the triethyl-phosphine were diluted with a large quantity of ether, and the temperature was not allowed to rise; whereas in previous experiments no ether was employed as a rule, and the two bodies were allowed to react on each other in the pure state. Much heat was developed, and as before stated the product of action was frequently heated to 100° C. to cause it to solidify.

Now it has been shown that the hydrobromate (and other salts) of triethyl-phosphorus betaine are decomposed when heated in such a manner that carbonic acid escapes, and a salt of triethyl-methyl-phosphonium remains.



$$(C_2H_5)_3P\left\langle\begin{array}{l}X\\ CH_2COOH\end{array}\right. = (C_2H_5)_3P\left\langle\begin{array}{l}X\\ CH_3\end{array}\right. + CO_2.$$

Whereas the product of action of bromacetic acid on triethyl-phosphine yields on heating only a small quantity of carbonic acid, but a large quantity of a solid volatile body (see p. 328). It is obvious then that the action of heat is a ready method for estimating the amount of hydrobromate of triethyl-phosphorus-betaine present in any specimen of the product of action of bromacetic acid on triethyl-phosphine.

2·9 grms. of the product just described, and which had been proved to contain hydrobromate of triethyl-phosphorus-betaine, were heated in an apparatus so arranged that any permanently gaseous products could be caught.

It began to effervesce at 200° C. At 215° C. the effervescence was very brisk, and at 230° it suddenly solidified to a pure white product. 192 cc. of gas were evolved.

The solid residue was heated over the naked flame, it fused, boiled, and *a considerable quantity of a pure white substance passed over at* 303° C., *which solidified in the condenser*. Here then is conclusive evidence that the product did not consist entirely of the hydrobromate of triethyl-phosphorus-betaine; had it done so no volatile body would have been formed, and 373 cc. of carbonic acid would have been produced. In round numbers, only half that quantity of gas was evolved, so that at least one-half of the substance consisted of a different body from the betaine compound.

Another experiment was made as follows:—12 grms. of triethyl-phosphine were added rapidly to 14 grms. of bromacetic acid. The mixture was allowed to grow very hot, and was cooled only when the phosphine boiled. As soon as all action was over, the viscous dark-brown product was divided roughly into two parts, one of which was heated in a distilling flask provided with the arrangement already described for catching liquid and gaseous products. The heating was performed with a Bunsen's burner, the distilling flask being placed on wire gauze. A volatile liquid first passed over, together with about 50 cc. of permanent gas. The temperature of the distillate then rose rapidly to 303° C., and the latter solidified on cooling. No more gas was evolved.

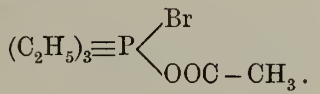
The other half of the product was dissolved in water, and boiled with slaked lime* until the solution was alkaline. Only a trace of triethyl-phosphine was evolved. The solution was then filtered, mixed with excess of dilute sulphuric acid, and the precipitated sulphate of calcium separated from the solution by squeezing the mixture on a cloth filter. The dark-brown solution thus obtained was distilled until its volume was reduced by about three-fourths. The colourless distillate was saturated with oxide of silver, and the mixture boiled and filtered.

On cooling abundance of crystalline matter separated, having the appearance of acetate of silver. It was dried in the desiccator, and a determination of silver made.

0·3202 gave 0 2057 Ag = 64·3 per cent. Ag.

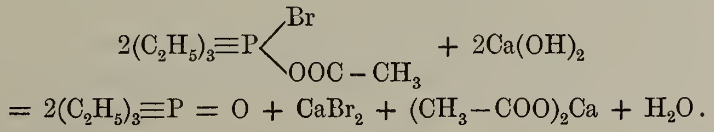
	Obtained.	Calculated for $C_2H_3O_2Ag$.
Silver,	64·3	64·6

Now, in this experiment the triethyl-phosphine and bromacetic acid were mixed in the pure state, and the temperature was allowed to rise considerably. 10 grms. or thereabouts of the product yielded when heated, only 50 cc. of gas (presumably carbonic acid); whereas, had the product consisted entirely of the betaine hydrobromate, 850 cc. of carbonic acid should have been evolved. Therefore only about 5 per cent. of the product consisted of the betaine hydrobromate. Of what did the remaining 95 per cent. consist? The action of the slaked lime may, the author thinks, be considered as proving it to be the aceto-bromide of triethyl-phosphine—



$$(C_2H_5)_3\equiv P\begin{cases}Br\\ OOC-CH_3.\end{cases}$$

The lime acting in the same manner as caustic potash, and giving bromide and acetate of calcium together with oxide of triethyl-phosphine.



$$2(C_2H_5)_3\equiv P\begin{cases}Br\\ OOC-CH_3\end{cases} + 2Ca(OH)_2$$
$$= 2(C_2H_5)_3\equiv P = O + CaBr_2 + (CH_3-COO)_2Ca + H_2O.$$

As before pointed out, any bromacetate of triethyl-phosphine would have been detected by the evolution of triethyl-phosphine on the addition of the alkali; whereas in this particular experiment mere traces of that body were given off.

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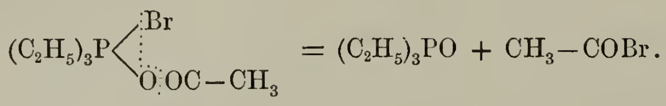
* Employed instead of caustic potash, on account of its insolubility.

There is another very powerful argument in support of this view of the nature of the product.

There is no doubt whatever that when it is heated bromide of acetyl is evolved (see below). Now, that is exactly what might be expected to occur with the aceto-bromide. Thus—



$$(C_2H_5)_3P\left\langle\begin{matrix} Br \\ \vdots \\ O\,OC-CH_3\end{matrix}\right. = (C_2H_5)_3PO + CH_3-COBr.$$

Action of Heat on the product of action of Bromacetic Acid on Triethyl-Phosphine.

In some of his earlier experiments on the product of action of bromacetic acid on triethyl-phosphine, the author had observed that when it is heated a crystalline body volatilises.

This fact seemed to be one of importance, and he therefore determined to obtain this crystalline body in quantity, and to examine its properties.

6 grms. of triethyl-phosphine were mixed in the usual way with 7 grms. of bromacetic acid, without diluting the latter with ether. When the action was at an end the product was at once submitted to the action of heat. It fused at a low temperature; a few cubic centimetres of gas were evolved, and later a small quantity of a pungent fuming liquid distilled. This fuming liquid on redistillation passed over before 100° C. It had the odour of bromide of acetyle, and its properties agreed with those of that body. On mixing it with water much heat was evolved, and on distilling the mixture (previously diluted with a considerable quantity of water) acetic acid passed over, and was identified by its silver salt. The residue contained hydrobromic acid. Moreover, on mixing some of the fuming liquid with fused acetate of potash, the odour of acetic anhydride was at once apparent. There can be no question therefore that it consisted mainly of bromide of acetyle.

After the fuming liquid had passed over the thermometer rose rapidly, and a crystalline solid began to appear in the tube used as condenser. The distillation was stopped when nothing but a black carbonaceous mass remained in the distilling flask. The crystalline solid amounted to about 7 grms. in weight. It was melted out of the condensing tube, transferred to a distilling flask, and heated. It fused, and at first a little hydrobromic acid was evolved. The thermometer then rose to 303° C., and remained stationary,* whilst a colourless liquid passed over, solidifying to a white crystalline mass on cooling. At the end of the distillation the thermometer stood at 305° C., and about 5 grms. of the crystalline product were obtained.

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* The condensing tube was changed when the temperature became constant.

It was melted out into a test tube, and three weighed tubes filled with it. These were then sealed up, and used for determinations of carbon, hydrogen, and bromine.

Bromine—

0·6233 gave 0·4682 $AgBr$=0·19818 Br=31·7 per cent.

Carbon and Hydrogen. (By combustion of the substance with oxide of copper and chromate of lead, a stream of oxygen being passed through the combustion tube at the end of the analysis)[*]—

(1) 0·45361 gave 0·3184 H_2O = 0·03577 H = 7·8 per cent. H.
0·4536 „ 0·607 CO_2 = 0·065545 H = 36·5 „ C.
(2) 0·3329 gave 0·2436 HO_2 = 0·02706 H = 8·1 per cent. H.
0·3329 „ 0·4515 CO_2 = 0·12313 C = 37·0 „ C.

In another experiment, conducted in the same manner with 12 grms. of the phosphine and 14 grms. of bromacetic acid, the same phenomena were observed· 17 grms. of crude crystalline product were obtained. This was distilled twice. It began to boil at 302°, the temperature was constant at 303°, and the distillation was ended at 306°.

The portion boiling from 302°–304° was at once melted into a test tube, and three small tubes were filled for analysis and sealed off.

Bromine—

0·7504 grms. gave 0·553 $AgBr$=0·234074 Br=31·2 per cent.
0·4203[†] „ 0·1320 „ =31·4 „

Carbon and Hydrogen—

0·349 gave 0·2578 H_2O=0·02864 H=8·2 per cent.
0·349 „ 0·4810 „ =0·13117 C=37·6 „

Another specimen similarly prepared boiled between 303°–308° C. The results of its analysis were as follows :—

Bromine—Volumetrically.

(1) 0·296 gave 0·09120 Br=30·9 per cent. Bromine.
(2) 0·800 „ 0·24880 „ =31·0 „

Carbon and Hydrogen—[‡]

0·4951 gave 0·6584 CO_2=0·179564 C=36·3 per cent. Carbon,
0·4951 „ 0·3623 „ =0·040255 H=8·1 „ Hydrogen.

In these analyses the carbon and bromine agree with the percentages required for a product of addition, of one molecule of bromacetic acid and one of triethyl-phosphine.

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[*] This combustion cannot be relied upon, as the substance volatilised with unexpected rapidity, and probably some carbonic acid was lost.

[†] Volumetrically by Voldhardt's method.

[‡] This combustion may have given a slight deficiency in carbon, as the substance volatilised very rapidly when it was first melted out of the tube.

	I.	II.	III.	IV.	Calculated for $C_8H_{18}PO_2Br$
Carbon, .	36·5	37·0	37·6	36·3	37·4
Hydrogen, .	7·8	8·1	8·2	8·1	7·0
Bromine, .	31·7	31·2	31·4	$\overbrace{30{\cdot}9 \quad 31{\cdot}0}$	31·1

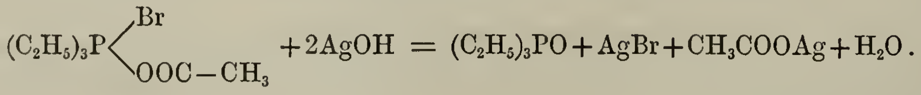
but the percentage of hydrogen is too high.

As the bromine was readily precipitated by nitrate of silver, it was considered that the body could scarcely be the bromacetate of triethyl-phosphine $\left((C_2H_5)_3\,P{<}\begin{matrix}H\\OOC-CH_2Br\end{matrix}\right)$, and as the hydrobromate of triethyl-phosphorus-betaine $\left((C_2H_5)_3P{<}\begin{matrix}Br\\CH_2-COOH\end{matrix}\right)$ had been shown to give abundance of carbonic acid, and to yield a different substance when heated, the new body could not be identical with it.

There remains the isomer of the two preceding bodies $(C_2H_5)_3P{<}\begin{matrix}Br\\OOC-CH_3\end{matrix}$ the aceto-bromide of triethyl-phosphine. It is quite conceivable that it would be volatile without decomposition, and it is probable, if not certain, that its bromine would be precipitated by nitrate of silver. The evidence appeared to be in favour of the identity of this substance with the volatile product in question, although the high percentage of hydrogen which the latter contained was against this view of its composition.

The product was very deliquescent, and soluble in alcohol and chloroform, but not in ether. It yielded no sparingly soluble compound with chloride of platinum neither when alcoholic solutions of the two were mixed nor when it was converted into chloride (by action of oxide of silver and hydrochloric acid). Attempts were made to determine its vapour density by VICTOR MEYER's method (using vapour of mercury as the source of heat), but without success, as it charred.

It was considered probable that, by acting on it with oxide of silver, its nature could be determined. For if its constitution were expressed by the formula $(C_2H_5)_3P{<}\begin{matrix}Br\\OOC-CH_3,\end{matrix}$ oxide of silver should give either a corresponding hydrate, or oxide of triethyl-phosphine and acetate of silver.



$$(C_2H_5)_3P{<}\begin{matrix}Br\\ \\OOC-CH_3\end{matrix} + 2AgOH = (C_2H_5)_3PO + AgBr + CH_3COOAg + H_2O\,.$$

Several experiments were tried on the action of oxide of silver on the product. The first of these showed that oxide of triethyl-phosphine is formed. The oxide was collected in the pure state; its boiling-point determined, as well as other of its characteristic properties. The bromide of silver produced at the same time was identified, but no acetate or other soluble salt of silver could be detected. One very carefully conducted experiment may be described to show how this was proved. 10 grms. of the product boiling between 304°–306°, were dissolved in water and mixed with excess of oxide of silver. Bromide of silver was precipitated, but no gas was evolved. The mixture of bromide and oxide of silver was then thoroughly squeezed from the solution in a cloth filter, suspended in water, and a current of sulphuretted hydrogen passed for some time until the mixture was thoroughly saturated. The aqueous solution was then filtered off from the sulphide of silver, and was heated in a distilling flask. No acetic acid passed over. When hydrobromic acid of constant boiling-point began to distil, the residue was heated in a water bath and evaporated to dryness. A few flakes of crystalline matter (less than 0·5 grm.) remained. Neither acetate of silver then, nor any other salt of silver could have been precipitated with the bromide except in minute quantity. The aqueous solution squeezed from the bromide of silver was heated in a distilling flask connected with an apparatus for collecting any gas that might be evolved, but none came off. Water at first distilled, and later 5–7 grms. of oxide of triethyl-phosphine boiling at 240°, and solidifying in the condenser. There remained in the distilling flask only a drop or two of a substance which was too small in quantity to be investigated. This experiment shows then, that when the product is acted on with oxide of silver, only bromide of silver and oxide of triethyl-phosphine are produced.

The results of these experiments are decidedly antagonistic to the view that the volatile body consists of aceto-bromide of triethyl-phosphine, and in fact may be considered as proving that it is not that substance. They indicate, on the other hand, that it consists of a compound of hydrobromic acid with oxide of triethyl-phosphine.

Crafts and Silva* have investigated the action of hydrobromic acid on oxide of triethyl-phosphine. By heating the latter with a 64 per cent solution of the former to 110° C. they obtained a product which boiled at 205°–210° C. under a pressure of 2 inches of mercury. This was redistilled under a pressure of 1½ inch of mercury, and boiled at 198°–203° C.

The author subjoins the results of the analyses of these two products, together with the mean of the numbers obtained by himself with the volatile product boiling at 303° C., and the numbers calculated for a compound of four molecules of oxide of triethyl-phosphine with three molecules of hydrobromic acid—

	Crafts' and Silva's product boiling at—		The author's	Calculated for
	205°–210°.	198°–203°.	product.	$4[P(C_2H_5)_3O],3HBr$.
Carbon, . . .	35·72	36·18	36·85	36·9
Hydrogen, . .	8·03	8·23	8·05	7·7
Bromine, . .	32·17	31·16	31·22	30·8

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* Journal of the Chemical Society, 1871, p. 637.

Crafts and Silva also passed hydrobromic acid gas into the dry phosphine oxide, and distilled the product. It began to boil at 260°, and about half passed over at 270–°300° C. A residue was left in the retort at 310°, which began to decompose.

The author considered it advisable to repeat this experiment.

Action of Hydrobromic Acid on Oxide of Triethyl-Phosphine.

7–8 grms. of the oxide were fused and a current of hydrobromic acid passed through it. The gas was absorbed eagerly, much heat was disengaged, and the product was coloured brown. As soon as the hydrobromic acid ceased to be absorbed, the product was submitted to distillation. Below 300° a little liquid passed over, the thermometer then rose slowly, whilst a colourless liquid passed over, which solidified on cooling. It had much the same appearance as the volatile product obtained by heating bromacetic acid and triethyl-phosphine, but it did not solidify quite so readily as that substance. The thermometer was tolerably constant from 320°–325° C., but a good deal of residue remained above this temperature. In another experiment the oxide of the phosphine was not saturated with hydrobromic acid, but was treated with rather more than 30 per cent. of its weight of the gas, which as before was eagerly absorbed. On distilling the product thus obtained only a few drops of liquid passed below 303°. But from this temperature to 308° almost every drop of the product passed over, and solidified on cooling to a white solid.

A determination of the bromine which it contained was made with the following results :—

0·3968 required 15·8 cc. decinormal $AgNO_3$=31·9 per cent. Br
0·4761 „ 19·0 „ „ „ =31·8 „

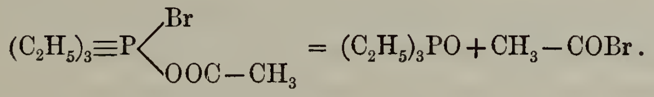
Although these numbers are somewhat higher than those obtained with the product of the action of heat on bromacetic acid and triethyl-phosphine, the difference is but slight, and very probably it would have been even less had the substance been re-distilled.

The author considers that there can be no doubt as to the nature of the volatile body obtained by heating the triethyl-phosphine and bromacetic acid ; it is simply a compound of phosphine oxide with hydrobromic acid, or a mixture of the two substances, similar to hydrobromic acid, or hydrochloric acid solutions of constant boiling point.

Crafts and Silva take the latter view of the nature of the substance obtained by them by the action of hydrobromic acid on the phosphine oxide. In the memoir already quoted they say, "Hydrobromic, like hydrochloric acid, combines with the oxide of triethyl-phosphine in the same way that these acids combine with water, and it is only under exceptional circumstances that a compound with a simple chemical formula is formed." The author, however, is by no means convinced of the correctness of this statement, for the numbers obtained by them agree very well (as he has shown) with a simple chemical formula, and although the latter does not consist of one molcule of the oxide and one molecule of the acid, it must be remembered that phosphine oxides combine with other bodies frequently in somewhat indefinite molecular proportions, in the same manner that silicic acid combines with bases. Further experiments are, however, necessary to decide the question.

The action of heat on the product of union of triethyl-phosphine and bromacetic acid cannot be expressed by any simple equation.

It is, however, probable, from the fact that some bromide of acetyl is evolved, that the first action of heat is as follows:—

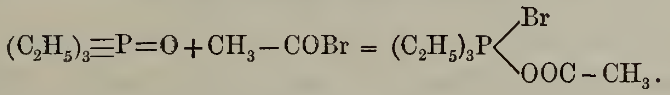


$$(C_2H_5)_3{\equiv}P\begin{matrix}\diagup Br\\ \diagdown OOC-CH_3\end{matrix} = (C_2H_5)_3PO + CH_3-COBr.$$

The phosphine oxide then removes hydrobromic acid from the bromide of acetyl, and the residue CH_2-CO becomes carbonised.

Action of Bromide of Acetyl on Oxide of Triethyl-Phosphine.

Whilst the experiments which have just been described were in progress, and the author had come to the conclusion that, under certain conditions, bromacetic acid and triethyl-phosphine unite to form the aceto-bromide of triethyl-phosphine, Dr Crum Brown suggested that it would be worth while to try the action of bromide of acetyl on the oxide of triethyl-phosphine, as by that means the same body ought to be formed.



$$(C_2H_5)_3{\equiv}P{=}O + CH_3-COBr = (C_2H_5)_3P\begin{matrix}\diagup Br\\ \diagdown OOC-CH_3.\end{matrix}$$

The experiment was accordingly tried.

The two substances react with energy, and if they are undiluted much heat is evolved, the mixture grows brown, and on cooling solidifies to a buttery mass, *having exactly the same appearance, and, so far as could be ascertained, the same properties as the product of action of bromacetic acid on triethyl-phosphine.*

On heating, this product behaved exactly like the latter; hydrobromic acid and a small quantity of bromide of acetyl passed over first; the thermometer* then rose to 308° C., and remained stationary at that temperature, whilst a colourless liquid distilled, which solidified on cooling, and had the appearance

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* The thermometer employed was different from that used in previous experiments, and the author cannot vouch for its accuracy.

of the product obtained by the action of heat on bromacetic acid and triethyl-phosphine, but was rather softer and more buttery.

Determination of the bromine it contained gave the following numbers :—

(1) 0·7472 required 29·8cc decinormal $AgNO_3$ = 31·9 per cent. Bromine .
(2) 0·909 ,. 36·9 „ „ „ = 32·5 „
(3) 0·5665 „ 23·0 ,, „ „ = 32·5 „

These numbers are somewhat higher than those obtained with the product of action of heat on bromacetic acid and triethyl-phosphine, but agree with those which Crafts and Silva found in the product of action of hydrobromic acid on the phosphine oxide, before it had been re-distilled.

Although the author feels convinced that all three products have a similar composition, he is unable at present to account for the slight differences observed in the amount of bromine which they contain.

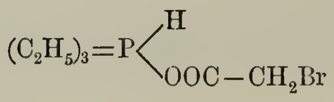
The experiment on the action of bromide of acetyl on oxide of triethyl-phosphine may be considered as confirming the view that the author has already advanced concerning the nature of the product formed by the action of bromacetic acid on triethyl-phosphine.

The experiments just described show that the action of bromacetic action on triethyl-phosphine varies with the conditions in a very interesting and remarkable manner.

The author thinks that he has proved that, at low temperatures, the two substances react so as to produce about equal quantities of hydrobromate of triethyl-phosphorus betaine and aceto-bromide of triethyl-phosphine, or a mixture of the latter with bromacetate of triethyl-phosphine.

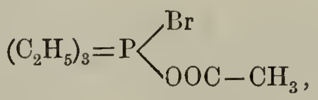
At intermediate temperatures very little of the hydrobromate is formed, and the product consists of the bromacetate and aceto-bromide; whilst at higher temperatures the aceto-bromide is almost the sole product.

Considering the very powerful affinity of phosphorus for bromine, the transformation of



$$(C_2H_5)_3{=}P\begin{cases} H \\ OOC-CH_2Br \end{cases}$$

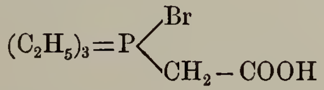
into



$$(C_2H_5)_3{=}P\begin{cases} Br \\ OOC-CH_3, \end{cases}$$

is readily intelligible, and there can be little doubt that bromacetate of triethyl-phosphine is a very unstable body.

Now, in addition to having a strong affinity for bromine, phosphorus has if anything a greater attraction for oxygen, whilst its affinity for carbon is slight, so that it is almost surprising that



$$(C_2H_5)_3{=}P\left\langle\begin{array}{l}Br\\CH_2-COOH\end{array}\right.$$

should be capable of existence at all. And it is certainly a remarkable feature in the history of these substances that this body should lose oxygen when heated (in the form of carbonic acid). It might rather be expected that it would, when heated, be converted into the aceto-bromide. But all attempts made in this direction have been unsuccessful.

In conclusion, I have to express my thanks to my assistant, Mr N. Collie, for the assistance he has rendered me during these experiments.

Fig. 1.

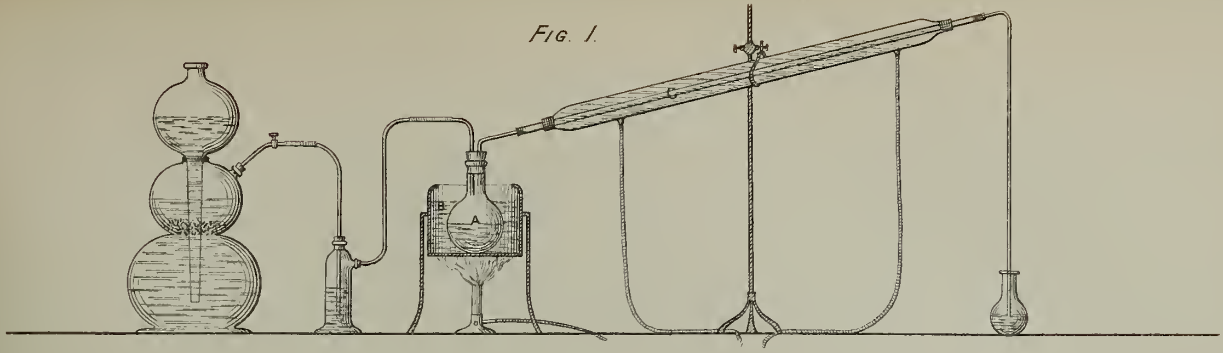


Fig. 2.

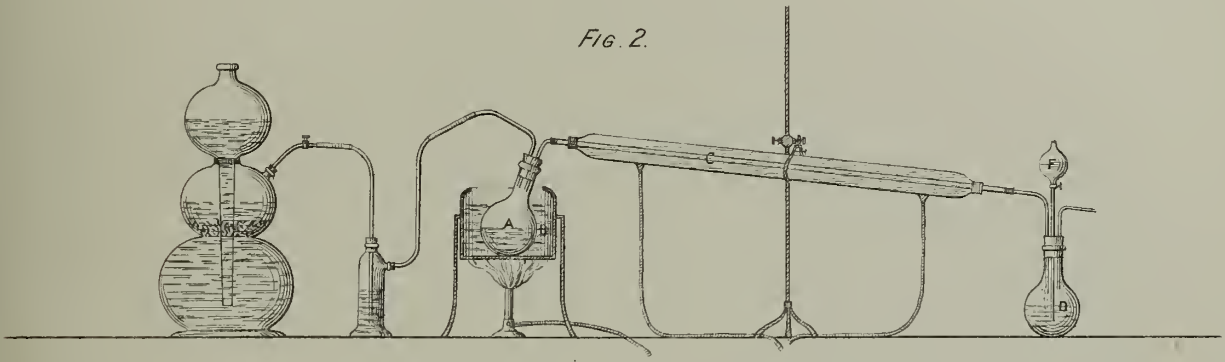


Fig. 3.

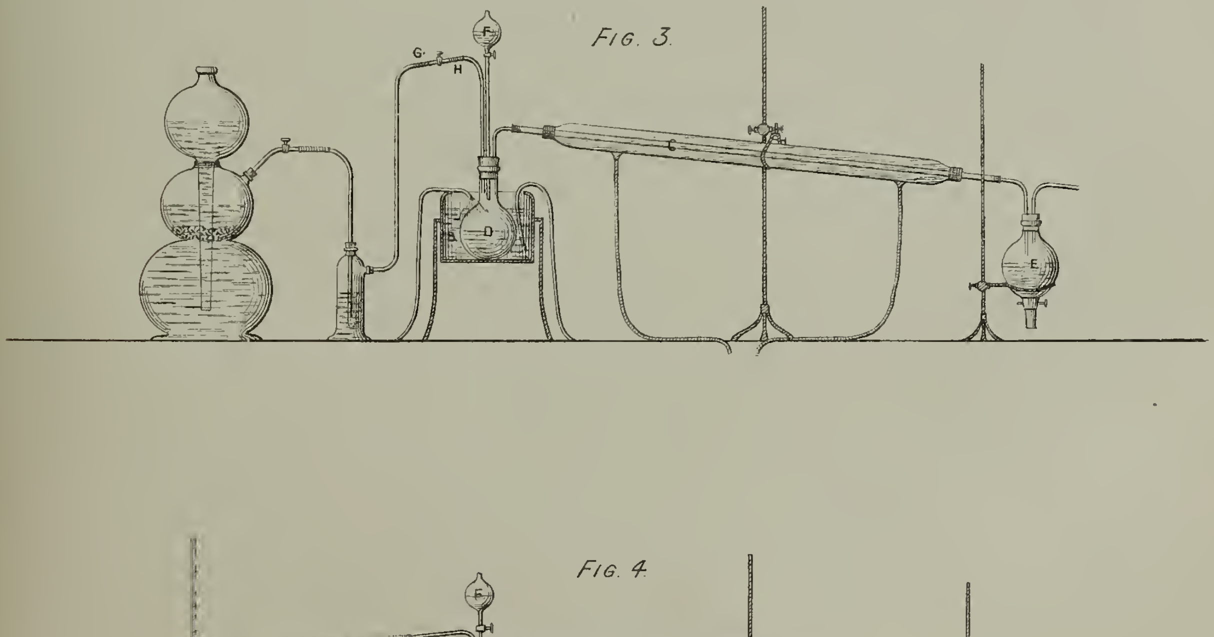
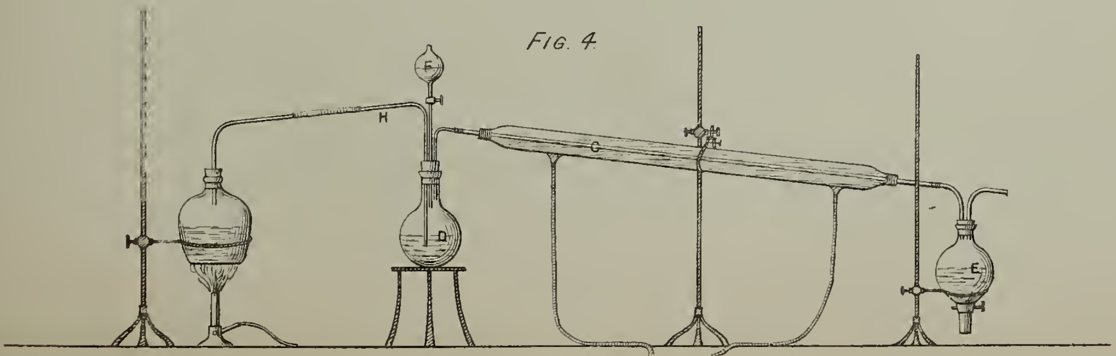


Fig. 4.



J. Bartholomew. Edinr.

XII.—*On Dust, Fogs, and Clouds.* By John Aitken.

(Read, Part I., December 20, 1880; Part II., February 7, 1881.)

Part I.

Water is perhaps the most abundant and most universally distributed form of matter on the earth. It has to perform more varied functions and more important duties than any other kind of matter with which we are acquainted. From its close connection with all forms of life, it has been the subject of deepest interest in all ages. It is constantly changing from one of its states to another. At one time it is solid, now liquid, and then gaseous. These changes take place in regular succession, with every return of day and night, and every successive season; and these changes are constantly repeating themselves with every returning cycle. Of these changes, the one which perhaps has the greatest interest for us, and which has for long ages been the subject of special observation, is the change of water from its vaporous state, to its condensation into clouds, and descent as rain. Ever since man first "observed the winds" and "regarded the clouds," and discovered that "fair weather cometh out of the north," this has been the subject of intensest human interest, and at present forms one of the most important parts of the science of meteorology, a science in which perhaps more observations have been made and recorded than in all the other sciences together.

In the present paper I intend confining my remarks to this change of water from its gaseous or vaporous to its liquid state, with particular reference to that change when it takes place in the cloudy condensation of our atmosphere. Let us look briefly at the process as it goes on in nature. As the heat of the sun increases, and the temperature of the earth rises, more and more water becomes evaporated from its surface, and passes from its liquid form to its invisible gaseous condition; and so long as the temperature continues to increase, more and more vapour is added to the air. This increased amount of vapour in hot air compared to cold air is generally explained by saying that hot air dissolves more water than cold air. This, however, is not the case. Air has no solvent action whatever on water vapour. Water vapour rises into air to the same amount that it would do into a vacuum at the same temperature, only it rises into air more slowly than into a vacuum, and the amount of vapour which can remain in the air is independent of the amount of air present, that is, independent of the pressure of the air, and depends only on the temperature.

After air has become what is called "saturated" with vapour, that is, when the vapour tension is that due to the temperature, a momentary condition of stability is attained. Suppose the temperature to fall, a change must now take place. All the water cannot remain as invisible vapour; some of it must condense out into its visible form. It is this condensed water held in mechanical suspension in the air to which we give the names of fog, cloud, mist, and rain, phenomena having some resemblance to each other, yet possessing marked differences. The particles composing a fog, for instance, are so fine they scarcely fall through the air, a cloud is a little coarser in the grain, while a mist is coarser still in texture, and rain is any of these while falling, whether it be a wetting mist or a drenching rain. And the question now comes, Why this difference? Why should the water vapour condense out of the air in one case in particles so minute they seem to have no weight, and remain suspended in the air, while in another case they are large grained and fall rapidly?

As the key to the answer to this question is given by a very simple experiment, it will be well for us here to have a clear conception of the conditions of that experiment. Here are two large glass receivers, both connected to this boiler by means of pipes. If we now allow steam to pass into this receiver, which we shall call A, you will see the steam whenever it begins to enter. There it comes, rising in a dense cloud, and soon you see the receiver gets filled with the condensed vapour, forming a beautiful white foggy cloud, so dense that you cannot see through it. Let us now pass some steam into the other receiver, which we shall call B. Observe—nay, you may strain your eyes as much as you please, you cannot see when the steam begins to enter, and now it has been rushing in for some time, and yet you cannot see it. There is not the slightest appearance of cloudiness in the receiver, yet it is as full of water vapour as the receiver A, which still remains densely packed with fog.

Now, why this difference in the two cases? Simply this. The receiver A, which is so full of fog, was at the beginning of the experiment full of ordinary air—the air of this room—while the other receiver B was also full of the air of this room, but before entering the receiver it was passed through a filter of cotton-wool, and all dust removed from it. The great difference, then, between the appearance of these two receivers is due to the dust in the air. Dusty air—that is, ordinary air, gives a dense white cloud of condensed vapour. Dustless air gives no fogging whatever.

But why should there be this difference in the two cases? Why should dust have this peculiar action? or rather, Why does not the water vapour condense into its visible form in air free from dust? The air is "supersaturated" in both cases, but in the one case it condenses out and forms a cloudiness, while in the other it remains in its invisible vaporous form. It will be necessary to diverge here a little from our immediate subject, to say a few words on the conditions under which water changes from one of its forms to another.

We have what are called the "freezing-point" and the "boiling-point" of water. These are, of course, the same as the melting-point and the condensing-points of water. Water at 0° C. will freeze if cooled, or melt if heated. It will pass into vapour if heated above 100° C., and will pass from vapour to liquid if cooled below 100° C., that is, at standard pressure. But something more than mere temperature is required to bring about these changes. Before the change can take place, a "free surface" must be present, at which the change can take place. I may here say that what I mean by a "free surface" is a surface at which the water is free to change its condition. For instance, the surface of a piece of ice in water is a "free surface" at which the ice may change to water, or the water change to ice. Again, a surface of water bounded by its own vapour is a "free surface," at which the water may vaporize, or vapour condense. What are called the "freezing" and "boiling points" of water are the temperatures at which these changes take place at such "free surfaces." When there is no "free surface" in the water, we have at present no knowledge whatever as to the temperature at which these changes will take place.

It is well known that water may be cooled in the absence of "free surfaces" far below the "freezing-point" without becoming solid. Some years ago* I showed reason for believing that ice in the absence of "free surfaces" could be heated to a temperature above the "freezing-point" without melting. Professor Carnelly has quite lately shown this to be possible, and has succeeded in raising the temperature of ice to 180° C.† Further, I have shown in the paper above referred to, that if water be deprived of all "free surfaces," it may be heated in metal vessels while under atmospheric pressure to a temperature far above the "boiling-point," when it passes into vapour with explosive violence.

From this we see that it requires a lower temperature to cause a molecule of water to adhere to another molecule of water to form ice, than for a molecule of water to adhere to a molecule of ice. Also that it requires a much higher temperature to cause a molecule of water surrounded on every side by other water molecules to pass into vapour, than for a water molecule bounded on one side by a gas or vapour molecule to pass into a state of vapour; and that a necessary condition for water changing its state is the presence of a "free surface" or "surfaces," at which the change can take place, if these changes are

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* "Transactions Royal Scottish Society of Arts," 1874–75.

† "Nature," vol. xxii. p. 435.

to take place at the "freezing" and "boiling points." At present we do not know at what temperatures these changes take place when no "free surfaces" are present. Indeed, we are not certain that it is possible for these changes to take place at all, save in the presence of a "free surface."

Returning now to the condensation of the water vapour, we see from the experiments given that precisely the same conditions are necessary for the condensation of a vapour as for its formation. Molecules of vapour do not combine with each other, and form a particle of fog or mist; but a "free surface" must be present for them to condense upon. The vapour accordingly condenses on the dust suspended in the air, because the dust particles form "free surfaces" at which the condensation can take place at a higher temperature than where they are not present. Where there is abundance of dust there is abundance of "free surfaces," and the visible condensed vapour forms a dense cloud; but where there are no dust particles present there are no "free surfaces," and no vapour is condensed into its visible form, but remains in a supersaturated vaporous condition till the circulation brings it in contact with the "free surfaces" of the sides of the receiver, where it is condensed.

We see, then, that each fog particle in the experiment was built on a dust particle. This indicates an enormous *number* of dust particles in the air. We must not, however, suppose that the particles of that dense fog we saw in the receiver A represented all the dust particles in the air experimented on. The experiment indicated an extremely foul state of the air indeed, but it does not tell the whole truth. Those fog particles only represent a small part of the dust particles present. That this is really the case is easily shown in the following way:—Let as much steam be blown in as will form a dense fog. Now allow this fog to settle, but do not allow any dusty air to enter. After the fog has settled blow in more steam. Again you will find a dense fog condensed on the dust which escaped the first condensation. Allow this again to settle, and repeat the process a number of times, when you will find, after many repetitions, that there is still fog forming. But it will also be noticed that after each condensation the fog becomes less and less dense, till at last it ceases to appear as fog; but on closely looking into the receiver the condensed vapour will be seen falling as fine rain. When the steam was blown in the first time the fog was very fine textured; each particle was so small it floated easily in the air. After each condensation the fog became less dense; it at the same time became more coarse-grained and heavier, and was seen falling slowly. Near the end, no fog was visible, and nothing but a fine rain to be seen falling. If the air was still further purified, even the rain seemed to cease.

This experiment may be made in another way. A large globular glass flask is provided, having a tight-fitting indiarubber stopper, through which pass two pipes. One of these pipes is connected to an air-pump, and the other terminates in a stop-cock. To the other opening of the stop-cock is securely fixed a tube tightly packed with cotton-wool. Some water is placed in the flask to moisten the air. If now the stop-cock is closed, and one or two strokes are made with the pump, so as to cool the air by expansion, it will be noticed that a fog immediately appears in the flask. This fog is fine textured, close grained, and will scarcely settle. Now pump out a good deal of the air from the flask, and allow air, filtered through the cotton-wool, to enter in its place. After the temperature equilibrium is established, again make one or two strokes with the pump. The fog again appears, but is now open-textured and coarse-grained. Repeat the process, admitting more and more filtered air each time, and it will now be observed that the dense light fog which at first appeared gradually gives place to one coarser and coarser in texture, till at last no fog appears ; but on looking closely a fine rain, as in the previous experiment, will be seen showering down inside the flask. If the process is continued still further the rain ceases, there being no more "free surfaces" to form nuclei for rain drops.

These two ways of experimenting, as might be expected, give exactly the same result, the conditions being so similar. In one the condensation is produced by the cold air mixing with the hot steam ; in the other the "saturated" air is cooled by expansion in the flask. These experiments show clearly that when there is dust in the air the vapour condenses out in a visible form, but when no dust is present it remains in a supersaturated vaporous state. That the air, when no dust is present, is really supersaturated, is evident from the fact that when the dust particles become few, the fog particles are not only few, but are much heavier than when they were numerous, and also by their increasing in size as they fall through the air. Each falling particle becomes a "free surface," at which the supersaturated vapour can condense and increase the size of the drop. Another way of showing the supersaturated condition of the air is to allow unfiltered air to enter in place of filtered air. The unfiltered air will at once show itself by the vapour condensing on its dust. It will be seen rising from the jet into the pure air, falling over and spreading itself over the bottom like a fountain of some viscous cloudy fluid.

It was in the autumn of 1875, when studying the action of "free surfaces" in water when changing from one state to another, that I first observed the conditions necessary for cloudy condensation. I knew that water could be cooled below the freezing-point without freezing. I was almost certain ice could be heated above the freezing-point without melting. I had shown that water could be heated above the boiling-point, and that the nature of the vessel in which it was boiled had no influence on the boiling-point, and all that was necessary for cooling the water below the freezing-point and for superheating the ice, and the water, was an absence of "free surfaces" at which they might change their state. Arrived at this point, the presumption was very strong that water vapour could be cooled below the boiling-point for the pressure without condensing. It was on looking for some experimental illustration of the cooling of vapour in air below the temperature corresponding to the pressure that I thought that the dust in the air formed "free surfaces" on which the vapour condensed and prevented it getting supersaturated. Arrangements were at once made for passing the air experimented on through a cotton-wool filter, and it was then that I first found that air which was free from dust gave no cloudy condensation when mixed with steam, and that the supersaturated air remained perfectly clear.

Shortly after this, the investigation had to be abandoned, and all that remained of it was a sketch of the apparatus in my notebook, together with a description of the experiments made with it, till about the middle of November last, when the investigation was continued. The apparatus with which the experiments were made before the Society is the same as when used in the first experiments.

The conclusions which may be drawn from these experiments are—1st, that when water vapour condenses in the atmosphere, it always does so on some solid nucleus; 2d, that the dust particles in the air form the nuclei on which it condenses; 3d, if there was no dust in the air there would be no fogs, no clouds, no mists, and probably no rain. As we do not at present know anything about the temperature of condensation of vapour where there are no free surfaces, we cannot tell whether the vapour in a perfectly pure atmosphere would ever condense to form rain; but if it did, the rain would fall from a nearly cloudless sky.

I have said that if there was no dust there would be no fogs, clouds, nor mists; but that is not all the change which would be wrought on the face of nature by the absence of dust. When the air got into the condition in which rain falls—that is, burdened with supersaturated vapour—it would convert everything on the surface of the earth into a condenser, on which it would deposit itself. Every blade of grass and every branch of tree would drip with moisture deposited by the passing air; our dresses would become wet and dripping, and umbrellas useless; but our miseries would not end here. The insides of our houses would become wet; the walls and every object in the room would run with moisture.

We have in this fine dust a most beautiful illustration of how the little things in this world work great effects in virtue of their numbers. The importance of the office, and the magnitude of the effects wrought by these less than microscopic dust particles, strike one with as great wonder, as the great depths and vast areas of rock which, the palæontologist tells us, is composed of the remains of microscopic animals.

Let us now look more closely into the action of dust in producing cloudiness. It is very evident that the results are not always alike. In one case the condensed vapour takes the form of a fog, so fine that it easily floats in the air and never seems to settle. In another case the cloudiness is coarser grained and settles down slowly, and in another case it is a very coarse-grained mist which falls quickly (of course I am not here speaking of the coarse grainedness produced by a number of small particles combining to form one). From the experiments described, it would appear that, when the dust is present in great quantities, the condensed vapour forms a fog, because as there are a great number of dust nuclei each nucleus only gets a very little vapour, and is not made much larger or heavier, so it continues to float in the air. As the number of dust nuclei diminish, the amount of vapour condensed on each particle increases, their size and weight therefore also increase. So that as the density of the cloudiness decreases the size of the particles increases, and their tendency to settle down also increases. Fogs will, therefore, only be produced when there is abundance of dust nuclei and plenty of vapour. There is probably also something due to the composition of the dust particles; some kinds of dust seem to form better nuclei than others.

We now come to the question of what forms this dust. What is its composition? Whence its source? I have been unable to get any trustworthy information as to the chemical composition of the dust. The only analysis I have seen is of dust collected in rooms. Now it is evident that as this dust has settled down, it will be, so to speak, winnowed dust, and will therefore contain too small a proportion of the finer particles.

As to where this dust comes from, it is evident it will have many sources. Everything in nature which tends to break up matter into minute parts will contribute its share. In all probability the spray from the ocean, after it is dried and nothing but a fine salt-dust left, is perhaps one of the most important sources of cloud-producing dust. It is well known that this form of dust is ever present in our atmosphere, and is constantly settling on every object, as evidenced by the yellow sodium flame seen when bodies are heated. There is also meteoric dust, and volcanic dust and condensed gases. At present, however, I wish to confine our attention to the action of heat as a producer of atmospheric dust, and more especially in relation to its fog-producing power.

Most of us on entering a darkened room, into which the sun is shining through a small opening in the shutters, have observed the very peculiar effect of the sun's rays when seen under these conditions, the path of the beam of light being distinctly visible, shining like a luminous bar amidst the surrounding darkness. On closely looking at it, it is seen that this peculiar effect is produced by the dust motes floating in the air of the room reflecting the light, and becoming visible as they pass through the path of the beam. We are struck by the marvellous amount of dust thus revealed ever floating in our atmosphere, and which under ordinary conditions of light are not observed. It is known that when air containing this dust is highly heated or passed through a flame, all these motes are destroyed, and the path of the sun's rays becomes invisible.

Returning now to the question of fogs, one might naturally conclude from what we have said that air which had passed over or through a flame or through a fire, where the combustion was perfect, ought to be nearly dustless, and, therefore, ought not to be a good medium for fogs. Before, however, coming to any conclusion on this point, it was deemed necessary to make more direct experiments, and we shall presently see that, however natural our conclusion is, it is very far wrong. Heating the air may cause the dust motes to become invisible; but so far as my experiments go, they prove that the heating of the air by the flame does not remove the dust, but rather acts in the opposite way, and increases the number of the particles. The heat would seem to destroy the light-reflecting power of the dust, by breaking up the larger motes into smaller ones, and by carbonising or in some way changing their colour, and thus make them less light-reflecting.

Powerful as the sun's rays are as a dust revealer, I feel confident we have in the fog-producing power of the air a test far simpler, more powerful and delicate, than the most brilliant beam at our disposal. When steam escapes into the air it condenses on the dust particles, and thus by simply magnifying their size, makes their number evident to the eye. Every fog particle in the air was represented by a dust particle before the steam was added, but these were invisible to the eye till increased in size by the vapour. This would seem to indicate a condition of the atmosphere too impure to be true, yet I think we are justified in our conclusion, as it has been shown that when there is no dust there is no fogging. In the future, therefore, we will be compelled to look upon our "breath" as seen on a cold morning, as evidence of the dusty state of the air. And every puff of steam as it escapes into the atmosphere will remind us still more powerfully of the same disagreeable fact. If it was not for dust we would never see our "breath," nor would wreathes of steam be seen floating in the air, nor would our railway stations and tunnels be thick with its cloudiness. The only consolation we have is, this fine dust is not easily wetted. The air we breathe is not deprived of all its dust in its passage through the lungs. The air which we exhale is still active as a fog-producer. If, for instance, we inhale the air by the nostrils, and pass it by the mouth to the experimental receiver, we find it still full of dust and fog-producing. We might have expected, that after passing over so much wetted surface, the dust would have been all taken out of the air. This difficulty of wetting the dust in the air may be illustrated by passing air through "washing bottles," after which it will still be found to be full of dust. Further, during wet weather, after rain has fallen for a long time, all the dust is not washed out of the air. It is still active as a fog-producer, though in a less degree than during dry weather.

I believe that at present some attempts are being made to collect and estimate the dust in the air. These observations deal with the weight and composition of the dust. I would here suggest that other observations be made by this fog-producing power of the air, to get not the weight or composition of the dust, but the relative multitude of the dust-specks in it at different times. There seems a possibility of there being some relation between dust and certain questions of climate, rainfall, &c.

The composition of the dust will also be of great importance in determining its power as a cloud-producer, as it is evident some kinds of dust will have a greater attraction for water vapour than others. Fine sodic chloride dust, for instance, we would expect would condense vapour, before it was cooled to the saturated point, on account of the great attraction that salt has for water. The instrument for these observations might be made to depend, either on the density of the fog produced by steam, or on its density when produced by reduction of pressure, as in the air-pump experiment.

Before making any experiment on the fog-producing powers of flames and combustion, it was necessary to test the effect of heat on the apparatus to be used, so as to be certain the effect was entirely due to the flame and nothing due to the heating of the apparatus used in collecting the hot gases. I accordingly experimented in the following manner:—The cotton-wool filter was detached from the experimental receiver, and there was placed between it and the receiver a short length of glass tube, so arranged that the air after passing through the filter should pass through the tube on its way to the receiver. The tube was so arranged that it could easily be taken out to be cleaned, and opened for introducing into it any substance the effect of which we might wish to test. The receiver was connected to an aspirator, by means of which filtered air was drawn into the apparatus.

The glass tube was first carefully washed with soap and water, and then with sulphuric acid, the acid being carefully washed off before the tube was put in its place. Air was now drawn through the apparatus, the air being tested from time to time by the admission of steam into the receiver. At first the steam gave rise to cloudiness, but as the dust gradually got cleared out the clouding become less and less, till at last it disappeared, indicating a dustless state of the air in the receiver. After this condition was attained the glass tube, through which the filtered air was passing, was heated, to get the effect, if any, due to heating glass, and also to make sure that the effect produced by any substance placed in the tube was due to that substance alone. The result of heating the clean and empty tube was most remarkable, and very unexpected. A slight heating was sufficient to give rise to a very dense fog, on admission of steam to the receiver. We might have imagined that the careful washing the tube received was sufficient to make the glass clean. Yet we see it was still so foul that heat drove off sufficient matter in a fine state of division as to give rise to a dense fog. The glass tube was now highly heated, to see if heat would cleanse it. After cooling it was again heated to the same amount as at first. It was now found to be quite inactive. No fogging whatever appeared in the receiver. If, however, the tube was again highly heated fogging appeared. In testing different substances placed in the tube, it was therefore necessary to use only a low degree of heat, so that none of the effect might be due to the tube. After each experiment the tube was highly heated, to thoroughly cleanse it, before introducing the substance to be tested. When this was done, and a lower degree of heat employed, I could perfectly trust to the tube being inactive.

The next experiment was made with a small piece of brass wire placed in the testing tube. While it was cold there was of course no fogging, but when slightly heated, a dense clouding resulted. A piece of iron wire, and other substances, all gave a similar result. The wires were now highly heated in a Bunsen flame before being put in the testing tube. On heating they were now found to be quite inactive, not the slightest fogging appeared. The high temperature had acted on them as it acted on the glass, and destroyed their dust-producing powers.

A piece of brass wire was now carefully filed bright, so as to remove all uncleanness from it, it was then placed in the experimental tube, care being taken that it was not touched with the hands. When heated it only gave rise to the faintest cloudiness. These experiments prove that the cloudiness was produced by some matter driven off by the heat from the outside of the metal. The slight cloudiness produced by the filed wire being due to the slight contamination got when being filed.

The amount of matter which is driven off these wires by heat is extremely small, and its result as a fog-producer so great, that this apparatus places in our hands a means of detecting in gases quantities of matter so small as almost to rival in delicacy the spectroscope. The following experiment will give an idea of the marvellous smallness of the amount of matter which may be detected in this way. If we take a small piece of fine iron wire, $\frac{1}{100}$ of a grain in weight, and place it in the experimental tube, and apply heat, it will give rise to a very decided cloudiness. Now take the wire out, and if you so much as touch it with your fingers, on again returning it to the tube and heating, the fact of your having touched the $\frac{1}{100}$ of a grain of iron wire will be declared by the fog which forms in the receiver. The effect seemed so great for so small a cause, that I repeated the experiment a great number of times, sometimes putting in the wire and getting the fog, and sometimes going through all the motions and changes necessary for, but not putting it in, and getting no fog, that I am compelled to come to the conclusion, that the fogging is really caused by the contamination due to the touch.

A great number of different substances were tested in this apparatus, and, as might have been expected, all were active fog-producers. Amongst other substances tried were different salts. One point noticed was that their activity did not depend on their power of evaporating or subliming. Camphor, though subliming and evaporating quickly, scarcely ever gave any fog, only a heavy coarse-grained fog which settled at once, while ammonic carbonate, sodic carbonate, and sodic chloride were very active, indeed the latter salt is one of the most active substances I have tried. If we place a crystal of sodic chloride $\frac{1}{100}$ grain in weight in the tube, and apply heat, it will continue to give off nuclei sufficient to form a dense fog for a long time, without apparently losing in size.

We see from these experiments that when testing the fog-producing power of a flame, it will not do to collect the products of combustion and draw them into our experimental receiver, as the heat would raise a dust from the surface of the collecting tube sufficient to cause a dense fog; another method of experiment was therefore devised. It was, however, necessary before proceeding further, to test the effect of the gas to be burned, to see if it was active as a fog-producer. Gas from the gas pipes was accordingly passed into the experimental receiver, and tested with steam, and found to be perfectly inactive. No cloudiness appeared. Any effect then produced by the burning gas could not be due to dust carried in by the gas.

The apparatus was now arranged in the following manner to test the fog-producing powers of the products of combustion from a gas flame:—Two receivers were arranged alongside each other, and connected by means of a pipe. Gas was led into the first receiver by a pipe terminating a short distance inside the receiver in a glass tube, the end of which was drawn to a fine jet at which the gas was burned. The receiver used for this purpose was so large that the flame could not heat the glass sufficiently to make it active as a fog-producer. After the gas was lighted, a current of filtered air was drawn through the receiver to supply oxygen for the flame. The products of combustion were drawn into the second receiver through the connecting pipe. In this second receiver the products of combustion were tested from time to time with steam.

At first, of course, the air which came would be unfiltered dusty air; but as nothing but filtered air entered, this dusty air ought gradually to give place to pure air. It was found, however, that after filtered air had been drawn through for a long time, there was not the slightest sign of the air becoming purer. To make sure the fogging was due to the flame, the gas was turned off, and combustion stopped, while the circulation was kept up. In a very short time after this was done, the air showed a marked decrease in cloudiness, and after a time became pure.

This method of testing the effect of combustion does not seem, at first sight, the best. The intention was to have, first, circulated the air till perfectly pure, and steam gave no cloudiness, and then to light the gas and see the effect. The difficulty of working in this way was that I could not light the gas without introducing a disturbing element. It was intended to have lit the gas by means of an incandescent platinum wire, but on testing the effect of the hot wire alone, it was found to make the air active, and powerfully fog-producing. By highly heating the wire, it was possible to make it less active at lower temperatures, but the temperature produced by igniting the gas would again make it active.

I have great hesitation in coming to any conclusion from this experiment. At first sight it would look as if the small flame is very far from being a dust destroyer, and is on the contrary a very active producer of it. It will be remembered that the flame was fed with filtered air, and the result of the combustion of filtered air and dustless gas is an intensely fog-producing atmosphere, and that the fogging is due to dust cannot, I think, be doubted, as the products of combustion, when filtered, give no cloudiness when steam is added. Yet the question may be asked, Was the dust produced by the combustion? It seems almost possible it might be the result of soda driven off by the heat from the glass jet.

On the 8th and 12th of January this experiment was repeated. The glass jet at which the gas was burned being removed, and a platinum one put in its place. Platinum was selected because it was thought in the highest degree improbable that any nuclei could be driven off the platinum by the heat of the gas flame. After the jet was fixed in its place it was highly heated to thoroughly cleanse and make it inactive at the lower temperature produced by the flame. The gas was lit, and the receiver then put in its place, and the supply of filtered air drawn through the apparatus. The result was the same as before. Increase of fogging on the gas being lighted, and the fogging continued so long as the gas was kept burning, and only stopped when the flame was put out.

There seemed a possibility that the fogging might be due to some residual motes still remaining in the receiver getting into the flame and being broken up by the heat into a great number of parts. The experiment was accordingly varied to meet this. A fine platinum wire, which could be heated by a battery, was arranged so that the gas might be lit by it without opening the receiver, the platinum wire being previously highly heated to cleanse it as much as possible. The receivers being closed, and the gas not lit, air was drawn through the apparatus till the air in the receivers was purified ; and no cloudy condensation took place on admitting steam. Contact with the battery was now made, and the gas lit. At once a densely fogging atmosphere was produced.

No doubt part of this fogging was due to nuclei driven off the heated platinum wire, but as the wire was previously cleansed, and only heated for a short time, and quickly removed from the flame, there would be but little due to this cause, and what dust it did give off would be so fine that the heat of the flame would not be likely to break it up any further, and it would be gradually removed by the circulation, and its place filled with filtered air. It was, however, found that though the supply of air was kept up, and the flame kept burning for some time, the fogging showed no signs of decreasing. On shutting off the gas, the fogging at once began to diminish, and soon cleared away, showing that the fogging was due to the products of combustion.

These experiments seem to indicate that the combustion of dustless gas and dustless air do of themselves give rise to condensation nuclei, and do not act by simply breaking up larger dust motes into smaller ones. These nuclei produced by the combustion of gas must be extremely small, as a very small flame so loads a considerable current of dustless air as to cause it to become full of a very fine and closely packed form of fog when mixed with steam.

The question may here be put, Is it really dust which is driven off by the heat from the surface of glass, from the brass and iron wires, and from the other substances ? It is extremely difficult to get a direct answer to this question, but I think that, reasoning from the known conditions necessary for the condensation of vapour, it is extremely probable that it really is an extremely fine form of solid matter which is produced under these circumstances. Further, they have all been put to the test of the cotton-wool filter, and all of them have been filtered out and the air made non-cloud-producing. If it was some gas or vapour which was produced by the heat, we see no reason why the cotton-wool should have kept them so completely back.

Another set of experiments was now made to test the fog-producing power of air and gases from different sources. The air to be tested was introduced into the experimental receiver, and steam blown in and mixed with it. Its fog-producing power was tested by the density of the cloudiness produced, and also by the time the fogging took to settle. It was always found that the air of the laboratory when gas was burning gave a denser fog than the air outside, sometimes two or three times as dense. The products of combustion from a Bunsen flame and from a smoky flame were compared. They were found to be about equally bad, and both much worse than the air in which they were burned. These products were collected by holding the open end of the receiver over the flame, taking care not to heat the glass. Products of combustion from a clear part and from a smoky part of a fire were tested, and found to be about equally foggy, and both much worse than the air of the room.

From these experiments it would appear that combustion under all conditions is bad as a fog-producer ; bad, whether the combustion be perfect, as in a Bunsen flame and a clear fire, or imperfect as in a smoky flame and smoky fire. It is therefore hopeless to expect that by adopting fires having a perfect combustion, such as the gas ones now so much advocated, we would thereby diminish the fogs which at present, under certain conditions, envelop our towns, and give rise to so much that is both disagreeable and detrimental. All fires, however perfect the combustion, are fog-producers when accompanied by certain conditions of moisture and temperature. From this it will be observed that it is not the visible dust motes seen in the air that form the nuclei of fog and cloud particles, as these may be all destroyed by combustion, and yet the air remain fog-producing. No doubt these motes also play their part in the condensation, but their number is too small to be of importance. The fog and cloud nuclei are a much finer form of dust, are quite invisible, and though ever present in enormous quantities in our atmosphere, their effects are almost unobserved.

A number of experiments have been made by burning and highly heating different substances to test their fog-producing powers, and I have found that highly heated sodic chloride, as, for instance, when burned in an alcohol flame, or salt water spray heated in a Bunsen flame, gives rise to an extremely dense fog when tested with steam. But perhaps the most active of all substances I have yet tried is burning sulphur. The fog produced when steam has been blown into air in which a very little sulphur has been burned is so dense that if ever fog was "cut" it might or should be. So dense is it that it is impossible to see through a depth of more than 5 centimetres of it. The sulphides when burned also give similar results.

These experiments evidently introduce a new element into the investigation. We have here not only to do with the attraction of the different molecules of the same kind, but the gaseous molecules in this case have also chemical affinities for each other. It is very difficult to understand this marvellous fog-producing power of burned sulphur. Sulphur in burning gives rise to sulphurous acid. Now from experiment I have made with sulphurous acid prepared from sulphite of soda and sulphuric acid, and also from copper and sulphuric acid, the sulphurous acid being carefully dried with sulphuric acid, I do not find it active as a fog-producer. It gives rise to no fumes, it does not increase the fogging of dusty supersaturated air, and produces no fog in filtered supersaturated air.

Sulphuric acid vapour, it is well known, gives rise to dense fumes by combining with the moisture of the air, and I find, under certain conditions, it also gives rise to a dense fog with steam, but I also find that these fumes and fog owe their formation to dust. This is illustrated by the following experiment.

In a retort was placed a quantity of sulphuric acid. The stopper of the retort was removed, and in its place was put a tube connecting the retort with a cotton-wool filter. The neck of the retort was connected to a wash-bottle by means of a glass tube. An aspirator drew the air out of the wash-bottle, and thus kept up a current of air from the filter through the retort to the wash-bottle, the air bringing the sulphuric acid vapour along with it. At first, when unfiltered air passed, dense fumes filled the retort and wash-bottle, but when the filter was introduced the cloudiness gradually disappeared. The absence of dust entirely prevented any foggy condensation, even though there were chemical affinities. After the experiment had been continued for some time, slight fumes began to appear, even when filtered air was passing, but this only happened when the acid became very concentrated, and much acid evaporated, and the fumes with filtered air were very slight, while unfiltered air gave very dense fumes.

It is not necessary to suppose the want of dust prevented the chemical affinities from acting, it only prevented the new compound from condensing in cloud form. When the acid was weak its vapour would combine with the moisture in the air, but would remain as vapour when there was no dust for it to condense upon. But when the acid became highly concentrated, the molecular strain would be greatly increased on account of the vapour tension being greatly in excess of that due to the temperature, and it would then seem to be able to condense without the presence of a "free surface." There is, of course, the possibility that the filtering of the air was not perfect. I may remark here that the fumes of highly concentrated sulphuric acid are found to be an excellent fog-producer. If we dip a glass rod in the acid, and heat it highly, and allow a little of the fumes to pass into the experimental receiver, steam will now give a very dense fog indeed.

The effect of dust in producing the cloudy form of condensation of other vapours than water was tried. With all the vapours experimented on, which included alcohol, benzol, and paraffin oil, it was found that pure air gave no clouding whatever, while unfiltered air gave more or less cloudiness with all of them.

The cause of the blue colour of the sky has long afforded interesting matter for speculation. The theory which seems most satisfactorily to explain its blue colour depends upon the property which very small particles of matter have of scattering only the rays of the blue end of the spectrum, and the question is, What are these very small particles composed of? It has been suggested that they are very small particles of condensed water vapour. Now, we have shown the high improbability of water vapour ever condensing out in a visible form in pure air, and that if it did condense in those circumstances, the particles would be large. From the all-pervading presence of the infinitesimal atmospheric dust, the idea naturally suggests itself, that the blue sky may be caused by the light reflected by this dust. What seems to support this theory is that, as we ascend to high elevations, the sky becomes deeper blue, this being caused by fewer and only the finer of the dust particles being able to keep floating in the thin air at these elevations. Further, after rain the sky is darker blue, this deepening of the colour being caused by much of the dust being washed out by the falling rain.

I wish now to apply the result of these experiments to the great fog question, which Dr Alfred Carpenter opened at the last Social Science meeting, and to which at present so much attention is being directed. The increased frequency and density of our town fogs are now becoming so great as to call for immediate action. But before doing anything, a much clearer knowledge of the conditions which produce a fog is necessary, or much time will be lost and expense uselessly incurred. I wish, therefore, to call attention to the teaching of the experiments described, so far as they bear on this important question. What I have to say on this point must, however, be received with reservation. The conditions of a laboratory experiment are so different and on so small a scale, that it is not safe to carry their teaching to the utmost limit, and apply them to the processes which go on in nature. We may, however, look to these experiments for facts from which to reason, and for processes which will enable us to understand the grander workings of nature.

We have seen that fogs and clouds are produced by the condensation of vapour on the dust particles floating in the air. The condensation is produced by cold, the result of radiation or expansion of the air, either by reduction of barometric pressure or by the elevation of the air into higher regions. A fog, therefore, before it appears, is every particle of it represented by a particle of very fine invisible dust; the thick visible fog was previously represented by an invisible dust cloud. Now, it is very evident that if there is an enormous number of these dust particles in the air, so that they are very close to each other, then each particle will only get a very small amount of vapour condensed upon it. It will therefore become but little heavier, and will float easily in the air. To this light and dense form of condensation we give the name of fog. If there are fewer dust particles, then each particle gets more vapour, and each particle is heavier and settles sooner. It must not be supposed, from this, that rain only falls when these dust particles are few, and the vapour particles very large, because there seems to be always enough dust in the air to make the cloud particles small enough to keep suspended. Their union and fall as rain is determined by certain conditions on which the present inquiry throws no light. But of clouds there are vast degrees of texture, the fog being the finest grained, most dense and persistent, almost never settling down.

From this view it will be seen that the vapour condenses on the solid matter floating in the air, whether that matter be fine dust or condensed smoke. This view I am aware is different from the one generally received, namely, that cloud particles are hollow vesicles, hollow to enable them to float, and that smoke, &c., attaches itself to the outside of these vesicles.

Since, then, fogs are produced by an over-abundance of fine atmospheric dust in a moist atmosphere, and as we have but little control over the moisture in the air, our attention must be directed principally to the diminution of the atmospheric dust, if we wish to reduce the density of fogs. We have seen that all forms of combustion, however perfect, are great producers of this less than microscopic dust. The brilliant flame, the transparent flame, and the smoky flame are all alike fog-producers. Perhaps there may be some form of combustion which is not a dust-producer, or some form of combustion which may give a coarse-grained dust. If there is, it ought to be more generally known. As a correction of the present form of combustion, perhaps something could be done to arrest the dust before it escapes into the atmosphere. But any plan which at present suggests itself is too troublesome and expensive ever to be put into general use. To prevent mistakes I may here remark, that when speaking of the dust produced by combustion, I do not mean the dust usually spoken of in connection with fires, as it is comparatively heavy, and soon settles to the ground, nor do I refer to smoke or soot. The dust I refer to is the invisible dust, so fine that it scarcely settles out of the air. If we put air into the experimental receiver and leave it for days without any communication with the outer air, we will still find it fog-producing, though in a very marked degree less than at first.

All our present forms of combustion not only increase the number and density of our town fogs, but add to them evils unknown in the fogs which veil our hills and overhang our rivers. In the country the fogs are white and pure, while in towns they are loaded with smoke and other products of imperfect combustion, making the air unwholesome to breathe and filthy to live in. But why should these two miseries always come together? Either the fog or the smoke is bad enough alone; why should the smoke which usually rises and is carried away by the winds fall to the ground when we have fogs? I think that the conditions which account for the fog also account for the smoke falling. When we have fogs, the atmosphere is nearly saturated with vapour, and the smoke particles, being good radiators, are soon cooled, and form nuclei on which the vapour condenses. The smoke particles thus become loaded with moisture, which prevents them rising, and by sinking into our streets add their murky thickness to the foggy air. This seems to explain the well-known sign of falling smoke being an indication of coming rain. That the colour or blackness of what is called a pea-soup fog is due to smoke, is, I think, evident from the fact that a town fog enters our houses and carries its murky thickness into our rooms, and will not be induced to make itself invisible however warmly we treat it. It will on no account dissolve into thin air, however warm our rooms, for the simple reason that heat only dissolves the moisture and leaves the smoke, which constitutes a room fog, to settle slowly, and soil and destroy the furniture. If the fog was pure, that is to say, was a true fog and nothing but a fog, such as one sees in the country, it would dissolve when heated, as every well-conditioned country fog does—at least I never remember meeting a fog in a country house.

But while admitting the bad effects of a fog aggravated by smoke, yet we must not forget the probable good effects of the smoke. It has been elsewhere pointed out that the suspended smoke or soot may exercise the well-known disinfectant properties possessed by the different forms of carbon. Before utterly condemning smoke it will be necessary fully to consider its value as a deodoriser. And further, we must remind those who are crying for more perfect combustion in our furnaces and grates, that combustion, however perfect, will not remove or diminish fogs. It will, however, make them cleaner, take away their pea-soupy character, but will not make them less frequent, less sulphurous, less persistent, or less dense.

We have shown that sulphur in its different forms when burned is most active as a fog-producer. Now, almost all our coals contain sulphur, which is burned along with the coal, and it is certainly worth considering whether some restriction ought not to be put on the amount of sulphur in the coal used in towns. The quantity of burned sulphur that escapes from our chimneys is very great. Suppose we put the amount of coal annually consumed in the London district at a little over 7,400,000 tons. Now, the average amount of sulphur in English coal is more than 1·2 per cent. Suppose that it is 1 per cent., so as to be within the mark, that would give 74,000 tons of sulphur burned every year in London fires, or at the rate of about 200 tons in an average day, and the amount will be greater in a winter day—a quantity somewhat alarming, and quite sufficient to account for the density of our fogs. Its presence and effects during our fogs is very evident in the discoloured metal on our street door and in our houses.

But, like smoky fires, burnt sulphur is not an unmitigated evil. During fogs the air is still and stagnant; there is no current to clear away the foul smells and deadly germs that float in the air, and which might possibly be more deadly than they are if it were not for the powerful antiseptic properties of the sulphurous acid formed by the burning sulphur. Before condemning the smoke and fog-producing sulphur, it would be well for us thoroughly to investigate their saving properties and weigh their advantages, lest we substitute a great and hidden danger for an evident but less evil.

While we look upon fires and all forms of combustion as fog-producers, yet we must remember there is ever present plenty of dust in the air to form clouds and even fogs; fires simply increase the amount of the dust. Now it is evident that as the rain is constantly washing the dust out of the air, fresh supplies must therefore be constantly added.

We have every reason for supposing that there are immense quantities of very fine salt-dust ever floating in the air. This is evidenced by the ever-present sodium lime that at one time so troubled spectroscopists. One source of the supply of this salt-dust is evidently the ocean, and it affords us another example of how very closely the phenomena of nature are interlinked. The ocean, which under a tropical sun quietly yields up its waters to be carried away by the passing air, almost looks as if he repented the gift, when tossed and angry under tempestuous winds, as he sends forth his spray, which dried and disguised as fine dust becomes his messenger to cause the waters to cease from their vaporous wanderings, descend in fertilising showers, and again return to their liquid home.

Part II.

Since making my first communication to this Society on Dust, Fogs, and Clouds, many of the experiments have been repeated under different conditions and with improved arrangements of apparatus. I shall first give a short description of the changes made in this direction, which seem to fill up some points wanting in the first paper, and shall then describe some experiments made in a department of the subject which I have only touched upon.

We have seen that when steam is blown into dustless air there is no cloudy condensation, and that the vapour remained supersaturated till it came in contact with the sides of the receiver, on which it deposited itself. My next experiments were to determine to what extent dustless air can be supersaturated without the vapour condensing into drops—to determine whether vapour molecules can combine with one another to form a liquid, or whether they must have a nucleus to condense upon even when the vapour is very highly supersaturated. It is evidently very difficult to get a definite answer to this question, and I shall only describe the direction in which I sought to get an answer, the experiments not being sufficiently conclusive to settle the point.

The first thing to be done was evidently to get quit of all "free surfaces" of all nuclei of condensation, and the experiments have resolved themselves very much into questions of filtration, as I have not yet arranged any experiment in which I have been certain there might not have been some nuclei present. The first step in this direction was to test the action of the filter through which the air passed. All the cotton-wool was removed from the filter and a fresh quantity put in. At first only a thin layer was used, and its effect tested, noting the degree of cloudy condensation produced. More cotton-wool was then put over the first layer, and the improvement noted. Fresh quantities were added till no improvement was observed. Then double the total quantity was put in, and the filter was now considered to be doing all that cotton-wool could do to purify the air of the receiver from dust.

The result was—when a small quantity of steam was blown into the receiver there was no cloudy condensation whatever; the receiver remained perfectly clear. But when the steam valve was opened wider and more steam allowed to enter, although no effect was noticed at first, yet after a time the vapour became so supersaturated that it condensed and fell as fine rain. If a still greater amount of steam was blown in, then it was seen condensing on entering the receiver, and the falling rainy condensation was seen tossed about by the rush of the entering steam.

Attention was now directed to the steam. It seemed possible that nuclei might be given off from the hot sides of the boiler, and from the hot parts from which the steam was rising. To prevent any nuclei which might be formed in this way from entering the receiver, the end of the steam pipe inside the receiver was covered with a cotton-wool filter. The result was, however, as before, with little steam, no condensation, with much steam, rainy condensation. On account of the tendency of the cotton-wool to get wetted by the steam, the action of the filter did not seem satisfactory, some parts getting wet and stopping the passage of the steam, and throwing all the duty on the weak parts. The experiment was accordingly arranged in the following way:—The steam was generated in a glass flask. This flask, filled with water, was placed in a vessel full of water, kept boiling during the experiment. In order to make the water in the glass flask boil, or rather evaporate, under these conditions, a stream of filtered air was blown through it, and the mixture of air and vapour blown into the receiver. Again the result was as before—rainy condensation when highly supersaturated. By this last arrangement it seems impossible any nuclei could be given off from the vessel in which the water was boiled, and the fine drops given off by the bubbling of the air and the vapour in the flask are probably all caught on the sides of the pipes, because if they did enter they would form nuclei in very slightly supersaturated, as well as in highly supersaturated vapour. We may therefore conclude from these experiments that the nuclei of the rainy condensation in highly supersaturated vapour are either some fine form of dust which the cotton-wool cannot keep back, or are produced by the vapour molecules combining together without a nucleus.

If all nuclei are absent, water may be cooled below the "freezing-point" or heated above the "boiling-point" without any change taking place; but there seems to be a limit to the amount it may be cooled or heated under these conditions without the water freezing or boiling. However carefully we may make the experiments after the water has been cooled to a certain amount, it always freezes without the presence of a free surface, and it also boils without the presence of a free surface when heated much above its "boiling-point." In these cases there always, however, appears to be some want of continuity or uniformity produced by the presence of some substance which exercises an influence on the water, and determines a weak point at which the change begins, and when once begun progress is of course rapid. In water we can easily understand how the sides of the vessel and the surfaces of foreign matter, &c., will form weak points, from which "free surfaces" are developed, extending into the mass of the liquid; but it is much more difficult to understand how weak points can be formed in gases, and even when started they have no power of propagating themselves. These considerations would seem to suggest that the rainy condensation in filtered air may be produced by some form of nuclei which passes the cotton-wool filter, and which are perhaps very small, and do not become active as nuclei till a considerable degree of supersaturation is attained.

There are, however, certain considerations which show that if the degree of supersaturation is sufficiently great, then condensation will probably take place without nuclei. Professor JAMES THOMSON* has shown that the isothermal curves obtained by Dr ANDREWS from his experiments on carbonic acid at temperatures below the critical temperature of that substance may not be really so discontinuous as they appear, and that there may be a condition of that substance which would be represented by a continuation of the vapour part of the curve beyond the "boiling" or "condensing line." To test this point Professor THOMSON suggested an experiment in which saturated steam, surrounded by a heated vessel, was to be expanded till it was cooled below its condensing point for its pressure, and the effect on the volume and pressure noted. This experiment, I believe, has never been made. We, however, see from the experiments described, that the theoretical extension of the curve discovered by Professor THOMSON has a real existence. This curve of Professor THOMSON'S shows that the degree of supersaturation possible has a perfectly definite limit, beyond which supersaturation is impossible. Further, if we examine these curves of Dr ANDREWS, which we may extend to water, they show us that it is only for temperatures below the critical temperature of the substance that supersaturation is possible. At temperatures above the critical

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[*] "Proceedings of the Royal Society," No. 130, 1871.

temperature there is no boiling and condensation, the change being perfectly continuous from the one state to the other, if under those conditions we can say there are two states.

All the previously described experiments have been made at temperatures at which the condensed water was in a liquid state. It was now desirable that they should be made at lower temperatures, to see if the same conditions are necessary when the vapour condenses at temperatures below the "freezing-point," and passes from the gaseous to the solid state. The experiments were made with the air-pump arrangement of apparatus, the condensation being effected by the cooling produced by expansion in the receiver. In the first experiments the receiver was placed in a freezing mixture. They were, however, repeated under more favourable conditions during the severe cold of January last. The apparatus was removed to the open air and experiments made with it. The temperature at the time was 8° Fahr. The results were the same as at higher temperatures—cloudy condensation with unfiltered air, and no condensation when filtered air was used. The amount of cloudiness produced was not so great as at higher temperatures. This is due to the smaller amount of vapour in the air at the lower temperature.

I did not succeed in observing any of the optical phenomena produced by small crystals of ice in our atmosphere. This was probably due to the conditions under which the crystals in the experiment were produced. As the crystals were rapidly formed, there would not be time for the vapour molecules to arrange themselves in the simpler forms of crystallisation, but by being forcibly compelled to solidify, would form complicated shapes, which do not give rise to any peculiar optical phenomena.

In the first part of this paper I have referred to the detection of small quantities of matter driven off by heat from pieces of iron, brass, and other kinds of matter. By the arrangement of apparatus then described, it was shown to be possible to detect the dust drawn off so small a piece of iron wire as the $\frac{1}{100}$ of a grain. In later experiments in this direction, the apparatus has been entirely changed. In place of using the supersaturation produced by mixing steam and cold air, the air-pump arrangement of apparatus has been employed, and is found to work much more satisfactorily than the other. The impurities drawn off so small a piece of iron wire as the $\frac{1}{2000}$ of a grain can with ease be detected with it.

The arrangement of the apparatus for this purpose is as follows:—A glass flask provided with a tight-fitting stopper, through which pass two tubes, which rise to a short distance into the interior of the flask. One tube is connected to an air-pump, the other terminates in a stop-cock, to which is attached a cotton-wool filter. A piece of glass tube is introduced about the middle of the length of this pipe. Some water being placed in the flask, the apparatus is complete. The glass tube must now be thoroughly cleansed. This is done by highly heating it in a Bunsen flame, while air is being drawn through it. The end of the glass tube next the filter is now opened, and three or four small pieces of iron wire introduced into it. The pieces of wire are placed some distance from each other, and near one end of the tube. The tube is now closed, and the Bunsen flame placed under the other end of the tube, and far enough away from the pieces of iron so as not to heat them. The air in the apparatus is now thoroughly cleansed by pumping out the air and admitting filtered air, till no cloudiness appears. During this process the height of the flame has been reduced, so as the temperature may not be high enough to drive anything off the glass tube. When the air is quite pure, and all rainy condensation ceased, the flame is reduced to about one-half, so as to leave a good margin of safety. After this is done, one of the small pieces of iron wire is drawn from the cold part of the tube by means of a magnet, and dropped in the hot part, and two or three strokes of the pump are made, to cause a current of air to pass through the tube and bring whatever impurities are driven off the iron into the flask. The stop-cock at the filter is now closed, and a slight vacuum made. The amount of nuclei given off by the wire is indicated by the amount of cloudy condensation which now takes place.

To make further certain that the impurities came from the wire, the piece of iron is now removed by means of the magnet, when the filtered air is now found to come into the flask without any nuclei, the air remaining cloudless on expansion. To make still further certain of the result, another of the pieces of wire is drawn into the hot part of the tube, when the cloudiness again appears, and again disappears after its removal, or after it has been highly heated.

The pieces of iron wire experimented on weighed from $\frac{1}{1000}$ to $\frac{1}{2000}$ of a grain. With pieces so small as this, so abundant and evident is the cloudiness produced, that I feel certain that if I could have manipulated, say the $\frac{1}{100,000}$ of a grain, the effect would have been perfectly definite and decided. Thousands of particles driven off the $\frac{1}{2000}$ of a grain, and the wire not perceptibly lighter afterwards, indicates almost molecular dimensions. It seems probable that some of the nuclei in these experiments are driven off as gases or vapours. These gases and vapours will afterwards condense when cooled in the receiver. It is not necessary that these gases should have nuclei on which to condense, as they will be *highly* supersaturated when cooled to the temperature of the receiver, and we know that it is only when supersaturation is slight that nuclei are necessary. These gases will, according to their composition, condense either to solid or liquid nuclei, on which the water vapour will condense.

In the first part of this paper attention has been called to the importance of the composition of the atmospheric dust. It was pointed out that some kinds of dust will have a greater attraction for water vapour than others, and that chloride of sodium dust would probably condense vapour and cause fogging in an atmosphere which was not saturated.

There are evidently two ways in which dust may exert an attraction for water vapour, and determine its condensation while still unsaturated. The first is the attraction which the surface of some kinds of matter has for vapour, a power which they have of condensing a film of water on their surface. This power they possess at all degrees of saturation, but the amount they condense depends on the degree of saturation. Glass might be taken as an example of a substance whose surface has a strong affinity for water, a fact which disagreeably demonstrates itself in the conducting power of glass insulators of electrical apparatus in damp weather. The dust nuclei are so small that the condensing power of fine pores is not likely to have any influence. The other form of attraction which may exist between the dust and water vapour, is the chemical affinity which exists between the two. This will evidently depend on the composition of the dust or nuclei. As an example of this form of attraction, it will be sufficient here to mention the well-known affinity which chloride of sodium and other salts have for water, causing them to become wet when the air is moist.

We shall presently see that besides these two ways in which nuclei may condense vapour in unsaturated air, there is another way in which the condensation may be produced in unsaturated as well as in saturated air without nuclei. This happens when there are gases or vapours present which have an affinity for each other, and the resulting compound is in a highly supersaturated condition. These new compounds under these conditions condense and form nuclei, which may be solid or liquid, and may or may not have affinity for water.

Now it is evident that if there are any kinds of matter in the form of dust in the air which have an affinity for water vapour, they will determine condensation in unsaturated air. Some experiments were made to see to what extent cloudy condensation could be produced under these conditions. My first experiments were made by burning sulphur, and vapourising chloride of sodium. A small quantity of sulphur was lighted, and an open-mouthed receiver held over it for a few seconds, and then placed on the table. At first scarcely anything was visible, but after a time a decided haze made its appearance, and the density of this haze or fog was always in proportion to the moisture present in the air. The damper the air the thicker the fogging, and if the air was nearly saturated, the result was very remarkable. If the inside of the receiver was wetted so as to moisten the air, the sulphur products were a little more evident, and on placing the receiver on the table, a thin haze could be seen. After a time, however, this haze grew denser and denser, and after fifteen or twenty minutes the receiver was full of a dense white fog, which remained for a long time.

Similar results were got by vapourising chloride of sodium. The salt was in some cases vapourised by a BUNSEN flame. It was also vapourised by placing it on a piece of hot iron, and the receiver held over it to collect the vapour, which condensed and formed nuclei, which determined the condensation of the water in unsaturated air. In some experiments the salt was vaporised in a heated platinum tube and drawn along with air through a coil of pipe to cool it, before admitting it into the receiver. In these experiments the density of the fogging was in proportion to the vapour present, and if the experiment was made in a wetted receiver, the fog took some time to attain its maximum density.

The condensing power of sulphur products and salt can be illustrated in another way. The air with either of these substances in suspension, is drawn through a coil of pipe to cool it. If now this stream of air is made to strike any wetted surface, the wetted surface looks as if it had suddenly become heated—a stream of condensed vapour flows away from it. This vapour is, of course, invisible if ordinary air is used, and without the powerfully condensing nuclei.

Experiments on a larger scale were also made with these two substances. A little sulphur was burned in a cellar, the air of which was damp, but not saturated. The temperature was about 43° Fahr., and the wet and dry bulb thermometers showed a difference of from $\frac{1}{2}$° to 1° during the experiments. After the sulphur was burned a fogginess was evident, but, on returning half an hour afterwards, the fogging was found to have increased very greatly in density, the air was very thick, and not the slightest smell of sulphurous acid perceptible. This fog hung about the cellar for many hours. The experiment was repeated with chloride of sodium, the salt being sprinkled over an alcohol flame. The result was similar to the sulphur products, a fogging which gradually increased in density, and very slowly cleared away.

Experiments have also been made by burning sulphur in the open air. When the air is dry the fumes can only be traced a short distance, but as the amount of moisture increases the cloudiness becomes more and more evident, and in certain conditions of the atmosphere the cloudiness can be distinctly seen flowing away in the passing air, leaving the sulphur in a pale thin stream of vapour, which gradually increases in size and density, and rolls away in a horizontal cloudy column, ten or fifteen feet in diameter, clearly marked out from the surrounding air.

There may be a certain amount of doubt as to the action of the heated salt in these experiments. When heated in the BUNSEN flame it is probable decomposition of some of the salt takes place, and part of the result may be due to the hydrochloric acid set free. In order to prevent this decomposition as much as possible, I have made some experiments at as low temperatures as possible, and the results are the same as when higher temperatures are used, allowance being made for the smaller amount of salt volatilised.

The action of the products of combustion of sulphur would appear to be something like the following:—When the sulphur combines with the oxygen of the air, sulphurous acid is formed. I have shown in the first part of this paper that sulphurous acid has but little condensing power; we must therefore look to the change which takes place in the sulphurous acid for the explanation of the wonderful condensing power of the sulphur products. The sulphurous acid becomes further oxidised in the air, and sulphuric acid is produced, and it is the great affinity which this sulphuric acid has for water which enables it to rob the air of its moisture and condense it in visible form. It does not seem to take long for the sulphurous to change to sulphuric acid in the air. A short time after the sulphur was burned in the cellar all smell of sulphurous acid was gone, and I am informed by Dr Wallace that he has found that all traces of sulphurous acid cease at a short distance from calcining ironstone bings in which much sulphur is being burned. The gradual thickening of the sulphur fog will probably be in part due to this gradual change of sulphurous to sulphuric acid. The gradual thickening of these fogs is also in part due to the slow evaporation of the water from the sides of the receiver, and subsequent condensation on the absorbing nuclei.

I find that the fumes from highly concentrated sulphuric acid have a fog-producing power similar to the products of combustion of sulphur. If we highly heat a glass rod wetted with sulphuric acid, or heat the acid in a platinum cup, and admit a little of the fumes into the receiver, they are found to have a very strong fog-producing power.

The above represents something like what the action of sulphuric acid is in moist air, in which there are no other vapours or gases with which this acid tends to combine. Before considering these more complicated effects I shall describe some experiments made to test the action of acid vapours on moist filtered air. The apparatus consisted of the air-pump arrangement, with test receiver or flask, one pipe as before being connected with the air-pump, and the other with the filter. Between the receiver and the filter was placed a test tube, in which was placed the acid to be experimented upon. The filtered air was caused to bubble through the acid on its way to the moist air in the receiver, the acid being generally kept at the temperature of the room.

When nitric acid is put in the test tube and filtered air passed through it, it is found that its vapour always gives rise to fumes when mixed with the moist air in the receiver. These fumes—as cloudy condensation in unsaturated air may be called—may therefore be produced without nuclei when nitric acid is used. When the air in the receiver is expanded and cooled, this cloudy condensation becomes thicker.

When commercial hydrochloric acid is put in the test tube, its vapour does not give rise to fumes on mixing with the moist air in the receiver, and on expanding and cooling the air, no fumes appear, only the rainy form of condensation is produced. A quantity of very strong hydrochloric acid was prepared by keeping the solution in which the acid was condensed in a freezing mixture. This acid fumed abundantly in the air, but gave no fumes in filtered air, and only rainy condensation when the pressure was reduced.

These two acids act very differently, the first condensing freely at many centres, and without nuclei, and giving a foggy condensation in pure and unsaturated air, while the hydrochloric acid only condenses with difficulty, and at few centres, and only gives the rainy form of condensation when supersaturated.

The next experiments were made with commercial sulphuric acid, and also with some of the acid concentrated by boiling in a glass vessel. The air which had passed through this acid gave no fumes, but on making the slightest expansion a fog appeared. This fog is quite characteristic of sulphuric acid, and is quite different from any artificial fog I have seen. The particles are extremely small, and the display of colour remarkably brilliant, and when properly lighted rivalling in distinctness the colours of the soap bubble. This beautiful fog is only got when the acid is strong, and I think is best produced when the entering air is dry. This point, however, requires confirmation, though the result might be expected, as the surface of the acid will then be less weakened by moisture abstracted from the air. After the acid has absorbed much vapour, or if water has been added to it, the fogging decreases and gives place to the rainy form of condensation when expansion is made. This rainy condensation also disappears when the acid is very weak. If we heat the strong acid to a temperature of about 60° or 70° C., the vapour condenses and forms fumes in pure air without nuclei, and without being expanded.

These experiments show that water vapour may be condensed without nuclei being present. The affinities which the vapours of the acids have for the water, causing the formation of new compounds, and these compounds being highly supersaturated, condense easily without nuclei, and in certain circumstances this condensation may be determined in even unsaturated air. These water-acid nuclei once formed, continue to act as centres of condensation. In these cases the manufactured nuclei are liquid, but solid nuclei may be formed in a similar manner. This may be shown by the following experiment. Place hydrochloric acid in the receiver or flask, and pump out all the air and replace it with filtered air. If, after this is done, and the acid shows no sign of cloudiness, and nothing but rainy condensation on expansion, we take the stopper out of a bottle of ammonia and hold it near the filter, so that the escaping gaseous ammonia may pass along with the air through the filter, the ammonia on arriving in the flask will combine with the hydrochloric acid and form a dense cloud of sal-ammoniac. When the ammonia and the hydrochloric acid combine in the filtered air, the tension of the sal-ammoniac vapour so formed is enormously greater than that due to the temperature, and it easily condenses without nuclei. This experiment suggests that part of the rainy condensation given by hydrochloric acid may be due to the ammonia in the air combining with the acid and forming sal-ammoniac nuclei on which the vapour condenses.

These experiments show how nuclei may be formed from gases in the air, and these nuclei may have so great an affinity for water vapour as to cause it to condense on them from an unsaturated atmosphere.

Returning again to the action of the products of combustion of sulphur in air, we have seen that these products alone can determine the condensation of water vapour from unsaturated air. There are, however, many substances in the air with which this acid will tend to combine. It would be impossible to go over all the substances in the air which have affinities for this acid, and consider the effects of these new compounds, in moist air. I have, however, selected one, which from the magnitude of its effects deserves special notice. That substance is ammonia, another of the products of combustion of our coal fires. If we take an open-mouthed receiver wetted on the inside, and hold it over a little burning sulphur for a few seconds, as in the previous experiment, we will get a thin haze, which we know tends to thicken. But if on placing the receiver on its tray, we put a drop of ammonia on a piece of glass and introduce it into the receiver, the result is very striking. Dense fumes will be seen to rise from the ammonia, and in a few minutes the receiver will be full of a fog so thick it will be impossible to see an object in the middle of the receiver. In this case there are evidently formed solid nuclei, composed of sulphite and sulphate of ammonium, in a very fine state of subdivision. The intense cloudiness is only in part due to this solid, the greater part is due to the condensation of water vapour. If the experiment is made in dry air the fogging is not nearly so intense as in moist air. By burning a larger amount of sulphur in the moist air of the receiver, we can easily make a fog so very intense that it is impossible to see through an inch of it. This fog is found to be very suitable for experiments on vortex rings, as it is easily prepared, and the " dead " rings dissolve, and do not thicken the air of the room to the same extent as the usual sal-ammoniac rings.

Experiments were also made in the cellar with this fog-producer. The wet and dry bulb thermometers at the time showed a difference of fully one degree. Yet by burning a few grains of sulphur, and dropping on a piece of paper a little ammonia, the cellar became filled with a most intense fog, many times more intense than would be produced by the sulphur alone.

Using the same apparatus as was used for determining the fuming power of the different acids in filtered air, it is found that when experimenting on sulphuric acid and vapour of ammonia, that sulphate fumes are formed in the receiver if the acid is slightly heated, thus showing that this sulphate dust can form without nuclei. It, however, seems in the highest degree probable that when dust is present the dust particles will form the centres on which the sulphate will condense.

Almost all salts when heated in a BUNSEN flame produce nuclei which determine condensation in unsaturated air. The condensing power of the different products, however, differ greatly. The bicarbonate of soda gives but little effect, while chloride of calcium and bromide of potassium are much more powerful. But by far the most powerful artificial fog-producing substance when used in this way is the chloride of magnesium. If we put a small quantity of this salt on a piece of wire-cloth, and heat it with the BUNSEN flame, and collect the products in a wetted receiver, the fog will be seen rapidly forming and showering down the sides of the receiver. As rapidly as the water is evaporated from the sides of the receiver it is condensed by the active nuclei in the gases. After the receiver has been placed on the table for a few minutes it will be found full of a fog so dense it is only possible to see through a depth of five centimeters of it. When a little of this chloride was heated in an alcohol flame in the cellar the result was a fog many times more dense than that produced by sulphur alone. The fog-producing power of the heated chloride of magnesium would appear to be due to the salt being decomposed by the heat, and free hydrochloric acid being driven off in a highly concentrated state. The amount of hydrochloric acid is, however, small considering the density of the resulting fog. The density of this fog is very much greater than the fog produced by hydrochloric acid prepared from chloride of sodium and sulphuric acid.

In all these cases the reactions are excessively difficult to trace. Other experiments in which the action is much simpler were made by burning a little sodium in the receiver. The combustion of this substance gives rise to its oxides in a fine state of division. This fine soda-dust when mixed with dry air gives but little cloudiness, but when mixed with damp air a dense fogging results. Potassium when burned gives a similar effect, but the fog is not so intense.

We may conclude from these experiments—1. That as regards cloudy condensation of vapour in our atmosphere there is dust and dust. Some kinds of dust have such an affinity for water that they determine the condensation of vapour in unsaturated air, while other kinds of dust only form nuclei when the air is supersaturated, that is, they only form free surfaces on which the vapour may condense and prevent supersaturation. In many of the experiments it was noticed that when the air was nearly purified, when all the dust which had an affinity for vapour had received its burden of water and settled down, that there remained to near the end of the experiment some particles which seemed to require a certain degree of supersaturation before they became active. In highly supersaturated air all kinds of dust will form nuclei and determine condensation, but in unsaturated air only those kinds of dust which have an affinity for water will be active. We have precisely corresponding phenonema to this in freezing, melting, and boiling. We have water in a solid state at a temperature above the "melting-point," when it is combined with some other substance, as in the water of crystallisation of salts. Water may be liquid at a temperature below the "freezing-point" when mixed with some salts. Water boils at a temperature above its "boiling-point" when it holds some salts in solution, and boils below its "boiling-point" when mixed with some substance having a lower "boiling-point" than water.

2. This affinity which some kinds of dust have for vapour explains why it is that our breath and escaping steam dissolve even in foggy air. The large cloudy particles in our breath and in condensed steam tend to evaporate in the same air in which condensation is taking place, because the dust particles on which the breath has condensed have had their affinities more than satisfied, they therefore tend to part with their surplus by evaporisation in the same air as those particles which have not had their affinities satisfied tend to condense it.

3. Dry fogs are produced by the affinity which the dust particles have for water vapour, in virtue of which they are enabled to condense vapour in unsaturated air. From the experiments with chloride of sodium, from the known affinity of that salt for water, and from the fact that great quantities of salt-dust are ever present in the air, it is evident that if it is not *the* cause of dry fogs in the country it must play some part in those phenomena. There will doubtless be other kinds of nuclei having affinities for water which will cause dry fogs. The nature and composition of these other nuclei will probably be best arrived at by collecting the fog particles by washing or otherwise, and analysing them.

4. That as the products of combustion of the sulphur in our coals, especially when mixed with the other products of combustion, such as ammonia, have the power of determining the condensation of water vapour in unsaturated air, and give rise to a very fine-textured dry fog, they are probably one of the chief causes of our town fogs, as they have a greater condensing power than the products of combustion of pure coal.

Though there may seem to be but little doubt that products of combustion when mixed with the sulphur compounds are most active producers of town fogs, yet we must not rest satisfied that they explain everything. There may be other causes at work, and conditions yet requiring explanation, but as these involve intricate chemical reactions, it will be advisable that the matter be now handed over to the consideration of the chemist.

These chemical nuclei, as they might be called, though found in far greatest abundance in the air of our towns, will no doubt be also found in the air of the country. We know that sulphuric acid and ammonia are constantly being produced by decomposing animal and vegetable matter, and we know that these substances, along with nitric acid and other gases and vapours, are always present in the air.

Again, we have the gases given off from volcanoes, and the amount from this source must be considerable. There are about two hundred active volcanoes constantly discharging their gases into our atmosphere, and it has been roughly calculated that volcanoes evolve ten times more carbonic acid than is given off by the combustion of all kinds of carbonised material. With this carbonic acid there is given off great quantities of sulphurous and other gases which will condense and form nuclei.

Vegetation, both when alive and when dead, gives off vast quantities of small organic particles, and microscopic life, which almost seem to populate the air we breath, and will of course add much to the dust in our atmosphere.

Professor TYNDALL has shown that light decomposes certain gases and vapours, and that this decomposition is greatly aided by the presence of other gases or vapours. It seems therefore probable that the sun's rays will decompose some of the gases and vapours in the air, and if these decomposed substances have a lower vapour tension than the substance from which they are formed, they condense into very fine particles. These particles may be solid or liquid, and will form nuclei for the condensation of water vapour.

We know that there are ever present in our atmosphere great quantities of chloride of sodium and other kinds of dust which have affinities for water. These dust particles by their affinities for water vapour cause condensation to take place in unsaturated air, and if present in great quantities give rise to dry fogs. Let us look briefly at the effect of this affinity between the dust and the vapour. If there was no affinity between the two, then condensation would only begin when supersaturation began, and those dust particles which permitted the vapour to condense on them easiest would get most vapour, and would tend to grow largest. This would evidently tend to inequality in the size of the cloud particles which would determine the fall of some of them through the others. But if there is an affinity between the dust and the vapour, then each particle of dust tends to take the same amount of vapour, and if one particle gets more than its proportion, the others tend to rob it of its surplus. This evidently tends to equality in the size of the cloud particles, and tends also to prevent any of them falling through the others, and thus prevents it beginning to rain, that is, if rain drops are formed by the collision and union of the quickly falling particles with those falling more slowly. It would thus seem that while on one side if we have no dust we would have no clouds and probably no rain, as we don't know whether the air would ever become sufficiently supersaturated to condense without nuclei. On the other hand, an over-abundance of dust having affinities for water vapour also prevents the vapour falling as rain, as the vapour under these conditions condenses into minute particles which all tend to be of equal size, and none of them are able to fall quickly enough amongst the others to cause collisions. The result is the condensed vapour cloud instead of falling in minute parts as rain, tends to fall as a whole. The air becomes so loaded with the water held in mechanical suspension that it is dragged downwards by its weight. If we make artificial fogs with sulphur fumes and ammonia, or by heating chloride of magnesium, the fog is so heavy it can be poured from one vessel to another.

After the affinities of the dust particles are satisfied, this tendency to stability no longer exists. After this stage the growth of the particles becomes unequal, and, as has been shown by Professor CLERK MAXWELL,* the larger drops or particles in a cloud tend to rob the smaller ones, or rather, from what we now know, will tend to prevent them growing after the affinities of the nuclei are satisfied.

It would appear, then, that condensation will always begin in our atmosphere before the air is saturated. There is, however, still much to be done in this department of our subject to determine whether the amount of cloudy condensation is always the same for the same degree of saturation, or if it varies; and if it varies, to find the composition and source of the nuclei which cause the variations.

I feel that these two papers only start this inquiry. Much, very much, still remains to be done. Like a traveller who has landed in an unknown country, I am conscious my faltering steps have extended but little beyond the starting-point. All around extends the unknown, and the distance is closed in by many an Alpine peak, whose slopes will require more vigorous steps than mine to surmount. It is with reluctance I am compelled for the present to abandon the investigation. It is, however, to be hoped it will be taken up by those better fitted for the work, and that soon the roughness of the way will be levelled, the difficulties bridged, the country mapped, and its resources developed.

* "Theory of Heat," Professor CLERK MAXWELL, p. 270.

XIII..—*The Effect of Permanent Elongation on the Specific Resistance of Metallic Wires.* By THOMAS GRAY, B.Sc., Demonstrator in Physics and Instructor in Telegraphy, Imperial College of Engineering, Tokio, Japan. (Plate XVIII*a*.)

(Received 23d October 1880.)

The object of this investigation was to obtain information as to the change of specific resistance produced in wires of various metals by different amounts of elongation. The present paper refers to experiments on copper, iron, and German silver wires.

Besides the effect of permanent elongation, I have added the results of a number of observations on the effect of elastic elongation. These results were obtained in the course of the other experiments, and, the two taken together, may serve to throw some light on the cause of the change of resistance.

In order to render the effect of elastic elongation intelligible, it is necessary to form an estimate of the change of section due to the stretching. This can be readily done if we know the ratio of linear contraction, at right angles to the direction of pull, to the extension in the direction of pull. If we suppose this wire isotropic this can be obtained from the YOUNG's and rigidity moduluses (THOMSON and TAIT's "Natural Philosophy," § 684). I give a determination of these constants for several of the wires experimented on, both before and after a measured amount of elongation, from which an approximate estimate of the above ratio is derived.

In reckoning the change of specific resistance, the resistance of 1 metre, weighing 1 gramme, has been taken as the specific resistance of the material. I have thus left out of account the effect due to any change of density which may have resulted from the stretching of the wires. This change of density was in the later experiments carefully noted, and is recorded in the tables of results. It will be found, on examination, that the change of density was in every case small, that it sometimes increased and sometimes diminished, but that, in either case, there was little difference in the change of resistance. So far as these experiments go then, no effect, due to change of density simply, was discovered.

The fact that the density remained almost constant all through the experiments, gives a very easy method of observing the effect of elastic elongation. Generally the density of a wire is diminished by elastic elongation, and therefore, if change of form is sufficient to account for the change of resistance, the effect of elastic elongation should be somewhat *less* than that of permanent elongation. I find, however, that if the change of resistance due to stretching be measured when the stretching weight remains on the wire, the effect is considerably *greater* than if it be measured, for the same elongation, with the weight off. This shows that the resistance of the wire is increased by pulling it, altogether independently of the change of form due to the pull. This same result has been obtained by THOMSON (" Electro-Dynamic Qualities of Metals," Phil. Trans., 1856) and by TOMLINSON (Proc. Roy. Soc., 1877, vol. xxvi.).

The ratio of lateral to longitudinal change of dimensions was used by THOMSON, and afterwards by TOMLINSON, in the deductions from their experiments. A glance at the table of results for the elasticity constants given in this paper is sufficient to show that the same results follows from that method of treating my results. Although I have given the determinations which I made of the elastic constants, and of the ratios of lateral to longitudinal change of dimensions deduced from them, I do not consider it likely that the ratio is sufficiently accurate to base any calculation of the effect of pull upon. The constants are chiefly valuable as giving an indication of the quality of the wires used.

The apparatus used in the electrical part of the experiment is shown in fig. 1, which is a plan of the arrangement. In the figure, A represents an ordinary wire bridge, by ELLIOT, consisting of a platinum wire w 1 metre long, and ·12 centimetres diameter, attached at its ends to thick copper bars furnished with binding screws. The effective length of this bridge wire was increased by the addition of a coil of German silver wire C to each end. The total length of the wire was thus made equivalent to 22430 divisions of the scale S. Along this wire a contact key K can be moved, and the position of its contact with the wire read on a scale of millimetres S attached to the base of the instrument. This allowed a change of resistance of $\frac{1}{10000}$ of the whole to be easily observed, a degree of accuracy beyond what could be expected in the elongation readings. The wires under experiment, and the standard wire with which its resistance was compared, are represented at a and b. These two wires were in every case of exactly the same material, and were arranged side by side, so as to avoid variation due to change of temperature in the exposed wires.

The galvanometer G, used in the bridge, was a THOMSON's dead beat instrument, having an internal resistance of 0·325 Ohms. The galvanometer zero was controlled by a magnet m placed in front, and its sensibility by a second magnet m_1 placed at the side. The battery B consisted of a single small DANIELL's element—this being quite sufficiently powerful when the magnet m_1 was properly adjusted. K_1 is a key used in the ordinary way for making and breaking the battery circuit. The elongations of the wire a were measured on a scale of millimetres M, the length of the wire being reckoned in terms of the divisions of this scale.

These instruments were arranged, as shown, on a table T; the wires a and b were carried along side by side above the table; the former passed over a pulley and was attached to a scale pan, on which the stretching weights were placed.

In fitting these arrangements, the resistances of the coils CC were first carefully measured and made as nearly equal as possible. These coils were then fixed in their positions, and the middle point of the coils and bridge wire determined as follows:—two equal resistances R and R_1 were introduced into the bridge, and the position of the key K found, where no deflection was obtained when it was depressed; R and R_1 were then interchanged and the position of K for zero deflection again determined. The resistances RR_1 were then varied, until, by interchanging, the same position was obtained for K; this point was taken as the middle of the coils and bridge wire.

The value of one division of the scale S was then determined by varying one of the resistances RR_1 by a known amount, and noting the number of divisions the key K had to be moved in order to again establish a balance. If this number of divisions be n, the total reduced length of the bridge wire $2l$, and the resistances introduced be R and $R+r$, we have the following equation for the value of l in scale divisions.

$$\frac{l-n}{l+n}=\frac{R}{R+r};$$

and therefore

$$l=n\frac{2R+r}{r}$$

This supplies the data necessary for the determination of a and b at any time.

Suppose now that at the beginning of an experiment

$$\frac{a}{b}=\frac{A}{B},$$

and that after the wire a had been stretched

$$\frac{a_1}{b}=\frac{A_1}{B_1}.$$

Then we have

$$\frac{a_1}{a}=\frac{A_1}{B_1}.\ \frac{B}{A}, \text{ and therefore } a_1=a\frac{A_1}{B_1}\ \frac{B}{A}.$$

Again, suppose that at the beginning of the experiment the length of a is l, and after stretching l_1. Then the ratio of the resistances before and after stretching is $\frac{a_1}{a}=\frac{l_1^2}{l^2}$ (according to the definition of specific resistance given above), or the supposition that the specific resistance does not change. The percentage increase of resistance can be obtained from these two equations; it is equal to

$$100\left\{\frac{A_1Bl^2}{B_1Al_1^2}-1\right\}.$$

In determining the moduluses of elasticity, the method of direct elongation was adopted for the YOUNG'S modulus, and the method of torsional vibrations for the rigidity modulus. The arrangement adopted in the case of the length modulus is shown in fig. 2. The wire to be experimented on W, together with another wire *w*, soldered to it at the upper end, were fixed firmly between the jaws of a vice.

To the lower end of the wire *w* a frame F was attached. This frame formed part of a pulley and index arrangement for multiplying the elongation of the wire; the whole of this arrangement was held straight by two heavy balls BB. The multiplication produced by the arrangement was exactly 20, as found both by measurement and by experiment. A wire, 4 metres long, could thus be tested for elongation with as great accuracy as one 80 metres long, when the elongation is observed directly. I have found this mode of observation very satisfactory, and certainly much better than the method of direct observation, either with the naked eye or by means of a cathetometer. The latter instrument, when used to measure elongations by means of a scale graduated on itself, is worse than useless.

The modulus of rigidity was determined by attaching to the lower end of the wire W a cylinder of sheet brass (according to the method adopted by THOMSON), and observing the period of torsional vibration. Having determined the period, the rigidity is obtained from the equation

$$n=\frac{8\pi^3 l^3 \mu}{g T^2 V^2}$$

where T is the period, l the length of the wire, V its volume, and μ the moment of inertia of the vibrator.

In the cases of two iron wires, one copper, and one German silver wire, the moduluses were determined, both before and after stretching. The results of these observations are given in the following table; the first column gives a description of the specimen referred to, the second gives the weight per metre of the wire, the third the percentage conductivity of pure metal, according to JENKIN'S table, the fourth the percentage elongation, the fifth the modulus of rigidity, the sixth the length modulus, and the seventh the ratio of the lateral contraction to longitudinal extension as derived from columns five and six, and the density of the wire.

Perhaps the most curious point connected with these results is the direction of the change of rigidity produced by stretching. This subject was first treated by THOMSON ("Proc. Roy. Soc.," 1865), but the direction of change was in the cases given by him uniformly a diminution. With the exception of the iron, No. 3 specimen, my results give the opposite change. I hope to go into this more fully at a future opportunity, with special arrangements for that alone.

Description of Specimen.	Weight per Metre in Grammes.	Percentage Conductivity.	Percentage Elongation.	Modulus of Rigidity.	Length Modulus.	$\frac{MD}{2n}-1.$
Iron, No. 1, . .	3·337	*116·	...	...	...	...
„ No. 2, . .	4·534	64·5	0	812×10^6	242×10^6	0·130
„ „ . .	...	...	3·4	813×10^6	248×10^6	0·156
„ No. 3, . .	4·462	88·9	0	700 „	248 „	0·352
„ „ . .	...	...	3·4	683 „	253 „	0·414
Copper, No. 1, .	5·022	98·0	0	483 „	125 „	0·136
„ „ . .	...	...	10·6	489 „	134 „	0·217
„ No. 2, .	22·68	92·0	0	427 „	128 „	0·332
German silver, .	5·118	63·1	0	494 „	155 „	0·379
„ „ .	...	...	9·65	498 „	159 „	0·434

In the appended tables of results the first column gives the date on which the experiment was conducted. I give these dates because it seems possible that, if the experiment be left for any considerable time, a gradual change may take place in the stretched wire, thus rendering the results on different days at variance. An examination of the tables shows that in the cases of copper and German silver scarcely any change takes place after the first few minutes. In the case of iron, however, a very marked change takes place. In consequence of this I give time readings for one of the wires extending over about twenty-four hours after stretching the wire. These readings are shown in Table V. No. 5, and are represented graphically by the curve marked "time variation for iron." This variation is interesting, and will be made the subject of special investigation. It is possible to account for the change, either by molecular rearrangement in the wire or by oxidation of the surface. I do not think that the second can have any sensible influence, as oxidation would increase the resistance, both of the standard and of the stretched wire, and since the stretched wire had in each case a clean surface, it ought to have been more affected than the standard, which was used for several experiments, and had been for some time exposed. For these reasons I think that oxidation would have had an opposite effect, namely, to show *increased* instead of *diminished* resistance. The experiment shown in the curve seems to indicate a change proportional to logarithm of the time.

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* This high value for the conductivity of this wire was verified by repeated measurements.

The second column gives the weight on the wire when the resistance was measured; the third column gives the percentage elongation, being the sum of the permanent and elastic elongations in each case; the fourth column gives the percentage increase of specific resistance from the beginning; the fifth column gives the density in those cases where it was determined; the sixth column gives the number of the experiment in the order of their performance for each specimen.

The mean of the first four experiments on Japanese copper gives 0·55 per cent. increase of specific resistance per 1 per cent. increase of length. This number is increased to 0·61 if the fifth experiment be included. The fifth experiment was made for the purpose of finding the effect of elastic elongation, and the change of density due to stretching. The only difference in the performance was the occasional removal of the weights, and a more rapid stretching than in the previous cases. Whether either of these causes may have influenced the result I am unable without more investigation to say.

The experiment on English copper given in Table II. shows an increase of 0·61 per cent. per 1 per cent. increase of length, which corresponds with the mean of the five experiments on Japanese wire. This wire was much thicker than the Japanese, the former being No. 15 B.W.G., and the latter 22 B.W.G. The variation of copper due to stretching seems very nearly proportional to the amount of stretch.

In the case of the iron wires, the variation was least for the specimen of English iron (Table III.), and greatest for a very hard strong specimen of Japanese iron (Table V.). Probably the difference is mostly due to the greater elastic elongation in the harder specimens. The percentages may be roughly taken as about 0·73, 0·79, and 0·82 increase of specific resistance per 1 per cent. increase of length.

One of the curves for the Table IV. is somewhat irregular; the irregularity is perhaps due to the fact that the wire was heated in a Bunsen flame before experimenting on it. Generally the curves of results for iron show convexity upwards on the whole, but have a marked hollow towards the middle pòrtion which runs through all the curves.

The German silver wires gave the smallest variation of all that were tried, being about 0·54 per cent. per 1 per cent. for the first 4 or 5 per cent. of elongation, and rather less as the elongation increases. One of the experiments on German silver shows considerable irregularity; this must have been due, I think, to want of homogeniety in the wire, but possibly in part to error of observation.

The result of Table I. No. 5 shows a variation of 2·57 per cent. per 1 per cent. for elastic elongation in this specimen of copper. On the other hand, the English copper shows a variation after it has been stretched 7 per cent. of

7·7 per cent. per 1 per cent. of elastic elongation, and after stretching 15 per cent. the variation becomes 7 per cent. per 1 per cent. increase of length.

Table IV. No. 2 gives a variation of 3·3 per cent. per 1 per cent., and No. 3 3·6 per cent. per 1 per cent. of elongation for that specimen of iron, while from Table V. we obtain the successive variations, 4·8, 4·7, 4·8, 4·6 per cent. per 1 per cent. of elongation.

Table VI. No. 3 gives four determinations of the variation due to elastic elongation, from which it appears to pass through a maximum after a certain degree of permanent elongation, and then again diminishes as the elongation is increased. The values obtained in this case were 0·75, 1·04, 0·86, and 0·71, the corresponding permanent elongations being 9·20, 11·71, 15·73, and 16·59 per cent. The results which I have given for the effect of elastic elongation after different degrees of permanent elongation must be considered as strictly preliminary. The arrangement I had made for the purpose of observing the effect of permanent elongation was not sufficiently sensitive to give very accurate results for elastic elongation, but I think them sufficiently accurate to indicate that there is a change, and the direction of that change. I hope by rearranging the apparatus, and removing the pulley over which the wire passes, so that the elongations can be inferred from HOOKE's law, and by increasing the resistances CC, to obtain a series of reliable results on this latter part of the subject.

TABLE I.—*Specimen of Japanese Copper.*

Date.	Weight on the Iron in lbs.	Percentage Elongation.	Percentage Increase of Specific Resistance.	Density.	Number of Experiment.
13th April, ...	10·	0·000	0·000	...	No. 1.
„	14·	0·89	0·59	...	...
„	16·25	1·68	1·12	...	...
„	18·5	2·57	1·75	...	...
„	21·	3·58	2·26	...	...
„	21·	5·05	3·32	...	...
14th April, ...	23·	6·71	3·65	...	...
15th April, ...	10·00	0·00	0·00	...	No. 2.
„	21·00	1·23	0·82	...	...
„	22·5	2·01	1·13	...	...
„	23·5	3·06	1·56	...	...
„	24·5	3·49	1·66	...	...
„	26·	4·07	2·18	...	...
„	27·	5·07	2·66	...	...
„	28·	6·33	3·41	...	...
„	29·	7·20	3·56	...	...
16th April, ...	35·5	8·58	4·84	...	...
„	37·	9·03	4·80	...	...
„	37·	9·90	5·14	...	...

TABLE I.—*continued.*

Date.	Weight on the Iron in lbs.	Percentage Elongation.	Percentage Increase of Specific Resistance.	Density.	Number of Experiment.
17th April, . . .	10·00	0·00	0·00	...	No. 3.
" . . .	15·00	0·37	0·22	...	...
" . . .	17·5	0·69	0·32	...	...
" . . .	20·	1·34	0·66	...	...
" . . .	21·	1·80	0·84	...	...
" . . .	22·	2·00	1·02	...	...
" . . .	24·	2·43	1·36	...	...
" . . .	24·	3·33	1·94	...	...
" . . .	25·	3·65	2·34	...	...
" . . .	26·	4·38	2·96	...	...
" . . .	26·	5·47	3·24	...	...
19th April, . . .	27·	5·90	3·36	...	...
" . . .	28·	6·08	3·46	...	...
" . . .	29·	7·48	4·20	...	...
" . . .	30·	8·88	5·24	...	...
" . . .	31·	9·63	5·79	...	...
20th April, . . .	31·	10·02	6·38	...	...
" . . .	31·	10·21	6·54	...	...
27th April, . . .	32·5	10·36	6·58	...	...
" . . .	32·5	11·17	6·60	...	...
1st May, . . .	17·50	0·00	0·00	...	No. 4.
" . . .	17·50	0·95	0·54	...	...
" . . .	19·	1·17	0·82	...	...
3d May, . . .	20·	1·98	1·24	...	...
" . . .	21·	2·25	1·40	...	...
" . . .	21·	2·50	1·51	...	...
" . . .	22·	3·11	1·77	...	...
" . . .	23·	3·78	2·32	...	...
" . . .	24·5	4·48	2·70	...	...
" . . .	27·0	6·04	3·82	...	...
" . . .	29·0	8·34	4·98	...	...
" . . .	30·0	9·85	5·72	...	...
" . . .	31·0	10·64	6·16	...	...
" . . .	31·5	11·46	6·40	...	...
" . . .	31·5	12·11	6·94	...	...
" . . .	32·	12·66	7·06	...	...
" . . .	32·25	13·71	7·74	...	...
4th May, . . .	32·4	14·62	8·26	...	...
" . . .	32·7	14·90	8·40	...	...
" . . .	33·	15·85	8·80	...	...
" . . .	33·4	16·91	9·40	...	...
22d June, . . .	5·00	0·00	0·00	8·945	No. 5.
" . . .	15·50	0·95	0·68	...	...
" . . .	20·50	3·40	2·46	...	...
" . . .	25·	6·32	4·44	...	...
" . . .	5·	6·21*	4·33 (?)	...	...

* Probably slightly stretched by removing the weight.

TABLE I.—*continued.*

Date.	Weight on the Iron in lbs.	Percentage Elongation.	Percentage Increase of Specific Resistance.	Density.	Number of Experiment.
22d June, ...	25·	6·35	4·50	...	No. 5.
„	27·	8·33	5·44	...	...
„	28·	10·76	7·32	...	...
„	30·	14·39	9·74	...	...
„	5·	14·24	9·34	...	...
„	25·	14·38	9·70	...	...
23d June, ...	25·	14·38	9·69	...	...
„	30·	15·92	10·73	8·884	...

TABLE II.—*Specimen of English Copper.*

Date.	Weight on the Iron in lbs.	Percentage Elongation.	Percentage Increase of Specific Resistance.	Density.	Number of Experiment.
17th June, ...	19·00	0·00	0·00	8·895	No. 1.
„	93·	1·23	1·04	...	...
„	103·	2·64	1·94	...	...
„	112·	4·79	2·96	...	...
„	122·	6·01	4·26	...	...
„	127·	7·82	5·42	...	...
„	19·	7·70	4·40	...	...
„	102·	7·82	5·32	...	...
„	137·	9·53	6·48	...	...
„	141·	11·06	7·42	...	...
18th June, ...	141·	11·06	7·31	...	...
„	151·	12·60	7·90	...	...
„	27·	15·27	8·22	...	...
„	130·	15·44	9·38	8·873	...

TABLE III.—*Specimen of English Iron.*

Date.	Weight on the Iron in lbs.	Percentage Elongation.	Percentage Increase of Specific Resistance.	Density.	Number of Experiment.
12th May	16·00	0·00	0·00	...	No. 1.
„	20·00	0·39	0·26	...	...
„	22·25	1·10	0·78	...	...
„	24·50	1·95	1·46	...	...
„	26·75	3·32	2·36	...	...
„	26·75	3·66	2·62	...	...
„	27·75	4·24	3·04	...	...
„	29·95	7·12	5·18	...	...

TABLE VI.—*Specimen of German Silver.*

Date.	Weight on the Iron in lbs.	Percentage Elongation.	Percentage Increase of Specific Resistance.	Density.	Number of Experiment.
21st May, ...	10·00	0·00	0·00	...	No. 1.
„	32·	0·21	0·06	...	...
„	37·	0·54	0·30	...	...
24th May, ...	42·	1·76	1·00	...	...
„	45·	2·39	1·30	...	...
„	46·	3·01	1·76	...	...
„	50·	3·87	2·08	...	...
„	50·	4·45	2·36	...	...
„	52·	5·42	2·72	...	...
„	54·5	5·81	2·98	...	...
25th May, ...	54·5	6·72	3·24	...	...
„	56·	7·15	3·46	...	...
„	58·	7·85	3·68	...	...
„	60·5	9·18	4·12	...	...
„	61·5	10·38	4·48	...	...
„	62·5	11·23	4·76	...	...
„	64·25	12·19	5·04	...	...
„	64·5	12·62	5·12	...	...
26th May, ...	31·	...	...	...	No. 2.
„	40·5	1·04	0·66	...	...
„	41·5	1·44	0·84	...	...
„	43·5	2·20	0·62	...	...
„	47·	2·71	0·96	...	...
„	49·5	3·50	2·76	...	...
„	53·	4·01	2·78	...	...
„	53·	4·72	3·06	...	...
„	54·	5·41	3·42	...	...
„	55·5	5·70	4·40	...	...
„	56·5	6·27	4·54	...	...
„	57·5	6·50	4·64	...	...
„	58·5	7·31	4·94	...	...
„	59·5	7·99	5·10	...	...
„	60·	8·44	5·22	...	...
„	61·	9·00	5·32	...	...
„	62·	9·47	5·40	...	...
„	64·	9·70	5·58	...	...
„	66·	10·56	5·78	...	...
. . . .	19·	0·00	0·00	8·801	No. 3.
11th June, ...	32·	0·21	0·174	...	...
„	37·	1·25	0·74	...	...
„	40·	1·47	1·44	...	...
„	43·	3·56	1·96	...	...
„	46·	4·79	2·65	...	...
„	49·	6·11	3·43	...	...
„	50·	7 00	3·84	...	...
„	54·	8·27	4·35	...	...

TABLE VI.—*continued.*

Date.	Weight on the Iron in lbs.	Percentage Elongation.	Percentage Increase of Specific Resistance.	Density.	Number of Experiment.
11th June, . . .	55·	9·44	4·72	...	No. 3.
„ . . .	14·	9·20	4·54	...	...
„ . .	55·	9·44	4·72	...	...
„ . . .	57·	10·28	5·12	...	...
„ . . .	61·	11·87	5·56	...	...
„ . . .	14·	11·71	5·34	...	...
„ . . .	56·	11·99	5·63	...	...
12th June, . . .	56·	11·99	5·63	...	...
„ . . .	61·	13·34	5·71	...	...
„ . . .	63·	14·79	5·93	...	...
„ . . .	64·	16·02	6·46	...	...
„ . . .	14·00	15·73	6·21	...	...
„ . . .	58·	16·	6·43	...	...
„ . . .	65·	16·96	6·64	...	...
„ . . .	14·	16·59	6·43	...	...
„ . . .	61·	16·93	6·67	...	...
„ . . .	67·	17·72	6·83	8·786	...

Fig. 1.

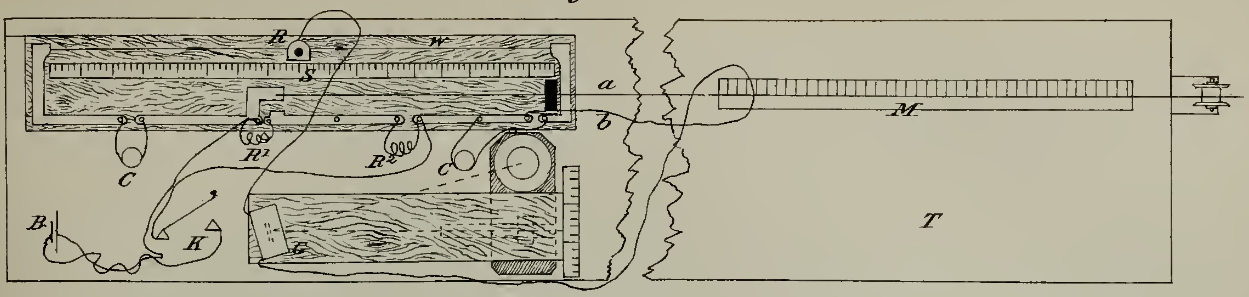
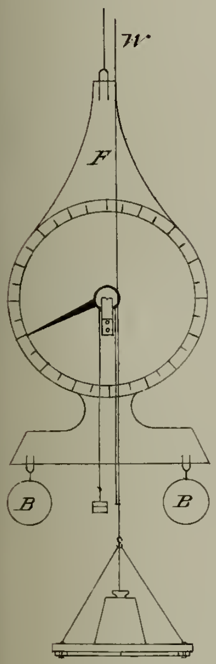

R
W
S
a
b
M
R¹
R²
C
C
B
K
G
T

Fig. 2.


W
F
B
B

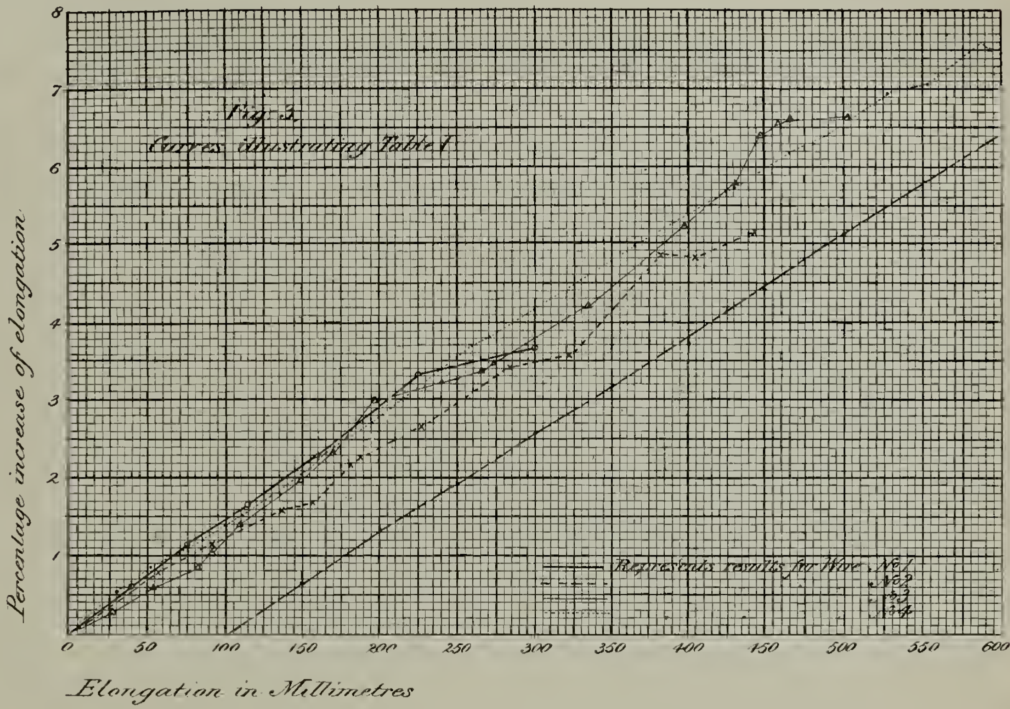


Fig. 3.
Curves illustrating Table I
Percentage increase of elongation
Elongation in Millimetres
0
1
2
3
4
5
6
7
8
0
50
100
150
200
250
300
350
400
450
500
550
600
Represents results for Wire No 1
No 2
No 3
No 4

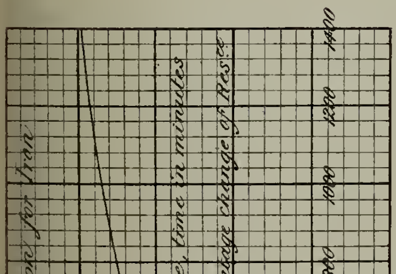


Fig. 4
Curve of Time Variation for Iron
Abscissae, time in minutes
Ordinates percentage change of Res^{ce}
0
200
400
600
800
1000
1200
1400
0.2
0.4
0.6

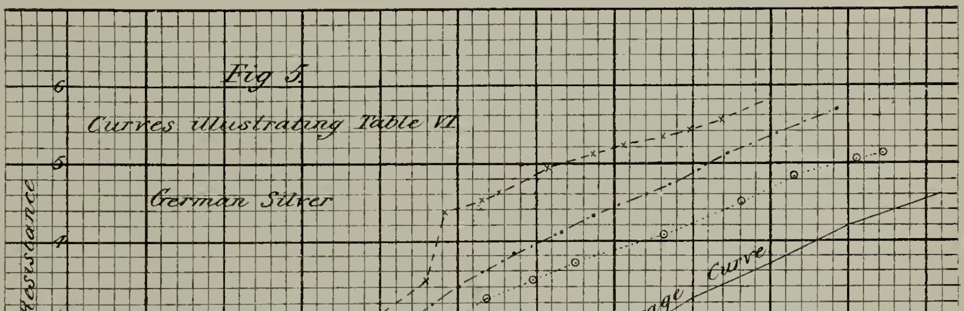


Fig. 5.
Curves illustrating Table VI
German Silver
Percentage increase of Resistance
Elongation in Millimetres
Average Curve
(1) Wire No 1
(2) Wire No 2
(3) Wire No 3
1
2
3
4
5
6
0
50
100
150
200
250
300
350
400
450
500
550

XIV.—*On the Histology of the Pedicellariæ and the Muscles of* Echinus sphæra (Forbes). By Patrick Geddes, F.R.S.E., Lecturer on Zoology in the School of Medicine, Edinburgh, and Frank E. Beddard, B.A., Assistant Demonstrator of Zoology, Oxford. (Plates XIX., XX., and XXI.)

(Read 17th January 1881.)

The structures known as pedicellariæ were first described by O. F. Müller.* He regarded them as parasitic organisms, and described under the generic name of Pedicellaria three species—*Pedicellaria tridens, P. triphylla,* and *P. globifera.* Lamarck, in the first edition of his "Animaux sans Vertèbres," published in 1801, and also in the second edition,† following Müller, classified the genus Pedicellaria with the Corynidæ and Hydridæ among the naked polyps. Cuvier also, in the first edition of the "Regne Animal," took the same view of the nature of pedicellariæ. It was not until 1825 that the real nature of these organs was recognised. Delle Chiaje,‡ in his work on invertebrate animals, asserted that pedicellariæ formed an integral portion of the Echinus, and were simply appendages of the test. The following quotation from his work shows that he thoroughly understood the true nature of these structures. He says (vol. ii. p. 324) :—"Fanno elleno parte integrale degli echini e servon loro per attacarsi a corpi adiacenti ed anche a ritenere gli animaletti da cibarsi."

The "Monographie de l'Echinus" § is the next contribution to the literature of this subject, and is one of the important. Valentin, in this work, figured and described the pedicellariæ of *Echinus lividus,* establishing at the same time the fact that the different forms of pedicellariæ are different species, and not merely stages of development. Besides describing the calcareous portions, he gave some account of the histology of the soft parts. The nomenclature which he introduced is the one now generally adopted. The three varieties of pedicellaria he named respectively *Pédicellaires ophiocéphales, P. tridactyles, P. gemmiformes,* and a fourth variety, which he considered to be an immature form of the *Pédicellaires ophiocephalés,* but which was subsequently proved by Perrier to be an adult variety, *P. trifoliés.* In the following table the correspondence between these names and those originally applied by O. F. Müller is given :—

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* Zoologia Danica, 1788, p. 16.

† Lamarck, "Histoire naturelle des animaux sans vertèbres," 2d edition, 1815, vol. ii. p. 75.

‡ Memoria sulla storia e notomia degli animali senza vertebre del regno di Napoli, Naples, 1823–29, vol. ii. p. 324.

§ Valentin, "Anatomie du genre Echinus," p. 46, *et seq.*

O. F. MÜLLER.		VALENTIN.
P. globifera	=	P. gemmiforme.
P. triphylla	=	P. ophiocéphale.
P. tridens	=	P. tridactyle.

This has been already pointed out by Mr W. P. SLADEN,[*] who decides in favour of retaining the nomenclature introduced by O. F. MÜLLER on the ground of priority. We prefer, however, on the whole, to use VALENTIN's names, both on account of their general acceptance and because they were the first names applied to pedicellariæ after the determination of their real nature; MÜLLER's nomenclature refers to pedicellariæ considered as a genus of parasitic animals.

In 1842 ERDL[†] gave an account of the pedicellariæ of *Echinus saxatilis* (=*E. lividus*). He described two chief forms of these organs the "klappen apparate" and "zangen apparate." The former appear to correspond to the gemmiform and ophiocephalous pedicellariæ, and the latter to the tridactyl. Both his figures and his descriptions, however, are mysterious and unsatisfactory, yet the best text-books of zoology, such as that of GEGENBAUR, still use his figures.

DUVERNOY[‡] was the next author who took up the subject of pedicellariæ. In his paper he first of all gives an excellent *resumé* of what had been done up to his time. The main point which he established was the fact that the different kinds of pedicellariæ, both in star-fish and in sea urchins, are characteristic of different species. His figures of pedicellariæ are good, but there are no details of structure given.

After DUVERNOY, HERAPATH[§] and PERRIER[||] described and figured a great variety of pedicellariæ of sea urchins and starfish. PERRIER is especially to be noted as having greatly extended the original discovery of DUVERNOY, that the pedicellariæ of different species differ. He proved that different genera are characterised by their own special varieties of pedicellariæ, the species making up each genus differing but slightly from each other in the forms of their pedicellariæ. His figures, however, are in many cases not very good. He again does not figure or describe, except in a very general way, the anatomy of the soft parts.

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[*] "On a Remarkable Form of Pedicellaria and the Functions performed thereby, together with General Observations on the Allied Forms of this Organ in the Echinidæ," Ann. Mag. Nat. Hist. Aug. 1881.

[†] "Ueber den Bau der Organe welche an der aüsseren Oberfläche der Seeigel sichtbar sind, Archiv für Naturgeschichte, 1842, p. 45.

[‡] "Memoire sur l'analogie de composition et sur quelques points de l'organization des Echinodermes," Memoires de l'Institut de France, 1849, vol. xx. p. 611.

[§] "On the Pedicellariæ of the Echinodermata," Quarterly Journal of Microscopical Science, 1865, p. 185.

[||] "Recherches sur les Pédicellaires et les Ambulacres des Asteries et des Oursins," Ann. des Sciences Naturelles, 1869 and 1870.

A. Agassiz,[*] in the Revision of the Echini, gives a number of excellent figures of the calcareous parts of the pedicellariæ of different kinds of sea urchins, besides summing up the facts known about the functions and development of these organs. The development is most satisfactorily to be studied in starfish, because in these animals the Pedicellariæ are in many cases massed round the bases of the larger spines, and so it is possible to say from the first what will become a spine, and what a pedicellaria. This distinction cannot be made in Echini. Both spines and pedicellariæ arise as a prolongation of the calcareous network at a very early stage; presently a constriction is formed at the base, and a tubercle on the surface of the test to which the spine is articulated. In the case of the pedicellariæ the calcareous prolongation becomes bifid, but in the earliest stages the two organs are absolutely indistinguishable. Hence the homology of the two organs is clear; and if anything further were needed to prove this homology, it is the presence in *Porocidaris* of pedicellariæ, surrounded by a scrobicular area like that which surrounds the spines.

In 1871 Mr Stewart[†] figured the pedicellariæ of *Cidaris*, and in 1874 Sir Wyville Thomson[‡] figured those of *Echinothuria*, *Porocidaris*, and other genera.

Up to the present time, therefore, as has been shown in the foregoing historical sketch, researches on the histology of pedicellariæ of sea urchins have been chiefly directed towards their hard parts. Of all the authors mentioned Valentin[§] has studied the soft parts most. The following are the results which he arrived at, stated as briefly as possible:—

Pédicellaires gemmiformes.—The soft parts consist of a layer of epithelium, a pigmented layer, and a fibrous membrane. The muscles he could not clearly distinguish.

P. tridactyles—The soft parts of stalk consist of a layer of epithelium, a pigment layer, and longitudinal and transverse (?) muscular fibres.

P. ophiocéphales.—A "ring" or triangle of transverse muscular fibres. The stalk he describes as having the same structure as the last variety, but containing longitudinal canals which he regards as blood-vessels.

Quite recently Mr Sladen[||] has investigated the histology of the gemmiform pedicellariæ by the help of modern methods, but we shall allude to his results farther on.

Since the appearance of the abstract of this paper in the *Comptes Rendus*,

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[*] Alexander Agassiz, "Revision of the Echini," Memoirs of Harvard Museum, vol. iii.

[†] "On the Minute Structure of Certain Hard Parts of the genus *Cidaris*," Quart. Journ. Micro. Science, 1871, p. 51.

[‡] "On the Echinoidea of the 'Porcupine' Deep-sea Dredging Expeditions," Phil. Trans., 1874, p. 719.

[§] Valentin, *loc. cit.*

[||] W. P. Sladen, *loc. cit.*

February 1881, Messrs Romanes and Ewart, in the "Croonian Lecture for 1881," an abstract of which has just been published,* describe a complete nervous supply to the spines and the pedicellariæ. This consists of delicate fibres connecting small bipolar cells, and reaches the mandibular muscles; in several preparations they observed delicate fibres which appeared to end in an epithelial pad on the inner surface of mandible. This nerve plexus was traced into connection with a sub-epithelial nerve plexus on the body wall.

With a view of elucidating the structure of the soft parts, we have studied in detail those of the large sea urchin, *Echinus sphæra* (Forbes). This species has four kinds of pedicellariæ, in the description of which the names introduced by Valentin will be replaced by their English equivalents, as is commonly done by British naturalists. Each pedicellaria consists of two parts—a "head" and a stalk—both of which contain a calcareous skeleton and associated soft parts. The skeleton of the stalk is a rod which articulates on to a tubercle on the surface of the test; the skeleton of the head consists of three valves, which are articulated together, and are capable of approximation and divarication by means of muscles. The soft parts consist of (1) a layer of epithelium covering the whole pedicellaria; (2) muscles attaching the base of the calcareous rod to the test; (3) muscles of head arranged in three masses connecting together the three calcareous valves, and serving to approximate them by their contraction; (4) muscles connecting the base of the valves with the top of the rod. Other curious structures will be reserved for description until the different kinds of pedicellariæ come to be dealt with severally.

The ophiocephalous pedicellariæ are by far the most abundant variety, and occur scattered all over the test in company with the other varieties, and also on the buccal membrane in a thick ring surrounding the mouth. In this situation, however, they differ slightly; the muscular mass between the top of the rod and the base of the valves is shorter, and the calcareous valves themselves are rather broader in proportion to their length, but in other respects they agree with the ophiocephalous pedicellariæ of the test.

The whole surface is covered with a layer of epithelium which some observers have supposed to be ciliated, and shows, on treatment with nitrate of silver, nucleated cells of a polygonal contour (Plate XX., figs. 2, 3).

The calcareous rod which supports the stalk is attached to a tubercle on the surface of the test by a number of muscular fibres, which show no signs of transverse striation. The rod itself is of a uniform diameter except at the proximal end, where it dilates slightly, and at the distal end where the muscles of the stalk are attached. It is made up of a series of minute cylindrical rods which are joined here and there by transverse pieces, giving the whole structure

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* Romanes and Ewart, "Observations on the Locomotor System of Echinodermata," Proceedings of the Royal Society of London, March 1881.

when intact a fenestrated appearance. The soft portion of the stalk between the distal end of the rod and the bases of the valves is made up of an outer layer of epithelium, which has already been described, and within this a sheath of fibres, which enclose a central core of an amorphous granular substance containing nuclei here and there, especially near the centre, but in which no definite cell outlines are discernible (Pl. XX. fig. 9).

The fibres are attached to the knob-like upper extremity of the calcareous rod below, and above they end in a very remarkable manner. The majority of the fibres are folded upon themselves just below the base of the calcareous valves, forming a series of loops, while at the two sides these bundles are prolonged much farther, and are wrapped round the semicircular arches of the calcareous valves, as shown in Pl. XX. fig. 4. This whole structure, when freed from its attachment to the valves by dissolving them away with chromic acid, is shown in fig. 5. The looped portion of the stalk fibres appear to be of the nature of elastic tissue, and at any rate are very unlike the rest of the fibre, being more highly refractive, with sharp outlines and clear central portion. The fibres of the stalk are of very varied diameter, and show a faint longitudinal striation. Their outlines are also somewhat indistinct; no transverse striation has been shown to exist in these fibres, and they are, in fact, very unlike the muscular fibres of the other parts of the pedicellariæ. It is probable that they are more of the nature of connective tissue, but this is of course a very difficult question to decide. Certain of the epithelial cells which have been already mentioned are continuous with delicate processes (Pl. XX., fig. 6), which run along the stalk.

The head of the pedicellaria now alone remains to be dealt with. Each of the three valves (Pl. XX. fig. 1), which make up the calcareous framework, is concavo-convex. The convex portion pointing outwards, the outline is more or less oval, and the valves are articulated to each other by three sharp teeth, the margin of the upper part of the valve being also provided with fine denticulations. The lower part of the valve is prolonged into a semicircular arch like the handle of a jug. From the inner surface of the valve arises an apophysis at right angles to the plane of the valve, which serves for the attachment of the transverse muscles. The valve is perforated throughout its whole extent by numerous foramina. Treated with acid the calcareous skeleton is dissolved, leaving behind a granular organic basis. The soft parts of the head consist of (1) the outer epithelium already described, (2) the transverse muscles, forming three masses arranged in the form of a triangle, the angles of which are formed by the apophysis of the calcareous valves, to which the muscles are attached directly, without the intervention of anything analogous to tendon; the fibres themselves are transversely striated (Pl. XX. fig. 12, *a*), the striation being visible only on treatment with certain reagents, and even then being often confined to comparatively few of the individual fibres making up the muscle masses, though sometimes all show striation. Treatment with chromic acid, KLEINENBERG's picric acid, osmic acid, and in one case gold chloride, showed the striation beautifully, while alcohol was entirely ineffective in that direction (Pl. XX. fig. 12, *e*). Occasionally on treatment with these reagents, parts of many of the fibres swelled out into a spindle-shaped mass (Pl. XX. fig. 12, *d*), continuous at both ends with unaltered fibre ; in this case no striation was ever observed. Rupturing the fibres showed that they were made up of an outer structureless sarcolemma and an inner muscular substance (Pl. XX. fig. 12, *b*).

The head also contains three hitherto undescribed pseudo-skeletal structures, of extremely curious structure, and of remarkable beauty (Pl. XX. figs. 10, 11). These, from their highly refractile character, sharp edges, and resistance to action of dilute acetic acid, appear to be of the nature of elastic tissue. Each of these masses is flat, and formed of a number of fibres folded and re-folded upon themselves, forming a complex series of loops and meshes. These structures are not to be confounded with the looped extremities of the figures of the stalk, and a glance at fig. 13, which represents a section through the head of one of these ophiocephalous pedicellariæ will show that the two structures are entirely distinct. The same figure shows the position of these structures. Each is situated outside the muscular mass of its own side, but between and in apparent contact with the calcareous valves, and alternating with them. Moreover, they lie transversely to the long axis of the pedicellaria, while the looped termination of the stalk fibres lies parallel to the same axis. No connection with any soft parts either of the head or the stalk has been observed by us, and it seems very possible that their function is analogous to that of the elastic hinge in the shells of Lamellibranchs, serving to divaricate the calcareous valves. This view is supported by the fact that neither by sections nor by teasing can any connection be made out between these plates of elastic tissue and any other structure, and perhaps also would account for the imperfectly (?) developed muscles of the stalk, their function, which would be presumably that of divaricating valves, being assumed by the mechanical action of these elastic structures. It is true that pedicellariæ, when killed by being placed in reagents, immediately close, but this may be accounted for by a rigid contraction of the approximator muscles.

The tridactyl pedicellariæ need not detain us long, as they are not in their structure very far removed from the variety that has just been discussed.

The three calcareous valves (Pl. XX. fig. 15), however, are of a very different shape ; the main part of each valve is a tapering rod, which is pierced by foramina, and furnished at both edges for a considerable distance downwards with minute denticulations ; the basal portion of valve is triangular with teeth at the side angles for articulation with the other valves ; from the middle line on the inner surface an apophysis is given off, which serves for the attachment of the transverse muscles.

The calcareous rod in the stem is similar to that of the other pedicellariæ.

With regard to the soft parts, the whole pedicellaria is covered with an epithelium in no way to be distinguished from that of the ophiocephalous pedicellariæ. The soft part of the stalk between the swollen upper end of the calcareous rod and the base of the valves has a similar structure, but the looped elastic tissue which forms the upper extremity of the stalk is very feebly marked. The transverse muscles arranged in the form of a triangle, and attached to the apophysis of the calcareous valves, need no description; everything that has been already said concerning these muscles in the case of the ophiocephalous pedicellariæ might be repeated here.

The coiled plates of elastic tissue, three in number, lying inside the calcareous valves of the head in the ophiocephalous pedicellariæ, we have found to exist in the tridactyl pedicellariæ, but only after a prolonged search, as they are so exceedingly minute and delicate as almost invariably to escape observation. Pl. XX., fig. 16, is a transverse section of one of these pedicellariæ taken just above the base of the head. The specimen has been hardened in chromic acid, so that the calcareous parts have been dissolved away, but their position can be easily made out, as the apophysis of each lies, of course, between each of the muscular masses. The three muscular masses are seen to form a triangle. Fig. 17 is a section taken so as to preserve intact the actual bases of the calcareous valves. The specimen was preserved in osmic acid. This figure may be compared with fig. 14, which is a precisely similar section taken from an ophiocephalous pedicellaria; in neither have the delicate calcareous valves been at all injured. The valves are covered externally by a layer of epithelium, and the three approximator muscles forming a triangle are attached to the apophysis of the valves.

The gemmiform pedicellariæ are scattered all over the test, and are about equal in number to the last mentioned variety, the ophiocephalous pedicellariæ being far more abundant than either of these two. Their structure will demand a careful and full account, since they differ in many particulars from the other kinds of pedicellariæ.

The stalk consists of an internal calcareous rod, resembling the same structure in the other pedicellariæ, but the knob-like swelling is rather larger. It is covered by a layer of epithelium, which is continuous over the whole pedicellaria.

The soft part of the stalk lying between the calcareous rod and the bases of the valves of the head is extremely reduced in size, having, in fact, only about half the length of the head. It consists of a bundle of plain muscular fibres, in which we have not succeeded in showing striation by the use of any reagents. These fibres are attached to the base of the valves, and to the lower part of the knob-like swelling at the extremity of the calcareous rod of the stalk, and, as in the case of the other muscles in the different pedicellariæ, there is no appearance of anything comparable to tendinous tissue. Those fibres present a very great contrast to the stalk fibres in the other pedicellariæ, being of a uniform diameter, with a sharp outline, and resembling very closely the transverse muscles of the head of this and the other kinds of pedicellariæ.

Plate XXI., fig. 6, shows the upper extremity of the rod with the stalk fibres attached to its lower portion. Fig. 7 is the same structure, but, viewed from above, the stalk fibres are attached all round, and radiate outwards from the calcareous rod. Fig. 8 is a section through the stem of a gemmiform pedicellaria, broken somewhere below the distal knob-like extremity; the rod itself is seen to be made up, as described above, of a number of delicate longitudinal bars connected by transverse pieces; outside the calcareous rod is the epithelial coating.

The structure of the head itself is very peculiar. When the three valves are closed, it is almost globular in shape. Each of the three calcareous valves (Pl. XXI. fig. 1) consists of a basal portion of a squarish shape with rounded angles; at the sides are tooth-like prolongations for articulation with the other valves; the upper part of the valve is prolonged into a slender hollow rod, triangular in section, and provided at its extremity with a sharp process at right angles to itself. The lower portion of the valve is provided with an apophysis for the attachment of the approximator muscles. Each of the three valves has attached to its outer surface a large glandular mass, which in the intact pedicellariæ almost entirely conceals the underlying calcareous parts. We have studied these pedicellariæ, as well as the others, both by teasing and by sections, but the latter method gives very good results in this case, because of the great development of soft parts which renders the cutting of sections far easier than in the other pedicellariæ, where complete sections cannot well be obtained, owing to the predominance of the calcareous skeleton of the "head" over the soft parts. Underneath the epithelium lie the three glandular bodies, the structure and relations of which will be best understood by describing in order the three sections given on Plate XXI. Fig. 10 is drawn from a section through the lower part of the head. Each of the glandular masses is somewhat kidney-shaped in section, and is attached to the outer surface of the calcareous valve of its own side. The centre is filled with a mass of glandular and somewhat elongated cells, outside which is a double layer of fine muscular fibres, unstriated, which cross each other nearly at right angles, and in a direction oblique to the long axis of gland. They no doubt serve to compress the gland and squeeze out the secretion. Surrounding the whole is seen the epithelium, which is thickened in a peculiar manner at the lower corners of each of the glandular masses. Connecting the apophysis of the calcareous valves are the transverse muscles, which, unlike the same muscles in the two varieties of pedicellariæ just discussed, do not appear to show any striation. On one side below the muscles are a number of small circular bodies (*a*), the nature of which we have been unable to determine.

Fig. 11 is a section taken higher up, about the middle of the head. The structure is almost identical with that of the section just described, but there is no special thickening of the outer epithelium, and the problematical bodies (*a*) are absent.

Fig. 12 is a section taken near the top. Each of the glandular masses has become double, the division being foreshadowed in the lower part of the glands by their kidney-shaped outline in transverse section. The layer of fine muscular fibres is continued round each of the halves of the divided gland, between which is seen the section of the rod-like upper end of the calcareous valve ; it is triangular in section, and hollow.

By teasing these pedicellariæ, the existence of the three plates of elastic tissue, which were described in the ophiocephalous and tridactyle pedicellariæ, was proved, but again, as in the case of the tridactyle pedicellariæ, with considerable difficulty, as they are here very fine and delicate (fig. 5). We did not succeed in seeing them in any of the sections. The muscular fibres of the stalk, as described above, are in direct attachment to the bases of the calcareous valves, and show none of the looped elastic fibres which form their termination in the ophiocephalous and tridactyle pedicellariæ.

Fig. 2 represents one of the calcareous valves, with its attached glandular mass separated from the other two, and viewed with its inner surface uppermost. The glandular mass is concealed by the fine muscular fibres which surround it. Lying on the calcareous valve, are about one-third of the way down the lower expanded portion, is seen a rounded body (*a*), which looks like a small gland.

Fig. 9 represents the whole of the head of one of these pedicellariæ pressed out and viewed from above.

The three muscular masses which form the approximator muscles of these pedicellariæ contain fibres which, as stated above, do not show any striation when treated with any reagents whatsoever, but under certain conditions they become swollen and spindle-shaped, as also do the transverse muscles of the ophiocephalous and tridactyle pedicellariæ. These two conditions of the transverse muscles of the gemmiform pedicellariæ are shown in Pl. XXI. fig. 3. Fig. 4 shows a few of the fibres which surround the central glandular masses of the pedicellariæ very highly magnified.

It is possible that these gemmiform pedicellariæ have an urticating function. Mr SLADEN * has, in a paper already alluded to, published an account of these

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* SLADEN, *loc. cit.*

same pedicellariæ in two other species of sea urchin (*Sphærechinus granularis* and *Echinus melo*). He considers that their function may be to secrete mucus. Our account of the structure of these pedicellariæ substantially bears out what has been said by him. There is, however, some difference of detail, owing, no doubt, to the different species that have formed the subject of Mr SLADEN'S investigation and our own, and we do not in all cases completely understand his figures. For example, on Plate XIII. fig. 10, of his paper, a transverse section of one of these pedicellariæ is given, in which there is no trace of the calcareous valves, nor is their position indicated.

We have been unable to make out in our own preparations the complex nervous arrangement described and figured by Mr SLADEN, although his results seem to be corroborated by those of Messrs ROMANES and EWART,* who describe a complete nervous system of fibres and cells in the pedicellariæ, as well as in the spines. These structures may perhaps correspond to what we have figured at Plate XXI. fig. 10.

The fourth and last variety of pedicellariæ which are found in this urchin are the trifoliate. These are exceedingly small, but their structure can be tolerably well made out without the aid of sections. They resemble very closely the ophiocephalous and tridactyle pedicellariæ, but do not possess coiled plates or loops.

The whole pedicellaria is shown on Plate XIX., and Plate XXI. fig. 13, shows the head and part of the stalk more highly magnified.

Observations made upon the structure of muscular fibres in the Echinoderms have been up to the present time entirely contradictory. WAGNER, † VON SIEBOLD, ‡ and JOHANNES MÜLLER § have asserted that there is no appearance of transverse striation. VALENTIN, on the contrary, in his monograph on the sea urchin, || maintains that the muscles of the spines and of the lantern are really striated, and DE QUATREFAGES ¶ has seen a transverse striation on the longitudinal muscles of Synapta. On the other hand, BAUER** has contradicted these observations, while LEYDIG†† has described a longitudinal and transverse striation in Echinus and Holothuria.

Finally, in the latest work on the subject—that of M. FREDERICQ—the striation of the muscles of the lantern of *Echinus sphæra* is denied.‡‡ How are all these contradictory statements to be reconciled ?

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* ROMANES and EWART, *loc. cit.*

† "Ueber die Anwendung histologischer Charactere auf die Zoologische Systematik," Arch. Anat. ünd Phys., 1835, p. 319.

‡ Anat. Comp. p. 81.

§ "Ueber den Bau der Echinodermen," Arch. Anat. ünd Phys., 1853, p. 319.

|| *Op. cit.* p. 101, 102.

¶ Sur le Synapta, "Annales d. Sc. Nat." 1842, vol. xvii. p. 43.

** "Beiträge zur Naturgeschichte der Synapta digitata," Nova Acta Acad. Cœs. Leop. 1864, vol. xxxi. p. 25.

†† "Kleinere Mittheilungen zur thierischen Gewebelehre," Arch. Anat. und Phys. 1854, p. 305.

‡‡ "Contributions a l'étude des Échinides," Arch. de Zool. Expérim., vol. v. 1876, p. 439.

Gegenbaur in his "Comparative Anatomy" (French translation by Carl Vogt, p. 298), remarks concerning Echinoderm muscle:—"Des recherches correspondant aux exigences de la science actuelle sur la structure des élements constituant les muscles des Echinodermes nous manquent encore."

By treating the muscles of the urchin with different reagents, and making a great number of preparations, we have seen all the phenomena which these authors describe. Frequently the adductor muscles of the valves of the pedicellariæ are clearly striated, and just as often they do not show the least trace of striation. The same is observable in the muscles of the lantern, and we have preparations which contain the plain unstriated fibres of Wagner and Fredericq, side by side with others where the striation is as distinct as in Valentin's drawings. More than this, in examining a single fibre throughout its whole length, there may often be seen a complete series of gradations between distinct striation and the entire absence of striation. The muscles of the spines we have also studied, and we have been able to show a marked appearance of striation.

Mr Haycraft has recently[*] put forward a new theory on the structure of voluntary muscle. He regards the fibrillæ not as simple cylinders, but as presenting wider and narrower portions in succession, so that their striation is not caused by an histological differentiation, but is simply an optical phenomenon produced by the unequal refraction which light undergoes in passing through the fibril. Without pledging ourselves to a general acceptation of this theory, and without asserting that the striation of the muscles of the Echinoderms is due to the same cause as that of the higher animals, we are perfectly convinced that the irregularity of the striation in the muscle of Echinus can only be explained in this way. The fibres of the lantern show that the dark bands correspond with the wide portions of the fibres, and the light bands with the narrow portions, and when the edges of the fibre become perfectly straight, then the striations disappear altogether (Plate XXI. figs. 14. 15, 16).

It is probable, as has been already suggested by others, that the striation has something to do with the state of contraction of the muscle; but before deciding upon this question, we hope to make further researches, and also to investigate the pedicellariæ of other Echinoderms.

This paper was commenced by one of us at the Laboratoire de Zoologie Expérimentale at Roscoff in 1878, and continued and concluded by the other at the same place in 1880. To M. de Lacaze-Duthiers, as well as to M. Delage and the whole staff of the Zoological Station, our most cordial thanks are due and tendered.

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[*] "On the cause of the striation of voluntary muscular tissue," Proc. Roy. Soc., Feb. 1881.

DESCRIPTION OF PLATES.

PLATE XIX.

View of a portion of surface of test of *Echinus sphæra*, showing spine and various kinds of pedicellariæ grouped round it, × 60.

- *a.* Ophiocephalous.
- *b.* Tridactyle.
- *c.* Gemmiform.
- *d.* Trifoliate.

PLATE XX.

Ophiocephalous pedicellariæ (figs. 1–14.

Fig. 1. Calcareous valve viewed from inner surface, × 120.

Fig. 2. Epithelium of stalk treated with silver nitrate, × 120.

Fig. 3. Same more highly magnified, × 540.

Fig. 4. Base of valves showing how the fibres of stalk are wrapped round the semicircular arches, × 120.

Fig. 5. Looped terminations of stalk fibres freed from their attachment to semicircular arches, and spread out × 200.

Fig. 6. Epithelial cells continuous with long processes, × 540.

Figs. 7 and 8 are views of the triangle of approximator muscles, in a peculiar state of contraction, in which both extremities of each muscle mass is swollen, × 30.

Fig. 9. Central granular core of soft part of stalk, showing nuclei and a few ensheathing fibres, × 540.

Figs. 10, 11. Coiled elastic plates, × 540.

Fig. 12. Fibres from approximator muscles of head; (*a*) fibre treated with osmic acid, showing striation; (*b*) fibre broken across, showing sarcolemma; (*c*) plain fibre prepared with alcohol; (*d*) fibres with spindled-shaped swelling, showing nuclei, × 540.

Fig. 13. Cross section of head which has been prepared with gold chloride, so that calcareous parts are dissolved away and not shown. In the centre of muscular triangle is seen the looped extremity of stalk fibres, and outside the three coiled plates of elastic tissue, × 120.

Fig. 14. Section showing base of calcareous valves, × 120.

Tridactyle pedicellariæ (figs. 15–17).

Fig. 15. Calcareous valve viewed from inside, × 120.

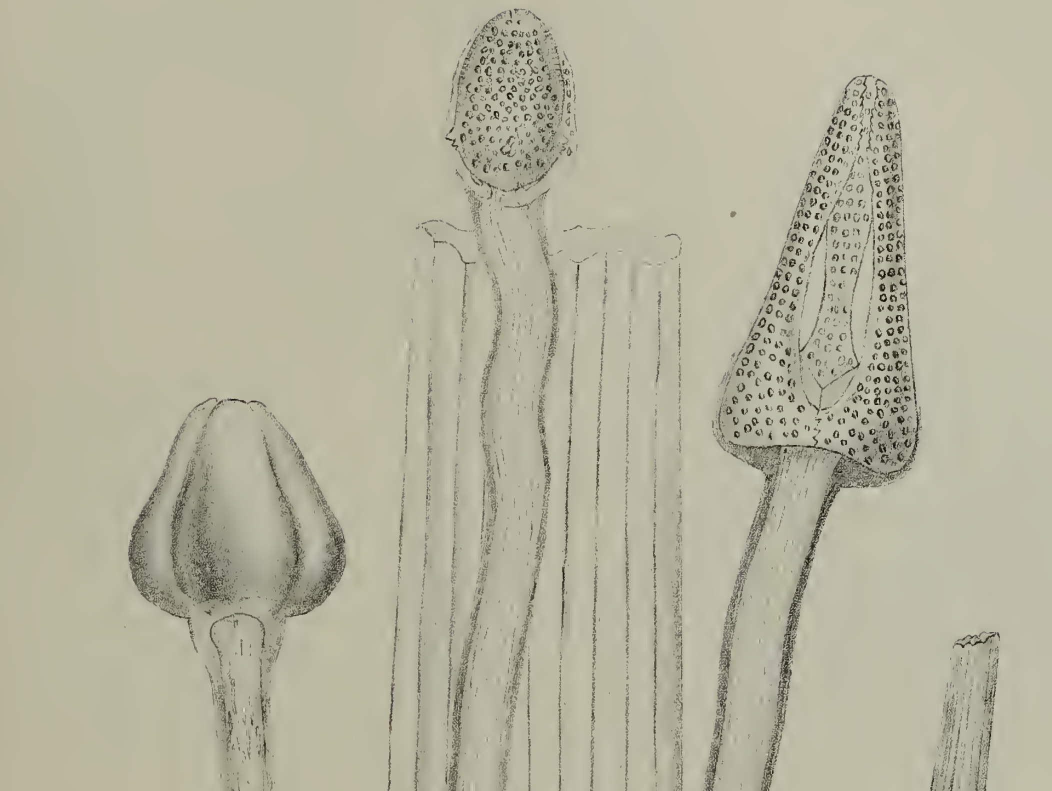
Fig. 16. Section through head just above base of calcareous valves, × 120.

Fig. 17. Section showing base of calcareous valves, × 120.

Plate XXI.

Gemmiform pedicellariæ (Figs. 1–12).

Fig. 1. Calcareousvalve viewed from within, × 120.
Fig. 2. Calcareous valve, with its attached glandular mass viewed from below; (*a*) pair of small glands, × 120.
Fig. 3. Transverse muscles of head, × 540.
Fig. 4. Fibres from muscular covering of glandular mass, × 540.
Fig. 5. Coiled plate of elastic tissue, × 540.
Fig. 6. Head of calcareous rod of stem, showing attachment of muscles serving for divarication of valves, × 250.
Fig. 7. The same viewed from above, × 250.
Fig. 8. Section of stem; calcareous rod covered by epithelium, × 250.
Fig. 9. View of head of pedicellaria opened from above, × 60.
Fig. 10. Section through basal portion of head, × 150.
Fig. 11. Section through middle portion of head, × 150.
Fig. 12. Section through upper part of head; only one of the three valves with its attached gland is seen, × 150.
Fig. 13. Trifoliate pedicellaria, × 75.
Fig. 14. Muscle of œsophagus from *Echinocardium cordatum*, × 320.
Fig. 15. Muscles of lantern showing alternate darker and lighter striæ, the dark striæ corresponding with thick portion of fibre; (*a*) fibre showing nucleus, × 540.
Fig. 16. Muscle of spine showing similar structure, × 850.
Fig. 17. Branched muscular fibre.



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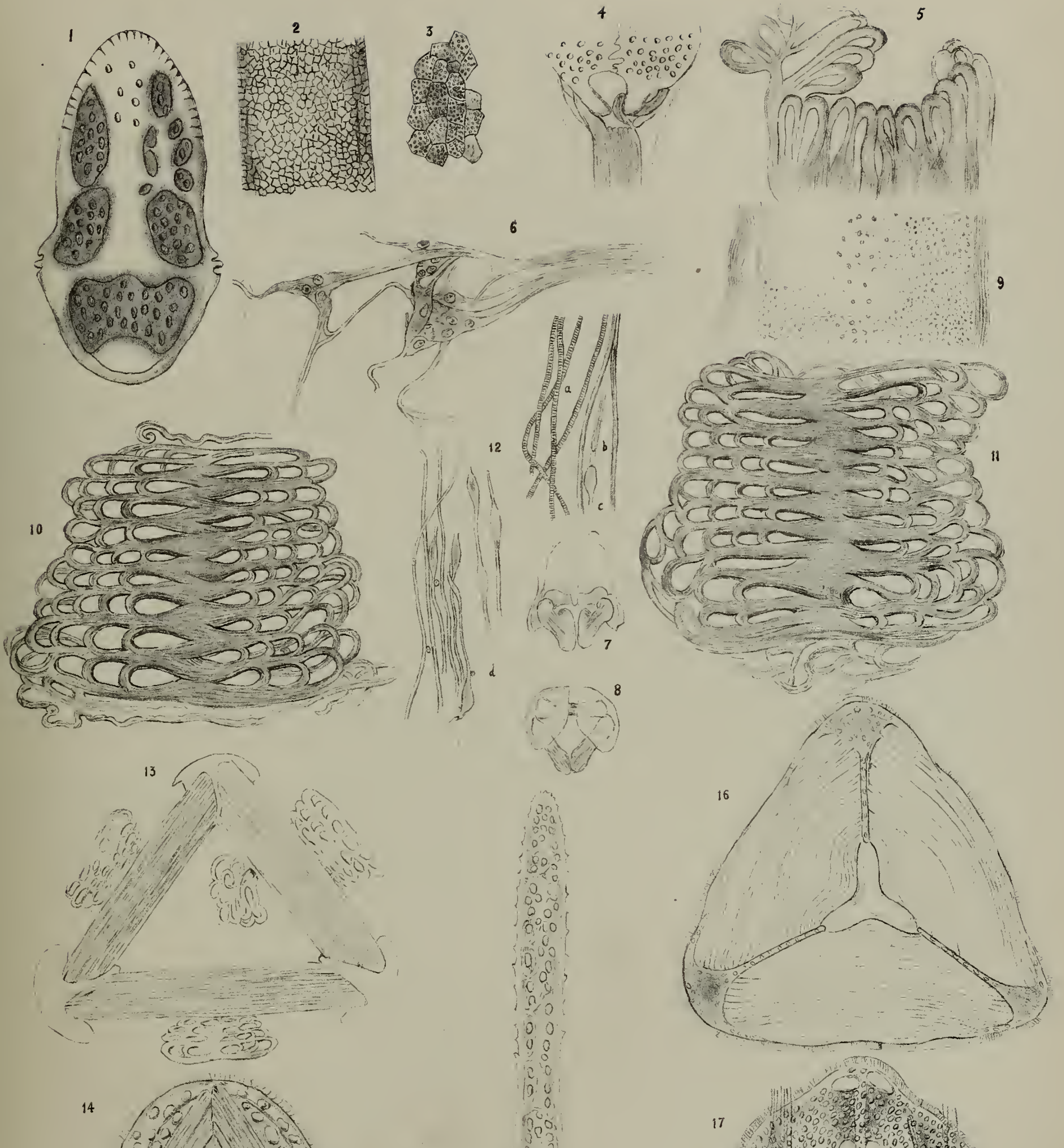

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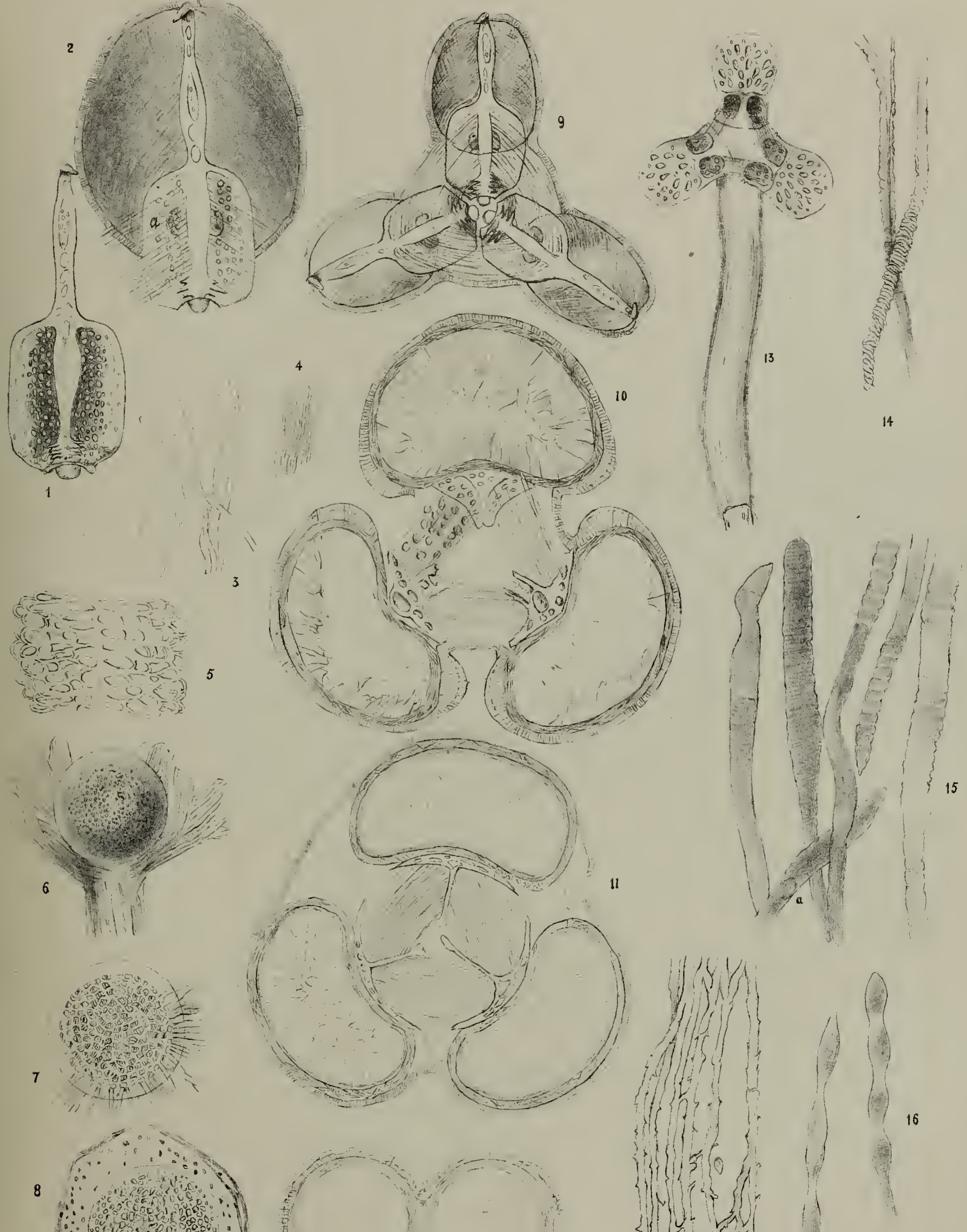

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J. Bartholomew, Edinr.

XV.—*On some new Species of Fossil Scorpions from the Carboniferous Rocks of Scotland and the English Borders, with a Review of the Genera* Eoscorpius *and* Mazonia *of Messrs Meek and Worthen.* By B. N. Peach, A.R.S.M., F.R.S.E., of the Geological Survey of Scotland. (Plates XXII. and XXIII.)

(Received 24th June 1881).

In the progress of the Geological Survey of the South of Scotland, specimens referable to the genus *Eoscorpius* have been gradually accumulating. In 1876 J. Bennie, Fossil Collector to the Survey, obtained an example from the Coal-measures of Fife. Since then fragments have been disinterred by him and by A. Macconochie, also Fossil Collector to the Survey, from the Calciferous Sandstone series in the counties of Edinburgh, Berwick, Roxburgh, Dumfries, and Northumberland and Cumberland. It was not till the spring of last year (1880) that they began to be found in such a state as to necessitate a description of the fossils. In the summer of that year A. Macconochie obtained an almost entire example from the neighbourhood of Langholm, in Dumfriesshire. This year (1881) J. Bennie has secured several good though fragmentary specimens from the neighbourhood of Edinburgh, while A. Macconochie has sent in several from the counties of Berwick and Northumberland. In my capacity of Acting Palæontologist, I have had an opportunity of studying these remains, and by the permission of A. C. Ramsay, LL.D., F.R.S., Director General of the Geological Survey of Great Britain, and Professor A. Geikie, LL.D., F.R.S., Director of the Geological Survey of Scotland, I have been allowed to describe them.

Previous Literature relating to Carboniferous Scorpions.

In 1835 Count Sternberg published a description of a fossil scorpion from the Coal formation of Chomle, near Radnitz, Bohemia.

In 1836 Corda described and named the above specimen under the appellation of *Cyclopthalmus senior*, from the smaller eyes being arranged in a circlet round the two central larger ones. (Corda in "Böhmischen Verhandlungen," 1836, and Wiegmann's "Archiv," 1836, vol. ii. p. 360). Figured in the Transactions of the Bohemian Museum.

In the same year Dr Buckland reproduced the figures in his "Bridgewater Treatise," pls. 46′ and 46″, fig. 13, the description being given in vol. i. p. 407.

In 1839 Corda added a new genus to the Pseudo-scorpions under the name of *Miciolabis*, the specimens being obtained from the same locality as the *Cyclopthalmus*.

In 1868 Messrs Meek and Worthen described the remains of a fossil scorpion (*Eoscorpius*) from the Lower Carboniferous Rocks of Mazon Creek, Morris Grundy County, Illinois, U.S.A., in the "American Journal of Science and Art," 2d ser. vol. xlv. p. 25, and also in the "Memoirs of the Geological Survey of Illinois and Iowa," vol. iii. p. 560. They also describe a specimen which they consider to belong to the Pseudo-scorpions, and call it *Mazonia Woodiana*, from the locality whence it was derived, Mazon Creek (*ibid.* p. 563)

In 1873 Henry Woodward, Esq., F.R.S., read a paper before the Geological Society of London on remains of fossil scorpions from the Coal-measures of England and a doubtful tail segment from the Carboniferous Limestone series of Carluke, Scotland, which he refers to the genus *Eoscorpius*, Meek and Worthen, and ranks under one species *Eoscorpius Anglicus* (Quart. Journal of the Geolog. Soc., vol. xxxii. p. 57).

In 1881 a newspaper notice of a meeting of the Geological Society of Glasgow records the exhibition of a tail segment of *Eoscorpius* by Mr Coutts from the Carboniferous Limestone Rocks of East Kilbride, Scotland.

DESCRIPTION.

Genus *Eoscorpius*, Meek and Worthen, 1868.*

Eoscorpius tuberculatus, n. sp. (Plate XXIII. figs. 8 to 8*h*).

The characters of this species are made out from several fragmentary specimens obtained from the valley of the Forth. These all show it to have been small. One specimen exhibits the carapace and six of the segments of the abdomen. If the rest of the body bore the same proportions to this as obtains in the present *Scorpio afer*, the whole animal ought to be about 2½ inches long from the anterior margin of the carapace to the point of the tail sting.

Cephalothorax.—The carapace is subquadrate with rounded off angles, and narrower in front than behind. It is produced into a slight peak anteriorly in the middle line. The posterior margin is concave, and bordered by a broad band which is slightly peaked backwards in the middle. A deep depression divides the carapace into right and left halves. On each side of it the test is raised into swollen cheek-like lobes which occupy the whole breadth at the anterior and antero-lateral margins, which they overhang and entirely hide when the carapace is viewed from above. From this they taper backwards to blunt points on each side of the depression near the posterior margin. Exterior to these are two less raised triangular areas which occupy the remaining portions of the carapace. Towards the anterior end of the mesial furrow rises a comparatively large pyriform eminence with its narrow end directed backwards, the broader portion being set with two large circular or slightly oval simple eyes placed so as to look upwards, forwards, and slightly outwards. The eminence is composed of two connate tubes which rise at an angle of about 20° from the plane of the sulcus in which they are set, and diverge outwards at an angle of from 30° to 40°. The corneas of the eyes appear like "bull's eyes" at the mouths of the tubes. In cases where the overlapping cheek-like lobes of

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* "American Journ. Science and Arts," 2d ser., vol. xlv. p. 25.

the carapace have been pushed aside by the fossil being crushed obliquely, smaller eyes are seen at the antero-lateral angles. In one case three were observed on one side, though it is probable that there was at least one more still hidden. From the specimens at command the exact number cannot be made out. The character of the test of the carapace is horny, and where swollen up it is thicker than at other parts, and dotted over with larger and smaller tubercles in an irregular manner. The floor of the sulcus and the eminence bearing the mesial eyes are smooth, while the triangular areas at the posterior angles are thin and wrinkled.

Appendages of Cephalothorax.—Falces unknown. Palpi chelate, short, and comparatively stout. Walking limbs unknown, with the exception of the coxæ of four of the limbs on one side, which are preserved as triangular flattened plates converging in front of the segment bearing the comb organs.

Abdomen.—Six segments only are preserved. The dorsal plates of those in front are short, each succeeding segment gradually becoming deeper, so that the sixth is three times the depth of the first. All seem to be about equally broad. They all have a broad thickened smooth articular margin in front, the parts left uncovered being dotted all over with smaller tubercles, and the posterior margin slightly fimbriated and set with two rows of larger tubercles. Their lateral margins are rounded. The ventral plates of only the first four segments are preserved. Nothing can be said of the first two, except that one of them bears the combs. The third is an apron-like flap, narrow in front and widening posteriorly, and rounded at the angles. It is as deep as three of the dorsal plates opposite which it is placed. Within the rounded postero-lateral angles of this plate two fine slits occur which are the openings into the air sacs. The fourth is too much crushed for description. These plates are united by their lateral margins to the dorsal portions by longitudinally folded thinner skin, which is constricted opposite the articulations.

Abdominal Appendages.—The combs are large in proportion to the animal. In the best specimen they are well preserved, though they are folded back upon themselves, so as only to show their form near the tips. They seem to be made up of a broad triangular rachis ornamented with an irregular embossed scale-like pattern, which reminds one of that on *Eurypterus* and *Pterygotus*, and edged at the lower side with a row of comparatively large leaf-like teeth. These are constricted at their bases, they then suddenly expand, the sides then become parallel, and as suddenly become truncated to a blunt point. Being nearly all of a length when seen together, their upper and lower edges form nearly parallel lines. In their present crushed state the individual leaflets overlap each other like the splints of a venetian blind.

Tail and Poison Gland unknown.

The above characters have been ascertained from the study of several specimens collected by J. BENNIE, Fossil Collector to the Survey. The first and best specimen (fig. 8), was obtained from the Coal-measures at Blair Point, near Dysart. The others, with one exception, were obtained by him from the Calciferous Sandstone series from Redhall and Cramond, in the vicinity of Edinburgh. The specimen from which figs. *f* and *g* were taken was got by Mr THOMAS JARDINE from Redhall, during one of Professor GEIKIE's class excursions.

This species has been purposely described first because the carapace and eyes have been found together in the same specimen with the comb-like organs. It will be necessary to refer to this again when the genera *Eoscorpius* and *Mazonia* of Meek and Worthen come to be discussed.

Eoscorpius glaber, n. sp. (Plate XXII. figs. 2 to 2*l*).

Body, without the tail and appendages, about $1\frac{1}{2}$ inches long.

Cephalo-thorax.—The inner surface of portions of the carapace only is seen. It appears to be smooth and not tuberculated. Eyes not observed. Falces: a pair of stout cheliceræ, having the biting edges denticulated. Palpi cheliform, the biting portions being remarkably long compared with the rest of the limb. The basal joints of the palpi are strongly tuberculated and act as jaws. Walking limbs: four on each side, the foremost being short and directed forwards, the next even shorter, and the last two pairs being much longer than the rest and directed backwards, the hindermost being the longest, though they do not extend beyond the fifth abdominal segment. The basal joints or the coxæ of these limbs in their present flattened state appear as triangular plates, which converge upon the thorax, those of the first pair probably acting with the palpi as maxillæ. The other three almost meet near the middle line, and enclose some small plates, the number and arrangement of which are not shown. The second joints are short and subquadrate, the third joints are longer and flattened laterally; the fifth short, with the under margin gibbous, making it easily recognisable. The tarsi are each composed of one joint, somewhat narrower at the base than the extremity (which is the case with all the limb joints) where it is produced beneath into a strong spine. The manus is supplied with a stout fixed spine and two movable hooks, which do not seem to be toothed on their lower margins.

The *abdomen*, exclusive of tail, consists of seven segments, the dorsal portions of which are represented by seven subovate plates, the front ones being not so deep as those farther back. The first six are all of nearly equal breadth. The seventh narrows so suddenly that its posterior margin is only half the breadth of the anterior one, which is as broad as the posterior margin of the sixth segment. All the segments have a broad marginal band in front. Five ventral plates are visible, each corresponding in shape and breadth to the dorsal plate from the third to the seventh segment inclusive, except the foremost which is much deeper. Slit-like spiracles, surrounded with a raised margin, have been observed within the postero-lateral angles of those of the third and fourth segment, and it is probable that the next two bear them also. The ventral portions of the first two segments are only made known by the cast of one side of the comb-like organ, a magnified representation of which is given in fig. 2*g*, in which the rachis of the comb is seen to be ornamented by a similar embossed pattern to that of *E. tuberculatus.*

Tail.—Only the first joint of this is preserved in the form of a narrow cylindrical body now flattened, of the same breadth as the posterior margin of the seventh segment, and bearing longitudinal crests. The test is smooth, or only slightly wrinkled throughout, except on the palpi, which bear a very few tubercles. It is from this character, which is so unlike the preceding *E. tuberculatus,* that the name is proposed.

Observations.—As the specimen from which the above description is taken is one of the most complete and best preserved of the fossil scorpions in the Survey Collection, it may be allowable to make some remarks regarding it. It occurs embedded in shale, which has split so well that portion of the specimen adheres to one side and portion to the other. Fig. 2*a* shows the dorsal aspect of the parts that are represented by a darker shade, and the cast of the ventral surface where it is lighter. Fig. 2 being the counterpart is just the converse. In one respect this is unfortunate, as it precludes the possibility of making out the character and position of the eyes which have not been observed. On the other hand it has given us a view of the parts on the ventral surface of the animal. From the manner in which it has been crushed, the abdomen looks a good deal broader than it would do otherwise, for not only do we see the full breadth of the dorsal plates from a back view, but also a portion of the ventral plates bent over, as well as the intervening folded test. I have endeavoured to represent the appearance of the fossils to the naked eye as truthfully as possible in figs. 2 and 2*a*. To illustrate them by showing my own interpretation of them I have prepared fig. 2*b*, exhibiting the ventral aspect, which combines all the parts found in both specimens, the portion of the tail not shaded and drawn with dotted lines being the only parts supplied entirely from inference. Both for reference to these and the other specimens I have made an outline drawing of a recent scorpion in the same position, fig. 1. Fig. 2*l* shows the posterior angles of the third and fourth ventral plates, considerably magnified, to exhibit the stigmata for comparison with a corresponding portion of one of the segments of a recent scorpion (fig. 2*m*). An enlarged outline of one of the chelaceræ is given in fig. 2*e* to show the denticulation. Portions of the two last joints of one of the hindermost walking feet, showing the arrangement of the spines and claws, are shown magnified in fig. 2*h*. It is unnecessary to enter into the microscopic structure of the test at this stage, for when we come to treat of the disjecta membra of the collection, we shall have to discuss it, and show that the smallest portion of skin is sufficient to reveal the nature of its original possessor.

Collector—A. MACCONOCHIE.

Locality.—River Esk, four miles south of Langholm, Dumfriesshire.

Horizon.—Near the base of the Cementstone group (Lower Carboniferous).

Since the above was written another specimen of this smooth-skinned scorpion has been obtained by J. BENNIE among some of the shales forming the plant-bed from Redhall, Water of Leith, near Edinburgh. Fortunately this specimen exhibits the interior of portion of the carapace which, though very imperfect, shows that it had similar large mesial eyes to those of *E. tuberculatus*. The only portion of the antero-lateral margin preserved bears one of the small lateral eyes. The cheeks of the carapace have been embossed into lobes like *E. tuberculatus*, but no tuberculations are observable. The inner side of the lobes is marked with radiating wavy grooves, which are probably vascular markings. Similar markings are found on casts of *E. inflatus* to be described. The junction line of the raised lobes with the posterior wrinkled portion of the carapace is strengthened by buttresses of folded test, and the posterior margin by a wide band which is corrugated transversely. Some of the body segments are preserved, but in too crushed a state for study. It also shows the cheliceræ, which are strongly denticulated One of the palpi of the same form as those of fig. 2 shows that the nipping edge is supplied with numerous fine saw-like teeth and terminates in a bluntly-hooked end. Four of the tail segments are also preserved. One flattened laterally exhibits the anterior articular surface, and in addition shows that the body of the segment, which is cylindrical, was ornamented beneath with longitudinal ridges, four of which are seen on the exposed side, showing that it must have been fluted like an Ionic pillar, see fig. 2*d*. Another segment lying loose has been compressed vertically, and shows the posterior articular face as a perfect ring, and is seen to pass down through more than one layer of the shaly fire-clay in which it is embedded. This scorpion must have been considerably dismembered before being covered up previous to fossilization.

Locality—Redhall, Water of Leith, near Slateford, Edinburgh.

Horizon.—Calciferous Sandstone series.

Eoscorpius euglyptus, n. sp. (Plate XXII. figs. 3 to 3*d*).

A large species, so called from the beauty of its combs.

Cephalothorax.—Carapace unknown. The chelicerae are strongly denticulated. Palpi large and cheliform, the basal joints strongly tuberculated, and acting with the coxæ of the first walking limb as jaws. The second joints of the palpi are marked on their under side with diverging lines of tubercles. The whole limb is strong and set with tubercles and strong spine-like hairs. The biting portions long, and hooked at the extremities, the biting edge being supplied with regular, very fine saw-like teeth, set with the points directed inwards. At intervals a larger tooth interrupts the evenness of the line. Walking limbs four on each side, portions of all of which have been preserved (figs. 3 and 3*a*). The coxæ of the six hindermost are triangular in shape, the posterior ones being the longest. They converge upon four small plates, which enclose a small lozenge-shaped space or plate, where their angles intersect, the coxæ along with these latter forming an efficient sternum. The first movable joints are small and triangular, the next are long and somewhat flattened laterally, having their under edge marked with a row of tubercles which make this portion easily recognised in the fossil state. Only the extremity of one walking limb is preserved, and as that is crushed on to one of the palpi, it does not show its structure well, though it can be seen to be supplied with movable claws.

Abdomen.—The only portion of this preserved exhibits the ventral side of part of the first four segments. The interior of portion of two dorsal plates is seen, the posterior margin of one being supplied with a row of tubercles which appear on the inside as pits. The genital orifice is situated in the middle line just beneath the small plates of the sternum. It is covered by a small valve-like plate in shape like a half disc, which is hinged on the straight side to allow it to open upwards. In the specimen from which fig. 3 was taken the operculum is open. On its inner side a narrow raised line, which divides it mesially, fits into a corresponding groove when it is shut. Both on the lid and the portion covered by it, the skin is puckered up and "drawn" into the orifice, which appears as a transverse slit almost as wide as the hinge of the valve. Placed on each side of the orifice and slightly beneath it two mounds rise to which the bases of the combs are articulated. These organs are, roughly speaking, in the form of two right angle triangles with the most acute angles directed outwards and articulated by their right angles, the remaining angles meeting in the middle line. The hypothenuse is occupied by the leaflets or "teeth" of the comb, which appear to the naked eye like a fringe a line in depth. When magnified, the triangular rachis is seen to be ornamented with a similar embossed scale-like pattern to that on the preceding species, while the fringe resolves itself into a row of very numerous overlapping leaflets, narrow at the bases, with parallel sides, and suddenly cut off to a point, reminding one of the blade of an ancient Greek sword. Towards the inner part of the row, the fringe is single, but near the tips, there is the appearance of a double row of leaflets which overlap in an imbricating manner like tiles.

Observations.—This must have been a large species, for if the other parts wanting be in proportion to those we have preserved it ought to bear favourable comparison with the Indian scorpions for size. I propose to name it from its exceedingly beautiful combs which are the most complex that have as yet come under my notice in the present collection. Fossil combs often turn up among the disjecta membra of scorpion, so that a specific character founded on these may be useful for recognition. The tuberculations on the under edge of the third joint of the walking limbs, and on the dorsal segments are sufficient to distinguish it from *E. glaber,* while the comb is quite distinct in shape from *E. carbonarius* (Meek and Worthen), and its limbs seem to be shorter and stouter. From *E. Anglicus* (Woodward), the shape of the palpi at once distinguishes it.

Locality.—River Esk, four miles south of Langholm, Dumfriesshire.

Horizon.—Near the base of the Cementstone group, Calciferous Sandstone series (Lower Carboniferous).

Collector.—A. Macconochie.

Eoscorpius, sp. (Plate XXIII. figs. 11 to 11*a*).

A specimen which among other crushed and unrecognisable portions of a small scorpion shows more than half of a carapace which is distinct from that of *E. tuberculatus.* It has a corresponding groove mesially, near the anterior of which is set an eminence with two eyes directed forwards. The swollen cheek-like portions, however, are much more complicated by being divided by lateral grooves into three distinct portions on each side. One of these is small and elongated, well-covered with tubercles, and lies just within and parallel to the antero-lateral margin. The middle portion is the largest, and rises above the rest of the carapace, with steep sides all round, the side overlooking the mesial groove being steepest. This eminence is covered with large irregular pustules, some of which are compound, almost like a strawberry. The posterior eminence representing the hinder portion of the swollen cheek in *E. tuberculatus* is triangular in shape and divided into two horns by a deep mesial depression and is almost free from tubercles. The postero-lateral angles are rounded, and enclose, with the outer margin of the eminence, triangular areas of the wrinkled test as in *E. tuberculatus.* Mesial eyes are two large simple ones, set in front of an elongated triangular eminence, which has its apex directed backwards. The eminence, as in *E. tuberculatus,* is nothing more than two connate tubes, which very gradually rise from the level of the floor of the mesial sulcus, and the long axes of which diverge at an angle of only 15° to 20°, no portions of the tubes being free, differing in both the latter characteristics from *E. tuberculatus.* Four lateral eyes are visible on the right antero-lateral margin. Behind the fourth the margin is incomplete, so that there may have been more. One of the lateral eyes is shown magnified in fig. 11*a*.

Fig. 13 shows a portion of a carapace from Dalmeny railway cutting.

From the character of the pustulation it probably belongs to the same species as the above. The above carapace is interesting in being intermediate in character between *E. tuberculatus* and a carapace, which is not an uncommon fossil in the Langholm bed, which, however, has the tubes of its mesial eyes separated throughout by a sulcus.

Locality.—River Esk, four miles south from Langholm, Dumfriesshire.

Horizon.—Near the base of the Cementstone group, Calciferous Sandstone series (Lower Carboniferous).

Collector.—A. MACCONOCHIE.

Eoscorpius inflatus, n. sp. (Plate XXIII. figs. 12 to 12*d*).

All that is known of this scorpion is the carapace, which is not an uncommon fossil in the shales at the locality on the River Esk, near Langholm, Dumfriesshire, which has proved so rich in other rarities. Owing to the thicker portions of the test being generally filled with calcareous calculi till not a portion of the original material is visible, the carapaces are not crushed but still retain their original raised or embossed character. In a few cases where the calculi are sparse the carapaces are flattened, and the nature of the horny skin is revealed. It is evident from this that the calculi must have been introduced in the interval between the death of the scorpion and its interment, and it shows that the remains must have been subjected for some time to the action of "hard water."

Specific Characters.—Carapace subovate, a little broader than long, and narrower in front than behind. The greater portion of the surface is puffed up into six lobules, arranged symmetrically in pairs, and divided off from each other by deep sulci. Two of these mounds, of an elongated shape, form the antero-lateral margins, one on each side. Two large, almost circular, mounds occupy the greater part of the posterior portions of the carapace, and two smaller, triangular, ones are situated between them and those first described. A deep mesial furrow runs from the anterior to the posterior margin, and sends off branches between the monticules. Near the anterior end of this furrow two small tubes, which in this case are separated by a groove, rise gradually from the carapace, and diverge at a slight angle, the front extremities being occupied by two large circular eyes, smaller in proportion to the carapace than in any of the formerly described species. Underneath the elongated mounds occupying the antero-lateral margins, and entirely overhung by them, are at least four small oval eminences on each side which appear to be lateral eyes. These fossils are invariably preserved "back up," a circumstance that is easily accounted for (see fig. 12*c*).

The carapace is ornamented by numerous pustulations on the raised portions, while the sulci are plain, and the posterior and postero-lateral portions thin and wrinkled. The only portions of the carapace usually exposed are the thickened raised mounds, and it is only in one or two out of over thirty specimens in the Survey Collection that the posterior portion of the carapace is preserved.

Observations.—The appearance of the above fossil when filled in with calculi is much like a gigantic ostracod, and bears a great resemblance to *Beyrichia*, though the test, where not destroyed by calculi, exhibits under the microscope the characters borne by that of spiders and insects. By treating those that are most destroyed by calculi with hydrochloric acid the calcareous matter can be dissolved out, and as the test is not soluble, the portions not entirely split up still exhibit structure. It is just possible that this is not a portion of a scorpion, but that it is referable to the genus *Cyclus* (de Koninck), undoubted species of which occur in the same beds with the above fossil and with their tests similarly infested. It may be as well to mention that almost all the fossil scorpions in the Survey Collection have the horny substance of the test still preserved. It is elastic, of a brownish-red colour and slightly transparent, and seems to have undergone very little alteration. It is quite insoluble even in strong hydrochloric acid,—a useful character, as it allows the specimens to be cleaned for microscopic examination.

Disjecta Membra.—Among the fragments that cannot with certainty be referred to any known species, there are many specimens that help to clear up points in the morphology of these ancient scorpions. Combs often occur, and it is a fortunate circumstance that they are so easily recognisable and so characteristic. Figs. 16 and 16*a* represent a portion of one, both natural size and enlarged, showing the nature of ornament like irregularly dropping embossed scales, reminding one very much of that on *Eurypterus* and *Pterygotus*. A few of the teeth which fringed the lower edge are still preserved. This specimen comes from the rich bed near Langholm. Several combs are found among the fragments from the Calciferous Sandstone near Edinburgh.

The abdominal plates are also frequently obtained. Fig. 17 represents one from the ventral surface (natural size), with the combs pressed through it. This probably belongs to *E. tuberculatus*, several carapaces of which have been obtained from the same beds near Cramond. Walking legs are not uncommon. Fig. 6 is a copy of an almost perfect one from Coldstream, Berwickshire, from the Cementstone group (Lower Carboniferous). Some fragments of the walking legs from Berwickshire are very large, being over two inches long and one third of an inch wide in their flattened state, showing to what a large size some of these old scorpions must have attained. Fig. 4 shows the tarsus and manus of one (natural size) from the well-known locality of Lennel Braes, River Tweed, near Coldstream. The spines and movable terminal hooks are well shown. This must have belonged to a very large individual. Fig. 5

is the tarsal joint of a still larger one, but even the owner of this must have been small compared with the scorpion to which the penultimate joint of the *Palpus* represented in fig. 18 (natural size) belonged. Fig. 20 is a drawing of a tail segment from Cramond which shows the articular surface on the anterior portion, the longitudinal ridges, and the abruptly truncated posterior margin. The only portion referable to the poison gland is a specimen represented by fig. 21. It is ovoid in shape, and has its articular surface placed not symmetrically but slightly on one side. It is unfortunate that at the very place where the sting should be, an ostracod shell (*Leperditia*) interferes with the specimen. The line of the ventral margin is seen beyond this, but soon becomes lost. A harder portion of the test of a scorpion is seen where the sting should be were it present, but it would not be safe to say definitely that it was the sting itself, however much it might suggest its being such. The poison gland of a recent American scorpion is drawn in fig. 22 for comparison.

Figs. 18*a*, 18*b* show the microscopic structure of the test of the specimen represented in fig. 18. It is composed of two layers, the upper surface being made up of a network of hexagonal cells. Irregularly placed depressions are found at intervals, and these sometimes pass through both layers. In other instances they are merely dimples as it were in the test. When the test supports hairs each always rises out of the centre of such a depression (fig. 18*a*). The tuberculations seem to be very irregularly disposed over the test of such species as exhibit them. The movable claws of *E. glaber* do not seem to be serrated on the lower edges, while those of the foot from Lennel Braes (fig. 4) appear to be notched. Fig. 18*c* represents the magnified muscular bundles found in the joint of the specimen (fig. 18).

The disjecta membra show that there must be several species of scorpion in these Carboniferous rocks besides those which have been found sufficiently complete to show specific characters, a fact that should incite local geologists to search for them. That they are not rare, may be inferred from the fact that nearly one hundred fragments have been got by the Survey collectors from several widely separated localities and horizons since the year commenced.

The type specimen of *E. carbonarius* for which Messrs MEEK and WORTHEN made the genus, unfortunately did not exhibit any of the organs on which generic classification usually proceeds.* The consideration of the present collection puts us in a better position, and while retaining their name I would propose the following characters as being distinctive of the genus.

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* *Vide* Messrs MEEK and WORTHEN'S description in the "Memoirs of the Geological Survey of Illinois," vol. iii. pp. 560–562. Figs. 23 to 23*b* are a reproduction of the woodcut accompanying their description.

Genus *Eoscorpius*, Meek and Worthen.*

Generic Characters.—True scorpions with inflated carapaces bearing two large mesial eyes in front of tubes, directed so as to look "obliquely forwards, outwards, and upwards," and placed near the anterior margin, and in addition eight or more small lateral eyes placed half at each of the rounded anterior margins. Falces and palpi chelate. Walking limbs eight in number, and ending in movable claws. Combs ornamented with an embossed scale-like pattern and bearing numerous short and stout leaflets. Body suddenly narrows at the seventh abdominal segment, and becomes a narrow cylindrical jointed tail, the joints being fluted longitudinally on the ventral surface.

From *Cyclopthalmus* (Corda), the only other described Carboniferous genus, the arrangement of the eyes distinguishes it. In the former, the lateral eyes are placed in a circlet round the large mesial ones, from which arrangement, the name is derived; † the falces are not chelate, and the abdomen does not contract suddenly at the spring of the tail as in the latter. The position, size, and arrangement of the large mesial eyes and the more elaborate combs distinguish *Eoscorpius* from recent genera.

Although there seems to be sufficient reason to separate the genus from any recent one, these ancient scorpions appear not to differ in any essential character from those now living. As far as the horny test, the only part now preserved to us, is concerned, they were as highly organised and specialised towards the beginning of the Carboniferous period as their descendants at the present day. It is unfortunate on that account that Messrs MEEK and WORTHEN should have chosen the name *Eoscorpius,* for the dawn of the scorpion family must have been at a much earlier period, and we may hope that their remains will yet turn up in the Devonian and Silurian plant-beds when these come to be thoroughly searched.

In the same volume in which they described the *E. carbonarius,* Messrs MEEK and WORTHEN give a description of a fossil from the Carboniferous rocks of Illinois, which they consider to be the remains of a pseudo-scorpion, and to which they give the name of *Mazonia Woodiana,* forming the genus for its reception.‡ Figs. 24 and 24*a* give a copy of some of the figures. After having had the opportunity of studying the above collection of Scotch scorpions, I have little hesitation in looking upon their *Mazonia* as a true scorpion, and their remarks show them to have had a strong inclination in the same direction. The

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* "American Journ. Science and Arts," 2d ser. vol. xlv. p. 25.

† *Vide* Buckland's "Bridgewater Treatise," vol. ii. pls. 46′ and 46″, where there is a reproduction of CORDA's figures. Fig. 25 is a copy after Buckland of the carapace of *C. senior* enlarged, showing the mesial and lateral eyes.

‡ "Geological Survey of Illinois," vol. iii. pp. 563–565.

carapace of the *Mazonia* is almost identical with that of *E. tuberculatus* above described. Had their fossil been preserved so that the overhanging portion of the carapace above the antero-lateral margin had been pushed back, the lateral eyes, which in all probability exist, would no doubt have settled the question. Fig. 24 is a copy of their figure; the firm lines show the boundaries of the portions they found preserved, while the dotted lines show what was left to conjecture. Only one of the antero-lateral angles is preserved (the left), and even there the lateral eyes could not be seen if the carapace were like that of any of our species of *Eoscorpius.* The posterior lateral angles seem to be broken away also. The inflated portion of the carapace, the large mesial eyes placed in the same position, and identical in arrangement and structure with that exhibited by the present *E. tuberculatus*—so much so that the same words were unwittingly used in this description of the latter as those employed by Messrs MEEK and WORTHEN in describing their *Mazonia*—all tend to show that the two are very nearly allied. This conjecture is greatly strengthened by the study of the abdomen of their figure. The dorsal portions of seven segments are shown with just space enough between the posterior margin of the carapace and the first segment for another, but there is no reason to believe that there ever was an eighth.* The seventh is suddenly contracted posteriorly, and abruptly truncated, evidently pointing to there having been a tail attached to it. The detached limb which is preserved is in all probability, from its elongated appearance, one of the hinder walking legs, and not one of the palpi. A comparison of the *Mazonia* carapace with their figure of the *E. carbonarius* is also very instructive (fig. 23). If their figure of the latter be a good representation of the specimen, then the posterior part of the eminence on which the mesial eyes was set is still shown, and the rim of the left mesial eye is also apparent. Taking all these things into consideration there is every reason to look upon the *Mazonia* as belonging to their genus *Eoscorpius,* but a distinct species from their *E. carbonarius.* It would then require to be changed to *E. Woodianus.*

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* The lithographer has shaded this space as if it were a portion of another segment, a mistake which was not observed till the plates were struck off.

EXPLANATION OF PLATES.

EXPLANATION OF PLATES.

Plate XXII.

Fig. 1. Ventral aspect of a recent scorpion of the family *Buthides* (Koch), for comparison with the fossils with which it closely agrees in its proportions.*

Fig. 2. *Eoscorpius glaber*, N.S. Natural size. The darker portions show where the test is retained—the lighter portions, the parts represented by casts. This remark holds good for all the figures. From Langholm.

Fig. 2*a*. *E. glaber*. Counterpart of fig. 2.

Fig. 2*b*. Figure combining all the parts exhibited in figs. 2 and 2*a* to compare with fig. 1. The darker shaded portions show the ventral parts, and the lighter, the dorsal, the dotted portion of the tail left unshaded is added from inference.

Fig. 2*c*. *E. glaber*. Natural size. From specimen obtained from Redhall, showing carapace, several body segments, cheliceræ, chelæ, some of the walking limbs, and four tail joints of a dismembered individual. It occurs in a shaly fire-clay crammed with seeds, Carpolithes Grantoni (Linley and Hutton), fern stems, and leaves (Cyclopteris, &c.).

Fig. 2*d*. Interior of carapace of fig. 2*c*, showing mesial eyes as depressions, one lateral eye, raised lobes with vascular markings and posterior margin. Magnified 3 diameters.

Fig. 2*e*. Left mandible of fig. 2*c* to show denticulation. Magnified 3 diameters.

Fig. 2*f*. Right palpus of fig. 2*c*. Magnified 3 diameters.

Fig. 2*g*. Cast of rachis of comb of fig. 2 to show nature of its embossed markings. Magnified 3 diameters.

Fig. 2*h*. Foot of hindermost left walking limb of fig. 2*a* to show spines and hooks. Magnified 3 diameters.

Fig. 2*i*. A tail-joint of fig. 2*c*, showing the character of its anterior articulation and the fluting on its ventral surface. Magnified 3 diameters.

Fig. 2*k*. Another tail-joint of fig. 2*c*, showing posterior articular surface "end on." Magnified 3 diameters.

Fig. 2*l*. Portion of fig. 2*a* to show two of the stigmata or breathing slits at right posterior angles of the third and fourth ventral plates of the abdomen; as also the longitudinally folded skin connecting the dorsal and ventral plates. Magnified about 3 diameters.

Fig. 2*m*. Stigma at corresponding angle of the third abdominal plate of a recent scorpion, for comparison with fig. 2*l*. Magnified nearly 3 diameters.

Fig. 3. *E. euglyptus*, N.S. Natural size of specimen, obtained from near Langholm.

Fig. 3*a*. To show more clearly the portions exhibited by fig. 3 for comparison with fig. 1.

Fig. 3*b*. Portion of fig. 3, magnified 3 diameters, showing the operculum raised so as to expose the genital orifice; also the combs in place, and the nature of their ornamentation. The dotted lines show the probable extension of combs.

Fig. 3*c*. Portion of comb of fig. 3, magnified, 10 diameters, to show nature of fringe of leaflets near distal end.

Fig. 3*d*. Portion of comb of fig. 3, magnified about 20 diameters, showing that the fringe is made up of a double row of leaflets nearer its apical end.

Fig. 4. Tarsus and hand of a very large scorpion from Lennel Braes. Natural size.

Fig. 5. Tarsus of scorpion from Cramond. Natural size.

Fig. 6. Leg of scorpion from Coldstream. Natural size.

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* This scorpion agrees very closely with the description of Gervais of his *Scorpio Cummingii* in Walckenaer's "Insectes Aptères," and would fall under the genus *Ischnurus* of Koch.

Plate XXIII.

Fig. 7. Dorsal aspect of recent scorpion, fig. 1.

Fig. 8. *Eoscorpius tuberculatus.* Natural size. From specimen obtained from Blair Point, Fife, showing six abdominal segments with the combs in place. The carapace, shown by cast, is displaced, turned round, and lying underneath the abdomen.

Fig 8*a*. *E. tuberculatus.* Portion of carapace, magnified 2 diameters, to show mesial eye and one lateral one. Taken from counterpart of specimen from which fig. 8 was obtained.

Fig. 8*b*. *E. tuberculatus.* Flattened carapace showing mesial and lateral eyes. From Cramond. Magnified 2 diameters.

Fig. 8*c*. *E. tuberculatus.* Portion of another carapace from Cramond. Magnified about 3 diameters.

Fig. 8*d*. Portion of fig. 8, magnified 3½ diameters, to show nature of the combs, the right comb being represented only by a cast.

Fig. 8*e*. The tip of the right comb from counterpart of specimen represented in fig. 8. Magnified about 6 diameters.

Fig. 8*f*. *E. tuberculatus.* Two dorsal segments to show nature of articular facet and the arrangement of tuberculation. Specimen from Redhall. Magnified 4 diameters.

Fig. 8*g*. Ventral abdominal plate showing stigma, from same small piece of shale as fig. 8*f*. Magnified 4 diameters.

Fig. 8*h*. Magnified portion of test of fifth dorsal segment of fig. 8.

Fig. 9. View of left side of first seven abdominal segments of recent scorpion, showing the coxa of hindermost leg, and combs in place, to illustrate the position in which specimen represented by fig. 8 is fossilized.

Fig. 9*a*. Dorsal plate of recent scorpion, magnified 2 diameters, to compare with fig. 8*f*.

Fig. 10. Comb of recent scorpion, magnified 5 diameters, for comparison with figs. 8*d* and 8*e*.

Fig. 11. *Eoscorpius*, species. Portion of carapace, magnified 3½ diameters, showing mesial and lateral eyes, and lobes of carapace subdivided into lobules. From Langholm.

Fig. 11*a*. One of the lateral eyes of fig. 11. Magnified 8 diameters.

Fig. 12. *E. inflatus.* Portion of carapace, natural size, showing the mesial eyes and the lobes divided into lobules. From Langholm.

Fig. 12*a*. *E. inflatus.* Carapace of another specimen. Magnified 2 diameters. From Langholm.

Fig. 12*b*. *E. inflatus.* Cast of portion of carapace of another individual, magnified 4 diameters, to show vascular markings. From Langholm.

Fig. 12*c*. *E. inflatus.* View of front portion of cast of carapace of another individual, magnified about 3 diameters, looking obliquely at the left antero-lateral margin, a portion of the anterior lobe being removed to show four of the lateral eyes on the left side (*l*, *l*, *l*, *l*); shows also the mesial eyes (*m*, *m*) and one of the lateral eyes on the right margin (*l′*). From Langholm.

Fig. 12*d*. Sketch taken "face on" to show relative position of mesial and lateral eyes in *E. inflatus.*

Fig. 13. Portion of scorpion, probably lobe of carapace. Natural size. From Cramond.

Fig. 14. Flattened joint of walking limb ? of scorpion. Natural size. From Cramond.

Fig. 15. Portion of second joint of palpus of scorpion. Natural size. From Pathhead Mill, Dunse.

Fig. 16. Natural size of portion of comb of scorpion, *E. euglyptus* ? From Langholm.

Fig. 16*a*. Same magnified 4 diameters, to show nature of ornament.

Fig. 17. Third ventral abdominal segment and portions of comb of scorpion. Natural size. From Cramond.

Fig. 18. Part of the hand and moveable finger-joints of palpus of scorpion. Natural size. From Langholm.

Fig. 18*a*. Portion of test detached from specimen fig. 18 to show nature of pits and hairs. Magnified about 20 diameters.

Fig. 18*b*. Portion of test highly magnified to show cellular external layer.

Fig. 18*c*. Bundle of muscular fibres seen in digital joint of palpus of fig. 18. Magnified 10 diameters.

Fig. 19. Five tail segments of scorpion, with portion of seventh abdominal segment, all attached, natural size, from Coldstream Bridge, to compare with figs. 7 and 20.

Fig. 20. Tail junk of scorpion, natural size, shows anterior articular surface and longitudinal grooving. From Cramond.

Fig. 21. Poison gland of scorpion, showing the nature of the articulation, hairs, &c. Magnified 4 diameters. From Larriston Burn, Upper Liddesdale. The depression near the narrow end is due to an ostracod shell *(Leperditia).*

Fig. 22. Poison gland and sting of recent scorpion, magnified 3 diameters, for comparison with 21.

Fig. 23. *E. carbonarius* (Meek and Worthen). Reproduction of Messrs MEEK and WORTHEN'S figures, from the "Memoirs of the Geological Survey of Illinois," vol. iii. p. 560.

Fig. 23*a*. *E. carbonarius*, magnified comb, *ibid.*

Fig. 23*b*. *E. carbonarius*, magnified dorsal plate, *ibid.*

Fig. 24. *Mazonia Woodiana* (Meek and Worthen). Reproduction of Messrs MEEK and WORTHEN'S figure, from the "Memoirs of the Geological Survey of Illinois," vol. iii. p. 563.

Fig. 24*a*. *M. Woodiana*, carapace magnified for comparison with the present collection, *ibid.*

Fig. 25. *Cyplophthalmus*, senior (Corda), carapace magnified. Reproduction of figure from BUCKLANDS' "Bridgewater Treatise," vol. ii. pl. 46′.

LIST OF LOCALITIES AND GEOLOGICAL HORIZONS FROM WHICH THE ABOVE FOSSILS HAVE BEEN OBTAINED.

COUNTY.	LOCALITY.	GEOLOGICAL HORIZON.
Fife,	Blair Point, near Dysart, . . .	Coal measures.
Edinburgh,	Redhall, Water of Leith, near Slateford, .	Calciferous sandstone series.
Linlithgow,	Cramond, about three miles N.W. from Edinburgh,	„ „
„	Dalmeny, Railway Cutting, . . .	„ „
Berwick,	Coldstream Bridge, River Tweed, . .	„ „
„	Lennel Braes, near Coldstream, . .	„ „
„	Pathhead Mill, Blackadder Water, near Dunse,	„ „
Roxburgh,	Larriston, Upper Liddesdale, . .	„ „
Dumfries,	River Esk, near Glencartholm, Langholm, .	„ „

The calciferous sandstone series of Scotland is now regarded by the Geological Survey as the equivalent of part of the lower portion of the carboniferous limestone series of England.


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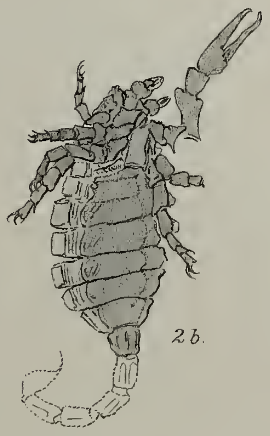
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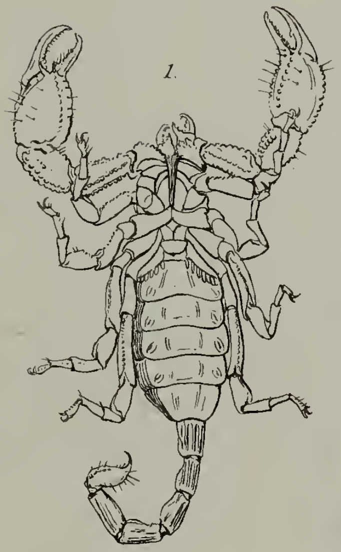
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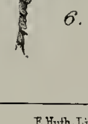
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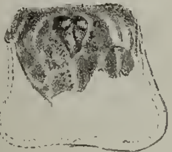
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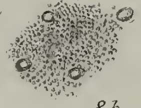
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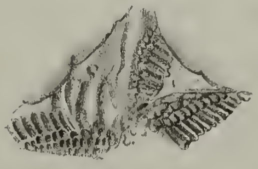
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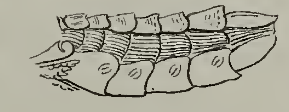
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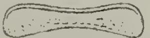
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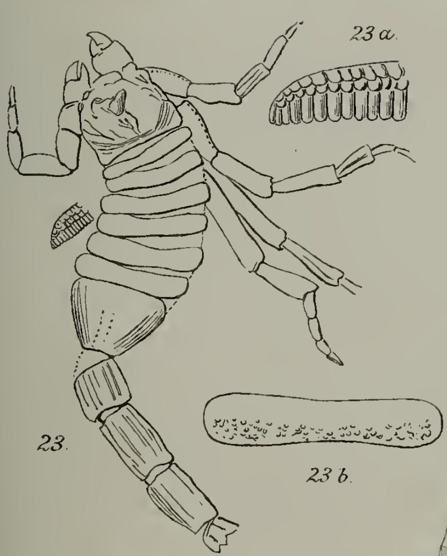

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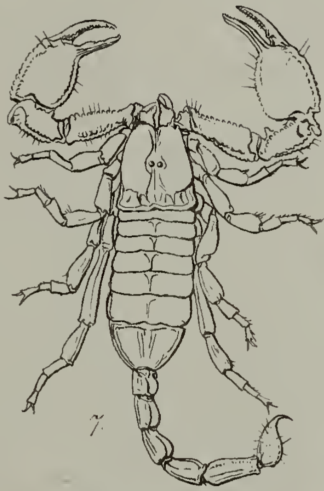
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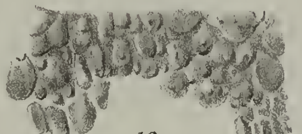
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18 b.


18 c.


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12 a.


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18 a.


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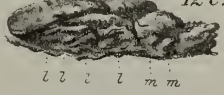

12 c.


12 d.


12 b.


18.


21.

B. N. Peach del.

F. Huth, Lithʳ Edinʳ

XVI.—*Effects of Strain on Electric Conductivity.* By AUGUST WITKOWSKI. (Communicated by SIR WILLIAM THOMSON.)

(Read 21st February, 1881.)

In the following communication an account is given of some experiments made in the Physical Laboratory of the Glasgow University, whose object was the measurement of the change of conductivity produced by strain in a metal conductor.

Two constants are required in order to determine this alteration in the most general case of a homogeneous isotropic conductor, strained in any way, as may be easily inferred from the analogy with elastic strains and stresses, constants expressing the change produced by uniform cubical compression and by simple distortion. The determination of the latter for brass is the object of the present paper.

The method proposed by SIR WILLIAM THOMSON for this purpose is shortly described in the Proceedings of the Roy. Soc. 1879. SIR WILLIAM THOMSON has added arrangements admitting of accurate measurements, consisting of apparatus represented in the annexed diagram, which may be described as follows:—

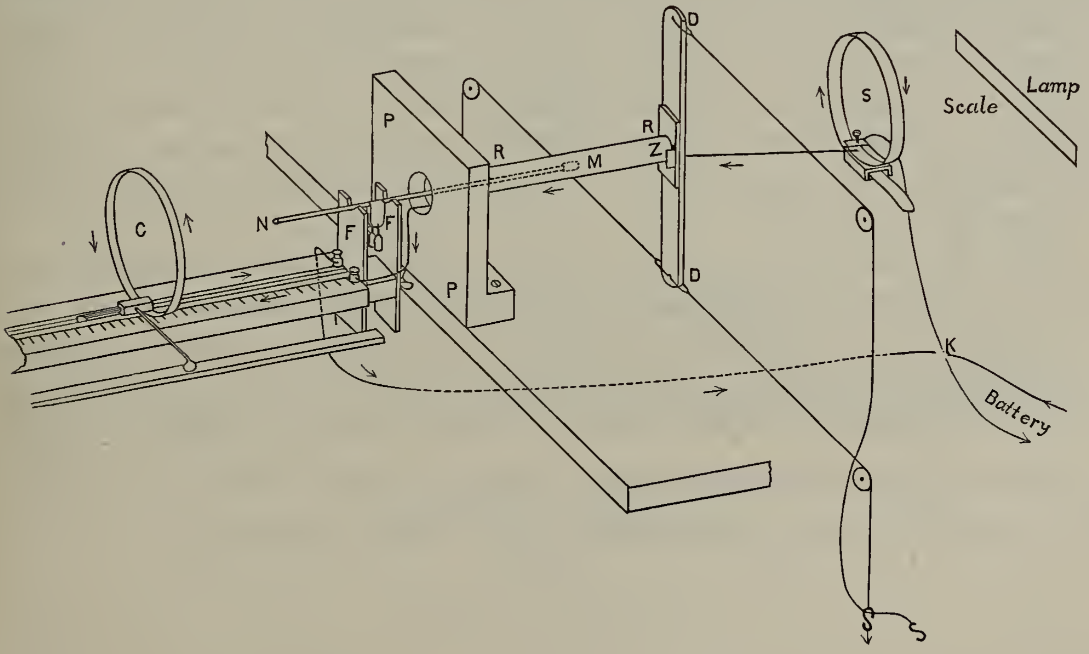

FIG. 1.

R is a brass tube (length = 17·8, external diam. = 1·48, internal diam. = 1·29 cm.) fastened firmly by means of a collar and screws to the wooden support P, and bearing on its free end a lever D, whose ends are the points of application of twisting forces, produced by weights and transmitted by a system of cords and pulleys, sufficiently indicated in the diagram. The amount of twist is measured by means of a telescope, and a scale reflected in the mirror Z. An electric current, produced by a single DANIELL'S cell of several square meters surface, and therefore very small internal resistance, is conducted along the tube. Within the tube there is suspended at the end of a brass rod MN, resting on the fork-shaped supports F, one of SIR WILLIAM THOMSON'S well known galvanometer mirrors, with magnets on the back. The magnets are perpendicular to the axis of the tube, and the stream lines being parallel to it, the current has no tendency to deflect the magnet. When the tube is twisted a directing force is found to be experienced by the magnet, the direction being that of a force exerted by helical stream lines, following the lines of greatest compression of the twisted material.*

The remaining parts of the apparatus, to be presently described, are intended to measure the intensity of this force. C is a stout copper strip, bent so as to form a circular arc of nearly 360 degrees. Its ends are insulated from one another by a piece of vulcanite; and slide over two brass rods which transmit the current. The circle C is supported by suitable means, so as to remain always in a plane perpendicular to the axis of the tube, the axis passing through the centre of the tube. The circle thus forms part of the circuit and exerts a force on the magnet. Another nearly circular coil S on the opposite side of the magnet, arranged so as to have its diameter easily altered, carries the current in such a direction as to compensate the force exerted on M by the coil C, when placed at a convenient distance from the magnet. This distance must be altered, of course, when the tube is twisted, and from the amount of shifting the intensity of the magnetic force exerted by the helical stream lines may be calculated.

Now, the explanation given by Sir WILLIAM THOMSON of the phenomenon above described is this—When the tube is twisted, the material forming it is compressed in one direction and pulled out in another, the lines of greatest compression and pull being inclined at angles of 45° to the axis of the tube, in a plane tangential to a coaxial cylinder, passing through the point in question. Denote by $\frac{c}{\sqrt{2}}$ the components (equal of course) of the current c, per unit area, along these directions in the unstrained state. Then we shall have

$$\frac{c}{\sqrt{2}}(1+e) \text{ and } \frac{c}{\sqrt{2}}(1-e)$$

---

* In making the experiments described below, it was found necessary to reduce the earth's magnetic force nearly to nothing by means of steel magnets properly arranged for the purpose.

as components along these lines, when the twist is applied, which being now different in amount give a component $=ce$ in a direction perpendicular to the axis and bisecting the angle between them, e denoting a coefficient depending on the strain. Thus the effect is that of a set of stream lines parallel to the axis, and a true solenoid superimposed upon them (see Trans. Roy. Soc., 1879, Part I. p. 74).

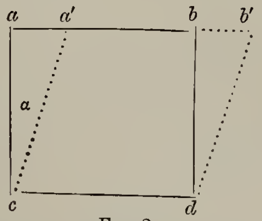

FIG. 2.

Let us now define the constant connecting the conductivity with the strain. Consider a cube of the conducting material, whose conductivity, uniform in all directions, is k, and let it be distorted to the amount indicated by the dotted lines (fig. 2), then we shall have

$$k(1+a\sigma) \text{ and } k(1-a\sigma)$$

as expressions for the conductivity in the strained material in the directions $a'd$ and cb', σ denoting a constant and a the amount of distortion, represented by the angle aca'. In the case of a tube, twisted at the rate ϕ per length L, the distortion in a cylindrical layer, radius ρ, is $\frac{\rho\phi}{L}$, and therefore the quantity denoted above by e is equal to $\sigma\frac{\rho\phi}{L}$.

Now, the magnetic force exerted by a solenoid of length L and radius ρ, carrying a current $=c\sigma\frac{\rho\phi}{L}d\rho$ per unit length, on a point in the middle of its axis is

$$\frac{2\pi c\sigma\phi\rho d\rho}{\sqrt{\rho^2+\left(\frac{L}{2}\right)^2}}.$$

Denoting by $d\rho$ the thickness of the layer, we find for the action of the tube

$$F=2\pi c\sigma\phi\left\{\sqrt{R_2^2+\left(\frac{L}{2}\right)^2}-\sqrt{R_1^2+\left(\frac{L}{2}\right)^2}\right\}$$

R_1 and R_2 being its inner and outer radius; or introducing the strength of the current $i=c\pi(R_2^2-R_1^2)$,

$$F=\frac{2\left\{\sqrt{R_2^2+\left(\frac{L}{2}\right)^2}-\sqrt{R_1^2+\left(\frac{L}{2}\right)^2}\right\}}{R_2^2-R_1^2}\sigma\phi i.$$

Denote by D_1 the distance from the magnet at which the circle C must be placed in order to compensate the magnetic force Mi, exerted by the circle S (and possibly also by other unmovable parts of the apparatus) before twisting; by D_2 the corresponding distance, when the weights are put on; and by

r the radius of the circle C ($=5{\cdot}2$ cm.), then we have the following equations of equilibrium :—

$$\frac{2\pi r^2 i}{(r^2+D_1^2)^{\frac{3}{2}}}=Mi$$

and

$$\frac{2\pi r^2 i}{(r^2+D_2^2)^{\frac{3}{2}}}=Mi+F$$

hence

$$\sigma=\frac{K}{\varphi}\left\{\frac{1}{(r^2+D_2^2)^{\frac{3}{2}}}-\frac{1}{(r^2+D_1^2)^{\frac{3}{2}}}\right\}$$

where

$$K=\frac{\pi r^2(R_2^2-R_1^2)}{\sqrt{R_2^2+\left(\frac{L}{2}\right)^2}-\sqrt{R_1^2+\left(\frac{L}{2}\right)^2}}$$

a constant depending on the dimensions of the apparatus. For the apparatus described above we have—

$$K=1515{\cdot}9655\,.$$

The mode of experimenting is now obvious. The magnet, attached to the light mirror, is maintained in a plane perpendicular to the axis of the tube, and this position ascertained by observing the spot of light reflected on a scale from a lamp placed in the prolongation of the axis.

A few further remarks appear necessary. Although the proceeding described is a true "zero method," the exact positions of the compensating circle C cannot be easily determined by simply shifting it along the scale, and even the deflections of the spot of light caused by twisting the tube are so small as to be scarcely visible. The circuit contained for that reason a reversing-key K, and after the approximate position of the circle had been found, more exact readings were taken by comparing the vibrations of the magnet, produced by reversing the current, while the circle C occupied two positions on both sides of the presumed zero position.

Another remark that should be made is this. The effects of permanent strain are well known to interfere in all experiments concerned with elastic bodies. They do so in the present case more than in others, inasmuch as the constant σ for permanent strains seems to exceed considerably the value found for elastic strains. Thus the distances D_1 and D_2 were found variable to a considerable extent, and the positions of the compensating coil, corresponding to equilibrium, were successively shifted, the shifting coinciding in direction with the quasi-elastic shifting, when the tube was twisted again and again in the same way. Several trials were necessary to bring the apparatus into such a condition that both the tube and the compensating coil should return to their initial positions when the weights were removed, with the precision that might be expected. It is to this elastic part of the phenomenon that the value of σ given below is related.

The following is an instance of a set of experiments:—

Weights: on each side 8 *lbs.; distance of mirror from scale,* 253 *cms.*

Weights off,		Weights on.	
D_1 cms.	Reading on Scale.	D_2 cms.	Reading on Scale.
52·2	50·0	46·3	62·4
50·9	50·3	46·0	62·5
50·4	50·3	45·9	62·5
50·4	50·3	45·8	62·4
50·3	50·3	45·9	62·5
50·4	50·3	45·9	62·5
50·4	50·3	45·9	62·5

For the distances D_1 and D_2 the numbers 50·4 and 45·9 being adopted, we calculate $\phi = 0·02409$ and $\sigma = 0·155$.

The weights were varied in different experiments from 4 to 28 lbs., and the proportionality of change of conductivity and strain, assumed in the above formula, was between these limits sufficiently proved.

The main average value obtained for the constant σ and the used specimen of brass is

$$\sigma = 0·158 .$$

Now, the way followed usually in determining coefficients of elasticity might be used also in the present case, and the other constant alluded to above determined by observing the change of resistance of a stretched wire.

I find for that resistance the approximate formula,

$$r = R(1 + s\lambda)$$

R being the resistance of the unstrained wire, r that of the strained, λ the longitudinal strain, and s expressed as follows:—

$$s = 1 + 2\mu + \frac{4}{3}\,\sigma(1+\mu) + \rho(1-2\mu) .$$

Here μ denotes the "Poisson's ratio," σ the constant forming the subject of the experiments described above, and ρ is to be defined as follows:—Take a homogeneous isotropic conductor, strain it (without altering its shape) so as to diminish its volume in the ratio $\frac{1}{1-\theta}$, then its conductivity, being k in the unstrained state, becomes $=k(1+\rho\theta)$.

An approximate evaluation of this constant is now possible, experiments on increase of resistance for stretched brass wires being made by Mr TOMLINSON (Proc. Roy. Soc., 1877). According to his results a brass cube-centimeter opposing a resistance $=719{\cdot}4\times10^{-8}$ (mean) to the passage of a current between its faces, being longitudinally strained to an extent $\lambda=10120\times10^{-13}$ exhibits an increase of resistance (in the direction of strain) equal to 1704×10^{-17}.

Mr TOMLINSON adopts for brass the value,

$$s=2{\cdot}203.$$

Now, taking for brass $\mu=0{\cdot}34$ (rather uncertain), and substituting for σ the number given above, we calculate

$$\rho=0{\cdot}75.$$

XVII.—*On the Constitution of the Lines forming the Low-Temperature Spectrum of Oxygen.* By Piazzi Smyth, Astronomer Royal for Scotland.

(Read 30th January 1882.)—Ordered by the Council to be issued with Professor Smyth's paper on "Gaseous Spectra."

I had added (at p. 140 of my paper on "Gaseous Spectra") to the "small dispersion" account therein given of the above mentioned spectrum of luminous oxygen gas,—that two, if not four, of its very few and scanty lines appeared, when viewed with much higher dispersion, to be double; but that I hoped to give a more exact account of them, after completing some arrangements then in progress for increasing both the dispersion and magnifying power of my spectroscope.

These improvements, together with a great advance in definition, were finished last November, and almost the first result they yielded was, to much more than confirm what I had only suspected before; and to do so, moreover, with such vigour and certainty, as to make me inquire right and left for several weeks to ascertain if what I then saw, was really a new discovery, or had perhaps been known long before to older and better spectroscopists.

So far as I have been able to gather, the thing is new, and promises to be important to theorists in molecular vibrations, on account of what it fulfils. To explain this, let me refer to Dr. Arthur Schuster's valuable paper in the "Transactions of the Royal Society," London, for 1879, "On the Spectra of the Metalloids; Spectrum of Oxygen." Beginning his exposition of the low-temperature spectrum—after having treated very fully of the exceedingly different high-temperature spectrum, of oxygen,—with the late Prof. Plucker's account of it, and concluding with his own confirmatory observations, Dr. Schuster shows that the low spectrum had always been found to consist of only four single, wide-apart lines,—viz., one in the orange, one in the citron, another in the green, and another still in the indigo-violet; and to that spectrum, containing only four such solitary, single, simple lines, the learned Doctor gave the second or *alias* name of "the compound-line" spectrum of oxygen.

The reason for such an apparent misnomer, or *lucus à non lucendo,* was, that at the very moderate temperature of electric illumination at which this trifling lined spectrum of oxygen appears, most other gases do give forth very compound-line spectra indeed; spectra with hundreds or even thousands of lines, arranged in peculiar bands or parcels, and known generally as "fluted spectra." Hence Dr. Schuster's name for what he saw in oxygen, while principally intended to show the physical circumstances under, or temperature level on, which it is produced,—might perhaps privately have been intended to indicate that he had somehow an idea that if the lines were not compound, they ought to have been, and would one day be found so to be.

That, so far as I can ascertain, is the furthest point the subject has even yet reached elsewhere; and it was at that point that I had taken it up in 1879 and 1880, in the paper already printed by this Society. In the regular course of that paper, going through many gases, with single prism power only, I abundantly confirmed Messrs. PLUCKER'S and SCHUSTER'S four wide apart lines, as constituting in themselves alone, almost the whole and entire low-temperature spectrum of oxygen; I did indeed also find a strong line in the scarlet-red, besides two in the red or ultra-red, and two in the citron-green, of extreme faintness, and only probably belonging to the same spectrum. But they did not in any way alter the apparent anomaly of the Doctor's name; for each of these new lines was also solitary: and what are after all nine, or to keep within more certain bounds five, simple lines standing separate, and along a length where 10,000 such could take their places without interfering with each other!

But when I looked last November with the improved apparatus, what a change was there! for, of the five certain lines, no less than four were found to be triple; after a fluted fashion too. These four truly compound lines then were,—mine in the scarlet-red, and PLUCKER and SCHUSTER'S three lines in the orange, the citron and the green respectively; but their last line in the indigo-violet remained persistently and positively single. Still, with four-fifths of this most scanty spectrum, now proved to consist of triplets instead of single lines, Dr. SCHUSTER'S original and really most happy name for it, of "the compound-line spectrum" of oxygen was fully justified, at the same time that the miniature scale of the triplets seemed to make the physical nature of oxygen more markedly different than ever, from all other known gases; for they, at the same temperature level, generally make their bands or compound line arrangements, on a comparatively enormous scale, and in multitudinous groupings.

To those who are engaged in chemical spectroscopy it will at once convey an idea of the small-sized triplicity of these oxygen lines to be told, that from the first to the second of each triplet the distance is one-fifth that of the well-known salt-line double; and from the second to the third is between one-eighth and one-ninth of the same space; while the salt-line double itself is only one-eighth of the average distance apart of the stronger flutings of the citron-band of the carbo-hydrogen blow-pipe flame, which band has some six or seven of such flutings within its easily perceivable breadth.

Or, again, if we should on the black board represent the separation of the first and second of any oxygen triplet by a tenth of an inch, and from the second to the third by six-hundredths of an inch (when it will require a good eye from the other side of the table to separate them), that would indicate a scale for the whole spectrum, or from red to violet, of 25 feet; and that is rather more than three times as long as the late Professor ANGSTRÖM'S grand and almost universally followed "Normal Solar Spectrum."

For bright line, chemical, spectroscopy, and especially with the faint light of incandescent gas in a low temperature electric spark, it is by no means usual or easy to separate lines so very close together as the members of one of the oxygen triplets. A few words of explanation may, therefore, be demanded of me in proof that the resolution was real, and not an optical deception. The propriety of the demand, too, I am quite ready to allow, knowing only too well that there are prisms which will fringe every bright line with diffraction repetitions; or, when out of the best focus, will double or treble any line, and others again that make them so broad and hazy that clear separation of very close lines would be utterly impossible.

As my gas-vacuum tube spectroscope admits only of a deviation range up to 45°, or that of a single white-flint prism of 52° refracting angle, I was compelled to have recourse to compound prisms to get up the necessary dispersion for crucial cases, say that of seven or eight such prisms. Now, although some beautiful compounds were made for me both in France and this country, they invariably failed in the item of perfect definition. I then tried a large fluid bisulphide-of-carbon prism made in Paris, but that failed in several ways. So lately I entered into a contract with an exceedingly skilful as well as persevering optician in London, viz., Mr. ADAM HILGER, to make two large bisulphide prisms, having a clear circular aperture of 2·1 inches in diameter, a refracting angle of 104°, anti-prisms of crown glass square at the ends, and a central angular bored block of the same material to hold the fluid.

The troubles poor Mr. HILGER had to go through were almost overwhelming. He bored through block after block of crown glass only to find after an hour, or a day, or a week that it fell in pieces of its own accord, until he had a heap of tunnelled fragments large enough to make a cautionary photograph of. And when he had at last succeeded by his unconquerable perseverance in securing two blocks that stood, and the anti-prisms were to be fastened on their faces, he tried almost every patented and unpatented cement before he found one, or rather a particular method of using it, which could withstand the action of the bisulphide for more than a day or two.

At last, however, though long after the contracted time, he brought the two prisms here complete, and they passed successfully through the severest trial I had prepared for them, viz., that when a hydrogen line was at its brightest, shining like a ray of sunlight in a dark field, its light must be entirely and sharply confined to the width of opening of the slit for the time being. Not, however, until some months after, when the telescope power was also improved, and a new class of difficulties with the prisms had been overcome, could the desired trial on oxygen be made. Now, whereas I had, as mentioned already, on previous occasions with the best compound glass prisms I could procure, seen only an uncertain idea that some of the oxygen lines might be double, I now saw the real triplicity of four of the lines, and measured them micrometrically with a degree of certainty and satisfaction that I had never dreamt of with the older apparatus; and this triplicity of these lines never came out more remarkably than when the singularity of really single lines, such as those of hydrogen impurities in the same gas tube, was rendered most distinctly. I will, therefore, now only seek to conclude with a few words on the bearing of this tripleness of the oxygen lines,—first, on the disputed question of the existence of oxygen in the atmosphere of the sun; and, second, on the absence of hitherto recognised oxygen manifestations, though oxygen is so well known to exist as a large part of the earth's atmosphere, in the telluric rays that become visible in the solar spectrum at sunrise or sunset.

Oxygen in the Sun.

For many years it was a sort of crying wonder that the spectroscope showed no traces in the sun of so necessary a gas to combustion as oxygen. The expected test being, that we should see there as dark lines all the lines which are seen bright, when oxygen gas, on being rendered incandescent in a *high*-electric temperature, then shows what is called its "elemental-line spectrum." But not one of those lines could be detected by its dark counterpart in the sun. At length Professor HENRY DRAPER, of New York, from a series of experiments made with extraordinary skill and power, announced that oxygen appears in the solar spectrum not in its dark but in its bright lines, outshining where they come the brightness of the sun's continuous spectrum background. Yet though he gallantly made a voyage from New York to London especially to describe his experiments, and was honourably received and attentively heard, there are some persons there who are not convinced yet.

Now Dr. SCHUSTER had already compared his four lines, though of the low-temperature oxygen spectrum, with ANGSTRÖM'S normal solar spectrum map, under the idea apparently that, though the solar oxygen might have been rendered incandescent in the very hottest central regions of the sun, it might have its Fraunhofer dark correspondences checked off by cooler oxygen vapour outside. But as his then knowledge of oxygen low temperature lines made them only four single, simple, thin lines, the comparison was not attended with any very certain result; for there are so many of such lines, unclaimed for any element, strewed all along the solar spectrum. But now that I had found four out of five lines to be triplets of an accurate kind, could anything further in the way of identification be ascertained?

In apparently the very place of the three fainter of the above-described triplets there is a close double of peculiarly thin Fraunhofer lines depicted by Professor ANGSTRÖM in his normal solar spectrum map; and in the place of the brightest of them, viz., SCHUSTER'S orange line, there is a triple* of the same kind of *ultra* thin lines; and not one member of all those four groups has been claimed for any known element by the great Swedish physicist. Yet I am by no means satisfied that the degree of correspondence is conclusive; and can only hope that those who have the means will positively confront the new oxygen triples with the sun itself, and inform us what they find.

Oxygen of the Earth's Atmosphere in the Telluric Solar Spectrum.

If the long silence of the spectroscope touching oxygen in the sun was a wonder, and perhaps something the reverse of praise to those who used the supposed all-powerful instrument, what shall be said for its continued silence as to the presence of any free oxygen in the earth's atmosphere, when *some* gases that are therein do make themselves most signally conspicuous on the solar spectrum, in the shape of dark lines or bands, growing as the sun descends in altitude, until they become at last more grandly thick and black than all the truly solar markings put together.

Amongst these gigantic cases of Fraunhofer lines of some kind of telluric gaseous origin, we do indeed know, by a sort of inductive process rather than by any positive proof, that the band too hastily called "little a" and other bands and lines near C, and near D, are the spectroscopic proofs of *watery vapour*, as an invisible but potent gas in our atmosphere. But what makes the far greater A, or great B, and the α (alpha) band, no one pretends to know.

At first sight it might well be suggested that they must be formed by one or other or both of the two grand constituents of the earth's atmosphere as established by the chemists, viz., oxygen and nitrogen. But there we are instantly met by ANGSTRÖM'S inflexible law, promulgated by him in 1853, and repeated at page 39 of the description of his Normal Solar Spectrum in 1868; viz, that "a gas in the state of incandescence emits luminous rays of the same refrangibility as those which it can absorb." Or, conversely, when it acts by

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* That triplicity is indeed there broken in upon by a far stronger line, which ANGSTRÖM traces to sodium, (Na); but such cases of mere optical *juxta*-position are frequent in the crowds of lines in much of the solar spectrum, without any physical connection being supposed to be implied thereby.

absorption, it produces dark, in all the spectrum places where, when in a state of incandescence, it produced bright, lines.

Now we know by laboratory experiments what bright lines are given out by both oxygen and nitrogen in various states of incandescence ; and not one of those lines is in the place, and at the same time endowed with the physiognomy, of great A or great B, or of the α (alpha) band of the sunset solar spectrum.

To get over this astonishing difficulty, ANGSTRÖM, who held that all these three bands are of a similar visible constitution, viz., a thick line and then a band of thin lines stretching out towards the red end of the spectrum—suggested that they might be produced by "carbonic acid." But over and above the difficulty that carbonic acid is an almost insensible impurity in the open air, and could hardly be expected to extinguish every sign of the existence of the atmosphere's two great constituents,—we do know the spectrum given by incandescent carbonic acid in the laboratory, and it cannot claim to having a band in the place of either A or B or α (alpha), besides its series being turned in the opposite direction, or every band vanishing towards the violet, in place of the red, end of the spectrum.

Evidently then, in despair, this sorely tried and now departed philosopher of Upsala, but who is still our chief authority in this line, on page 41 of his Memoir already cited, after acknowledging that he had, in another place, suggested "carbonic acid," says further, perhaps it is ozone which produces these bands. No reason is given, but the prudent caution is inserted,—if there is free ozone in the earth's atmosphere. Or, again, he adds as a third supposition, perhaps they are produced by "fluorescence of oxygen," a gas which he there states gives forth "a faint phosphorescence in a Geissler gas-vacuum tube when an electric current is caused to pass through it." But this is just as far from presenting us with the very definite lines constituting the bands of great A, great B, and α (alpha) of the sun-set telluric solar spectrum, as before.

Now I have not, any more than all the rest of the world at this moment, any positive and proved means of raising Professor ANGSTRÖM out of the difficulties he eventually sunk under. But the minute triplicity of the greater part of the low temperature lines of the oxygen spectrum described in the beginning of this paper, may perhaps let in a chink of light upon the difficulty, when combined with the true constituent features of these grand telluric lines A, B, and α (alpha) as set forth in my Lisbon solar spectrum, so recently honoured by the Royal Society, Edinburgh, with their Makdougall-Brisbane Prize.

ANGSTRÖM, observing these three bands when they were thick and clumsy at sunset, pronounced their constitution as being exactly similar in every case. I, on the contrary, observing them in a high sun, when they were divested of the rotundity of flesh, and only their thin, linear, bones appeared, found the ultimate constitution of the α (alpha), to be perfectly different from that of A and B; for in place of many regular and symmetrically arranged powerful lines, it was made up of little doublets and triplets of both inconceivable minuteness and of very irregular occurrence (see the said Lisbon spectrum as printed in Vol. XXIX. of the Society's Transactions). These Lilliputian foundation stones of the α (alpha) band appeared to me at the time almost ridiculous in their smallness;—but now I recognise them as having a close family resemblance to the triplicity of the low-temperature oxygen lines which I have been trying hereinbefore to describe. They are not indeed the very same, for they are in different spectrum places; but they do give the idea (suggested also by some points in both the aurora spectrum and cometary spectra not yet reproduced in any laboratory electrical experiments) that there is a temperature-level in Nature for the incandescence of gases, much lower than the low-temperature oxygen spectrum of these pages. Wherefore, if we could artificially produce that kind of ultra low-temperature illumination, electric probably, we might find that the α (alpha) band in the solar sunset spectrum represented the oxygen, while the A and B bands showed us the nitrogen gas thereof; they two being the mighty gas constituents known so well to everyone, *except telluric-line solar spectroscopists,* to exist in the earth's atmosphere; and in such overpowering quantity as to practically exclude everything else except watery vapour.

Dulau 7°
5.4.82

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PRINTED BY NEILL AND COMPANY, EDINBURGH.

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OF THE

ROYAL SOCIETY OF EDINBURGH.

VOL. XXX. PART II.—FOR THE SESSION 1881–82

1883

CONTENTS.

XVIII.—*Chapters on the Mineralogy of Scotland. Chapter Seventh.—Ores of Manganese, Iron, Chromium, and Titanium.* By Professor HEDDLE.

(Read 20th February 1882.)

I have thrown together, in this chapter, the ores of several members of a family of the elements, which may be called the *family of the magnetics;** and I have also, from its frequent chemical association with iron, placed titanium along with them.

No attempt was made by me to analyse the ordinarily-employed iron ores, but only such as, from their apparent purity, or from the excellence of the specimens, appeared to be of mineralogical interest.

Specimens of doubtful, or of an unrecognised appearance were, however, also examined; and the so doing led to the discovery or recognition, for the first time as British, of the two minerals, *Turgite* and *Martite.*

ORES OF MANGANESE.

I have verified the occurrence of *manganite* on Laverock-braes Farm, Grandholm, Aberdeenshire; and of *pyrolusite* at Arndilly, near Rothes; but I have not yet analysed the specimens which I there collected. The first manganese ore which I have analysed is *psilomelane,* from the Orkneys.

GEORGE LOW, writing in 1774, says:—"The ores of iron in Hoy are of two kinds, and found in great plenty in two different places. That dug near the kirk is hematites. . . . . Another kind may be had in vast quantities from Hoy Head, where it runs in many regular veins in the very brink of the sea rocks. This is blacker than the former in appearance: it is much more solid and weightier, looks as if it had been once in fusion, and had settled in a number of bubbles, which I dare say had not been the case: its first formation is from an indefinite number of small particles or drops adhering very firmly together, and growing still more solid as they imbibe more of the iron, till at length it becomes a flint-like mass of the colour above described. Some years ago a company of adventurers from London dug several tons of this last, which they imagined was an ore of cobalt, but without foundation. They sent several specimens to London, but how it turned out I could never learn. The work, however, was given up. When Mr. BANKS was in Orkney on his way from Iceland he took a step to this mine, and smelted a piece of the ore, and assured me of its being iron."

A little west of the highest point of Holy Head there is a turret-like pro-

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* Though the members of this family are not all magnetic, yet it includes all the metals which are so.

jection called Braebrough. About three hundred yards further south, a locality called Lead Geo is reached. As the ruins of a turf hut are to be seen here, and as the writer found a buried deposit of about four-hundred weight of the ore, near to where there were evident signs of working, there can be no question that this is the locality alluded to by Low ; and, as no galena is now at least to be seen here, the following extract of a letter of Mr. Low may probably explain the name of Lead Geo. "Has not your friend* perhaps something mistaken the words of the historian with respect to the black and white lead (Plumbum album et nigrum) Buch. History? I have never heard of black lead or 'wad' to be found here, but common lead in many places."

The common confusion between *wad* and *graphite*, taken along with the manner in which the hands are soiled in working among the ores which occur at this spot, doubtless led to the adoption of the incorrect name.

The ore described by Low is, however, not one of iron, but is, for the most part, *psilomelane;* his "flint-like mass" is a very dense *wad.* There is, it is true, a small quantity of *limonite,* but not enough to explain the extraordinary statement as to iron having been smelted *upon the spot* apparently,—for so the language used would imply.† Low's description of the ore is most accurate, and, as it will be seen, most suggestive and shrewd.

The veins are situated about 200 feet below the summit of the cliff, here called 1130 feet in height.

There are three or four veins still to be with difficulty seen; for the working has, from the precarious footing and the danger of the position, been of a rough and destructive description.

The appearance of the *psilomelane* varies in each of the veins; it occurs in finer masses here than at probably any other known locality.

In its commonest and least interesting appearance, it presents itself in mammillated masses, with an obscure fibrous structure, and a dull lustre. Of this variety, the specimens, merely as such, are the finest. Such masses sheathe the sides of the vein, enveloping any loose or projecting processes which may occur in its vacuous centre. Though the surfaces of these mammillations are dull, and so soft as to soil the hands, they may, when dry, be polished by friction; but when wet, the mineral may by brushing be diffused through water to a large extent.

There is therefore in these specimens a certain approach to *wad.*

Another appearance, though a rare one, is in large flat sheets, which possess a mirror-like lustre, and have little trace of fibrous structure.

In another vein it is of an exceedingly peculiar appearance, resembling a

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* PENNANT. Mr. ANDERSON, in his introduction to Low's work, very clearly shows the *vampire character* of PENNANT'S friendship for Low.

† *Could* Sir JOSEPH BANKS have "smelted" iron—anywhere?

quantity of wires, of the thickness of needles, laid longitudinally together. The wires can be separated from one another with perfect ease. They pass transversely from side to side of the vein, which is about eight inches in width.

Another vein is of the nature of a dense *wad:* it is about two inches in width, is devoid of structure, if it be not of a granular description, and it breaks with a well-marked conchoidal fracture. This, therefore, is probably Low's "flint-like mass."

There is one marked fact which is to be observed of all these veins; it is that at their sides, the yellow, loose-grained sandstone-rock is stained by the manganese, in a manner which forcibly conveys the impression that the ore did not *exude* from the rock into the vein-rent, but was *poured* into the rent, and then soaked to a small extent into the porous stone. The limit of the stain is a sharp line of demarcation; it does not shade off with a fainter tinge to the smallest extent.

Low, in his remarks upon this ore, says that it "looks as if it had been once in fusion, and had settled in a number of bubbles." Though its usual occurrence, in fibrous mammillations after the manner of the hematites, by no means indicates such a mode of deposition, yet I have already had to allude to indications of its having been *intruded* into the veins from without; and there are certain modes of its occurrence now to be described, which go a very long way indeed to show that some portion of it at least had been in a state of liquidity from heat.

These modes of occurrence group themselves into four varieties.

1. Drops which seem to have been sprinkled over a surface.
2. Drops which seem to have fallen into narrow spaces, and to have moulded themselves to the bounding walls of those spaces.
3. Pendulous masses which seem to have run down the surface of the sustaining substance.
4. Drops which exhibit shrinkage markings, and which, having fallen one upon another, have taken an impression or cast of the shrinkage markings of the underlying drop; and which drops are free from all attachments.

In the case of the first three varieties, the so-called drops invariably lie upon the surface of the glossy limonite: in the case of the last they do not do so, but upon either the mammillated psilomelane, or upon other drops.

In the first two cases the drops are perfectly spherical, except where in contact with their support, or where by juxtaposition they impinge upon each other. They vary in size from the smallest sparrow-hail, to bullets which would be about four to the pound.

Their internal structure is obscurely fibrous. The pendulous masses have also an obscurely fibrous structure; but the drops which come under head No. 4 do not show any structure,—being like flint when broken.

Certain specimens show slabs of the rock partially coated with a thin layer of the glossy limonite.

The rock has a very vitrified appearance; and the absence of the iron compound from *part* of its surface, considered along with the reniform margin of of the portions of limonite which sheathe it, is of difficult explanation under any supposition of its having been deposited from water.

Over the smooth and glossy surface of this limonite, and occasionally also over the sandstone itself, there are sprinkled vermiform aggregates of minute spheres of coalescent psilomelane.

The limonite layer is here about the sixteenth of an inch in thickness.

In other specimens it is about the fourth of an inch, and the surface, though glossy, is stalactitically fibrous and rough; globules larger than swan-shot are singly or confluently sprinkled over this.

In still others, the glossy limonite (which sheaths botryoidal psilomelane) has a thickness not much exceeding that of a coat of varnish; and upon this, large rounded masses lie; and narrow, tortuous, and more recently formed drops overlie both the limonite and these drops of psilomelane.

Of these specimens it may be argued that they are not cases of droppings at all, but merely of local segregations of matter which had not deposited itself in a uniform layer over the surface of the limonite; and that it had not done so on account of the smoothness of the latter not only affording but few points or centres for radiant growth, but on account of its oil-like surface acting repellantly to the exercise of ordinary adhesion; and that once that crystalline shoots emanated from the few rough centres which did exist, the succeeding growths were localised at these,—as is so frequently seen in zeolites of a radiating character.

While giving all due weight to this argument, it has to be replied that the manner in which the limonite ordinarily coats the psilomelane, negatives the idea that there had been any repulsion between the two minerals; and that the above argument in no way meets the fact of some of the drops reposing upon the comparatively rough sandstone.

Certain rare specimens show an apparent flow of molten matter over the limonite.

Others seem occasionally to point to a large drop or drops of a plastic substance which has taken a cast of the narrow crevice into which they had fallen. None such were found adherent to the *upper* part of any drusic cavity.

The drops have often fitted themselves in between the two coats of the psilomelane which had sheathed the surfaces of the rock-rents.

The specimens which fall to be considered under the fourth head, however, seem to be inexplicable upon any view save that of a succession of molten masses alighting upon one another, after the lapse of definite periods of time,

—each period having been of such a duration as sufficed for the solidification of each preceding drop.

In these, a number, sometimes a large number, of *loose* drops are superimposed upon one another, without even so much adhesion as to allow the specimen to be removed from the rock without their falling apart.

There is here no limonite,—drop lies upon drop in immediate contact.

The surface of each drop is highly polished; but it is marked throughout with a number of projecting ridges, which bear the most perfect resemblance to a solidified crust that has been rent and roughened by the contraction of a shrinking and still liquid centre.

Each drop has taken *the most perfect cast* of that which it has fallen upon (or at least of what it lies upon), both as regards the converging curvitures thereof, and the above-mentioned linear rugosities; and each drop is on *its upper surface* lined and roughened in a perfectly similar way.

If it be a large drop, it envelops several of those which are smaller and inferior, filling up every interstice between them; and the rugosities upon the upper surface of a large drop are ever larger and more boldly marked than those upon a small one; as might be expected from the contraction of a more ample mass.

While such a structure as this is in every way accordant with igneous liquidity, it appears to be altogether inexplicable upon the theory of watery solution, or of deposition of particles which had been in suspension in a liquid; and the observant Mr. Low was fully justified in saying that it "looks as if it had been once in fusion, and had settled in a number of bubbles."

I may here state that I possess from another locality a specimen of perfectly amorphous psilomelane, which fills up all the interstices between a number of "stalactites" of hematite—and these stalactites have a markedly scorified appearance.

But the question of the liquefiability of the mineral may be, to some extent, determined by actual experiment.

In ascertaining the amount of the water in the two manganesian minerals which occur here, it was found that after the application of the heat—nearly a white heat—obtainable from a three-jet Griffin blast furnace, the crushed powder of the psilomelane had agglutinated throughout; while the portion thereof which was in contact with the sides and bottom of the crucible, had fused so far as to be firmly adherent thereto, and to have become glistening in lustre.

The fine powder of the wad, again (which differed from that of the psilomelane in its comportment under heat, in this, that it became brown at a red heat, while the colour of the psilomelane was unchanged), was not only fused to the crucible in its lower portions, under the influence of the white heat, but had collected into distinct drops, which were more or less rounded.

It has to be kept in view that, under the concentrated energy obtainable in close cavities, and with the larger amount of alkalies which the *unaltered* mineral would contain, the amount and ease of the liquefaction must have been more complete.

Psilomelane.

The massive sub-fibrous variety was that analysed.

S. G. 4·607

Manganous Oxide,	66·995	= 71·868	MnO,Mn_2O_3.
Cobalt Oxide,	1·478		
Magnesia,	·098		
Baryta,	14·876		
Potash,	·5		
Soda,	·003		
Oxygen,	6·712	6·658	
Water,	6·051	6·003	
		101·484	

Hygroscopic Water,	1·201 per cent.
Heated barely red, lost	6·051 of water.
„ bright red,	1·066 of oxygen.
„ to a white heat,	5·646 more.

Cavities in this psilomelane are rarely covered with a velvet coating of *mangansammat-erz.*

The *wad* which occurred as a vein of about two inches in thickness, of a blue-black colour, and brown streak, was analysed. When steeped in water a considerable quantity of a saline efflorescence exudes from it; as the specimen had been washed, some of the alkalies must have been thus lost.

S. G. 4·4.

This yielded—

Manganous Oxide,	64·87	= 69·58	MnO,Mn_2O_3.
Cobalt Oxide,	1·995		
Magnesia,	·199		
Baryta,	14·97		
Potash,	·247		
Soda,	·259		
Alumina,	1·097		
Silica,	·898		
Oxygen,	5·521		
Water,	5·688		
		100·454	

Hygroscopic Water, . .	·694
Heated barely red, lost, . .	5·688 of water.
„ bright red, . .	2·383 of oxygen.
„ white heat, . .	3·138 more.

These two analyses show that the "London adventurers" were not altogether wrong in conceiving the mineral to be an ore of cobalt.

From the old Workings of the Heegh-pirn Mine at Wanlockhead.

This psilomelane was found by Mr. Dudgeon and myself, among plates of grouped crystals of quartz, in a number of curved scales about the size of the nail, and three or four times its thickness. These curved scales stood upon their edges, as if they had coated some substance which had been afterwards dissolved away. They were of a brownish-black colour, and were soft and dull on their outer surface. They were not much harder within.

They were separated from quartz with much difficulty; so that the insoluble matter is doubtless quartz.

The specimens had on their surface a little plumbo-calcite, vanadinite, and a trace of chrysocolla.

The quantity of the mineral which could be gathered was too small for ascertaining the specific gravity.

Manganous Oxide, ...	= 76·31	MnO,Mn_2O_3.
Oxygen, ...	9·088	
Protoxide of Copper, . . .	·54	
Protoxide of Cobalt, . . .	·37	
Baryta, ...	3·66	
Lime, ...	·228	
Magnesia, ...	·012	
Potash, ...	4·088	
Soda, ...	·262	
Water, ...	4·02	
Insoluble, ...	2·11	
	100·688	

I have lately, through the kindness of Dr. Wilson of Wanlockhead, got much larger and finer specimens of psilomelane from the Leadhill mines. These are in botryoidal forms, though of a small size. Their fractured surface is blue-black and lustrous; being thus less like wad than the above.

A singular combination, apparently of wad and calcite, occurs at the Leadhills. It is in masses of the size of an egg. The structure is like that of an onion; the successive layers are about an eighth of an inch in thickness, and have the usual calcite cleavages. The inner layers are largely impregnated with wad, and have almost a black colour. This diminishes in quantity as the layers pass from the centre of the lump, the colour passing to brown. The impregnation *suddenly* ceases, when the concentric structure at once disappears. These layers, when placed in a weak acid, yield very varying amounts of insoluble matter,—apparently wad.

Here the manganesian mineral seems to have imparted to the calcite its own tendency to concentric deposition.

Wad.

This was found filling small cavities and rifts in white quartz boulders which lay in the bed of the "Dirty Burn," to the south of Dunoon, Argyllshire. These quartz boulders were quite fresh in appearance, and seemed to have been swept down from a corry in the Bishop's Hill. They contained in other cavities, chlorite, and pyrite in fine crystals. The "wad" was in a loose, incoherent, powdery state, and of a blue-black colour. It yielded 23·7 per cent. of water in the bath.

Dissolved in moderately strong acid, it yielded—

Manganous Oxide.	38·575
Ferric Oxide,	11·828
Alumina,	6·317
Lime,	2·784
Magnesia,	1·008
Potash,	1·497
Soda,	1·415
Water and Oxygen,	13·184
	76·608

And insoluble,—which, upon fusion with Fresenius's flux, yielded

Silica,	16·532
Alumina,	5·376
Lime,	·903
Magnesia,	·403
	23·214
	99·822

Insoluble Silica ·812 per cent.

This seems to be a very impure wad.

Craigtonite.

Stains, dendrites, and thin filmy coatings on rocks, are very frequently pronounced to be "manganese," or manganesian, if these have a brown, or even a blue colour. I have ascertained that this they sometimes are, to the extent at least of *containing* manganese. The substance I now notice is one such.

It occurs as a thin coating on red granite, in the upper quarry of Craigton, Hill of Fare, Aberdeen. Colour blue-black, here and there with the lustre of graphite; cuts with knife. Being only a thin coating, it was dissolved off the granite with very weak hydrochloric acid, which seemed hardly to affect the lepidomelane present in the granite; which seemed to be otherwise altogether unaffected. It contained, in addition to the lepidomelane, only red orthoclase and quartz.

Analysis of the solution gave—

Alumina,	32·203
Ferric Oxide,	38·305
Manganous Oxide,	7·458
Magnesia,	16·61
Potash,	4·745
Soda,	·678
Silica,	trace.

Chlorine was evolved during the solution, so that the manganese must have been partly at least in the state of Mn_3O_4.

This is the only specimen of such dendritic coatings which I have got in quantity sufficient for analysis. But the result lends some countenance to our considering such coatings, especially when they occur in Old Red Sandstone, as being, like this, a very impure wad. I have attached the name, merely to draw attention to this substance.

NATIVE IRON.

A chromiferous magnetite, afterwards to be noticed as occurring in the bed of the Dale Burn in Unst, was found to be so difficult of decomposition that comminution under water, with repeated decantation, was had recourse to. Towards the conclusion of the process, the pestle was found to jump over a number of particles which no force could reduce to powder, though several were found to be flattened out by the pressure into thin scales. These were thoroughly washed, and found to be strongly magnetic. When placed in an acidified solution of a copper-salt, they became instantly coated with the red metal. They readily dissolved in acid *without residue*, and gave the tests for iron. In the pounding of the magnetite it had never been touched by an iron or steel tool; and, from the time when they were collected to that in which they were examined as above by him, they were never out of the writer's possession. These grains, therefore, are *native iron.*

The occurrence of grains of this substance in a metamorphic rock is new, frequent as is its occurrence in rocks of an igneous nature; and the occurrence of metallic iron in a rock primarily of a sedimentary nature is difficult to explain. Until, however, a laminable, magnetic substance, which precipitates a salt of copper, which dissolves in acid without carbonaceous residue, and which gives the iron reactions, can be shown to be other than iron, this must stand for such. The grains had been protected from atmospheric action by a coating of magnetite, a substance lately proposed and patented for this very purpose.

It is perhaps necessary that I should here state that the pounding of this chromiferous magnetite under water was executed by the writer himself; and that he, upon the observation of the somewhat flattened metallic scales, called his assistants to witness the deposition of the copper upon the iron, from an acidified cuprous solution. Since the analysis of this Unst specimen, he has found metallic iron at a *second* locality, sheathed also in magnetite. In both cases the quantity was so minute as to preclude any examination for nickel; carbon was, however, in both cases absent; and the view entertained by the writer is that this is a meteoric dust of iron, which had settled to the bottom of the sea, in which its presently containing rock was being sedimented. Such a view receives much countenance from the discovery of such metallic dust at the bottom of certain oceans explored during the "Challenger" expedition.

Lately I have had occasion to examine for His Grace the Duke of Sutherland a quartz vein or reef, which occurs at Suisgill. The quartz *was seen* to contain ilmenite and magnetite; but, after crushing, it yielded so considerable a quantity of magnetic iron, which rusted with extreme rapidity, precipitated copper, and was bruised by a pestle, that I communicated with Messrs. JOHNSON & MATHEY (who had crushed the quartz), as to the possibility of its having been abraded from the stamps. The following reply was received:—

"In answer to your letter we beg to state that the sample of mineral sent by you was crushed in a cast-iron roller-mill. We do not, however, think that any particles of iron became mixed with the ore during the process of crushing.—Yours, &c., JOHNSON, MATHEY, & Co."

I accordingly examined the iron, so far as to quantitatively determine the *silica* and the *carbon*. Of the first, there was 12·1 per cent.; of the last, ·79. This being a proportion of carbon very much smaller than any cast-iron contains, it at least becomes a question if some *native iron* be not present in the rock,—sheathed, like that of Unst, in magnetite.

IRON ORES.

Specular Iron.

Found in the "China-Clay Quarry" near Pitfechie, Monymusk; this quarry is on the west side of the hill of Monymusk, in Aberdeenshire. It occurs almost solely filling cavities between quartz crystals. Is in bundles of foliated crystals of considerable size; jet black in colour; streak brownish; high lustre; powder orange-red.

Much of the quartz in the vicinity has a pavonine tarnish; probably from a thin coating of this mineral.

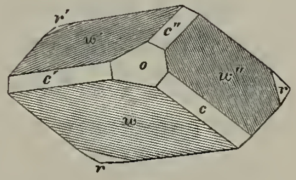
S. G. 4·583.

On 1·303 grammes—

Ferric Oxide, ...	81·704
Ferrous Oxide, ...	7·74
Alumina, ...	4·861
Manganous Oxide, ...	·076
Lime, ...	·601
Water, ...	1·178 to 1·868
Silica, ...	3·837
	99·997

This used to be regarded as an ore of manganese. Huge rough crystals of orthoclase occur in this quarry.

Specular iron—hematite—occurs in crystals of the form drawn, in gneiss, opposite to the Drongs, Hillswick, Shetland.



Martite.

This was given me by Professor Archer, as having been gathered on the sea-shore, on the north-west side of Bute. The parcel consisted of rolled octahedral crystals; a considerable portion of several of these was of a red colour and a loose structure; the largest quantity, however, was in hard blue-black lustrous crystals. A very few of these crystals were feebly magnetic, the largest quantity being entirely destitute of magnetism. The powder was red; but in other respects the mineral seemed to be unchanged magnetite, the hardness and gravity being normal. The black, lustrous, *apparently* unaltered crystals, were those chosen for analysis.

1 gramme yielded—

Ferric Oxide,	97·049
Ferrous Oxide, 1·105 – 1·089,	1·096
Manganous Oxide,	·2
Lime,	·952
Silica,	·77
	100·067

This is the first notice of this mineral as a British species.

Ilmenite.

I had hoped that my observations on the occurrence, and my analyses of ilmenite and of iserine, would at least have gone a long way in determining the question of the *specific identity*, or the opposite, of these substances. All that I can however say is, that I have been able to satisfy myself that the first named mineral may occur in granite, syenite, gneiss, and in primitive limestones; while it never, in Scotland at least, is to be found in volcanic rocks; and that the latter occurs *in these alone*, and is therefore entitled to BREITHAUPT'S name—*trappisches eisenerz*. Also, that the former appears in flat lamellar plates, and rarely in crystals; these are unquestionably rhombohedral; while the few minute forms which are with the microscope to be seen among the myriad "black sand" grains of the latter, if they be not octahedral or cubo-octahedral, are portions of much more acute rhombohedrons than are to be seen among the faces of the ordinary crystals of ilmenite.

That all the "black sands," however, which are to be found in Scotland,—very commonly coating the bottoms of runlets of water on the roads of a metamorphic district after rain,—are to be set down as iserine, I very much doubt. Many of these may consist of comminuted ilmenite; many are doubtless magnetite.

Ilmenite was first recognised as a British mineral by the writer, who found it in 1848, in flat crystals (form of fig. 8) imbedded in white quartz blocks, which lay upon the beach at the head of Loch Long. A year or two afterwards these blocks were traced by him to a belt, which occurs at a height of 700 feet, on the east side of Crois. Since then he has found it in so many localities in Scotland that he sets it down as being not only one of the most widely distributed, but *one of the most common minerals* in Scotland. It is however, though not confined thereto, very much more abundant in one special variety of gneiss than in all the other rocks of the country.

This rock is a chloritic gneiss. A great belt of this rock, in some spots tending to chlorite-slate, first appears in the east of the country, in the neighbourhood of Fortingall, passes south-westward, and reaches the ocean verge about Loch Killisport, and the island of Gigha.

It is in the less schistose—the most felspathic and highly convoluted portions of this rock—that the mineral occurs; where the quartz segregates in veins, with a more or less crystalline separation of the felspar, and a nodose segregation of chlorite in matted flaky crystals.

Where the quartz becomes stained with yellow, and, above all, where it is hyaline and of a purplish-brown colour, the ilmenite may be expected, with rutile, as a not infrequent associate.

The following are some of the localities in which the writer has found ilmenite in this belt of rock, tracing it from east to west.

In quartz, upon the east slope of the summit of a hill, 3240 feet high, which lies about a mile immediately to the south of Carn Marig, in Perthshire.

In quartz with chlorite, near Loch-na-Chat, at the east foot of Meall Garabh, Ben Lawers.

With chlorite, at the foot of Craig-an-Lochan, of Meall-nan-Tarmachan.

On the summit of Craig Cailliach, with rutile in quartz.

In brown hyaline quartz, with chlorite, on the north side of the Mid Hill, —and near Corrycharmaig, on the north slopes of Craig Mohr.

On the north-east side of Stob Luib.

About 300 feet from the summit of Ben More, on the north side, with chlorite in quartz.

On the south-east side of the summit of Am Binnean, in hyaline quartz.

In the southern rocky corries on the south side of the summit of Stob Garabh, with chlorite in quartz.

Near the summit of Cruach Arden.

On Meall Damph, in quartz.

On the south slope of the summit of Ben-a-Chasteal of Glen Falloch, with chlorite.

Ben-a-Chabhair, south side, with chlorite and quartz.

In quartz with chlorite, in a quarry on the north side of the road from Loch Lomond to Arrochar.

On the north-west slopes of Ben Ime, in quartz, in large foliated crystals, with chlorite. Their form is that of the figure. I have found *plates* of the mineral on this hill, three inches by two, and a quarter of an inch in thickness.

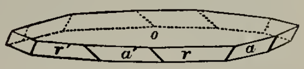


Fig. 1.

On Crois.

On the south side of the square pillar of the Cobbler, with rutile and chlorite.

On Ben Lochan, in quartz.

In the great rents on the summit of Ben Bheula, with rutile and chlorite.

In quartz with schorl, on the north side of Glen Finnart.

On the eastern slopes of Clach Beinn, above Loch Eck, in quartz.

In fact, wherever the quartz belts of the gneiss become associated with chlorite, along the whole of this range of mountains, ilmenite and rutile are to be expected.

The rock which carries ilmenite with a frequency next to chloritic gneiss, is ordinary gneiss; though it will be seen that it is almost invariably the case that it is where that rock becomes chloritic that the ilmenite occurs.

Some of the localities where the writer has found ilmenite in this rock are the following:—

In *Shetland*, at the Kebber-Geo, Point of Fethaland; in plates, imbedded in "potstone."

At Hillswick Ness, at Vanleep, opposite the Drongs; in curved lamellar plates in quartz, with chlorite and margarodite, in the vicinity of kyanite.

At the south end of the Wart of Skewsburgh, a little to the north of the "iron mine;" in quartz with kyanite. It is here almost in the clayslate, and is crystallised in forms, like those of Washingtonite (fig. 8).

In *Sutherland*, in quartz veins, along with chlorite, rutile, and muscovite, at the Clach-an-Eoin, between the mouth of the Borgie and the Naver.

In small loose boulders which had formed part of felspathic veins; with chlorite and quartz, near the north foot of Ben Hiel.

Inverness-shire.—With kyanite and chlorite, in the corry on the north side of Meall Buidh, east of Loch Tulla. With chlorite on the slopes east of the lake on Ben Creachan. Near Loch Treig, on the north slopes of Stob Coire Meadhoinich, with chlorite and hyaline quartz; and on the south slope of the cone of the hill, a distinct crystal (fig. 2) imbedded in lepidomelane gneiss. With chlorite in hyaline quartz on Stob Coire-na-Gaiphre. With chlorite in quartz, on the north-west slopes of Mullach-na-Coirean, Glen Nevis.

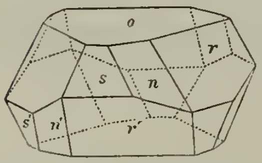


Fig. 2.

Aberdeenshire.—At Dobston Quarry, two miles west of Inverury, in thin plates; with lepidomelane, oligoclase, chlorite, apatite, and agalmatolite (?) in pseudomorphs after apatite (?).

Perthshire.—In Glen Shee, about one mile above the Bridge of Cally, on the west side of the Blackwater; in thin plates, with chlorite and epidote, in quartz veins.

Ben Dorean, near the top; on the south-west side, in white and green quartz, with chlorite and muscovite.

Banffshire.—In foliated talc, with chrysotile in a serpentine quarry, two miles west of Rothiemay.

In quartz, with pyrite and chlorite, on the north slopes of Alsait Hill, near Tomantoul.

Argyllshire.—At about the summit level of the Devil's Staircase; in a gneiss which shows no trace of chlorite, but only a brown mica, apparently lepidomelane. The ilmenite was in thin curved plates.

Loch Creran, on the south slopes of Fraochaidh, in chlorite and quartz.

Forfarshire.—With finely crystallised chlorite, in quartz veins, about three miles from the foot of Glen Effock, Tarfside.

In pegmatitic veins, on the north-west side of Garlat Hill, in the same district. The veins carry graphic combinations of quartz and white orthoclase, with crystallised kyanite (in twins), and muscovite. Also with kyanite, on the south-west side of the same hill.

Ilmenite also occurs in "primitive limestone;"—at least in that limestone which is a member of the same formation as that of the rocks above stated to be its matrix.

I have so found it, associated with sphene, crystallised repidolite, and pyrrhotite in Edentian Quarry, on the south side of Tullich Hill, Blair Athole.

With sphene in limestone, with repidolite veins, in a quarry on south side of the Garry, opposite Blair Athole.

In granite, and in syenite it rarely occurs.

In the coarse-grained veins of the granite of Anguston, in Aberdeenshire, it occurs along with orthoclase and oligoclase, sphene, Haughtonite, and Allanite.

In a large syenitic boulder, which lay upon the hill of Ben Bhreck, near Tongue, it was associated with a great assemblage of minerals, among which were amazon-stone, Babingtonite, sphene, Allanite, and orangite.

In quartzose veins of the granite quarry at Cassencarie, Dumfriesshire, with chlorite and epidote.

It is worthy of note that I have never found this mineral in Hebridian gneiss.

From among this large range of localities I have analysed the mineral from the following:—

1. Found in plicated crystals, imbedded in quartz, with chlorite and talc, at Vanleep, Hillswick, Shetland. Magnetite in crystals also occurs here. The crystals of ilmenite are from one to two inches in length and breadth, by one-eighth in thickness. They are much plicated, following the curvatures of the quartz.

S. G. 4·916.

Titanic Acid,	20·6
Silica,	1·4
Alumina,	1·443
Ferric Oxide,	63·549
Ferrous Oxide,	11·26
Manganous Oxide,	·018
Lime,	1·792
	100·062

2. Taken from the great amazonstone boulder, from the west side of Ben Bhreck, Tongue. Occurred very rarely in blue-black plates, between crystals of the felspar. It was in very small quantity. It was very much more readily powdered and elutriated than was usual for this mineral. The powder was reddish or brownish-black,—not *blue*-black, as is usual.

·464 grammes yielded—

Titanic Acid,	50·646
Ferric Oxide,	9·873
Ferrous Oxide,	17·784
Manganous Oxide,	5·172
Lime,	3·137
Magnesia,	11·637
Silica,	1·124
	99·373

This is very much the most highly titaniferous ilmenite which I have analysed.

3. From the "crocus" veins of the grey granite of Anguston, Aberdeenshire. Occurs in thin brown-black plates, up to an inch in length; these lay between the quartz crystals, and seemed to have been of late deposition. The sphene, and Allanite which accompanied it in small quantity, were deeper-seated in the vein, and were quite closely imbedded.

S. G. 4·908.

Titanic Acid,	23·67
Ferric Oxide,	43·064
Ferrous Oxide,	29·011
Manganous Oxide,	2·341
Lime,	1·006
Silica,	2·066
	101·158

When analysed by the "bisulphate process" only 22·88 per cent. of titanic acid was got; the above analysis was executed by employing Fresenius's flux.

4. MACKNIGHT, writing in 1810 of an elevated point of Ben More, says, "At this station veins appear filled with quartz, and containing also mica, chlorite, and a valuable variety of iron-glance, crystallised in thin tables" (*Mem. Wernerian Society*, vol. i.).

That which I analysed occurs in large foliated crystals about 300 feet below the summit of Ben More, Perthshire, on a small flat, near a knoll on the north-east side. It was associated with chlorite, and rarely tourmaline. The colour is blue-black; it has a high lustre.

This is without doubt MACKNIGHT's mineral.

On 1 gramme—

Titanic Acid,	18·4
Ferric Oxide,	55·305
Ferrous Oxide,	23·863
Lime,	1·344
Silica,	1·2
	100·412

5. From the hill Crois, north-west of Arrochar, Loch Long, Argyllshire; also from quartz boulders on the shore at head of Loch Long.

On the hill it occurs in rudely-formed crystals, imbedded in the quartz veins of chlorite slate, especially in a quartz cliff about half way up the hill. The colour is black, with but a slight tinge of blue. Powder brown. S.G. 4·86.

On 1 gramme—

Titanic Acid,	40·4
Ferric Oxide,	41·886
Ferrous Oxide,	15·402
Manganous Oxide,	·2
Lime,	1·456
Silica,	·7
	100·044

The ilmenites, iserines, and chromites proved so difficult of decomposition, that the most extreme perfection of comminution was found to be requisite before *any* of the processes of decomposition availed in resolving with certainty *the whole quantity operated on.* This, as afterwards to be noticed, was not, even with that precaution, in all cases accomplished. The following method of pulverisation was adopted. If it was found necessary—but not otherwise—the chips, cut up by pliers to fragments of the size of small shot, in order to separate quartz and other impurities, were *crushed, but no more,* in a diamond mortar. They were then transferred to an agate mortar, which held about three ounces of water. About five grains of the crushed mineral were placed in the mortar under half an ounce of water, and were rubbed under the water with the pestle till the powder was impalpable. About two ounces of water were then added and rubbed up. The grinding end of the pestle was then washed clean by a jet of water into the mortar, which in the so doing was now nearly filled. It was allowed to stand undisturbed for three minutes, when about two ounces of the muddy liquid was drawn off steadily by a pipette, and allowed to fall into a large precipitating glass, containing about thirty ounces of distilled water. This was left undisturbed for ten minutes, when its contents, all but about two ounces at the bottom, were poured into a second larger precipitating glass. This was again left undisturbed for a quarter of an hour, when all, but about three ounces, was poured into a capacious glass jar.

The coarser portions at the bottom of all the glasses employed were in turn returned to the mortar, and the process was continued and repeated, *until every portion of the quantity originally placed in the mortar was floated off*, and uniformly mixed in the one large settling jar. This was found to be absolutely necessary in some cases, (*e.g.*, in the magnetic sands from Granton), as some portions—either where there might be an admixture of ordinary magnetite, or some softening through incipient alteration into martite—were found to be much more readily comminuted than others. Such softer portions *were found to contain less titanium, and more ferric oxide.*

The settling was generally complete in three days.

Notwithstanding this extreme amount of subdivision, several of the substances examined partially resisted decomposition by the ordinary methods of fusion with Fresenius's flux,—potassium bisulphate,—and calcium and ammonium fluorides,—used singly, or even successively.

It was, where possible, found better to operate upon an entirely new quantity,—comminuting and floating off still more finely,—than to recomminute the unresolved portion (mixed up with some flux to prevent loss). It was observed that the quantity which had *first* escaped decomposition was more difficult to resolve even when recomminuted, than it was when fused up *along with a quantity which was undergoing decomposition.*

This is an illustration of "communication of energy," similar to silver imparting, in an alloy with platinum, the power of combination with nitric acid to the more noble metal.

In several cases of fusion with potassium bisulphate, the separation of the titanic acid was found to be either slow or incomplete, some of it coming down at later periods of the analysis. In such cases the following process, somewhat modified from one recommended in a foreign journal, was adopted.

After fusion with Fresenius's flux and solution in acidulated water, with separation of the silicic acid and some titanic acid, ammonium chloride in strong solution was added, and then ammonia in slight excess.

The precipitate of ferric oxide, alumina, and titanic acid, thus thrown down, was filtered off, washed, ignited, and weighed. It was then mixed with potassium bisulphate, and therewith fused. When cold the flux was dissolved in tartaric acid, made slightly alkaline with ammonia, and the iron separated by ammonium sulphide.

The alumina and titanic acid, with the filtrate, were evaporated to dryness, ignited, burned white, and then mixed with concentrated sulphuric acid, in order to convert the sulphate of potash into bisulphate.

After evaporation to dryness this was again fused; the enamel of the bisulphate of potash fusion was again dissolved, and it was then treated with an excess of caustic soda. This holds in solution the alumina completely, and leaves behind the insoluble titanate of soda.

This titanate of soda was filtered off, ignited, and once more fused with potassium bisulphate; from the solution of this, when diluted and boiled, all the titanic acid settles, although somewhat slowly.

The alumina was separated from its solution in caustic soda by neutralisation with acid, and reprecipitation by ammonia. The other parts of the process were those usually adopted. Though, from the number of fusions, very time-consuming, and though entailing somewhat more loss, this process was found to yield a slightly larger proportion of titanic acid than do any of the older processes, except the very tardy one with sulphuric acid; and the perfect purity of the titanic acid seemed to be by it more assured. Unless there is abundance of material to operate on, a bisulphate fusion is however to be preferred, as the evaporation to dryness of the mass, after the addition of the sulphuric acid, was sometimes extremely troublesome.

Iserine.

It is singular that, although former writers on Scottish minerals do not notice *ilmenite,* they should in several instances have noted the occurrence of *iserine,*—sometimes under that name, sometimes as "magnetic iron sand," and "black sand."

As before stated, however, they have sometimes confounded magnetite with true iserine; and they have also termed crystalline magnetite "titanic iron."

The records which we have of the occurrence of iserine in Scotland are the following:—

"On the bank of the Deveron, below the bridge of Macduff."

"On the shore of Canna."

"Titanic iron with hornblende on Carrick Common, in Roxburgh."

The fullest account we have, however, is one by THOMSON (*Philosophical Magazine,* vol. xxxv.) of two varieties which he analysed from different parts of the bed of the Don. The first, he terms "iron sand,"—the second, "iserine."

"1. *Iron sand.*—Iron black, magnetic, octahedric, brittle, easily powdered; powder greyish-black; S. G. 4·765; not acted on by acids; lustre feebly glimmering.

Protoxide of Iron,	85·3
Red Oxide of Titanium,	9·5
Arsenic,	1·
Silica,	1·
Alumina,	·5
Loss,	2·7

"2. *Iserine.*—Iron black to brown, angular grains, larger than iron sand, lustre semi-metallic, fracture conchoidal, brittle, easily powdered,—powder iron black; S. G. 4·490; scarcely attracted by the magnet.

Titanic Protoxide,	41·1
Protoxide of Iron,	39·4
Protoxide of Uranium,	3·4
Silica,	16·8
Alumina,	3·2
	103·9

"Abstracting impurities—

Titanium Protoxide,	48·8
Iron Protoxide,	48·2
Uranium,	4·

"

This statement of the presence of *arsenic* and *uranium* in such a compound induced me to examine "black sands" to a greater extent than I would otherwise have done. For the great difficulty of separating them at all satisfactorily from commingled siliceous sands, and the doubt which always remains as to the presence or absence of ordinary magnetite, made the investigation more or less of a drudgery. I did not *qualitatively* examine many of these black sands,—(though several quantitatively analysed were so examined),—but I was quite unable to detect either uranium or arsenic in any; though in several I found traces, larger or smaller, of chromium.

I hardly think that any one is in a position to pronounce unhesitatingly upon the nature of the "iron sands" so frequent upon the shores, and in the stream beds of Scotland. Even after having analysed these sands from several localities, I would not speak with much confidence, unless the sand could be traced to its rock source. If they lie near to, or on a lower level than an igneous rock, they probably are titanic ; if the rock, on the other hand, be granitic, or any of the schistose rocks other than chlorite state, they most probably consist merely of powdered magnetite. A rock of chlorite schist would yield ilmenite, rather in *fragments*, than in powder.

While it would be well-nigh endless to enumerate the localities in which I have observed " black sands " of a *doubtful* nature, I may note my having found iserine, in fragmentary-looking masses which have taken a cast of the faces of the contiguous minerals, in two classes of rocks.

First, in a diorite which passes into or assumes the features of syenite ; and secondly, in the denser varieties of the Tertiary doleritic and basaltic traps.

In the first named rock, it occurs in very small amount, in the diorite which is seen both to the east and to the west of Portsoy.

It is in quite visible particles or patches, in the easterly belt of that rock at Retannach, associated with labradorite, augite, paulite, and pyrrhotite. It is seen in fully larger pieces in the giant-crystalled diorite of Glen Bucket. Its associates here are hornblende, Biotite, sphene, and labradorite. With much the same associates, it is seen south-east of Tullyjuke, at the head of the Deskery, and on the north slopes of Morven ;—the rock here tending more to syenite, before it shades off into the granite of Cuilbleen. In granite itself, iserine seems to give place to magnetite ; the titanium finding a lodgment in *the sphenes*, which begin to show themselves where diorites shade off into syenites ;—which are characteristic of syenites ;—and which also affect the intermediate gradations of syenites into granites.

The iserine of traps is generally in minute grains. Here, as at localities near St. Andrews (Kinkell) and Elie, its associates are saponite, sanidine, olivine, and pyrope.

The largest imbedded particles which I have seen were from the acidic trap rock—termed " syenite "—of Ben Grigg, in Mull. These were shapeless, and in parts rusty brown ; they were not half the size of a bean.

Near Tilquilly, and at Badnagauch on the Deskery, in Aberdeenshire, similar-sized pieces are imbedded in diorite, along with dark green hornblende, labra dorite, Biotite, Allanite, and sphene.

The difficulty connected with the recognition of iserine may be shown by stating, that what I myself collected at the mouth of a stream at Sangoe Bay, Durness, Sutherland, as an *iron sand*, proved after examination to be totally non-magnetic, and was probably pulverised black *hornblende ;* and that another "black sand" sent me by Mr. ALEXANDER CRUICKSHANK of Aberdeen, as iserine from the parish of New Deer, proved after analysis to be pounded *schorl*, with merely a trace of magnetite. In this last case even inspection with the microscope did not suffice to disclose its nature.

Granting that most "black sands" are mixtures of true iserine with magnetite, the magnet does not suffice for their separation, for I have found that the more titaniferous portion is *occasionally* the more powerfully magnetic of the two; though this may be the result of a partial change of the magnetite into martite. With the exception of those from Elie and from St. Andrews, I regard all the samples analysed by me, as being probably mixtures.

1. Is found in very minute magnetic black grains in the sand of the shore, a little to the north of the Manse of Hoy, Orkney. A considerable quantity of black sand may be gathered, very little of which is magnetic. There is no appearance of the mineral in the flaggy rock of the neighbourhood, and as igneous rocks lie about a mile to the west, these probably were its matrix.

The magnetic portion yielded—

Titanic Acid, ...	18·4
Alumina, ...	·6
Ferric Oxide, ...	54·979
Ferrous Oxide, ...	14·422
Lime, ...	5·6
Magnesia, ...	·2
Silica, ...	6·1
	100·301

It appeared as very minute black grains, which differed considerably from ordinary granular iserine. When examined with the microscope they were found to consist almost entirely of oval grains with rounded outline. They shine like little bits of graphite; have few fractures, which are highly lustrous. There was very rarely a doubtful outline of a worn octahedron. The non-magnetic, or very feebly magnetic portion of this black sand, was, under the microscope, quite similar to the magnetic portion. That portion may have passed into martite.

2. Was found in very considerable quantity on the surface of a quicksand, on the west shore of the lake at Sandwood, on the west coast of Sutherland.

The Torridon sandstone forms the south shore of this lake, and the Hebridian gneiss, the greater part of its northern shore. The black sand probably came from the last named rock.

It yielded—

Titanic Acid,	10·6
Alumina,	·072
Ferric Oxide,	80·876
Ferrous Oxide,	5·961
Manganous Oxide,	·4
Lime,	·952
Silica,	1·5
	100·361

3. Occurs in imbedded fragmentary or sharp-angled masses, of the size of peas, in a basaltic dyke which cuts tufa, half a mile east of the Summer House on Elie Ness.

Colour velvet black, fracture conchoidal, very hard; associated with olivine, saponite, and pyrope.

On 1 gramme—

Titanic Acid,	21·3
Ferric Oxide,	42·673
Ferrous Oxide,	21·894
Manganous Oxide,	·7
Lime,	4·48
Magnesia,	1·6
Silica,	7·5
	100·147

4. Was found, along with Professor Geikie, in small, brilliant, crystalline, highly magnetic grains, on the surface of the sand, below the sandstone cliffs near Ardross Castle, St. Monance, Fifeshire.

On 1 gramme—

Titanic Acid,	16.
Ferric Oxide,	43·743
Ferrous Oxide,	28·01
Manganous Oxide,	·1
Lime,	4·4
Silica,	7·
	99·253

Under the microscope, showed as a mass of fine grains of a blue-black colour. Many of these seemed to be regular octahedrons.

5. Is found at the mouth of a small stream in small quantity, on the surface

of the sand; the stream enters the sea at the south end of the east sands of St. Andrews. It runs past a trap "agglomerate." The iserine is in highly brilliant but minute bluish-black grains, which are strongly magnetic.

1 gramme yielded—

Titanic Acid,	22·9
Ferric Oxide,	22·867
Ferrous Oxide,	30·98
Manganous Oxide,	1·
Lime,	5·936
Magnesia,	1·6
Silica,	15·1
	100·363

Under the microscope this showed as a fine-grained sand, the cleavages of which were not flat. Only one crystal was seen; it had one face truncated, and it seemed to be a rhombohedron.

6. Found in 1848, on the shore at Granton, Edinburghshire. It was about the spot where the west breakwater now leaves the shore. It occurred mixed, but not largely, with quartz sand. Was well washed therefrom, and then ultimately separated by the magnet. Two substances were present,—one granular and hackly, not strongly magnetic; the other, amounting to about one twentieth of the bulk, was strongly magnetic, of brilliant lustre, and apparently in octahedra, or fragments thereof.

The portion analysed was almost totally the *former* of these, there being of the latter an insufficiency for analysis.

The first analysis was by fusion with potassium bisulphate; the second by long continued treatment with sulphuric acid.

	1.	2.
Titanic Acid,	14·4	16·1
Alumina,	14·529	11·465
Ferric Oxide,	38·971	39·285
Manganous Oxide,	·6	·6
Lime,	7·616	7·896
Magnesia,	1·2	1·6
Silica,	23·2	24·
	101·516	100·946

7. Found about the year 1850, in large quantities on the sea-shore at Granton, Mid-Lothian, about a fourth of a mile westward of the breakwater. It lay, as is usual with these black sands, on the surface, and could be collected by merely scraping with the hands. It was afterwards separated from sea-sand

by the magnet. *Much the larger proportion of this* was decidedly, though none of it very strongly, magnetic; perhaps a fiftieth was very feebly or almost non-magnetic. An attempt was made to separate it totally from quartz sand, by stirring up in water and rapid decantation of the latter, but the separation was not quite perfect. The most highly magnetic portion of this sand yielded

On 1 gramme—

Titanic Acid,	19·4
Ferric Oxide,	37·972
Ferrous Oxide,	24·325
Manganous Oxide,	·8
Lime,	6·5
Silica,	10·8
	99·797

Examined with the microscope, this portion had a black colour inclining to blue. It showed many apparently regular octohedra; some of these had apparently all their six angles truncated by the faces of the cube. Two distorted cubes, like square prisms, were seen also. The truncation of six angles by *square* faces would *prove* this species to be cubic; and the crystals not to be, as held by some, acute rhombohedra with merely the summit and basal angles truncated.

8. The non-magnetic portion of the black sand, of which there was a comparatively small portion mixed with the more highly magnetic, yielded

On 1 gramme—

Titanic Acid,	15·
Ferric Oxide,	40·729
Ferrous Oxide,	18·244
Manganous Oxide,	1·
Lime,	7·
Silica,	18·1
	100·073

The colour of this portion was rusty brown.

Examined with the microscope, it showed a hackly structure, no crystals and no cleavages. There was a good deal of non-separable adherent silica.

These two black sands, therefore, though found within a short distance of each other, and gathered within two years of each other, differed considerably, both physically and chemically.

9. From the sea-shore, a little east of the mouth of the Almond, Mid-

Lothian. It is jet black, strongly magnetic, and appears free from sand or impurity.

It yielded, on 1 gramme—

Titanic Acid,	18·
Ferric Oxide,	39·607
Ferrous Oxide,	26·742
Manganous Oxide,	·6
Lime,	6·7
Silica,	8·4
	100·049

Being a composition very similar to that of the *bulk* of the Granton mineral.

Under the microscope this appeared as a powder of small grains, which were fragmentary, with cleavages which were not flat, but somewhat hackly. Only one crystal was seen; this had a truncation, the face of which was an isosceles triangle. Along with this, there is mixed a very small quantity of non-magnetic grains, which were much larger than the magnetic. All of these were rounded. They sometimes much resembled water-worn cassiterite;—sometimes they were like worn bits of somewhat rusty iron.

A highly-magnetic blue-black iron sand, of which the individual grains are for the most part perfect octahedra, occurs on the south shore of Macrahanish Bay, Cantyre, at a spot called the Geldrens. Though there is much igneous rock in the neighbourhood, yet this may have come from the gneiss, and be only magnetite.

MAGNETITE.

This mineral has been several times noted as occurring in Scotland, though I am not aware that any analysis of Scottish specimens have been anywhere published.

In glancing over the quoted localities, I find that such as are associated with rocks of chlorite slate, or of serpentine may be set down as correct; but several mistakes have been committed regarding granitic localities.

In the *Transactions of the Geological Society*, vol. ii. 1814, MACCULLOCH writes—"I should scarcely have introduced any remarks on Rona, were it not for the purpose of mentioning that wolfram, hitherto unnoticed in this spot, is found in the granite veins that traverse the gneiss of which this island is principally formed."

That *East* Rona is here referred to, and not *North* Rona, as quoted by GREG and LETTSOM, is shown by a reference to *Blue Bay*.

In Dr. MACCULLOCH's *Western Islands*, of date 1819, no mention is made of wolfram in Rona; his geological remarks on which conclude with "I have only to add, that tetrahedral grouped crystals of oxidulous iron are not unfrequent in the granite veins." GREG and LETTSOM give a figure of hemitrope octahedrons from the spot.

It was hardly excusable for a man like Dr. MACCULLOCH, whose compass was constantly picking out the errors of MACKENZIE's chart, to mistake magnetite for wolfram.

In the *Traveller's Guide through Scotland*,—written in 1806, by JOHN WATSON, father of the late Dr. WATSON WEMYSS of Denbrae, Fifeshire, and which *Guide* contains a fuller and more accurate account of Scottish minerals than any work I am acquainted with,—we read—"It is said that Mr. RASPE found a specimen of wolfram in Tiree." RASPE seems to have had a faculty of finding everything—everywhere. No one has found wolfram since his time in Tiree, so that *his* wolfram was probably also magnetite.

A common error seems to be to set down such magnetite as occurs in granite veins with a faint bluish tarnish, as being "titanic iron." We find even JAMESON doing this, in speaking of that which occurs in the granite veins of Harris. This my analysis below shows to be a magnetite which contains no trace of titanium.

The largest mass of magnetite I have seen in Scotland was a loose-lying lump which lay upon Drum-na-Raabm, in the Coolins. It consisted of interlocked crystals about the size of peas, and might have weighed forty or more pounds.

The largest *solid* lumps were got in blasting graphic-granite at Rispond, in Sutherland. These were cleavable masses, nearly the size of a fist.

I make no attempt to record the localities in which I have found magnetite in Scotland; it is of interest, however, to note its occurrence in definite crystals.

1. Among the cliffs, a little to the west of the houses at Aith, on the south shore of Feltar, in Shetland, it occurs in yellow precious serpentine, in minute *cubes*.

2. It occurs imbedded in massive aphrosiderite at Pundygeo, near Fethaland, Sutherland, in *hemitrope octahedra*, over half an inch in size (fig. 3).

3. In *dodecahedra*, with faces striated towards octahedral facettes; in serpentine, at Vanleep, opposite the Drongs, at Hillswick, Shetland.

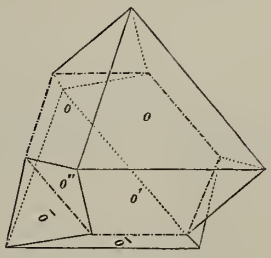


Fig 3.

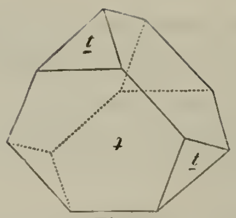


Fig. 4.

4. In *tetrahedral* crystals with octahedral modifications; in graphic granite, at Rispond, in Sutherland. (fig. 4).

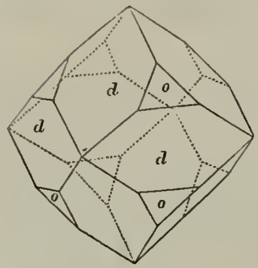


Fig. 5.

5. In the combination of the *octahedron* with *dodecahedron;* in coarse oligoclase-granite, in the cliffs near Caligaig (fig. 5).

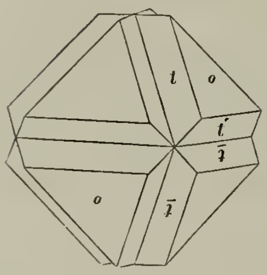


Fig. 6.

6. In twin *tetra-octahedrons,* in a syenite boulder near Tongue (fig. 6). With amazon stone, ilmenite, &c. *Octahedral* crystals also occur here.

7. In flattened *octahedra,* in the great granite veins of Roneval, in Harris.

The form is as figured—*o*. Figure *ro* is the simplest form of ilmenite; these are drawn in *natural* position (figs. 7 and 8).

The similarity of these, when the ilmenite crystal is placed in *vertical* position, quite excuses JAMESON setting this magnetite down as being ilmenite. But o on $r = 122°30'$, and r on $r' = 86°10'$ (fig. 8); while o on $o' = 109°28'$, and o' on $o'' = 109°28'$, (fig. 7).

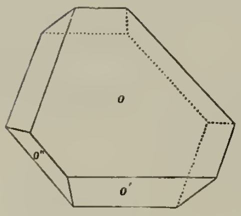


Fig. 7.

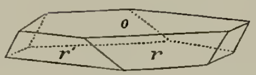


Fig. 8.

8. In granite, with dolomite and pale-green fibrous hornblende, in the Sallyvilly Quarry, near Alford, Aberdeenshire, in *twin tetra-octahedra,* somewhat like fig. 6.

9. In chlorite slate, at several spots on the shores of Loch Fyne, in minute *octahedra.*

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1. Is found imbedded in minutely foliated chlorite at Pundygeo, Fethaland, Shetland. It occurs in simple and also in hemistrope crystals, up to one inch in size.

Its colour is jet black, its lustre brilliant; the powder is blue-black. It is very difficult to reduce it to powder, even under water.

The crystals are somewhat penetrated by the chlorite, and so yield some foreign matter.

On 1 · gramme—

Ferric Oxide,	65 · 617
Ferrous Oxide,	32 · 166
Manganous Oxide,	· 5
Silica,	· 7
Alumina,	· 393
Lime,	· 223
Magnesia,	· 684
	100 · 184

2. This was taken from the "Great Boulder" at Tongue. It is in imbedded nodules, and rarely in octahedral crystals. The nodules are the size of peas and beans, of a jet or blue-black colour, and a high lustre. The powder is reddish-brown, and strongly magnetic.

1 · gramme gave—

Ferric Oxide,	83 · 482	
Ferrous Oxide,	12 · 632	12 · 7—12 · 564
Manganous Oxide,	1 · 2	
Silica,	1 · 2	
Alumina,	· 233	
Lime,	· 896	
Magnesia,	· 5	
	100 · 143	

This magnetite contained minute specks of *malleable metallic iron,* in the centres of some of the crystals or nodules.

3. Occurs in imbedded cleavable lumps, from the size of walnuts to that of the fist; in the graphic granite of Rispond. The colour is blue-black, and the powder brownish. S. G. 5 · 15.

It yielded on 1 · gramme—

Fe_2O_3,	63 · 186
FeO,	29 · 586
MnO,	· 4
CaO,	1 · 624
MgO,	1 · 1
Silica,	3 · 9
	99 · 796

Magnetite is here rarely seen in flattened octahedral crystals.

4. Occurs in imbedded patches, and rarely in dodecahedral crystals, in the granitic belts of the gneiss, on the cliffy shore opposite to the island of Koilskeer, in the north of Sutherland. The colour is somewhat of a brownish-black, the lustre rather dull.

It yielded—

Ferric Oxide,	89·632
Ferrous Oxide (Fe. 3·208—3·389), av.	4·241
Manganous Oxide,	·3
Lime,	2·688
Magnesia,	·9
Silica,	1·9
Titanic Acid,	·5
	100·161

There is here a marked passage into martite; but the specimen analysed was taken from a stone in a wall, and may have suffered from long exposure.

5. Was taken from the great granite veins in the east foot of Roneval, Harris. It is found, along with Haughtonite, in imbedded plates, which are rough flattened octahedrons.

These are sometimes an inch or more in size.

Their colour is blue-black; the colour of the powder is the same. S. G. 5·154.

It yielded on 1· gramme—

Ferric Oxide,	68·095
Ferrous Oxide,	29·014
Manganous Oxide,	·5
Alumina,	·615
Lime,	·168
Magnesia,	·6
Silica,	1·
	100·002

There was possibly a slight admixture of Haughtonite, but none was visible.

Chromiferous Magnetites.

I have stated above that I found several of the "magnetic iron sands" to contain traces of chromium.

Where these sands may have been extracted from a serpentinic rock, or from diorite, this may fairly enough be assigned to a small admixture of chromite. Dr. WOLLASTON states that the metallic specks which occur in the serpentine of Portsoy are chromite; and very probably there is an admixture of that substance with magnetite.

The substances, the analyses of which follow, cannot however be regarded as mere mixtures.

1. A black iron sand was found somewhat sparingly by Mr. DUDGEON and myself among the ordinary siliceous sands of the Dale Burn, in Unst, Shetland. The locality was at the point where the burn turns abruptly to the northward.

This sand was of a blue-black colour, decidedly but not strongly magnetic; under the microscope it seemed much split or cleaved; of a hackly fracture, and it showed no crystalline forms.

It was, so far as the small quantity obtained permitted, separated from siliceous and non-magnetic sand by repeated stirring up in water and decantation, and ultimately by the magnet.

When magnified it appeared to be, with the exception of a small admixture of siliceous grains, uniform.

On an analysis it afforded—

	1.	2.
Ferric Oxide, . .	57·285	62·464
Chromium Sesquioxide,	9·4	10·25
Ferrous Oxide, . .	24·944	27·199
Manganous Oxide, .	·4	·436
Lime, ...	1·12	...
Silica, ...	7·2	...
	100·349	100·349

2. Gives the proportion, after abstracting the silica and lime, as these are undoubtedly present from mere mechanical admixture.

The question is, can this be an *admixture* of magnetite with chromite?

No one point connected with it favours such a view. Its geographical and geological position does not;—it is found about two miles from the nearest chromite, with more than one hill ridge between; its altitude is greater than that of the chromite, and the stream which sweeps it towards the sea, flows from a hill of mica schist.

It was physically purified by the magnet, which readily abstracted it from the siliceous admixture. Chromite is, at most, and that only rarely, feebly magnetic.

Its powder had a uniform blue-black colour; the crushed powder of chromite is brown.

Lastly, an admixture of chromite with magnetite would not yield the percentages above given. The results of the analysis point rather to a *replacement* of ferric oxide by chromic oxide, though it is not altogether accordant with that.

3. A "black magnetic sand" was noted as occurring on the shores of the Loch of Trista, by Dr. Fleming (*Ed. Phil. Jour.*, vol. iv. p. 114). He says that it "occurs along with iron sand, imbedded in small grains, in the primitive limestone in the neighbourhood. Small crystals of sphene occur along with the iron sand imbedded in the limestone."

It is found both on the north and south shores of the lake in a granitic sand; in this it occurs to the amount of about one hundredth part of the whole.

The Rev. David Webster writes the author that it probably was derived from a valley to the north-west, called the Dullans, from whence a stream runs into the lake. The high state of the lake prevented the author from obtaining more than a trifling quantity of the sand; and he is indebted to Mr. Webster for the supply which he examined and analysed.

Mr. Webster holds the view that the sand is derived from masses of bog iron ore which sprinkle the surface in profusion, at the Dullans; these masses, however, when examined by the writer, yielded none of the sand; and even granting that they had done so, it could only have been caught up from the surface during the formation of a substance now recognised universally as an outcome of organic change.

Mr. Webster also sent the writer a very similar sand from the sea-shore on the east side of Trista Voe.

The sand from the Loch of Trista presents an appearance under the microscope which is different from that of any magnetic or "black iron sand" which I have examined. Among the grains there occur a few well-defined, and very slightly abraded octahedral crystals, evidently of the regular system; they are, as is the rest of the sand, jet black and lustrous. The great bulk of the sand is composed of rounded grains, which have at first sight a vitrified appearance; but this is due to their surfaces being pitted with a multitude of minute conchoidal fractures, doubtless from repeated collision in the surf of the lake; their fracture therefore is conchoidal, and the lustre is extremely high. Many of the grains still retain adherent transparent quartz, whence I assign their matrix to the gneissic rock.

Excepting the octahedral crystals, the appearance of the grains is uniform; there is no admixture; the proportional quantity of crystals is very small.

The sand had been originally separated from the granitic granules by the magnet, and the process was repeated several times to free it from quartz; it did not appear, however, that there was, as is frequently the case with magnetic sands, a more- and a less-strongly magnetic portion.

Mr. Webster, from observations on the spot, came to the same conclusion.

Notwithstanding the adherent quartz, I have no reason to doubt the conclusions of so excellent an observer as FLEMING, and therefore regard the occurrence of this ore in limestone as most interesting.

Ilmenite I know to occur in some of the primitive limestones of Aberdeen, along with sphene.

The powder of this sand was black, with a slight tinge of brown.

Its analysis yielded—

Ferric Acid,	56·692
Sesquioxide of Chromium,	17·53
Ferrous Oxide,	15·548
Manganous Oxide,	·6
Lime,	1·288
Magnesia,	3·9
Silica,	5·1
	100·658

There was no titanic acid.

The above, however, does not represent the total amount of the *ferrous* oxide.

It was found that the ordinarily elutriated mineral could not be decomposed by potassium fluoride and chlorhydric acid, for the determination of what amount of the iron was in the *ferrous* state. It was therefore attacked by calcium fluoride and chlorhydric acid, after having been again elutriated *twice,—thrice,*—and lastly, that portion only which was held in suspension in water for three days was used.

Quantities separately operated on as above gave respectively 15·026, 15·38, 15·548 per cent. of ferrous oxide. In every case, however, a quantity of *brown* powder remained undecomposed; the amount, even in the last case, was found to be as much as 37·82 per cent. of the whole quantity taken.

As elutriation, and our processes for decomposing minerals for the estimation of the ferrous oxide, can go no further, I must for the present rest, with the admission that the above probably does not correctly represent the composition of the mineral, *so far as the state of the oxidation of the iron is concerned.*

From the nearly constant quantity decomposed by the hydrofluoric and hydrochloric acids, it would appear as if two substances were *mixed* in this sand; but the microscopic appearances in no particular countenance such a view. Dr. FLEMING, however, it should be stated, regarded it as "iserine, mixed with iron sand" (? magnetite).

Although the above analysis, and that of the Unst sand now introduces for the first time a *magnetic* chromium-ore as British, such a compound has been before noticed.

Garrett, in his examination of the American ores, found a magnetic and a non-magnetic "chrome sand."

In his formulation of these he makes the

Non-magnetic, . . .	$\dot{\mathrm{Fe}}\,\dddot{\mathrm{Cr}}_2\ 89\cdot 42_3$,	$\dot{\mathrm{Fe}}\,\dddot{\mathrm{Fe}}_2\ 6\cdot 26$.
The Magnetic, . . .	$\dot{\mathrm{Fe}}\,\dddot{\mathrm{Cr}}_2\ 61\cdot 07_3$,	$\dot{\mathrm{Fe}}\,\dddot{\mathrm{Fe}}_2\ 38\cdot 64$.

The imperfect determination of the state of oxidation of the iron prevents the Shetland sands being tabulated in the same manner as yet. They are evidently much poorer in chromium.

All these analyses show that although the richest chrome ores are non-magnetic, valuable magnetic varieties, which may be said to shade off into *chromiferous magnetites*, exist; and large deposits of magnetic iron sands should be examined, in the hope that they may prove to be more or less rich in chromium. Should that metal be found to be a constituent of the sand, it would be of greater advantage to the manufacturer or extractor, that the same should prove to be *a mixture;* as ordinary chromite, however intractible, is markedly less so than this substance (which is apparently a compound) has proved to be.

CHROMITE.

1. From the large quarry at Hagdale, Unst, Shetland. The sample taken was a very crystalline mass, almost in isolated octahedra; the crystals were separated from one another by flakes of foliated pennite. After careful picking, small grains of translucent quartz were still visible, though none could be seen in the uncrushed mineral.

It was associated rarely with emerald nickel, and contained imbedded specks of a bronzy mineral which resembled Pentlandite. Other associates are talc, aragonite, and Kammererite.

On 1·001 grammes—

Silica, ...	·071		
From Alumina, . . .	·04		
	·111		
Protoxide of Iron, ...		17·519	19·465
Protoxide of Manganese, . . .		·499	
Sesquioxide of Chromium, . . .		44·555	
Lime, ...		1·286	
Alumina, ...		23·741	
Silica, ...		11·088	
		98·688	

The absence of magnesia from this sample is peculiar; as I found that some well-defined octahedral crystals from a vein near Buness House contained nearly half as much magnesia as chromium;—showing chromite to be a true spinel.

2. The substance now noticed was found by me in a single specimen near the summit, on the north-west front of the precipitous hill of Haiskeval, in Rum. Before analysis I conceived it to be martite. It occurred as a vein of about one quarter of an inch in thickness, imbedded in a granular brown belt of rock, in augitic trap; this belt was apparently chiefly altered olivine. The mineral was granular in structure, jet black in colour, highly lustrous, very hard, not magnetic, and had a S. G. = 4·163. It was evidently a uniform substance.

It was first fused with Fresenius's flux; but, as a small quantity of a fawn-coloured powder remained undissolved, a second quantity was fused with potassium bisulphate and nitre. No titanic acid being found, the insoluble powder of the first fusion was fused with the last-named salts, and found to contain chromium.

It was found that the mineral could not be decomposed by *any* of the processes usually employed for the ferrous oxide determination; so that the iron is merely *conjectured* to be in the ferrous state. The whole available quantity was employed in the analysis.

The insoluble precipitate of the first analysis was insoluble in hydrochloric acid. It was not weighed, but was re-fused, and the ferric oxide and chromium sesquioxide separated, and added to the results of the soluble portion of that analysis. The quantity of this insoluble precipitate was too minute to give any countenance to the view that the total amount of chromium can be assigned to an admixture of chromite with magnetite.

As a large excess was obtained in the first analysis by Fresenius's flux, the mineral was analysed a second time by fusion with potassium bisulphate, but with a very similar result.

The first analysis was by means of Fresenius flux, operating on ·43 grains; the second by potassium bisulphate, on ·93 grammes—

Chromium Sesquioxide, . . .	26·304	26·343
Alumina, ...	17·957	18·279
Ferrous Oxide, ...	34·239	34·112
Manganous Oxide, ...	·869	·752
Lime, ...	6·573	6·382
Magnesia, ...	13·913	14·086
Silica, ...	6·543	6·236
	106·398	106·191

Even if the chromium be tabulated as protoxide, there still would be an excess of over 2 per cent.

This unsatisfactory result, or sum total, leaves it much to be desired that the mineral should be re-examined; the more especially as the occurrence of chromite in augitic trap is altogether new.

TURGITE.

Found in isolated imbedded cubic crystals, in clay-slate, in the island of Kerrera; and also to the east of Oban. These crystals have invariably a hollow in their centre; they are red-brown, and stain the skin of the same colour.

They yielded—

	S. G. 3·534.
Ferric Oxide,	86·585
Lime,	·818
Water,	5·559
Silica,	7·692
	100·654

As unaltered pyrite occurs in the same rock in the vicinity of these crystals, they undoubtedly have resulted from the alteration of that mineral; and this may be regarded as a pseudo-pyrite.

GÖTHITE.

1. Occurs in fibrous reniform masses, the fibres being about an inch and a half in length, in veins in the cliffs of the gorge of the Burn of the Sail, in the Bring, Hoy, Orkney.

Its colour is chocolate-brown, sometimes banded with ochrey belts; its fibres are very minute; it is quite similar in appearance, and colour of powder, to limonite, but is somewhat harder. S. G. 4·13.

Ferric Oxide,	84·395
Ferrous Oxide,	·054
Manganous Oxide,	·1
Alumina,	1·295
Lime,	1·324
Water,	10·863
Silica,	2·
	100·031

The greater part of the silica was insoluble in acid.

Minute highly lustrous crystals of this mineral also spangle in the druses of a massive granular hematite, which is found at the same spot.

2. In the *Traveller's Guide through Scotland* we read :—" Beautiful specimens of radiated hematites are found in the quarry near Holyrood House. These are intermixed with steatites, green fibrous iron ore, and calcareous spar, forming a very uncommon mass.

" Veins of calcareous spar beautifully stripped (*sic*), also lac-lunæ, zeolite, and amethystine quartz crystals, are met with in many places."

These specimens from the Salisbury Crags occurred in fine plumose radiated crystals, of a high lustre, and deep brown colour.

Specific gravity 4·146. A little quartz was, however, visible in the specimen.

It yielded—

Ferric Oxide,	79·015
Ferrous Oxide,	7·187
Lime,	·28
Silica,	2·668
Water,	10·049
	99·199

Some clear imbedded quartz was visible after the most careful picking.

The " green fibrous iron ore " I can only guess to have been saponite. The lac-lunæ is rock-milk, an earthy or powdery form of calcite: analcime, Prehnite, and datholite were found here when the Crags were used as a quarry.

LIMONITE.

1. In my notice of the psilomelane from Hoy, it was stated that limonite was associated with the psilomelane; it is so associated in two of the veins only, and its appearance in them is very dissimilar. In both it is superimposed upon the manganese; but in the one it assumes, or rather attempts to assume, a minute stalactitic structure; the individual stalactites sometimes interlace and pass into a pseudo-fibrous or knitted appearance. The coating of limonite, however, in which this is seen has in itself the usual divergent fibrous growth. The fibrous surface is of a purplish-brown colour, and it has a certain amount of the tremulous lustred and half-scaly appearance of lepidocrokite. But the chief feature of this variety of limonite is that its surface, which is dull, has invariably a greenish to an ochery tint. When powdered it is ochrey-brown.

This variety has a specific gravity of 3·684.

It yielded, on 1·304 grammes—

Ferric Oxide,	78·787
Ferrous Oxide,	3·236
Manganous Oxide,	·153
Alumina,	· 56
Lime,	·472
Silica,	3·067
Water,	14·314
	100·589

When dissolved in cold HCl, a small quantity of light flocculent silica separates; upon applying heat, this goes entirely into solution.

2. The second variety of limonite at this locality I found directly coating the sandstone in one or two specimens. But it in general has assumed the botryoidal forms of the psilomelane; occasionally it is somewhat stalacitic, especially when it directly coats sandstone.

The surface of the mineral is highly polished, jet black, and splendidly lustrous. Its internal structure is divergent-fibrous; but it is tough. The internal colour is purplish-brown, and the lustre satin-like, or almost vitreous. Its powder is a very rich ochre-yellow.

It yielded—

Ferric Oxide,	82·135
Manganous Oxide,	·343
Lime,	·571
Magnesia,	·214
Silica,	3·315
Water,	13·87
	100·468

Here, also, some of the silica was in combination. The thickness of the coatings of this variety of limonite varies from the fourth of an inch to films of extreme thinness; these can always be discriminated from the psilomelane, by their brilliant lustre, and of course by their ochre tint. This variety, for the most part, forms the *black hematite* of old authors.

The results of these two analyses of limonite, taken in conjunction with the analyses of the psilomelane and of the wad, with which the limonite is associated, show a most peculiar antagonism to exist between the two closely chemically-allied metals, iron and manganese. Though here occurring together, formed to some extent possibly by similar processes, and superimposed in layers over each other, the iron ore has almost absolutely repelled the manganese; while no specimen of the psilomelane which I have examined contained a trace of iron.

I do not remember ever having examined a mineral which was so absolutely free from the minutest trace of iron as was this psilomelane.

3. From the mines which have been opened on the west side of the road passing from Cock Bridge to the Laoch mines. These mines lie near the north-east foot of Alsait Hill.

Colour, clove brown; lustre, vitreous; fracture, conchoidal; structure, massive and pilch like; powder, orange-brown.

On 1 · gramme—

S. G. 3 · 65.

Ferric Oxide,	52 · 094
Alumina,	8 · 215
Ferrous Oxide,	22 · 222
Manganous Oxide,	· 8
Lime,	· 672
Magnesia,	· 5
Silica,	· 7
Water,	14 · 569
	99 · 772

Loses in bath, 1 · 989 per cent. of water.

I do not know what to make of this. While gathering it, I conjectured from its appearance that it was the rare mineral *limnite;* but now, after analysis, it gives promise of being a new mineral. I have seen a substance identical in appearance, except that it was still more lustrous, at Leadhills. This last, however, may prove to be limnite. I have not yet obtained a sufficiency of the Leadhills mineral for analysis.

4. Occurs on the south side of Garron Point, north of Stonehaven, in a very peculiar green argillaceous rock, ordinarily called chlorite slate. It, however, much more resembles a glauconitic clay-slate, with a fissile structure.

The colour of the iron ore is ochre-brown; its structure is laminated or bedded, the layers being shown by thin rifts of a darker colour. It was called magnetite by Nicol.

It is hard, more like a laminated clay iron ore, than a simple mineral. It was once wrought by the Carron Iron Company.

On 1·3 grammes—

S. G.=3·191.

Silica,	·498	
From Alumina,	·004	
	·502 =	36·615
Alumina,		4·891
Ferric Oxide,		36·83
Ferrous Oxide,		4·335
Manganous Oxide,		·153
Lime,		5·643
Magnesia,		1·923
Water,		7·944
		100·334

Loses ·969 per cent. of water in the bath.

XIX.—*On the Nature of the Curves whose Intersections give the Imaginary Roots of an Algebraic Equation.* By Thomas Bond Sprague, M.A., F.R.S.E. (Plate XXIV.)

(Read 20th February 1882.)

" If the n roots of the equation

$$f(x)=x^n+p_1x^{n-1}+p_2x^{n-2}+\quad.\quad.\quad.\quad.\quad+p_n\quad.\quad.\quad.\quad.\quad=0$$

" are all real, then all the roots of the equations

$$\cos\left(k\frac{d}{dx}\right)f(x)=f(x)-\frac{k^2}{2}f''(x)+\frac{k^4}{4!}f^{\text{iv}}(x)-\quad.\quad.\quad.\quad.\quad=0$$

" and

$$\frac{1}{k}\sin\left(k\frac{d}{dx}\right)f(x)=f'(x)-\frac{k^2}{3!}f'''(x)+\frac{k^4}{5!}f^{\text{v}}(x)-\quad.\quad.\quad.\quad.\quad=0$$

" are also real, and one of the $n-1$ roots of the latter lies between each adjacent " two roots of the former."

In De Morgan's *Trigonometry and Double Algebra,* and in Todhunter's *Theory of Equations,* there is given a theorem of Cauchy's, which lays down a rule for determining the number of imaginary roots of the equation $f(x)=0$ that lie within any assigned limits. Todhunter says of it that it proposes to effect with respect to the roots in general what Sturm's theorem effects with respect to the *real* roots; but it seems to me that this is scarcely correct, and that the corresponding theorem as to the real roots, is that the number of such roots between a and b is the number of changes of sign of $f(x)$ when all values of x from a to b are substituted in $f(x)$.

If $h+ik$ is a root of $f(x)=0$ (where i is put for $\sqrt{-1}$), we have

$$f(h+ik)=e^{ik\frac{d}{dh}}f(h)=\left\{\cos\left(k\frac{d}{dh}\right)+i\sin\left(k\frac{d}{dh}\right)\right\}f(h)=0\,,$$

whence

$$\cos\left(k\frac{d}{dh}\right)f(h)=0\,,\ \text{and}\ \sin\left(k\frac{d}{dh}\right)f(h)=0\,.$$

It follows that h and k must satisfy these two equations; or, in other words, they are the co-ordinates of a point of intersection of the two curves represented by the equations

$$\cos\left(y\frac{d}{dx}\right)f(x)=0,\ \sin\left(y\frac{d}{dx}\right)f(x)=0\,.$$

The number of points of intersection will be the number of roots (real or imaginary) of the equation $f(x)=0$, k being of course zero for the real roots. Writing $p=0$, $q=0$, for the last two equations, so that $f(x+iy)=p+iq$, and assuming for the present that $f(x)=0$ has no equal roots, Cauchy's theorem asserts that we can ascertain how many intersections of the curves lie within any assigned area, by observing how often $p:q$ passes through the value 0 and changes its sign, when we substitute for x and y the co-ordinates of a moving point that traverses the contour of the area in the positive direction. If $p:q$ so changes sign l times from + to −, and m times from − to +, then the number of points of intersection is $\frac{1}{2}(l-m)$. Calling the two curves P and Q, it is obvious that $p:q$ passes through the value 0 and changes sign, only when the moving point crosses the curve P. When the moving point crosses the curve Q, $p:q$ changes sign; but, as it passes through the value ∞, this change of sign is not counted. Before proceeding further let us consider whether it is true of all curves that the number of intersections is determined by the above formula, or for what particular kinds of curves it holds good.

Suppose the point to move round the rectangle in any one of the figures (1), (2), (3); then in the first case it crosses the curve P twice, but on one occasion $p:q$ changes sign from + to −, and on the other from − to +. There is therefore, according to the rule, no point of intersection of P and Q within the rectangle; and this is the case. In fig. 2 the point also crosses P twice, and the same changes of sign occur, so that here again, according to the rule, there is no intersection within the rectangle; and this is the fact. In fig. 3 the point crosses P twice, and on each occasion there is a change of sign from + to −, so that $l=2$, $m=0$, and the rule gives us one point of intersection, which is correct. If, however, we suppose the curves P and Q to intersect in two points within the rectangle, as in figs. 4 and 5, we see that the rule does not hold good. In fig. 4, the point crosses P twice, and we have $l=1$, $m=1$; in fig. 5, the point crosses P four times, and we have $l=2$, $m=2$; in both cases, therefore, the rule would give us no intersections, whereas there are two. This shows that the rule does not apply to all kinds of curves, and it is not difficult to determine the general characteristics of the curves to which it does apply.

Suppose a branch of P to cut two branches of Q, thus giving two intersections, then, if we draw a rectangle to include these intersections, as in fig. 6, we see that the rule does not hold good. If, however, a second branch of P lies between the two branches of Q, as in fig. 7, the proper sequence of signs will be obtained, and the rule will hold good. In this case we get $l=4$, $m=0$, $\frac{1}{2}(l-m)=2$, which is the actual number of intersections of P and Q. Proceeding in the same way we see that, if there are an odd number of branches of P between the two branches of Q, the rule holds good, but not if the number of branches is even; and we conclude that, when the rule applies, if two intersections of P and Q occur on a branch of P, an odd number of double points of P lie between them. Similar reasoning shows that if two intersections of P and Q occur on a branch of Q, the rule will not apply unless an odd number of double points of Q lie between them. This explains why the rule does not apply, when the curves intersect as they do in figs. 4 and 5.

Looking again at fig. 7 we see that no two branches of P and Q can intersect again when prolonged; for, if they did, there would be two intersections of P and Q on one branch, either of P or Q, without any double point between. It is not at first sight obvious how far this conclusion would be modified by the existence of another branch of Q passing through the intersection, as the dotted curve in fig. 8. It is necessary therefore to consider multiple points of this kind, that is to say, points through which pass two or more branches of one curve and one or more of the other. First consider the case of two branches of P and two of Q passing through one point and arranged alternately, as shown in fig. 9. The simplest way in which such a point can arise is by two branches of P moving up towards a branch of Q, as if in fig. 10 the points A and B should move up and coincide with C. In that case two points of intersection of P and Q would coincide, and the multiple point in fig. 9 is therefore to be reckoned as two intersections of P and Q. The rule gives us $l=4$, $m=0$, $\frac{1}{2}(l-m)=2$, which is correct. If the branches are not arranged alternately, but occur as in fig. 11, the simplest way in which it can arise is by two branches of P joining to form a double point which is already a double point on Q. In this case it seems that the point should, notwithstanding its apparent complexity, not be counted as an intersection at all. This agrees with the rule, which gives $l-2$, $m=2$, $\frac{1}{2}(l-m)=0$. Similarly, if we have a point through which pass one branch of P and two branches of Q, this may be considered to have arisen from the union of two branches of Q which do not cut P, as the dotted curves in fig. 12, and the point will therefore not count as an intersection; this being again in agreement with the rule, which gives $l=1$, $m=1$, $\frac{1}{2}(l-m)=0$. In this way of reckoning intersections, the rule applies to such a curve as is shown in fig. 8. Here, if we take a contour to include the two points A, B, but not C, the rule gives $l=3$, $m=1$, $\frac{1}{2}(l-m)=1$; and this is correct, since, as we have seen, B does not count as an intersection. If the contour is drawn so as to include also C, we shall have $l=4$, $m=0$, $\frac{1}{2}(l-m)=2$, which also is correct.

Resuming consideration of figs. 7 and 8, we see that it follows from what we have proved that no branch of P which intersects Q can re-enter upon itself and form a closed curve, but it must always have two infinite branches; and the same is true of Q. We next observe that the rule will not hold unless the arrangement of the infinite branches follows a law similar to that we have seen to prevail among the intersections. If in figs. 13 and 14 we draw a contour to include the points of intersection A and B, we shall have in fig. 13, $l=2$, $m=2$, $\frac{1}{2}(l-m)=0$; and in fig. 14, $l=4$, $m=0$, $\frac{1}{2}(l-m)=2$; or the rule applies in the latter case, but not in the former. If, however, in fig. 13 we draw between A and B an infinite branch either of P or Q or an odd number of such branches either of P or Q, the proper sequence of signs is obtained and the rule applies. We thus see that between any two infinite branches of P on which there is an intersection, there must lie an odd number of infinite branches, either of P or Q; and the same is true of any two such branches of Q.

Applying the principles we have established, it is easy to show how to draw very complicated curves to which the rule will apply; but it seems unnecessary to pursue this part of the subject further.

Cauchy does not seem to have investigated the properties of the curves P and Q, but it will be found that an examination of them leads to a variety of interesting results, one of which I have stated at the outset of this paper.

As a first step in this direction we expand the equations

$$\cos\left(y\frac{d}{dx}\right)f(x)=0\,,\ \text{and}\ \sin\left(y\frac{d}{dx}\right)f(x)=0\,,$$

and thus get

$$f(x)-\frac{y^2}{2}f''(x)+\frac{y^4}{4!}f^{\text{iv}}(x)-\ldots\ldots=0\ .\ \ .\ \ .\ \ .\ \ .\ \ .\qquad(\text{P})$$

and

$$yf'(x)-\frac{y^3}{3!}f'''(x)+\frac{y^5}{5!}f^{\text{v}}(x)-\ \ldots\ldots=0\,.$$

The latter is satisfied by $y=0$, or the x-axis forms part of the locus of the equation: and putting $y=0$ in the former equation, we get $f(x)=0$. It is obvious that the points thus determined correspond to the real roots of the original equation, and that the imaginary roots correspond to the intersections of the curves represented by (P) and by

$$f'(x)-\frac{y^2}{3!}f'''(x)+\frac{y^4}{5!}f^{\text{v}}(x)-\ \ldots\ldots=0\qquad.\ \ .\ \ .\ \ .\qquad(\text{Q}).$$

The only case I propose to examine in any detail on the present occasion is when $f(x)=0$ has no imaginary roots. The two curves must then have no intersections corresponding to finite values of y, and we shall presently prove that this is the case. For this purpose we must trace the two curves, which for brevity we will call P and Q.

We first observe that since y enters the equations (P) and (Q) only in even powers, both curves are symmetrical with regard to the x-axis. Putting $y=0$, the points in which the curves cut that axis are determined by $f(x)=0, f'(x)=0$, respectively. By the theory of equations, since all the roots of the former are real, all the roots of the latter ($n-1$ in number) are also real, and one of them lies between each adjacent two roots of the former. We next observe that, if $f(x)=0$ has no equal roots, then $f'(x)=0$ has none, and each of the curves cuts the x-axis at right angles; that is to say, P has n branches and Q has $n-1$ branches, all of which cut the x-axis at right angles. In fact, if h is a value of

x that satisfies the equation $f(x)=0$, then $f(x)$ contains the factor $x-h$ once, and only once; and when x becomes equal to h and y vanishes, the limit of $y^2:(x-h)$ is finite, and the limit of $y:(x-h)$ is infinite. This is also an immediate result of the symmetry of each curve with regard to the x-axis.

If $f(x)=0$ has two equal roots, $f'(x)=0$ has one root equal to them. In this case P has a double point, through which passes a branch of Q cutting the x-axis at right angles, as shown in fig. 15, where the dotted curve belongs to Q. If $f(x)=0$ has three equal roots, two of the roots of $f'(x)=0$ and one of the roots of $f''(x)=0$, are equal to them. In this case P has a triple point, which is also a double point on Q, as indicated in fig. 16, where, as before, the dotted branches belong to Q and the others to P; and the middle branch of P cuts the x-axis at right angles. In general, if m roots of $f(x)=0$ are equal, P has a multiple point of the order m on the x-axis, and this is also a multiple point of the order $m-1$ on Q. If m is odd, one branch of P cuts the x-axis at right angles, and the others are inclined to it, two and two, at equal angles; and one branch of Q lies between each adjacent two of P. If m is even, one branch of Q cuts the x-axis at right angles, and the other branches of Q and all the branches of P, are symmetrically arranged as just described.

We will henceforward suppose that the roots of $f(x)=0$ are all real and unequal, in which case, as already shown, there are n branches of P and $n-1$ branches of Q, all of which cut the x-axis at right angles. We have next to consider the nature of the infinite branches, and for this purpose we must develop the equations (P) and (Q). The former gives us

$$\begin{aligned}&x^n+p_1x^{n-1}+p_2x^{n-2}+p_3x^{n-3}+\quad.\quad.\quad.\quad.\quad.\quad.\quad.\qquad+p_n\\&-\frac{y^2}{2}\Big\{n(n-1)x^{n-2}+(n-1)(n-2)p_1x^{n-3}+\quad.\quad.\quad.\qquad+2p_{n-2}\\&+\frac{y^2}{4\,!}\Big\{n(n-1)(n-2)(n-3)x^{n-4}+\quad.\quad.\quad.\quad.\quad.\quad\Big\}+\quad.\quad.\quad.\quad.\qquad=0.\end{aligned}$$

Or, re-arranging the terms according to their dimensions,

$$\begin{aligned}&x^n-\frac{n\,.\,n-1}{2}x^{n-2}y^2+\frac{n\,.\,n-1\,.\,n-2\,.\,n-3}{4\,!}x^{n-4}y^4-\quad.\quad.\quad.\quad.\\&+p_1\left\{x^{n-1}-\frac{n-1\,.\,n-2}{2}x^{n-3}y^2+\frac{n-1\,.\,n-2\,.\,n-3\,.\,n-4}{4}x^{n-5}y^4+\quad.\quad.\quad.\right\}\\&+p_2\left\{x^{n-2}-\frac{n-2\,.\,n-3}{2}x^{n-4}y^2+\quad.\quad.\quad.\quad.\right\}+\quad.\quad.\quad.\quad.\qquad=0\,.\end{aligned}$$

The directions of the infinite branches, n in number, are given by the terms of highest dimensions; and equating these to zero, we have

$$x^n-\frac{n\,.\,n-1}{2}x^{n-2}y^2+\frac{n\,.\,n-1\,.\,n-2\,.\,n-3}{4\,!}x^{n-4}y^4-\quad.\quad.\quad.\quad.\quad.\qquad=0\,.$$

Now since

$$(x+iy)^n=x^n+nix^{n-1}y-\frac{n\,.\,n-1}{2}x^{n-2}y^2-\frac{n\,.\,n-1\,.\,n-2}{3\,!}ix^{n-3}y^3+\ .\ .\ .\ .$$

$$(x-iy)^n=x^n-nix^{n-1}y-\frac{n\,.\,n-1}{2}x^{n-2}y^2+\ .\ .\ .\ .$$

we see that the above equation is equivalent to $(x+iy)^n+(x-iy)^n=0$.

If we put $x=r\cos\theta$ and $y=r\sin\theta$, this becomes

$$r^n\{(\cos\theta+i\sin\theta)^n+(\cos\theta-i\sin\theta)^n\}=0,$$

or $2r^n\cos n\theta=0$. Hence for the infinite branches we have $\cos n\theta=0$, or

$$n\theta=\frac{\pi}{2},\ \frac{3}{2}\pi,\ \frac{5}{2}\pi\ .\ .\ .\ .\ \frac{2n-1}{2}\pi,$$

and

$$\theta=\frac{\pi}{2n},\ \frac{3\pi}{2n},\ \frac{5\pi}{2n}\ .\ .\ .\ .\ \frac{2n-1}{2n}\pi.$$

This shows that there are n real asymptotes, the directions of which are arranged at equal intervals through the first two quadrants. Also since the equation

$$x^n-\frac{n\,.\,n-1}{2}x^{n-2}y^2+\frac{n\,.\,n-1\,.\,n-2\,.\,n-3}{4\,!}x^{n-4}y^4-\ .\ .\ .\ .\ .=0$$

is satisfied by $x=y\cot\frac{\pi}{2n}$, $y\cot\frac{3\pi}{2n}$, &c., the first member of it must be identical with the product

$$\left(x-y\cot\frac{\pi}{2n}\right)\left(x-y\cot\frac{3\pi}{2n}\right)\ .\ .\ .\ .\ \left(x-y\cot\frac{2n-1}{2n}\pi\right).$$

Having thus determined the direction of the asymptotes, we have next to find where they cut the x-axis. Take the asymptote for which $\theta=(2r-1)\pi:2n$; then, observing that the equation to P may be put in the form

$$\{(x+iy)^n+(x-iy)^n\}+p_1\{(x+iy)^{n-1}+(x-iy)^{n-1}\}$$
$$+p_2\{(x+iy)^{n-2}+(x-iy)^{n-2}\}+\ .\ .\ .\ .\ =0,$$

and that $x-y\cot\frac{2r-1}{2n}\pi$ is a factor of the first term, we have

$$x-y\cot\frac{2r-1}{2n}\pi+p_1\frac{x-y\cot\frac{2r-1}{2n}\pi}{(x+iy)^n+(x-iy)^n}\{(x+iy)^{n-1}+(x-iy)^{n-1}\}$$

$$+p_2\frac{x-y\cot\frac{2r-1}{2n}\pi}{(x+iy)^n+(x-iy)^n}\{(x+iy)^{n-2}+(x-iy)^{n-2}\}$$

$$+\;.\;\;.\;\;.\;\;.\qquad\qquad =0\quad .\;\;.\;\;.\;\;.\;\;.\;\;.\;\;.\quad (A).$$

If in the term multiplied by p_1 we substitute $y\cot\frac{2r-1}{2n}\pi$ for x, and neglect the following terms, which vanish when x and y are infinite, we shall obtain the equation to the asymptote. On making this substitution, the fraction,

$$\frac{x-y\cot\frac{2r-1}{2n}\pi}{(x+iy)^n+(x-iy)^n}\text{, takes the form }\frac{0}{0}.$$

Differentiating both numerator and denominator with respect to x, the value of the fraction is the same as that of

$$\frac{1}{n(x+iy)^{n-1}+n(x-iy)^{n-1}}$$

and the term multiplied by p_1 therefore becomes $\frac{p_1}{n}$ and the equation to the asymptote is

$$x-y\cot\frac{2r-1}{2n}\pi+\frac{p_1}{n}=0.$$

The intercept of the asymptote on the x-axis is therefore $-p_1:n$, or is the same for all the asymptotes, which therefore all intersect the x-axis in the same point. This result might have been at once obtained by observing that, if we increase the roots of the original equation $f(x)=0$ by the same quantity $p_1:n$, or transfer the origin of co-ordinates for that distance to the left, the term p_1x^{n-1} disappears from the equation.

We have next to determine the asymptotes of Q. Expanding the equation (Q), we get

$$nx^{n-1}+(n-1)p_1x^{n-2}+(n-2)p_2x^{n-3}+\;.\;.\;.\;.\;+p_{n-1}$$

$$-\frac{y^2}{3!}\Big\{n(n-1)(n-2)x^{n-3}+(n-1)(n-2)(n-3)p_1x^{n-4}+\;.\;.\;.\;.\Big\}$$

$$+\frac{y^4}{5!}\Big\{n(n-1)(n-2)(n-3)(n-4)x^{n-5}+\;.\;.\;.\;.\Big\}-\;.\;\;.\;\;.\;\;.\;\;.\qquad =0,$$

or

$$nx^{n-1}-\frac{n\,.\,n-1\,.\,n-2}{3\,!}x^{n-3}y^2+\frac{n\,.\,n-1\,.\,n-2\,.\,n-3\,.\,n-4}{5\,!}x^{n-5}y^4-\;.\;.\;.\;.$$

$$+p_1\Big\{(n-1)x^{n-2}-\frac{n-1\,.\,n-2\,.\,n-3}{3\,!}x^{n-4}y^2+\;.\;.\;.\;.\Big\}$$

$$+p_2\{(n-2)x^{n-3}-\;.\;.\;.\;.\}+\;.\;.\;.\;.=0,$$

or
$$(x+iy)^n-(x-iy)^n+p_1\{(x+iy)^{n-1}-(x-iy)^{n-1}\}$$
$$+p_2\{(x+iy)^{n-2}-(x-iy)^{n-2}\}+\ldots\ldots=0\,.$$

The directions of the asymptotes are given by $(x+iy)^n-(x-iy)^n=0$, and putting $x=r\cos\theta$, $y=r\sin\theta$, this leads to $r^n\sin n\theta=0$,

whence
$$n\theta=0\,,\ \pi\,,\ 2\pi\,,\ \ldots\ldots\ (n-1)\pi\,,$$

and
$$\theta=0\,,\ \frac{\pi}{n}\,,\ \frac{2\pi}{n}\,,\ \frac{3\pi}{n}\ \ldots\ldots\ \frac{n-1}{n}\pi\,.$$

The first of these values corresponds to the x-axis, which is not an asymptote, but is part of the locus of the equation $\sin\left(y\frac{d}{dx}\right)f(x)=0$; and the other values show us that the $n-1$ asymptotes of Q are all real, and that their directions bisect the angles between the directions of the asymptotes of P. It may be proved, as in the case of P, that all the asymptotes pass through the same point on the x-axis at a distance $-p_1:n$ from the origin, so that the n asymptotes of P and the $n-1$ asymptotes of Q all meet in a point, and midway between each adjacent two of the former lies one of the latter.

We will next examine whether the infinite branches lie above or below the asymptotes. For this purpose we resume the equation (A), (see p. 473), and expand x in a series proceeding by negative powers of y. It will, however, simplify the process very much if we transfer the origin to the point of intersection of the asymptotes, or, what comes to the same thing, put $p_1=0$, which may be done without any loss of generality. Putting also $\frac{2r-1}{2n}\pi=\alpha$, equation (A) becomes
$$x=y\cot\alpha-\frac{x-y\cot\alpha}{(x+iy)^n+(x-iy)^n}p_2\{(x+iy)^{n-2}+(x-iy)^{n-2}\}+\ldots\ldots$$

Our first approximation to the value of x is $x=y\cot\alpha$, and we shall get a second approximation by putting this value of x in the term involving p_2. Making this substitution, we get
$$(x+iy)^{n-2}+(x-iy)^{n-2}=\frac{y^{n-2}}{\sin^{n-2}\alpha}\{(\cos\alpha+i\sin\alpha)^{n-2}+(\cos\alpha-i\sin\alpha)^{n-2}\}$$
$$=\frac{2y^{n-2}}{\sin^{n-2}\alpha}\cos(n-2)\alpha\,.$$

Also we have seen that, when we make the same substitution,
$$\frac{x-y\cot\alpha}{(x+iy)^n+(x-iy)^n}\text{ becomes }=\frac{1}{n(x+iy)^{n-1}+n(x-iy)^{n-1}}=\frac{\sin_{n-1}\alpha}{2ny^{n-1}\cos(n-1)\alpha}$$

Hence we have approximately

$$x=y\cot\alpha-\frac{p_2\sin\alpha\cos(n-2)\alpha}{ny\cos(n-1)\alpha}.$$

Now since the roots of $f(x)=0$ are all real and $p_1=0$, we know from the theory of equations that p_2 is negative. And since $\alpha=\frac{2r-1}{2n}\pi$, and is therefore $<\pi$, $\sin\alpha$ is positive. Again

$$\cos(n-2)\alpha=\cos\frac{(n-2)(2r-1)}{2n}\pi=\cos\left(r-\frac{1}{2}-\frac{2r}{n}+\frac{1}{n}\right)\pi=(-1)^{r+1}\sin(2r-1)\frac{\pi}{n};$$

$$\cos(n-1)\alpha=\cos\frac{(n-1)(2r-1)}{2n}\pi=\cos\left(r-\frac{1}{2}-\frac{r}{n}+\frac{1}{2n}\right)\pi=(-1)^{r+1}\sin(2r-1)\frac{\pi}{2n}\cdot$$

Now r ranges from 1 to n, and $(2r-1)\frac{\pi}{2n}$ from $\frac{\pi}{2n}$ to $\frac{2n-1}{2n}\pi$ or $\pi-\frac{\pi}{2n}$; and $\sin\frac{2r-1}{2n}\pi$ is therefore always positive. Lastly, $(2r-1)\frac{\pi}{n}$ ranges from $\frac{\pi}{n}$ to $2\pi-\frac{\pi}{n}$, and $\sin(2r-1)\frac{\pi}{n}$ is positive when $(2r-1)\frac{\pi}{n}<\pi$, or $2r-1<n$ and $r<\frac{n+1}{2}$. The final result is that $x-y\cot\alpha$ is positive when (y being positive) the asymptote lies in the first quadrant, and negative when it lies in the second quadrant; or in both cases the infinite branch lies below the asymptote.

We have thus proved that the curve P has n branches, which cut the x-axis at right angles; and that it has n infinite branches, lying below the n asymptotes which are arranged at equal intervals through the first two quadrants.

For the infinite branches of Q, we have similarly, putting $\beta=r\pi:n$,

$$x=y\cot\beta-\frac{p_2\sin\beta}{ny}\cdot\frac{\sin(n-2)\beta}{\sin(n-1)\beta},\text{ approximately;}$$

and it may be proved, in the same way as for P, that (y being positive) the infinite branches lie below the asymptotes. We thus see that Q has $n-1$ branches, that cut the x-axis at right angles in points which lie singly between two corresponding points of P; also that it has $n-1$ infinite branches lying below the asymptotes which bisect the angles between the asymptotes of P. Again, since $f(x)=0$ has no imaginary roots, the curves P and Q cannot intersect; and it follows that from each point of intersection, either of P or Q, with the x-axis, a branch proceeds up to the corresponding asymptote, without cutting any other branch of either P or Q. This may be proved, as regards P and Q separately, directly from the equations.

Suppose the roots of $f(x)=0$, arranged in descending order of magnitude, to be a, b, c, ... l, then

$$f(x)=(x-a)(x-b)(x-c) \; . \; . \; . \; . \; (x-l) .$$

Hence $\qquad f(x+iy)=(x-a+iy)(x-b+iy) \; . \; . \; . \; . \; (x-l+iy)$

Now let $\qquad \frac{y}{x-a}=\tan \alpha , \; \frac{y}{x-b}=\tan \beta , \; . \; . \; . \; . \; \frac{y}{x-l}=\tan \lambda ;$

and put $\quad \mathrm{R}=\sqrt{\{(x-a)^2+y^2\}} \sqrt{\{(x-b)^2+y^2\}} \; . \; . \; . \; . \; \sqrt{\{(x-l)^2+y^2\}} .$

Then, by an obvious transformation,

$$\begin{aligned} f(x+iy) &= \mathrm{R}\, (\cos \alpha+i \sin \alpha)\, (\cos \beta+i \sin \beta) \; . \; . \; . \; . \\ &= \mathrm{R}\, \{ \cos\, (\alpha+\beta+ . \; . \; . \; .+\lambda)+i \sin\, (\alpha+\beta+ \; . \; . \; . \; .+\lambda)\} \quad . \quad \text{(B)}. \end{aligned}$$

But we have seen that

$$f\,(x+iy)=\cos \left(y\frac{d}{dx}\right)f\,(x)+i \sin \left(y\frac{d}{dx}\right)f\,(x) \quad . \quad . \quad . \quad . \quad \text{(C)}.$$

Hence $\cos \left(y\frac{d}{dx}\right)f(x)=0$ leads to $\cos\, (\alpha+\beta+ . \; . \; . \; .+\lambda)=0$, and $\alpha+\beta+ . \; . \; . \; . +\lambda=\frac{\pi}{2}+m\pi$, where m is an integer ; or to

$$\tan^{-1}\frac{y}{x-a}+\tan^{-1}\frac{y}{x-b}+ . \; . \; . \; .+\tan^{-1}\frac{y}{x-l}=\frac{\pi}{2}+m\pi .$$

This equation admits of an obvious geometrical interpretation. In fig. 17 let R be the point $(x, y,)$ and A, B, C . . . be points on the x-axis at distances from the origin a, b, c . . . . ; then the equation expresses that the sum of the angles RAX, RBX, RCX, ... is equal to $\frac{\pi}{2}$, or $\frac{3}{2}\pi$, or $\frac{5}{2}\pi$, or . . . . $\frac{2n-1}{2}\pi$. When y is positive, each of the angles is $<\pi$ and their sum is therefore $<n\pi$; and the curve has n branches, corresponding to these n values $\frac{\pi}{2}$, $\frac{3}{2}\pi$, ... , and passing through the points A, B, C . . . . respectively. Considering first the branch passing through A, we see that when R moves up to A (see fig. 18), the angle RAX is equal to $\pi : 2$ and each of the angles RBX, RCX . . . . vanishes, so that the sum is equal to $\pi : 2$. Next considering the branch passing through B, when R approaches B, RAX becomes equal to π, RBX to $\pi : 2$, and RCX, ... all vanish ; so that the sum of the angles is $3\pi : 2$. Similarly we see that for the branch passing through C, the sum of the angles when R approaches C, is $5\pi : 2$; and so on, for all the n branches.

Consider next the infinite branches. We have seen that the asymptotes are inclined to the x-axis at angles $\frac{\pi}{2n}$, $\frac{3\pi}{2n}$, $\frac{5\pi}{2n}$, ... $\frac{2n-1}{2n}\pi$; and when the point R moves off to an infinite distance, all the angles RAX, RBX . . . . become equal, and their sum will be $\pi : 2$ for the first asymptote, $3\pi : 2$ for the second, $5\pi : 2$ for the third, and so on, being equal to the sums of the angles when R approaches A, B, C . . . . respectively. We have thus proved that a branch proceeds from A to the first asymptote, another from B to the second asymptote, and so on; but it may be still more conclusively demonstrated as follows.

We have seen that the x-axis cuts the curve (P) in n real points, and that a line parallel to it at an infinite distance also cuts the curve in n real points, being coincident with the points in which it cuts the asymptotes; and I will now prove that any line parallel to the x-axis cuts the curve in n points. Suppose y to have the fixed value k, and x to receive all values from $+\infty$ to $-\infty$; then as x decreases from $+\infty$ to a, $\tan^{-1}\frac{k}{x-a}$ continually increases from 0 to $\frac{\pi}{2}$; and as x continues to decrease to $-\infty$, the angle similarly increases from $\pi : 2$ to π. A similar proposition is true of each of the angles: hence, as x decreases from $+\infty$ to $-\infty$, $\tan^{-1}\frac{k}{x-a}+\tan^{-1}\frac{k}{x-b}+ \ldots .$ (which we may call σ) continually increases from 0 to $n\pi$. In other words, as x decreases, each value of σ occurs only once; therefore, if we assign any value to σ between 0 and $n\pi$, there will be one value of x corresponding to it, and only one. Hence, assigning to σ the values, $\frac{\pi}{2}, \frac{3\pi}{2}, \ldots . \frac{2n-1}{2}\pi$, we get for each, one value of x; or in other words, whatever value k we assign to y, there are n real values of x which satisfy the equation (P). It is easily seen that if, instead of supposing $\tan^{-1}\frac{k}{x-a}$ to increase from 0 to π, we suppose it to increase from π to 2π, or from 2π to 3π, &c., and if we make the like suppositions with regard to the other angles, we shall always get the same values of x if we take in each case the proper value of σ.

Similarly for the curve Q, the equations (B) and (C) (see p. 436) show that $\sin\left(y\frac{d}{dx}\right)f(x)=0$, leads to $\sin(\alpha+\beta+ \ldots . +\lambda)=0$, or $\alpha+\beta+ \ldots . =m\pi$, where m is an integer; or $\sigma=\pi, 2\pi, 3\pi \ldots . (n-1)\pi$. Now we know that Q cuts the x-axis in $(n-1)$ points, one of which lies between A and B, another between B and C, and so on; and reasoning as above we see that when R moves up to the first of these points, σ becomes equal to π; for the second, 2π; and so on. Also the asymptotes are inclined to the x-axis at angles $\frac{\pi}{n}, \frac{2\pi}{n}, \frac{3\pi}{n} \ldots . \frac{n-1}{n}\pi$; and when R moves to infinity along the first asymptote, each of the angles $\alpha, \beta, \gamma \ldots .$ becomes equal to $\pi : n$, and their sum is π; for the second asymptote, the sum is 2π; and so on. Lastly, if we suppose y to have the fixed value k, and assign to σ the values, π, 2π, 3π . . . ., we get $(n-1)$ values of x; and since the values of σ lie singly between two adjacent values of σ for the curve P, we see that the $n-1$ points in which the straight line $y=k$, cuts the curve Q, lie singly between the n points in which it cuts P. Thus the proposition enunciated at the outset is completely established.

When the roots of $f(x)=0$ are not all real, the equations (P) and (Q) still admit of a simple geometrical interpretation. Suppose there is a pair of imaginary roots $f+ig$, $f-ig$; then the corresponding factors in $f(x+iy)$ become

$$\begin{aligned}(x-f-ig+iy)(x-f+ig+iy)&=R_1R_2(\cos\mu+i\sin\mu)(\cos\nu+i\sin\nu)\\&=R_1R_2\{\cos(\mu+\nu)+i\sin(\mu+\nu)\}\end{aligned}$$

if $R_1^2=(x-f)^2+(y-g)^2$, $R_2^2=(x-f)^2+(y+g)^2$, $\tan\mu=\frac{y-g}{x-f}$, $\tan\nu=\frac{y+g}{x-f}$.

It is easy to see from this that $\cos\left(y\frac{d}{dx}\right)f(x)=0$ leads to

$$\tan^{-1}\frac{y}{x-a}+\tan^{-1}\frac{y}{x-b}+\ .\ .\ .\ .\ +\tan^{-1}\frac{y-g}{x-f}+\tan^{-1}\frac{y+g}{x-f}+\ .\ .\ .\ .\ =\frac{\pi}{2}+m\pi.$$

In fig. 19, let R be the point (x, y), $OA=a$, $OB=b$, ... $OF=f$, $RS=RT=g$; then the equation expresses that the sum of the angles RAX, RBX . . . . SFX, TFX, ... is equal to $\frac{\pi}{2}$, or $\frac{3}{2}\pi$, or $\frac{5}{2}\pi$, &c.; or the curve P is the locus of a point for which this is the case. Similarly the curve Q is the locus of a point for which the sum of the angles is π, 2π, 3π, ... Whether the roots of $f(x)=0$ are real or imaginary, the n asymptotes of P and $n-1$ asymptotes of Q, are all real; but when some or all of the roots are imaginary, our demonstration that the infinite branches lie below the asymptotes, no longer applies; for p_2 may then be either positive or negative.

In conclusion, it may be useful to give a few examples of the actual forms of the curves.

First, we will take a case where all the roots are real

$$x^4-25x^2+60x-36=(x-1)(x-2)(x-3)(x+6)=0.$$

Then the equations to the two curves are

$$y^4-6x^2y^2+x^4+25(y^2-x^2)+60x-36=0\quad .\ .\ .\ .\quad (P)$$

$$2y^2x-2x^3+25x-30=0\quad .\ .\ .\ .\ .\quad (Q)$$

and the curves assume the shape shown in fig. 20, where the thin branches belong to P and the thick belong to Q. Consistently with what has gone before, P and Q do not intersect, but a branch of Q lies between each adjacent two branches of P; and, the equation being of the fourth degree, P has four asymptotes and Q has three, which all pass through the origin, and are arranged at equal angles around it as already explained.

Next take an equation with all its roots imaginary, say $1 \pm \sqrt{-1}$, $-1 \pm \sqrt{-2}$, so that $f(x) = (x^2 - 2x + 2)(x^2 + 2x + 3)$ and the equation is $x^4 + x^2 - 2x + 6 = 0$.

Then the equations to the two curves are

$$y^4 - 6x^2y^2 + x^4 - y^2 + x^2 - 2x + 6 = 0 \quad . \quad . \quad . \quad . \quad (P)$$

$$2y^2x - 2x^3 - x + 1 = 0 \quad . \quad . \quad . \quad . \quad (Q)$$

and the curves intersect in four points, as shown in fig. 21.

When the four roots are all imaginary, the curves may be arranged in a widely different way from that here shown. Thus, if the roots are $1 \pm 4\sqrt{-1}$, $-1 \pm 8\sqrt{-1}$, so that

$$x^4 + 78x^2 - 96x + 1105 = 0$$

the equations to the two curves may be put in the form

$$y^2 = 3x^2 + 39 \pm \sqrt{8x^4 + 156x^2 + 96x + 416} \quad . \quad . \quad . \quad . \quad (P)$$

$$y^2 = x^2 + 39 - \frac{24}{x} \quad . \quad . \quad . \quad . \quad (Q)$$

and the curves will lie as shown in fig. 22. They still intersect in four points, but the branches of the P curve now touch the asymptotes (1, 4), (2, 3), instead of (1, 2), (3, 4), as in fig. 21. It follows that there will be a transition position, in which the branches will touch the asymptotes (1, 3), (2, 4), and will cross, so that the curve P will have two double points.

Lastly, take an equation with two real and two imaginary roots, say $1 \pm \sqrt{-1}$, 2, -4, so that $x^4 - 10x^2 + 20x - 16 = 0$. Then the equations to the two curves become

$$y^2 = 3x^2 - 5 \pm \sqrt{8x^4 - 20x^2 - 20x + 41} \quad . \quad . \quad . \quad . \quad (P)$$

$$y^2 = x^2 - 5 + \frac{5}{x} \quad . \quad . \quad . \quad . \quad . \quad (Q).$$

In this case the curves intersect in two points, as shown in fig. 23. Here the real part of the imaginary roots lies between the two real roots; let us therefore take another instance in which this is not the case. Thus let the roots be $2 \pm \sqrt{-1}$, -1, -3, so that $x^4 - 8x^2 + 8x + 15 = 0$. Then the equations to the two curves are

$$y^2 = 3x^2 - 4 \pm \sqrt{8x^4 - 16x^2 - 8x + 1} \quad . \quad . \quad (P)$$

$$y^2 = x^2 - 4 + \frac{2}{x} \quad . \quad . \quad . \quad . \quad (Q)$$

and the curves intersect in two points, as shown in fig. 24. Comparing this with fig. 23, we see that, whereas the infinite branches of P then touched the asymptotes $(1, -4)$, $(2, 3)$, $(4, -1)$, $(-2, -3)$, they now touch the asymptotes $(1, 2)$, $(3, -2)$, $(4, -1)$, $(-3, -4)$. It follows that there must be a transition position in which the branches touch the asymptotes $(1, 3)$, $(2, -1)$, $(4, -1)$, $(2, -3)$, so that P has two double points.

If we now examine the relations of the P and Q curves in figs. 20–24, we see that they satisfy the conditions laid down at the outset, bearing in mind that the x-axis must in each case be considered, for this purpose, a part of the Q curve.

Since the foregoing was written I have met with some remarks of the late Professor De Morgan on the curves P and Q, contained in a paper of his read before the Cambridge Philosophical Society on 7th December 1857. He remarks that these curves "are such that two branches, one of each curve, "cannot inclose a space." This is a particular case of the properties investigated in the early part of this paper. He also remarks that the curves "always "intersect orthogonally," but he gives no proof of this. It may be proved as follows.

Let h, k, be the co-ordinates of a point of intersection of P and Q, and θ, θ', the angles which the tangents to P and Q at the point, respectively make with the x-axis. If $\phi(xy)=0$ is the equation to a curve, then for any point (x, y), $\frac{dy}{dx}=-\frac{d\phi}{dx}\div\frac{d\phi}{dy}$. Applying this formula to (P) and (Q) (p. 430) we have

$$\tan\theta=\frac{f'(h)-\frac{k^2}{2}f'''(h)+\frac{k^4}{4\,!}f^{\text{v}}(h)-\dots.}{kf''(h)-\frac{k^3}{3\,!}f^{\text{iv}}(h)+\dots.}$$

$$\tan\theta'=\frac{f''(h)-\frac{k^2}{3\,!}f^{\text{iv}}(h)+\frac{k^4}{5\,!}f^{\text{vi}}(h)-\dots.}{\frac{2k}{3\,!}f'''(h)-\frac{4k^3}{5\,!}f^{\text{v}}(h)+\dots.}$$

Hence

$$\tan\theta\tan\theta'=\frac{f'(h)\quad\frac{k^2}{2}f'''(h)+\frac{k^4}{4\,!}f^{\text{v}}(h)-\dots.}{\frac{2k^2}{3\,!}f'''(h)-\frac{4k^4}{5\,!}f^{\text{v}}(h)+\dots.}$$

and

$$\tan\theta\tan\theta'+1=\frac{f'(h)-\frac{k^2}{3\,!}f'''(h)+\frac{k^4}{5\,!}f^{\text{v}}(h)-\dots.}{\frac{2k^2}{3\,!}f'''(h)-\frac{4k^4}{5\,!}f^{\text{v}}(h)+\dots.}$$

and the numerator of this fraction $= 0$, since h, k, satisfy the equation (Q). Hence $\tan\theta\tan\theta'=-1$, or the tangents are at right angles to each other.

Fig 1.

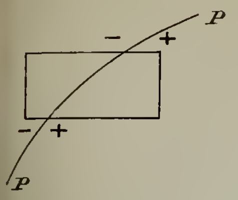


Fig. 2.

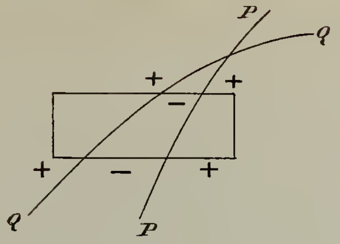
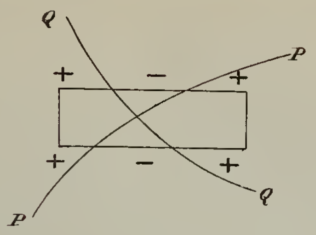


Fig. 3.



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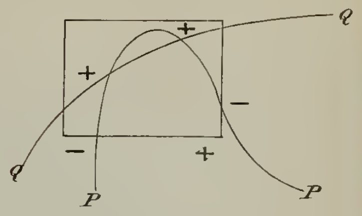


Fig. 5

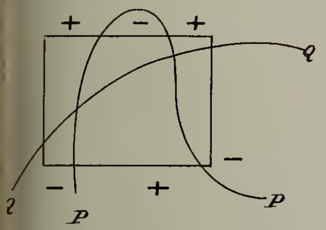


Fig. 6.

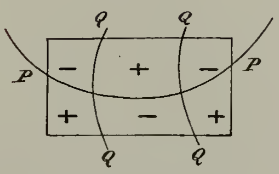
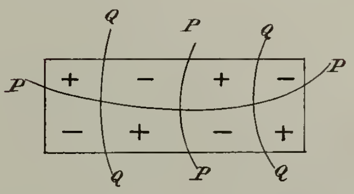


Fig. 7



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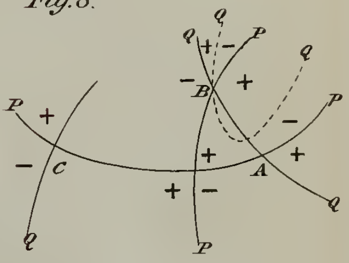


Fig. 9

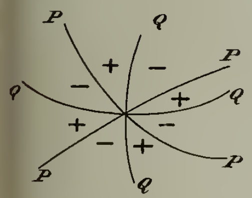


Fig. 10

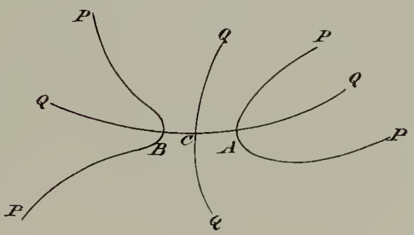


Fig. 11

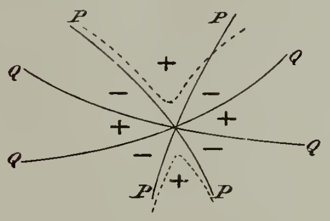


Fig. 12

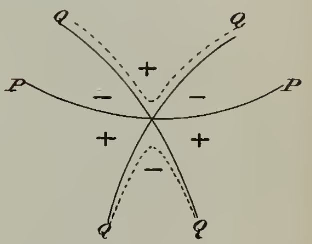


Fig. 13

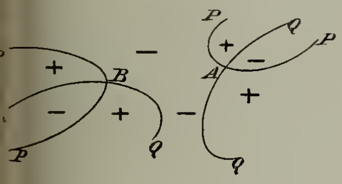


Fig. 14

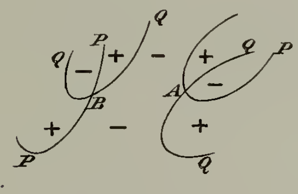


Fig. 15

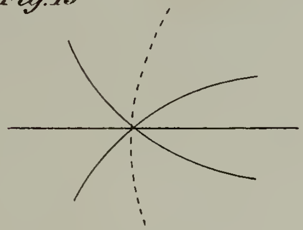


Fig. 16.

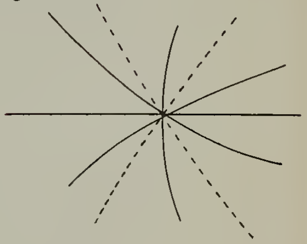


Fig. 17

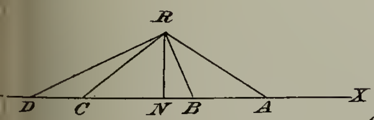


Fig. 18

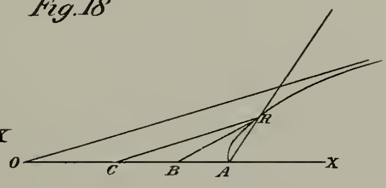


Fig. 19

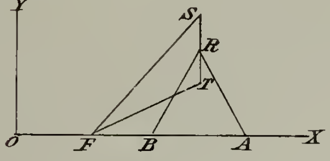


Fig. 20

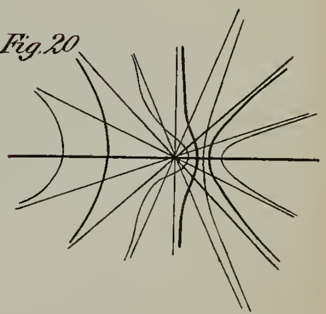


Fig. 21

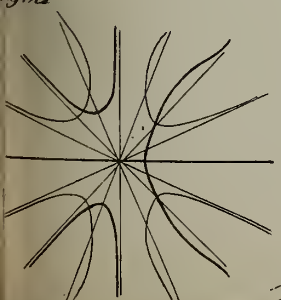


Fig. 22

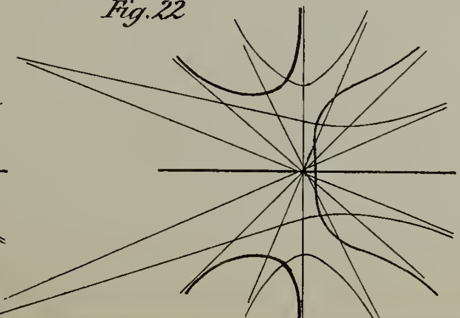


Fig. 23.

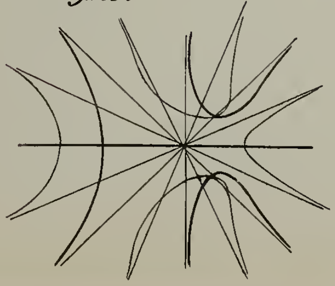
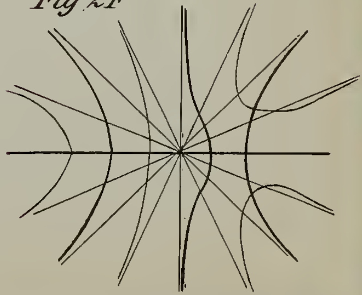


Fig. 24



J. Bartholomew Edin.^r

XX.—*On the Anatomy and Histology of* Pleurochæta Moseleyi. By F. E. Beddard, B.A, New College, Oxford. (Plates XXV. to XXVII.)

(Read 17th April 1882.)

Two specimens of the worm which forms the subject of this memoir were brought to Professor Moseley, in 1872, by a coolie trained for the purposes of collecting by Dr. Thwaites, F.R.S., the distinguished curator of the Peradeniya Gardens at Kandy; each was found at the bottom of a deep burrow, in company with a single egg-case, in the neighbourhood of that town. Professor Moseley entrusted me with them for study and description, and I have to thank him for much valuable assistance during the course of my work, which was carried on in the Oxford Natural History Museum.

This earthworm in external characters presents some resemblance to *Perichæta leucocycla* of Schmarda,* and my friend Mr. W. Hatchett Jackson informs me that its colour when it first arrived from Ceylon agreed perfectly with Schmarda's description of *P. leucocycla,* the white line on each segment being very noticeable. But its organisation differs to so marked an extent from all the other Perichætous worms which have been hitherto studied, that I am unable to regard it as really belonging to this group; and, moreover, Schmarda's description, except in the matter of the colour, does not in the least apply to the species I have studied. His species has no clitellum, and consists of 88 segments, each segment being provided with a continuous ring of setæ; in my species there is a distinct clitellum present, and the number of segments is 260, each provided with about 140 setæ not arranged in a continuous ring, but failing on the dorsal and on the ventral median line. Furthermore, the shape of the setæ differs in the two species; in Schmarda's worm the more swollen part is in the centre, while in the species which forms the subject of this memoir the more swollen part is in the upper third of the seta (*cf.* figure given by Schmarda with Plate XXVI. fig. 13).

The description given by Templeton† of *Megascolex cœruleus* agrees rather more closely with the worm I am about to describe, but differs in many important particulars; in *Megascolex* the circle of setæ is not continuous, there being left a dorsal area on which no setæ are developed. This description of

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* Schmarda, *Neue wirbellose Thiere.*

† *Proceedings of the Zoological Society,* 1844, pp. 89, 90.

TEMPLETON's is entirely misunderstood by SCHMARDA,* who makes him responsible for the statement that only a dorsal row of setæ is present, and LEON VAILLANT, in a work † which will be alluded to at greater length presently, falls apparently into the same error. In my annelid there is in addition a ventral area on which no setæ are developed, and this is rather more marked than the dorsal area, from the fact that it is perfectly regular and symmetrical, while in the former the setæ leave off at different distances from the median line in different segments, which causes it to appear rather less conspicuous than the ventral area; but at any rate an observer who noted the one could hardly fail to note the other. Moreover, in *Megascolex*, the generative organs are described as occupying the 16th, 17th, and 18th segments. SCHMARDA appears to consider that this description refers to the clitellum, which he accordingly states, on the authority of TEMPLETON, to be developed in those segments; in the annelid to be described here, the clitellum occupies about seven segments commencing after the 12th, and the testes are developed in the 12th: hence I have no hesitation in regarding this annelid as quite distinct from *Megascolex cœruleus.*

Whether SCHMARDA and myself are describing the same animal or not is rather difficult to say; I am on the whole inclined to suspect that we are, from the similarity of the colour; the absence of the clitellum and the number of the segments may be accounted for on the hypothesis that the specimen described by SCHMARDA was a young one. But whether this is so or not, a careful study has convinced me that this annelid cannot be classed with the genus *Perichæta,* since their affinities, which will be pointed out later on, are not of so close a character as to warrant the inclusion of the two types in the same genus; accordingly, I have placed it in a genus by itself, and propose for it the name *Pleurochæta Moseleyi.* The generic name serves to express the most important external character, viz., position of setæ in two lateral groups; the species I call after Professor MOSELEY, since it is through his liberality that I have had the opportunity of studying it.

I will give briefly the most important facts in the anatomy of this animal before discussing in detail its various structures.

Pleurochæta Moseleyi is about 28 inches in length, and is made up of some 260 segments, of which from seven to nine are occupied by the clitellum, and twelve are pre-clitellian. The setæ are developed in all the rings of the body, but are more numerous in the post-clitellian region, being there about 140 to each segment. Setæ are present in the ventral part of the clitellum. The alimentary canal consists of the ordinary divisions, pharynx, œsophagus,

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* *Loc. cit.*

† "Note sur l'Anatomie de deux espéces du genre Perichæta et essai de classification des Annelides Lumbriciens," *Annales des Sciences Naturelles,* 5th series, vol. x.

gizzard, small and large intestines; the large intestine is characterised by an extraordinary development of specialised glands. Certain of the anterior mesenteries are thickened and muscular; dorsal pores are very distinct, commencing after the clitellum, and extending to within eight or nine segments of the end of the body. No segmental organs were detected. Vascular system consists of a dorsal trunk, a ventral supra-nervian trunk, two small supra-intestinal trunks and two lateral; the dorsal and ventral vessels are united by six pairs of arches, which increase in size from before backwards, the last two pairs being the thickest. The other vessels are not directly united, but indirectly by means of capillaries. The generative system consists of one pair of testes, which have the form of racemose glands, and are situated in the 12th segment; of two receptacula seminis opening respectively between the 7th and 8th, and 8th and 9th segments; of four fimbriated organs, with ciliated openings into body cavity, and duct opening to exterior through body wall of segment behind; these organs, concerning the nature of which it is difficult to speak with certainty, are situated in 11th and 10th segments on anterior wall of mesentery. A pair of rosette-shaped glands are found on mesentery separating 11th from 10th segment, the nature of which again is doubtful. In the 17th, 18th, and 19th segments are three pairs of openings, the middlepair of which are continuous with the ducts of two large solid white glands; with the other two pairs of openings, no ducts were seen to be continuous. The clitellum extends from 13th segment to about 20th inclusive, and is readily distinguished from rest of body by its yellow glandular appearance; another pair of openings, to which Professor Moseley drew my attention, are situated in the 13th segment.

These are the main facts in the anatomy of *Pleurochæta.* I will now proceed to consider them in detail, and in so doing shall adopt the order in which M. Perrier, in his numerous and valuable memoirs on the anatomy of *Oligochæta* published in the *Archives de Zoologie Expérimentale* and other journals, describes the various organs and systems, for the purposes of an easier comparison.

Tegumentary System.

Under this head will be described the five layers which separate the body cavity of the animal from the external medium, commencing from the outside.

(1) *Cuticle.*—There is nothing particular to be said concerning its structure; it appears to resemble in every detail the same structure in other worms, exhibiting fine striæ running in two directions nearly at right angles to each other, and minute pores situated frequently at the intersection of two striæ.

(2) *Hypodermis.*—The cellular layer which underlies the cuticle is generally described by this name; concerning its structure in *Pleurochæta* I am not able

to say very much. The specimen from which my sections were taken, though admirable for displaying many points in the histology of the animal, had not its hypodermic layer well preserved, the constituent cells were not distinguishable, the whole was visible simply as a granular mass; this may be owing perhaps to the fact that the tissues were hardened with alcohol, which PERRIER states to be a very poor reagent for displaying the structure of the hypodermic cells. But one very important fact in the constitution of the hypodermic layer I was able to make out—the presence of capillaries. In a short paper on the epidermis of the leech, Professor LANKESTER,* describes and figures capillaries in the same situation lying between the epidermic cells, and at the same time states the only other annelid in which they had been hitherto found to be the earthworm, and there not generally throughout the body wall, but only in the clitellum. In *Pleurochæta* they are very evident, running up through the two muscular layers and ending in the hypodermis; their exact relation to the constituent cells I was unable to make out, for the reasons already stated, nor could I satisfy myself as to their exact mode of ending, though I should presume, from analogous cases, that they terminate in loops. In many of my sections, especially those stained in aniline blue, the capillaries of the integument were most beautifully conspicuous; the coagulated blood having taken up the staining fluid rather more than the surrounding muscles, connective tissue, &c. It is very possible that the distribution of capillaries to the outer epidermic layer of worms and other animals is much more common than is generally supposed, and they may have been in many cases overlooked, owing to their insignificant size; it seems natural that many of these animals without a specialised respiratory apparatus, should breathe by means of their skin; and this would be greatly facilitated where the epidermis and cuticle are at all thick, by a capillary network in the epidermis itself. I intend to direct my attention to this point on some future occasion.

(3) *Muscular Coats.*—The two muscular layers of the body wall are, as in other worms, an outer transverse and an inner longitudinal layer. The individual muscles are of various sizes, and appear to resemble in histological structure the muscles of other annelids. My observations agree with those of CLAPARÈDE and PERRIER.† The arrangement of the muscles is, however, very peculiar, and requires a minute description, as it appears to differ considerably from anything that has been yet observed, with the exception of *Pontodrilus* described by PERRIER in the memoir just alluded to. A transverse section through the body wall in a direction at right angles to the outer circular layer is shown in Plate XXVI. fig. 5. It will be observed, that immediately beneath

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* *Quarterly Journal of Microscopical Science*, vol. xx.

† *Archives de Zoologie Expérimentale*, vol. ix., 1881.

the hypoderm, which is represented diagrammatically, is a network of fibrous tissue, within the meshes of which lie the muscular fibres cut transversely, either singly or in groups of two or more. The strands of connective tissue separating the muscles appear to be elastic tissue; they are stouter in the lower part of the transverse coat than in the upper; towards the surface they become finer, but here and there stouter bands form largish compartments, which are again divided up by the finer bands between which lie the muscles. A more deeply stained continuous membrane separates the muscular from the hypodermic layer; beneath the fibrous bands of the circular coat are perfectly continuous with those of the longitudinal coat.

The longitudinal is essentially similar to the circular coat, but the fibrous bands are far slighter; in fact, unless the section is rather stretched, it is very easy to miss them altogether, but quite impossible in the case of the outer circular coat. The advantages of this elastic network to the animal must be enormous, giving its skin so great a flexibility, and that not at the expense of its muscles. It is rather difficult to compare the thickness of the two coats, as the presence of the elastic tissue renders them so easy of compression or of extension, that in the case of a given section one cannot say with certainty whether it really represents the skin of the animal in its normal condition or not. On the whole, it would appear that the two coats are about equal in thickness, except in the anterior part of the body where the longitudinal coat is considerably thicker (see Plate XXVI. fig. 15, which is taken from a young specimen, but would do perfectly well for the adult in this respect), and has a much more strongly developed fibrous meshwork (Plate XXVI. fig. 13). PERRIER[*] figures and describes a somewhat similar arrangement in *Pontodrilus marionis*, but apparently confined to the inner longitudinal coat; the meshes also enclose a far greater number of fibres.

In his researches into the common earthworm, CLAPARÉDE[†] figures and describes strands of fibrous tissue separating the bundles of muscular fibres in the inner longitudinal coat, giving to the muscles the bipinnate arrangement so characteristic of the earthworm. This is very evident on examining sections of the integument of the earthworm; but, as PERRIER remarks, it is not at all generally found among the *Oligochæta*. Comparing, however, sections of the integument of *Lumbricus* with that of *Pleurochæta*, and finally with the figures given by PERRIER of the same structure in *Urochæta*,[‡] it would seem that the arrangement in *Lumbricus* is only an extreme modification of what is found in *Pleurochæta*, and that there exist in this latter arrange-

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[*] PERRIER, *loc cit.*, pl. xvi. fig. 27.

[†] "Histologische Untersuchungen ueber den Regenwürm," *Zeitschrift für Wissensch. Zoologie*, 1869.

[‡] PERRIER, *Archives de Zoologie Experimentale*, vol. iii., 1874.

ments of the muscular fibres showing various intermediate stages between the bipinnate muscular bands of *Lumbricus* and the fibres of *Urochæta*, which are present in a continuous mass without any dividing septa of connective tissue. In *Lumbricus* the longitudinal muscular layer may be regarded as being composed of a series of compartments formed of trabeculæ of fibrous tissue, in the interior of which lie the actual muscular fibres. On Plate XXVI. fig. 10 is a diagram of this; the fibres are developed close to the septa themselves, and thus give rise to the bipinnate arrangement so well displayed in the drawings of CLAPARÈDE. In *Pleurochæta* a distribution of the muscular fibres exactly like this does not exist, but in the anterior segments the longitudinal coat is divided in a precisely similar manner into compartments, only that there are more muscular fibres in each compartment, and they are not all developed close to the septa. In a young specimen not more that 1½ inches in length, which I had the opportunity of examining, and which will be described in the last part of this memoir, a section through the anterior end of the body (Plate XXVI. fig. 15) showed the muscular fibres arranged in vertical lines, which were more thickly congregated in the neighbourhood of the septa, and possessing therefore an "orientation determinée," differing only in degree from that of *Lumbricus*. In the adult *Pleurochæta* sections through the body wall in the anterior region show a somewhat similar arrangement; the longitudinal coat, which is here rather more than double the thickness of the circular coat, is divided into compartments, bounded by very thick bands of fibrous tissue, the interior of each compartment being again subdivided by other trabeculæ; between each pair of compartments (Plate XXVI. fig. 13) there is frequently a space for the insertion of the lower end of a seta, in which only delicate fibres of connective tissue are visible: in this case, however, the muscle fibres have no fixed and definite arrangement, and they are not specially developed at the margin of the compartment. In the hinder part of the body the longitudinal muscular layer is not divided up, but here and there (Plate XXVI. fig. 4, *a*) a stronger trabecula serves to point out the boundary of regions which correspond to the anterior compartments; here too, as already stated, the development of fibrous tissue is much slighter than in the anterior part of the body; a comparison of figs. 4 and 13 will make this clear. Finally, in the figures of *Urochæta*, given by PERRIER, the longitudinal muscular layer (as well as the circular) is entirely without this fibrous network.

PERRIER, in his account of the anatomy of *Pontodrilus*, in which animal the longitudinal muscles are arranged in a manner similar to that which has already been described as occurring in the posterior region of the body wall of *Pleurochæta*, comparing the account given by CLAPARÈDE for *Lumbricus* with his own description of *Pontodrilus*, says (page 186), "La difference essentielle qui existe entre cette disposition et celle qui est propre aux Lombrics c'est que dans chaque groupe de faisceaux, ces derniers n'ont pas une orientation determinée et l'on ne retrouve plus par conséquent cet arrangement si regulier qui frappe tout de suite chez ces derniers animaux." I have attempted to show, in the preceding description of the muscular layers of *Pleurochæta*, that there are a series of transitions between the muscles of *Lumbricus* and those of other forms; this series is not very complete, but it serves to indicate that there is nothing really peculiar in the muscles of the former.

Setæ are found in great numbers in *Pleurochæta*, and their characteristic distribution has been already treated of. They are in shape like the ordinary forms of setæ among the *Oligochæta*, that of an elongated *S*; in *Pontodrilus* we have apparently the only exception to this rule; in that genus the setæ are straight and rod-like. The length of the setæ of *Pleurochæta* vary from ·035 mm. to ·066 mm.; they are therefore rather small in comparison with those of other *Oligochæta*; in *Pontodrilus*, for example, the length is about ·16 mm., and the largest setæ of *Lumbricus* that I have measured myself are from ·1 mm. to ·12 mm. Plate XXVI. fig. 13 shows one of the setæ in position. The section is taken from the anterior part of the body; the seta, which is of the ordinary amber yellow tint, lies in a diverticulum of the outer chitinous layer of the integument, and extends downwards through the circular muscular layer and someway into the longitudinal (*a* marks the boundary of the two coats); towards the middle of the seta there is a slight swelling, which appears to contain spaces filled with air; this swollen part is developed about the end of the upper third of the seta; in other worms its position is rather different; it appears to be fairly central in the *Perichæta* described by LEON VAILLANT.* In *Urochæta*† it is rather nearer the upper end, and also in *Lumbricus*.

The free extremity is curved rather sharply, the opposite end being rounded off, and very faintly bifurcate. The texture is uniform, except for the presence of faint wavy transverse markings and longitudinal striations. The arrangement of the setæ and the muscles which move them present no important differences from other *Oligochæta*. The seta is enclosed in a "cul-de-sac" formed by a fold of the cuticular membrane. Each is provided with its special muscles, which are inserted into the cuticular covering of the seta at one end, and at the other some of them appear to be inserted close to the hypoderm, and others to form part of a continuous layer of muscles connecting the several setæ of one segment, while others again seem to join the outer or transverse muscular layer of the body wall. These special muscles of the seta appear to be arranged in about six bundles, radiating outwards from the cuticular

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* VAILLANT, *loc. cit.*

† PERRIER, *loc. cit.*

covering of the seta; in Plate XXVI. fig. 16, which represents an oblique section through the body wall in the neighbourhood of a seta, three of these bundles are seen in longitudinal section reaching from the cuticle, which surrounds the seta itself, to the base of the hypoderm layer; the others are cut transversely, and lie behind the seta.

Clitellum.—The histological structure of this differentiated part of the integument will be best considered in this place in relation to the rest of the integument, while the description of the number of segments of which it is composed, and the positions of the apertures of the generative organs, will be deferred until the generative system is treated of.

The clitellum has been carefully studied by CLAPARÉDE,* and more recently by MOJSISOVICS,† in the common earthworm; and since this is the only type in which, up till the present, the clitellum has been accurately described and figured, it will be as well to give briefly the results of these two observers, for the sake of comparing it with the clitellum of *Pleurochæta*, which is in some respects different.

According to MOJSISOVICS, the clitellum of the earthworm differs from the rest of the integument (1) by the modification of the hypoderm cells, and (2) by the additional presence between the hypoderm and circular muscular coat of a glandular layer well supplied with blood-vessels. The hypoderm cells differ from those over the rest of the body by being much more granular; the glandular layer consists of several rows of flasked-shaped cells finely granular, and frequently possessing a nucleus, imbedded in a network of connective tissue. These two layers differ chemically, as is shown by coloration with picro-carmine and logwood (see figs. 9, 11 of his memoir). The capillaries extend half way up the outer hypoderm layer.

CLAPARÉDE's account differs somewhat; he figures a hypoderm layer distinct from the subjacent glandular layer, which latter he subdivides into "obere" and "untere Saülenregion;" beneath this again a special vascular layer. Accordingly the "hypoderm layer" of MOJSISOVICS equals the hypoderm *plus* the "obere Saülenregion" of CLAPARÉDE. Both observers agree that the glands are unicellular. MOJSISOVICS figures the capillaries extending half way up the hypoderm cells, leaving off just where, on CLAPARÉDE's interpretation, the hypoderm cells begin (compare figs. 9, 11 of MOJSISOVICS, with plate xlvi. fig. 1 of CLAPARÉDE's memoir), and this makes one almost suspect that the earlier idea of CLAPARÉDE may be after all the right one.

In *Pleurochæta* the glandular layer of the clitellum appears to be distinct from the hypoderm layer which covers it; there is a band of fibrous tissue dividing the glandular layer from the hypodermic; this band is readily seen

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* CLAPARÉDE, *loc. cit.*

† MOJSISOVICS, "Kleine beiträge zur Kenntniss der Anneliden," *Sitz. Acad. Wissensch.*, 1877.

in sections stained with picro-carmine, as it shows a rose tint, while the glandular tissue is stained of an orange-yellow; so far there is a similarity with the clitellum of *Lumbricus,* as understood by CLAPARÈDE; but in *Pleurochæta,* the capillaries, which are in this part of the integument larger, and far more numerous than over the rest of the body, are continued into the hypodermic layer, instead of stopping short at the septum, as they do in the earthworm. Unfortunately, none of the cells of the hypodermic layer were in a fit condition for examination; as in the case of the rest of the integument, nothing was left to indicate the form of the cells, and their relations to the capillaries. The glandular layer is divided up into columns by trabeculæ of connective tissue, running down to join a stouter fibrous septum, which separates off the glandular layer from the circular muscular coat. This septum (Plate XXVI. fig. 7) is perforated here and there for the transmission of blood-vessels. Between the trabeculæ lie the glandular cells, which do not seem to have any definite arrangement; they are of various sizes, occasionally provided with a nucleus at their lower end, and flask-shaped, the "neck" of the "flask" being produced upwards as the duct of the unicellular gland. The appearances displayed in fig. 17 do not mean that the glands are multicellular, they would seem rather to be the effect of reagents on a single cell. But though, as in *Lumbricus,* the glands of the clitellum are unicellular, there are here and there indications of the combination of the gland cells into veritable glands. Plate XXVI. fig. 3 shows this; here in a definite region the gland cells are massed together, forming a more or less oval-shaped body, while on either side the cells continue isolated from each other; but there is no common duct. Each cell is, as in the rest of the clitellum, as far as can be made out, provided with its own duct; this, however, is the first step in the formation of a specialised compound gland. These glands can be recognised on the clitellum with the naked eye as yellowish spots and patches. Plate XXVI. fig. 6 is a general view of a section through the clitellum; at *a* are the remains of the hypoderm cells, and the more or less distinct fibrous band separating the hypoderm from the subjacent glandular layer; in this latter lie the cells *b* of various sizes, arranged in columns by the trabeculæ of connective tissue *c*. Beneath these are the two muscular layers. As in the rest of the body, the muscular fibres in the two coats are divided up into groups, by branching and anastomosing trabeculæ. The muscular fibres of the circular coat are occasionally found trespassing on the outer side of the septum, which separates the glandular from the muscular coat (see fig. 11). Setæ are found on the clitellum, but their form is in nowise different from the setæ found over the rest of the body.

(4) *Peritoneal Membrane.*—This structure, which lines the peritoneal cavity,

forming therefore the innermost layer of the body wall, differs in no respect from the same structure in *Lumbricus.*

Body Cavity.

There is not very much to be said under this head. The body cavity communicates with the exterior by a series of dorsal pores, one to each segment, commencing after the clitellum, and continuing to within eight segments of the end of the body; these dorsal pores are very general in the *Oligochæta,* and are found in *Perichæta, Lumbricus,* and other genera, but not in *Pontodrilus* and *Urochæta.** Another fact of importance is the enormous thickening of some of the anterior mesenteries, which is not peculiar to *Pleurochæta,* but is found elsewhere. The last of these thick mesenteries separates the clitellum from the fore part of the body, and therefore marks the posterior boundary of the 12th segment. There appear to be six of these specially thickened mesenteries; they extend forward to the posterior end of the gizzard, the first one marking the boundary between the 6th and 7th segments; these mesenteries are united by ligamentous cords one to another, and as the "hearts" lie in this region of the body, their function may be to aid in their contraction, or perhaps they are merely protective. Similar thickened mesenteries are described by Perrier as existing in *Anteus* and *Urochæta*;† and as *Pleurochæta* ought possibly to be regarded as one of the Intraclitellian *Oligochæta,* this fact may be of some significance. A transverse section through one of these thickened mesenteries shows that they are composed of two layers of muscular fibres.

In the posterior region of the body the mesenteries are thin and membranous: in the most anterior segments the mesenteries are hardly at all separated, but are metamorphosed into a mass of muscles connecting the pharynx with the body wall (see Plate XXV. fig. 1).

As has been already mentioned, there are no segmental organs in *Pleurochæta*; it is, however, not a unique example; in a *Perichæta* from Java, Dr. Horst‡ asserts the absence of segmental organs, and generally throughout the genus *Perichæta* there is an absence or a very small development of these organs.

Alimentary Tract.

The alimentary canal of *Pleurochæta* resembles that of most other *Oligochæta* in its main divisions. The mouth leads into a pharynx, the walls of

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* Perrier, *loc. cit.,* p. 192.

† Perrier, *Arch. de Zool. Exp.,* vol. iii.

‡ Horst, "Ueber eine neue Perichæta von Java," *Nederlandisch. Archiv. für Zoologie,* iv. p. 163.

which are thick and muscular; the pharynx is bound to the body wall by a quantity of muscles running in every direction, in the interstices of which lie the pharyngeal glands; these glands are compound and tubular, and appear to ramify everywhere among the muscles of the pharynx. Their presence is noted by PERRIER[*] in *Pontodrilus,* but according to CLAPARÈDE,[†] they are absent from the earthworm. After the pharynx comes the œsophagus, which is folded several times upon itself, so as to occupy only one or two segments; the œsophagus is entirely unprovided with glands, and in this respect *Pleurochæta* differs from most other worms. In *Perichæta Houlleti,*[‡] for example, there are a great many variously specialised œsophageal glands; and in many other types, such as *Urochæta,* there are the so-called glands of Morren, opening into the œsophagus, which in the common earthworm have been termed the "calciferous glands."[§] The gizzard, which forms the next division of the alimentary canal, is somewhat pear-shaped, the broad end lying towards the fore part of the body. The posterior portion of the gizzard has enormously thickened muscular walls, the anterior portion (see Plate XXVII. fig. 8) is thinner and more glandular; its walls are thrown into longitudinal corrugations. The walls of the gizzard secret a chitinous layer which forms a perfectly continuous structure attached to the walls of the gizzard only at its two extremities; it presents the appearance of a cone of stiff white paper with various prominences and folds; its shape will be understood from a glance at fig. 8, where it is drawn in position in the interior of the gizzard. This cuticular lining exhibits in thin sections a certain structure: the whole membrane is perforated by a series of minute canals, and the inner half appears distinctly granular, while the outer half, with the exception of the canals, is homogeneous. The histological structure of the walls of the gizzard is not remarkable. There is an inner layer of tall columnar cells, which are about ·0125 mm. in length and ·0005 in breadth, and an outer layer of muscular fibres arranged in a direction transverse to the long axis of the gizzard, forming in fact a circular coat; near to the epithelium lining the gizzard there are also a set of muscular fibres running at right angles to circular muscles, radiating outwards from the epithelium; these fibres are, however, interspersed among the circular fibres, and do not form a distinct layer.

Leading out of the gizzard, we have the intestine, which is primarily divisible into two portions,—an anterior "small intestine," which extends from the 8th to the 16th segments, and a posterior "large intestine," which occupies the rest of the body, and is itself divisible into several regions. The small intestine is

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[*] PERRIER, *loc. cit.*

[†] CLAPARÈDE, *loc. cit.*

[‡] PERRIER, "Mémoires pour servir a l'histoire des Lombriciens terrestres," *Nouvelles Archives du Musèum,* 1872.

[§] *Vide* DARWIN on *Earthworms,* London, 1881.

considerably the narrower of the two; its diameter is about $\frac{1}{3}$ of that of the large intestine (see Plate XXV. figs. 1, 7), and its walls, at any rate in the first portion, where it is attached to the thick mesenteries already described, are stouter. In the 16th segment commences the large intestine quite suddenly, there being no transition between it and the small intestine. The large intestine extends from the 16th segment to the end of the body, with no alteration in size. When the intestine was first opened, the contents, consisting of earth, vegetable débris, &c., showed a marked dissimilarity in colour; in the anterior half the contents were of a pale yellowish colour, in the posterior half, of a rich and dark greenish-brown tint; this is no doubt owing to the fact that the glandular development of the posterior half of the large intestine is far greater; the intestine itself showed no signs of a typhlosole, and in this structural peculiarity *Pleurochæta* resembles *Pontodrilus*, the only remnant of the typhlosole being in these two forms the supra-intestinal vessel; in *Perichæta* and *Urochæta* also the typhlosole is very much simplified. In the first six segments occupied by the large intestine the glandular epithelium is chiefly developed in a double series of shallow dorsal pouches in lines running across them at right angles to the long axis of the intestine. The gland cells examined were large, and appeared to be loaded with the products of their secretion in in the form of yellow granules; at the 22nd segment the dorsal pouches become deeper; they are still arranged in pairs, one pair to each segment on either side of the median dorsal line; these pouches extend as far as the 44th segment (see Plate XXV. fig. 1) or thereabout, and are eminently glandular. In the first fourteen sets of pouches (*i.e.*, from the 22nd to 36th segments inclusive) there is developed on the septum dividing each pouch from the one following it a folded membrane, covered with large glandular cells altogether similar to those described, which extends down the side of the septum. After these comes another set of pouches forming a continuation of the series, but with the glandular substance arranged differently; each pouch contains eight or nine folds of a dark brown colour, extending right across it from the posterior to the anterior septum, presenting very much the appearance of a fish's gill; there are from six to eight pairs of these pouches. Beneath the dorsal blood-vessel is a longitudinal fibrous band running along the course of the intestine, and above the supra-nervian vessel, on the ventral surface of the intestine, is another fibrous tract. The pouches are arranged on either side of the dorsal fibrous band, and deepen gradually from the middle line outwards; in the region of the six posterior pouches there is an additional pair of fibrous bands developed on either side of the ventral band (see Plate XXV. fig. 8). Nothing like this has been to my knowledge described in any other Oligochætous worm. In the first part of the large intestine (down to about the 76th segment), which includes the region occupied by these pouches, the glandular development is very feeble, the intestine here being much paler in colour than in the posterior half; but cells similar to those already described in the dorsal pouches are found scattered about. Unfortunately, the intestine in this region was not in a very fit condition for histological examination, but a curious arrangement of the muscular coats could be made out. Instead of being separated into two layers, a longitudinal and a circular, as is generally the case in the alimentary tract, there appeared to be a simple network of muscular fibres running in every direction, most of them, however, being arranged parallel with the long axis of the intestine, and at right angles to it, but forming only one distinguishable layer; the fibres are of various diameters, anastomose with each other, and are frequently curled into spirals, as if this part of the intestine was capable of extension, and served rather as a store-house for the food, the most active part of the digestion taking place in the posterior half of the intestine, where there is a more abundant development of glandular epithelium and of specialised glands. The posterior half of the large intestine, commencing from about the 76th segment, and extending to the anus, is very different in appearance to the anterior half, being of a brownish colour, and showing under the microscope an abundant development of epithelium and the ordinary muscular coats (Plate XXVI. fig. 12). The walls are thrown into a series of transverse folds, one to each segment. In last thirty segments of the body the intestine is quite smooth internally, with the exception of three folds, but otherwise does not differ in appearance, and can hardly be distinguished as a special rectal region.

Plate XXVI. fig. 12 is a section through the intestine in the region of the "kidney-shaped glands," to be described shortly. The outer layer is composed of a quantity of large cells filled with granules, answering to the so-called hepatic cells on the intestine of the earthworm, which have, it is perhaps hardly necessary to remark, no relation to any intestinal secretion, but are merely the cells lining the body cavity of the animal. Beneath these come the muscular layers; the middle transverse coat being the most strongly developed, and divided up into compartments by septa of connective tissue; below the epithelium is a thin longitudinal layer, which may be muscular, or composed of connective tissue only.

From the 86th to the 101st segment or thereabouts, are a series of glandular bodies, in all fifteen pairs, which lie on the dorsal wall of the intestine, but are quite distinct from it, being separated by a layer of the granular cells already described as lining the perivisceral cavity in this region. Each of these glands is faintly divided into lobules by furrows running at right angles to the long axis of the gland, and is somewhat kidney-shaped in outline, opening into the alimentary canal by a short but distinct duct, situated on its under surface. In the region of these kidney-shaped glands the walls of the intestine are very vascular; the vessels are of a brownish tint, and exceedingly conspicuous;

their arrangement is as follows:—The dorsal vessel gives off on either side in each segment three vessels, of which one is very small, and supplies the mesentery (the mesentery receives its chief blood supply from the supra-nervian vessel). The other two vessels are large and very conspicuous; one runs over the kidney-shaped gland, sending off branches which run along its furrows; after leaving the gland it is distributed to the walls of the intestine: the other, which is somewhat larger, runs between the glands, being attached to the intestinal wall by a series of short branches, which appear to end abruptly (in blood spaces ?), and give this vessel a very characteristic appearance (see Plate XXV. figs. 11, 12). Throughout a considerable extent of the intestine, both anterior and posterior to the kidney-shaped glands, the blood-vessels were turgid, and appeared to be rather larger than the same vessels in the other parts of the intestine. Anterior to these glands, the vessels of one segment are represented in Plate XXV. fig. 10, where it will be seen that the vessel *a*, which is the homologue of the vessels which supply the glands, resembles the interglandular trunk, in being attached to the surface of the intestine by a series of short branches, ending, as far as could be made out, abruptly. These vessels just described appear, like the same vessels in other parts of the intestine, to end in a plexus (in two instances this was perfectly clear), and not to be connected with any sub-intestinal vessel, nor with the supra-nervian trunk. Whether a supra-intestinal trunk exists for the whole length of the intestinal tube or not I cannot say; it was traced as far back as the 20th segment, being in this region single instead of double, but having a trace of the other trunk running beside it. All the details of the intestinal circulation can only be made out by a series of careful injections; the facts given here are based upon a partial natural injection of the capillaries, which may of course be misleading. The general features of the circulation in this part of the body appear to be as follows:—The wall of the intestine itself is supplied with a rich network of vessels derived from the branches of the dorsal trunk (two in each segment). The supra-nervian trunk supplies the integument and the mesenteries, the latter receiving also a small twig from the dorsal vessel, which no doubt serves to put the dorsal and ventral systems into communication.

The kidney-shaped glands in transverse section (Plate XXVI. fig. 19; Plate XXVII. fig. 9) show an outer layer of granular cells, which belong, as already mentioned, to the perivisceral cavity, and not to the coat of the glands; below this is a fibrous layer, which sends off trabeculæ into the substance of the gland, larger ones dividing the gland into lobules or smaller ones lying simply between two adjacent columns of cells. The gland itself presents the appearance of a compound tubular gland, or perhaps rather of a folded membrane; the duct opens on to the transverse fold in the intestine. The cells which compose the glands are columnar, each provided with a nucleus, the outer border of the cell is hyaline, and does not stain deeply with colouring reagents.

The existence of these highly specialised glands is no doubt the most remarkable point in the anatomy of *Pleurochæta*, and their presence may perhaps be correlated with the absence of segmental organs.

Circulatory System.

The fact that the specimens at my disposal were preserved in spirit, hindered very accurate researches into the distribution of the smaller branches of the vascular system; but in the case of the more important vessels, their large size, and the frequent presence of coagulated blood, rendered their study fairly easy. Consequently, the following description is, I hope, correct for the main trunks of the vascular system, but some errors may have crept in with respect to the smaller vessels.

The vascular system of *Pleurochæta* consists of six longitudinal trunks.

(1) The dorsal vessel, (2, 3) two supra-intestinal trunks, (4, 5) two lateral or "intestino-tegumentary," and finally, (6) one ventral supra-nervian vessel. This system differs from that of any other Oligochætous worm by the presence of *two* supra-intestinal vessels, but with this exception conforms to the ordinary type, being very similar in its general arrangement to *Perichæta, Urochæta,* and *Pontodrilus.* The dorsal vessel lies on the dorsal side of the alimentary canal, in actual contact with it in the anterior and posterior portions; it is only in the region which lies between the 8th and 16th segment, that the dorsal vessel lies well above the alimentary canal, as shown in Plate XXVI. figs. 1, 2, which represent diagrammatic vertical sections through the body of the worm in this region. The dorsal vessel takes its origin from a capillary network on the anterior part of the pharynx, and has the remarkable peculiarity of not remaining a single uniform tube in its course backwards, but bifurcates no less than five times in the first eight segments, the bifurcations always coalescing again directly; this is shown on Plate XXV. fig. 2. The dorsal vessel gives off one or two branches in the anterior segments, and in the 8th, 9th, 10th, 11th, 12th, and 13th gives off a branch on either side, which unites it directly to the ventral trunk; these arches increase in size from before backwards, and the four last, which are the stoutest, are no doubt contractile, and function as "hearts." The moniliform character of these vessels described in other worms is very conspicuous here in the pairs occupying the 10th, 11th, 12th, and 13th segments; the two pairs anterior to these are much slighter, and before joining the ventral vessel give off on either side a trunk (Plate XXV. fig. 4, 5), which in the case of the posterior one, at least, gives off another branch perforating the mesentery behind (Plate XXVI. fig. 2, *a*). In the 7th segment, another pair of branches

are given off from the dorsal trunk, which after joining a branch supplying the vascular plexus on the surface of the gizzard, and then giving off three other small branches, which are distributed to the mesenteries, dividing 7th from 8th, and 8th from 9th segments, become united with the first arch—joining the dorsal and ventral vessels—before its division. This arrangement of vessels, as well as the vascular plexus on the gizzard, to be described shortly, is given in Plate XXV. fig. 5. The supra-intestinal vessels, two in number, I was unable to trace further forward than the 10th segment, or further backwards than the 20th; they would seem to be equivalent to the single "sus-intestinal" vessel described by PERRIER in *Pontodrilus*, *Perichæta*, and *Urochæta*, which he regards as the only representative of the typhlosole left in these worms. In *Urochæta* and *Perichæta*, certain of the "hearts," or transverse contractile trunks connecting the dorsal and ventral vessels, are in reality connected at their upper end with the supra-intestinal, and not the dorsal trunk; these are termed by PERRIER "cœurs intestinaux;" the anterior hearts connecting the dorsal vessel proper with the supra-nervian trunk being distinguished by the name of "cœurs lateraux." In *Pontodrilus*,* there are the same two sets of hearts, but the communications of the "cœurs intestinaux" are rather different; there are occupying segments 5 to 11 inclusive, a pair of lateral hearts to each, and in the two following segments are two pairs of intestinal hearts readily distinguishable from the others by their greater size. These last mentioned are not only connected with the supra-intestinal trunk, as in *Urochæta* and *Perichæta*, but also have a delicate branch connecting them with the dorsal vessel. This same arrangement is described by PERRIER as existing in *Titanus Forguesii*, a representative of an entirely distinct group, that of the Intraclitellians. In the Ante-clitellian forms, of which the common earthworm is an example, there is no such differentiation of the hearts; they all alike connect the dorsal vessel with the supra-nervian. "L'existence des cœurs intestinaux," says PERRIER, "paraît bien rèellement limitée aux Lombricidès intra et post-clitelliens," but whether all worms belonging to these two groups are thus provided is another question. In *Pleurochæta*, which, from the arrangement of its generative apertures, and their relation to the clitellum, ought perhaps to be classed with the Intraclitellians, but is most certainly not Ante-clitellian, no trace of any intestinal hearts was to be found, though after making myself acquainted with PERRIER'S memoirs, I naturally looked very carefully; still it is possible that the additional communication with the supra-intestinal vessel may be present; but at any rate the communication of all the hearts with the dorsal vessel is perfectly obvious, so that, in this respect, *Pleurochæta* differs materially from *Perichæta*.

At present our knowledge of the circulatory organs in the *Oligochæta* is not

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* PERRIER, *Arch. de Zool. Exp.*, vol. ix.

very extended, D'UDEKEM,* LANKESTER,† and CLAPARÈDE ‡ have made us thoroughly acquainted with these organs in *Lumbricus.* PERRIER § has increased our knowledge enormously with respect to the three genera, *Pontodrilus, Urochæta,* and *Perichæta;* to the last genus also VAILLANT || and HORST ¶ have added details of considerable importance; but of the circulatory organs in the many interesting genera described by PERRIER in the *Mémoires du Musèum,* owing to their bad state of preservation, not much could be asserted with confidence. It would be useless, therefore, with the comparatively scanty materials that we have at hand, to attempt to generalise; on the whole, in the number and character of the main trunks of the vascular system, *Pleurochæta* seems to stand midway between the Ante-clitellians, *e.g.*, the common earthworm, on the one hand, and the Intra and Post-clitellians on the other, with rather more affinities to the latter groups, but no more special relationship to any particular genera among those which compose these two somewhat heterogeneous groups can be made out.

The vascular system in the *Oligochæta,* as far as we know it, contrary to what we might expect from the analogy of other groups of animals, does not form a good basis for classification. The main trunks are constant through so many and so widely different genera, and the number and position of the hearts, which might at first sight seem likely to be useful in this direction, vary in the most capricious manner from one species to another; for example, in *Perichæta cingulata,* described by VAILLANT,** there are three pairs of hearts, and in a *Perichæta* described by HORST,†† there are in all six pairs of hearts, and one unpaired half-arch. Among the various species of *Perichæta* described by PERRIER, the same variations are observable—"l'appareil circulatoire possède une grande variabilité qui ne semble guère autoriser l'employer dans une caractéristique."

To resume the account of the vascular system of *Pleurochæta*; in the 11th, 12th, and 13th segments the hearts, connected as in the other segments with the dorsal vessel, give off two branches directly after issuing from it, the posterior one is distributed to the mesentery behind, and the anterior one to the walls of the alimentary canal; the mesenteric branch appears to be given off in the other segments anterior to the 11th, but not the intestinal, at least it was not visible in either of the specimens dissected. From the supra-intestinal

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[*] D'UDEKEM, *Nouv. Mém. de l'Acad. Roy. Brux.*, t. xxxv., 1865.

[†] LANKESTER, "On the Anatomy of the Earthworm," *Quarterly Journal of Microscopical Science,* 1864–65.

[‡] CLAPARÈDE, *loc. cit.*

[§] PERRIER's numerous memoirs already cited.

[||] VAILLANT, *loc. cit.*

[¶] HORST, *loc. cit.*

[**] VAILLANT, *loc. cit.*

[††] HORST, *loc. cit.*

[‡‡] PERRIER, *Nouvelles Archives du Musèum,* p. 26.

trunks two or three branches are given off to the walls of the intestine. These trunks with their branches are displayed in Plate XXV. fig. 3. Behind the 13th segment the dorsal vessel is ampullated, and appears to give off three branches in each segment.

The supra-intestinal vessels run back for some considerable distance, but they appear to unite into a single trunk, as has been already stated in the account of the alimentary tract, where also the details of the intestinal circulation are given.

The two lateral vessels at first run beneath the intestine, and are closely adherent to it (Plate XXVI. figs. 1, 2); in each segment a branch is given off to the mesentery. In Plate XXV. fig. 5 the distribution of the vessels in the anterior part of the body is shown, including the 7th, 8th, and 9th segments; the lateral vessel (*l*) has here moved from the under surface of the intestine, and occupies a lateral position; it gives off one mesenteric branch in the 9th segment and two in the 8th; in the 7th and 8th segments a branch is given to the vascular plexus on the surface of the gizzard, the ultimate ramifications of which are connected by direct anastomosis with the branches given off from the first of the transverse trunks uniting the dorsal and ventral vessels, and which have been already described. In the same figure the two anterior hearts (*h*) are shown; each before joining the supra-nervian vessel (*v*) gives off a trunk which supplies the body wall and mesentery. In fig. 6 the further course forward, and the termination of the lateral and supra-nervian trunks, is shown; they each give off corresponding branches to the mesenteries, which have the relation to each other of artery and vein; the lateral trunks terminate among the muscles of the pharynx, and the supra-nervian following closely the course of the nerve cord ends on the upper surface of the anterior part of the pharynx near to the cerebral ganglia.

The lateral vessels seem chiefly concerned with the blood supply of the mesenteries. I was unable to trace them further back than the 18th segment, which is no doubt owing to the fact that in this part of the body the mesenteries are supplied with blood by the supra-nervian trunk.

The supra-nervian vessel runs continuously from one end of the body to the other, lying just above the ventral nerve cord; in each segment it gives off a branch on either side, which supplies the body wall and mesentery; in the region of the hearts, however, this branch is not given off, the mesenteries being supplied from the dorsal and lateral vessels; in the anterior part of the body the ventral vessel runs between the spermathecæ, giving off two main branches on each side, which have been already described as corresponding to branches of the lateral vessels.

These are the chief facts in the circulatory system of *Pleurochæta;* a general scheme of the whole circulation is shown in Plate XXV. fig. 4.

Nervous System.

The nervous system of *Pleurochæta* consists of a pair of cerebral ganglia fused in the middle line, but still perfectly distinguishable, occupying the first segment of the body, which are connected with a ventral chain by a pair of commissures. From either end of the cerebral ganglia a bunch of nerve filaments is given off, running towards the anterior end of the body. The commissures uniting the cerebral ganglia with the ventral chain are swollen in the middle, where they give off a number of nerves, one set from the anterior surface and another from the posterior. This part of the nervous system is represented slightly magnified on Plate XXVII. fig. 1; the posterior part of the commissure is seen in this figure to be separated here and there from the main mass, and would appear to represent the rudiment of a visceral nervous system so generally developed in the *Oligochæta*, and to resemble more closely the visceral nervous system of *Urochæta*, which consists of a second œsophageal collar, rather than that of the other types of *Oligochæta*. In fig. 2 we have the anterior part of the ventral chain, together with the cerebral ganglia, and one of the commissures uniting the former with the latter. From the first ventral ganglion the nerves are given off anteriorly, but from all the rest the nerves are given off in pairs at right angles to the axis of the cord; from each ganglion three nerves take their origin on each side, of which two become united immediately after leaving the ganglion; there is in each segment another pair of nerves given off between each of the ganglia. After the 12th segment the ganglia diminish considerably in size. The first ventral ganglion is placed in the second segment of the body, and following this there is one to each of the other segments. On the upper surface of the cord is a hyaline band extending along its whole length; this appearance may be produced by the "giant nerve fibres" lying on the dorsal surface of the cord. These structures, which are very general throughout the Annelida, have received various names; they are the "giant nerve fibres" of LEYDIG, the "tubular fibres" of CLAPARÈDE, the "neural canal" of M'INTOSH; they have been compared to the notochord of the vertebrate, and also to the neural canal, but this latter hypothesis is not borne out by the description of the development of the medulla in *Lumbricus* by KOVALEVSKY and by KLEINENBERG. Quite recently SPENGEL* has described a single tubular body with coagulated fluid contents in the nerve cord of *Echiurus Pallasii*. In all annelids where these structures have been observed, they are seen to consist of three longitudinal tubes filled with a coagulated fluid, and provided each with a special fibrous sheath; this is the case, for instance, in *Lumbricus* and in *Pontodrilus*. In *Pleurochæta* these tubes are four in number, three of which are arranged on the ordinary plan, and the fourth, which is about equal in size

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* SPENGEL, *Zeitschrift für Wissenschaftliche Zoologie*, 1880.

to each of the two smaller lateral ones, lies beneath the central larger tube. Each of these tubes (see Plate XXVII. figs. 3, 4, 5) is provided with a special fibrous sheath, outside which is another thicker fibrous sheath; these outer coats, however, are more or less continuous with each other, and with the septa dividing up the interior of the medulla, and perhaps ought not to be regarded as forming another special sheath to each of the tubular fibres. This description is more in accord with that of CLAPARÉDE* for the common earthworm, than with the description of *Pontodrilus* by PERRIER,† who denies the presence of a special sheath to each of the tubular fibres. The nerve cord of *Pleurochæta* is surrounded by a thick membrane, which has the appearance of elastic tissue; in this are imbedded muscular fibres, sometimes singly and sometimes two or three together (fig. 3). The structure of the medulla itself varies according to the region from which the section is taken; fig. 4 is a section through one of the ganglia, and fig. 5 through the middle part of a commissure between two ganglia. The difference is at once apparent. There are no nerve cells in fig. 5. The nerve cells are developed on the under surface of the ganglia, and are found to extend some way along the commissures. Fig. 3 is a more highly magnified section through the middle of one of the ganglia. All the details given in the following description of the minute structure of the nerve cord will be found represented in one or all of the figures already mentioned.

Each ganglion is in reality composed of two fused ganglia, which is very clear on examining a section; the nerve cells are arranged in two lateral groups, and there are two circular areas separated off from the rest of the ganglion by septa of connective tissue, which are the interganglionic commissures uniting the different ganglia of the nerve cord with each other. In those parts which lie between the ganglia, the whole cord is made up of these commissural masses, there being no nerve cells present; these areas are occupied by a reticulum of connective tissue, in the meshes of which lie the nerve fibres, and a few small nerve cells differing altogether in size and appearance from the large nerve cells found in the ganglia. The rest of the ganglion is divided up by a finer meshwork of connective tissue, with stouter fibres here and there; the nerve cells, which are pear-shaped, lie with their apices pointing towards the interior of the ganglion; the processes of these cells, which are for the most part unipolar, were generally traced into connection with the fibres constituting the interganglionic connectives; each ganglion cell is provided with a large nucleus and nucleolus and lies in a space in the otherwise continuous meshwork. The fibres which make up the lateral branches given off in every

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* CLAPARÉDE, *loc. cit.*

† PERRIER, *Arch. de Zool. Exp.*, vol. ix.

segment from the nerve cord are almost entirely derived from the central commissural masses, but some take their origin from other parts of the ganglion.

Generative System.

The genital apparatus of *Pleurochæta* is manifested externally by the clitellum, by the apertures of the spermathecæ, and by four other pairs of apertures, of which three lie in a hollow sucker-like structure just at the posterior end of the clitellum, and the remaining pair still within the clitellum, but opening more anteriorly in the 13th segment.

The clitellum itself is a little difficult to map, but I have considered that all those segments form part of it upon which any glandular development is visible with the naked eye. Counting in this way, one specimen showed a clitellum consisting of seven, possibly eight segments, but in the last segment the glandular development was very slight, and the setæ were as numerous as in any of the posterior rings not belonging to the clitellum. In the other specimen the clitellum was far more strongly developed, occupying apparently nine segments, in the first and last of which a complete series of setæ were present. In the segments forming the clitellum, with the exceptions just mentioned, the development of setæ is very slight, and entirely confined to a small tract on either side of the median ventral region, where, as in the rest of the body, no setæ are developed. Among the *Oligochæta* some forms are provided with setæ on the clitellum, and some are not; in the species of *Perichæta* described by Horst the clitellum is marked by an absolute lack of setæ, but in *Perichæta affinis* described by Perrier, "on distingue parfois nettement le circle des soies caracteristique des Perichæta." The clitellum commences after the 12th ring, and its segments can be counted either by the mesenteries or by the lines of setæ which, as just described, exist on the clitellum of this animal; the last of the specially-thickened mesenteries forms its anterior boundary. Of the intimate structure an account has already been given, under the description of the body wall.

At the posterior end of the clitellum in the median ventral line is a hollowed out area (Plate XXV. fig. 9), upon which no glandular development has taken place; it is divided into four cavities, by two ridges running at right angles to each other; the transverse ridge bears upon the end nearest to the clitellum, on either side, an aperture which is continuous with the duct of a solid white gland (Plate XXV. fig. 7), occupying the 18th segment. Each of the four cavities or hollows formed by the two ridges bears another aperture; the anterior pair open into the 17th segment, and the posterior into the 19th. These apertures were not directly visible from the interior, being apparently covered by a layer of the peritoneum. No ducts were visible in communication with either of these pairs of orifices in either specimen.

The sucker-like structure is possibly used by the animal during copulation.

The two openings in the 13th segment, which were only visible in one of the two specimens at my disposal, had again no apparent duct connected with them.

The clitellum of *Pleurochæta* is remarkable for being composed of an unusually large number of segments; in *Perichæta* the number is almost constantly three; in *Pontodrilus* there are five, and in *Urochæta hystrix* as many as seven segments in the clitellum; but I am unable to recall any form except *Pleurochæta* in which there are more than this.

Perrier,* in an important memoir which has been already several times spoken of, divided the *Oligochæta* into three groups, according to the position of the male generative orifices.

(1) The *Anteclitellians*, e.g., *Lumbricus*.
(2) The *Intraclitellians*, e.g., *Urochæta*.
(3) The *Postclitellians*, e.g., *Perichæta*.

On Perrier's system the genus *Pleurochæta* would be regarded as one of the Intraclitellians, the generative openings lying within the clitellum; if, however, the apertures in the 17th and 19th segments in reality are connected with the testes, which unfortunately I have been unable to prove, then their position is somewhat intermediate between the Intra- and Postclitellians; whether this be so or not, the number and distribution of the generative orifices in *Pleurochæta* are so peculiar and so different to anything known in the *Oligochæta*, that Perrier's system would be very artificial, if it proposed to unite in one family two such very divergent types as *Urochæta* and *Pleurochæta*. In many characters *Pleurochæta* resembles *Perichæta*, which is one of the Postclitellian group; for instance, in the absence of segmental organs, in the presence of a pair of "prostate" glands, and in the fact that the ovaries are small and difficult to find (I have not satisfied myself as to their existence in *Pleurochæta*); the last two characters distinguish the Postclitellians as a group. On the other hand, the presence of two cæca on the alimentary canal, and the double spermathecæ, are invariably characteristic of *Perichæta*; these are absent from *Pleurochæta*.

The characters in which *Pleurochæta* agrees with the Intraclitellians are, firstly, the position of the generative openings (?); secondly, the possession of only one pair of testes, which is a character found also in *Urochæta* and *Titanus*, and remarked as of importance for classificatory purposes by Perrier, though it is not universal in the Intraclitellians. The thickening of the

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* Perrier, *Nouvelles Archives, &c.*

anterior mesenteries described above is also found in *Urochæta,* though, whether a modification of this kind can be made use of for the determination of systematic relations is perhaps more than doubtful. The structure of the alimentary canal at once distinguishes *Pleurochæta* from any described genus, as does also the distribution of the setæ. There seem to be no special relations with the Anteclitellians, except perhaps the absence of "cœurs intestinaux."

This *résumé* of the structural relation of *Pleurochæta* with other forms, leaving out for the present the consideration of the generative apertures, shows that it occupies a position between the Intraclitellians and Postclitellians, with perhaps rather closer affinities to the latter group, but that it cannot definitely be classed with either, but ought rather to form a group apart. This conclusion is stengthened when we come to study the generative apertures; they are so peculiar that they cannot be considered as conforming to the Postclitellian or Intraclitellian type, though they are more closely allied to the latter than to the former. We must then either regard the existing classification of PERRIER as unsatisfactory, since it is not elastic enough to comprehend this new genus, or a new group must be formed and added to the three groups already created by PERRIER; on the whole, the latter seems to be the wisest course. The state of our knowledge with respect to the *Oligochæta,* as has been remarked several times in the course of this memoir, is by no means advanced, and therefore it is useless at present to alter a classification which is extremely convenient; whether it will prove to be of permanent value is another question, which cannot yet be answered. On the principle of nomenclature adopted by PERRIER for the classification of the *Oligochæta Terricola*, it does not seem easy to select a name that will have any meaning; perhaps *Infraclitellian* will do, though it must be admitted that the name is not a very expressive one.

Returning to the description of the generative organs. *Pleurochæta* possesses one pair of testes situated in the 12th segment (see Plate XXV. fig. 7; Plate XXVII. fig. 10), and presenting the appearance of racemose glands, which is an extremely unusual character in the *Oligochæta,* but is paralleled in the case of *Plutellus** and *Digaster.*

In the 11th and 10th segments are two pairs of complicated folded organs (Plate XXVI. fig. 8), concerning the nature of which there is some uncertainty; they lie in either case on the posterior wall of their respective segments, and they are each continuous with a fine duct which runs backwards perforating the mesentery, and is lost in the body wall of the segment behind; it seems likely that these fimbriated organs are the expanded terminations of the vasa deferentia, but in this case we should expect to find them uniting into two tubes running down the body wall on either side of the nerve cord; nothing of this sort was

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* PERRIER, "Étude sur un genre nouveau de Lombriciens," *Arch. Zool. Exper.*, vol. ii. 1873.

visible, and they appear to open separately on to the exterior; however, in *Acanthodrilus*, a Postclitellian worm, there are four male apertures instead of two, so that, after all, there would be nothing so very remarkable in finding the same thing in *Pleurochœta*, though their being so far in advance of the testes would seem to throw some doubt on the hypothesis of their being vasa deferentia.

The histological structure of the fimbriated expansion is shown on Plate XXVI. figs. 14, 18; the last figure shows the columnar epithelium from above, the cells are seen to be of a polygonal contour; in transverse section (fig. 14) this layer of columnar cells with their cilia is seen, beneath is a layer of connective tissue which is crowded with blood-vessels. This extreme abundance of blood-vessels is very characteristic of these organs; when viewed entire from above, the epithelium is seen to cover a plexus so closely pressed together that there is hardly any space between two adjacent vessels; this largely developed vascular supply makes it doubtful whether these organs may not be after all the only remains of the segmental organs left in the animal.

On the opposite side of the mesentery, and corresponding with the anterior pair of fimbriated organs, are two small rosette-shaped glandular bodies (Plate XXVI. fig. 9); it is possible that these are the ovaries, though a careful histological examination revealed none of the characters peculiar to those organs; the absence, however, of ova may be perhaps accounted for by the fact that the animal was found in a burrow with its cocoon, which evidently had not long been deposited, and, accordingly, one would hardly expect to find the ovary, having for the time ceased from its function, to consist of anything more than a mass of indifferent cells; a second pair could not be found; on the view that these are ovaries, we may consider the fibriated bodies as oviducts; but in this case we have the anomaly of four oviducts to two ovaries, and the absence, as in *Anteus* ?), of vasa deferentia.

There are four spermathecæ opening in pairs between the 7th and 8th, and the 8th and 9th segments. Their position is shown in Plate XXV. figs. 6, 7; in the former figure, that of the posterior right hand spermatheca is considerably larger than the others; this is drawn from one of the two specimens that I dissected; in the other, all the four spermathecæ were as nearly as possible of the same size.

Each spermatheca (Plate XXV. fig. 13) consists of two divisions; the part opening externally is much smaller than the other, but has far thicker walls; the chief part of the spermatheca has thinner walls.

Cocoon and Embryos.

Each of the specimens of *Pleurochœta* was found, as already stated, at the bottom of a deep burrow, together with a single egg-case; these two cocoons differ slightly in size, the larger measuring 3·9 c. in length and 1·85 c. in breadth, and the smaller 3·1 c. in length and 1·9 c. in breadth. The cocoons are glassy in appearance and of a dull bottle-green colour, the smaller specimen with three bands of a darker green at one end, the larger specimen of a uniform colour. Each cocoon appeared to have two openings, one at each end; the anterior opening was obvious, but of the existence of the other I was not quite able to satisfy myself. The chitinous wall of the cocoon exhibits no particular structure. Plate XXVII. fig. 12 represents one of the cocoons of the natural size. The larger cocoon was opened, and contained two embryos slightly folded upon each other, as shown in fig. 11, and surrounded by a quantity of firm coagulated matter, which no doubt is the remains of the food yolk. The embryos lie, as represented in the figure, with their anterior extremities towards the orifice of the cocoon. The two embryos separated from each other, and entirely freed from the food yolk, are shown in figs. 6, 7. One of these two was selected for study, but my time was unfortunately limited, so that only a few points in its structure were made out. The first thing to which my attention was directed, was naturally the distribution of the setæ, but the embryos were so far advanced that the setæ were present in their full number, and with the characteristic distribution found in the adult (Plate XXVII. fig. 15). Fig. 13 of the same plate represents a vertical section through the body wall in the dorsal region, where the longitudinal muscular coat *t'* undergoes a curious alteration; instead of the fibres being arranged in compartments separated by trabeculæ of fibrous tissue, as in other parts of the body, there is a network of connective tissue, which has very much the appearance of the reticulum of fat, and which at the two sides becomes gradually continuous with the fibrous trabeculæ; about the middle of this reticulum is a single line of muscular fibres, which appear to be of a somewhat greater diameter than those in the other parts of the longitudinal coat. The circular coat undergoes also an alteration in this region; the fibres are more wavy, and less regular in their arrangement; this is displayed also in fig. 16, which represents a strip of the skin torn off and examined entire; moreover, the changes undergone by the two muscular coats are shared by the epithelium and by the cuticle, both of which are increased considerably in thickness. What the meaning of this is I cannot guess, neither had I any time to re-examine the adult to see if there was the same alteration of structure on the dorsal surface; since, however, this band was perfectly visible to the naked eye, and as there was no such difference apparent in the adult it would seem after all to be peculiar to the young specimen.

Postscript—(added Nov. 21).

(1) Since writing the above account of the anatomy of *Pleurochæta,* I find that a memoir has been overlooked which explains the anomalous structure of the dorsal vessel. This memoir is by Dr. F. VEJDOVSKY, and is abstracted in the *Journal of the Royal Microscopical Society* for 1880. Dr. VEJDOVSKY, in studying the development of *Criodrilus,* discovered that the dorsal vessel is formed by the coalescence of two completely separate rudiments—the same mode of development had been previously shown by KOVALEVSKY to take place in *Lumbricus*—these facts, VEJDOVSKY points out, are of extreme importance in considering the relationship between the *Annelida* on the one hand, and the *Vertebrata* and *Crustacea* on the other, since in the *Vertebrata* generally, and in *Apus* among the *Crustacea,* the heart is formed in the same way by the coalescence of two rudiments which at first are distinct. The *Hermellidæ,* according to DE QUATREFAGES, possess two dorsal vessels in the posterior part of the body which are joined into a single tube anteriorly, and in *Pleurochæta* the same embryonic character is shown in the dorsal vessel, but in a much more marked degree; it is evidently formed of two incompletely fused tubes (*cf.* Pl. XXV. fig. 2).

(2) I have attempted to show that there is a fundamental similarity in the structure of the muscles of the longitudinal coat throughout the *Oligochæta,* and that *Lumbricus* is not to be regarded as differing essentially from other *Oligochæta* in this respect. This conclusion is quite justified by the facts brought forward by the Drs. HERTWIG in their "Cœlomtheorie,"* which I had not read at the time that I was preparing this paper. These authors show the general similarity, both in structure and development, that exists between the muscles of the *Annelida, Chætognatha, Vertebrata,* and other orders in which there is a true enterocœle. In these groups the muscular tissue is developed from the epithelial lining of the perivisceral cavity, and almost without exception from the parietal layer; the elements—the fibrillæ—are invariably bound together to form higher unities; such as, for example, the fibril bundles of many vertebrates, and are also characterised by the regularity of their arrangement. In the *Mollusca* and *Platythelminthes,* and other groups in which there is not a true enterocœle, the muscles are developed from cells of the "mesenchym," which have the character of connective tissue cells; they frequently possess longitudinal striæ, which are not, however, to be regarded as expressing a fibrillation, and are always arranged irregularly, crossing each other in various directions, and contrasting very strongly with the regular arrangement of the "epithelial" muscles of the *Annelida, Vertebrata,* &c.

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* *Jen. Zeitsch. für Natürwiss.,* 1881.

On plate iii. of the "Cœlomtheorie" there are figures of the muscles in a great variety of animals belonging to different groups, and a comparison of fig. 13, with my drawing of the muscular compartments of the young *Pleurochæta* (Plate XXVI. fig. 15), shows a very striking resemblance, and it seems highly probable that the muscular compartments of *Pleurochæta* are homologous with the "Muskelkästchen" of *Petromyzon.* On page 6 of the "Cœlomtheorie," the authors sum up briefly the account of the anatomy and development of the muscles given in a previous memoir on the *Chætognatha:*—"As in the Actiniæ from the epithelial cells of the diverticula of the Archenteron, so in the Chætognatha from the parietal epithelial layer of the Cœlome (= Somatopleure) are secreted muscular fibrillæ, which become united into a lamella. In the further process of development of this lamella it becomes folded, and gives rise to muscle plates (Muskelblätter.)" This statement surely is not reconcilable with that made on page 63 of the same memoir:—"Each muscle plate (in Petromyzon) is formed by the neighbouring borders of two myoblasts . . . . . the close resemblance to the muscle plates in the Chætognatha, many Nematoda, and the Annelida, is so obvious, that it is sufficient merely to have called attention to it."* It is certainly quite true that the resemblance here remarked upon is very close, but of course there can be no real similarity in detail if the development in *Sagitta* is such as it is stated to be in the former of the two passages cited; there is clearly no "folding" in the case of *Petromyzon.* Still less can there be any comparison made between *Lumbricus* and *Petromyzon,* since, according to the Drs. HERTWIG, a second folding has taken place in *Lumbricus,* so that a "fibril" here is not the equivalent of a fibril in *Sagitta* or *Petromyzon;* at the same time, the letter *f* is made use of to denote the fibrils in all the three types, which is rather confusing, and might lead one at first to believe that they were considered to be homologous structures. The development of the muscles in *Lumbricus* is at present not known, so that any comparisons made with other forms can only have a slight value; the evidence that we have, however, appears to me to point to the conclusion that there is no need to imagine a second folding in the longitudinal muscles of *Lumbricus.* Had there been a second folding, we might have expected to find a septum of connective tissue between the secondary lamella, continuous with that separating the primary lamellæ; but this does not seem to be the case; although CLAPARÉDE describes the central fibrous septum as sending branches between the fibrils, the inter-fibrillar substance is of a very different appearance from that forming the septum, according to the figures given on plate iii. of the "Cœlomtheorie." It is a delicate granular substance with frequent nuclei, and is more like the part left over in the original myoblast after the secretion of the muscle fibrils. At any rate, the absence of capillaries and pigment granules, which are

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* *Jen. Zeitsch. für Natürwiss.,* 1880.

abundantly found in the septa, mark it out as something distinct. These facts (in the absence of embryological data) are also quite in harmony with the view that the muscle plate in *Lumbricus* is like that of *Petromyzon,* "formed by the neighbouring borders of two myoblasts," and that the septa form the boundaries of muscular compartments which are comparable to those of *Pleurochæta* or to the "Muskelkästchen" of *Petromyzon.*

EXPLANATION OF PLATES.

PLATE XXV.

d, Dorsal vessel.
s, Supra-intestinal.
b, Supra-nervian.
h, Heart.
l, Lateral vessel.
x, Prostate glands.
p, Dorsal pouches.
y, Spermathecæ.

Fig. 1.—General view of *Pleurochæta Moseleyi*, half natural size. *k*, kidney-shaped glands.

Fig. 2.—Dorsal vessel; *a* is the same as *a* in fig. 5.

Fig. 3.—Vessels of segments 11th, 12th, and 13th; the letter *i* lies on the intestine; *m*, mesenteries; the lateral vessels are left out to simplify the figure.

Fig. 4.—General scheme of circulation.

Fig. 5.—Vessels of segments 7th, 8th, and 9th.

Fig. 6.—Anterior course of lateral and supra-nervian trunks.

Fig. 7.—General view of the anterior part of the body, rather more than half the natural size. The main divisions of the alimentary canal are shown. *t*, testes; *o*, oviducts (?).

Fig. 8.—Portion of body with intestine laid open, to show the dorsal pouches; *c* points to the dorsal fibrous band, *h* to the ventral, and *a* to one of the lateral ones.

Fig. 9.—Clitellum showing the four pairs of apertures; three pairs close together at posterior margin, barely within the clitellum.

Fig. 10.—Vessels of one segment on one side—a little anterior to kidney-shaped glands.

Fig. 11.—One of the kidney-shaped glands, showing its duct and blood-vessels of same segment.

Fig. 12.—Three of the kidney-shaped glands, with adjacent blood-vessels. Twice natural size.

Fig. 13.—Spermatheca. About three times the natural size.

PLATE XXVI.

Fig. 1.—Diagrammatic transverse section through anterior part of body, to show arrangement of vascular trunks, which are lettered as in preceding plate. *n*, nerve cord.

Fig. 2.—Section through body in front of fig. 1, showing absence of supra-intestinal vessels.

Fig. 3.—Transverse section through clitellum, showing one of the glands. *t*, transverse muscular coat; *t'*, longitudinal. × 60.

Fig. 4.—Section through body wall cut transversely to the longitudinal coat, showing capillaries ending in epithelium. × 120.

Fig. 5.—Section through body wall cut transversely to circular coat: septa of fibrous tissue and muscular fibres between. × 120.

Fig. 6.—Section through clitellum. *a*, remains of hypoderm; below this gland cells; *t*, circular muscle coat; *t′*, longitudinal muscle coat. × 60.

Fig. 7.—Section through clitellum, more highly magnified. × 200.

Fig. 8.—Fimbriated organ. × 3.

Fig. 9.—Mesentery, showing relative positions of *a*, rosette-shaped body; *b*, fimbriated organ; *c*, ventral blood-vessel.

Fig. 10.—Diagram of longitudinal muscle coat of *Lumbricus*, cut transversely.

Fig. 11.—Portion of clitellum, to show invasion of muscular fibres into glandular layer. × 540.

Fig. 12.—Transverse section through intestine in region of kidney-shaped glands; *d*, cells of peritoneal cavity.

Fig. 13.—Section through body wall in anterior region, cut rather obliquely; *a*, marks boundary between circular and longitudinal coats; *b*, special muscular layer uniting setæ of one segment. × 200.

Fig. 14.—Transverse section through fimbriated organ.

Fig. 15.—Transverse section through anterior end of young *Pleurochæta*, to show the compartments in which the longitudinal muscles are arranged. × 200.

Fig. 16.—Oblique section through body wall, showing special muscles serving for the protrusion of the seta. × 120.

Fig. 17.—Unicellular glands, from clitellum. × 540.

Fig. 18.—Polygonal epithelial cells, from surface of fimbriated organ.

Fig. 19.—Section through kidney-shaped gland. *a*, septum between two lobules. × 20.

PLATE XXVII.

Fig. 1.—Commissure connecting cerebral ganglia with ventral nerve chain.

Fig. 2.—Anterior part of nerve cord. *c*, cerebral ganglia; *b*, commissure, enlarged in fig. 1.

Fig. 3.—Section through a ganglion of ventral chain. × 200.

Fig. 4.—Section through a ganglion of ventral chain. × 30.

Fig. 5.—Section through middle part of commissure uniting two ganglia. × 60.

Figs. 6, 7. Embryos taken from cocoon. Natural size.

Fig. 8.—Gizzard cut open in middle, showing the chitinous lining, *a*. Natural size.

Fig. 9.—Section of a portion of one of the kidney-shaped glands. × 200.

Fig. 10.—Stout mesenteries in anterior part of body. Natural size.

Fig. 11.—Embryos from cocoon before being separated from each other. Natural size.

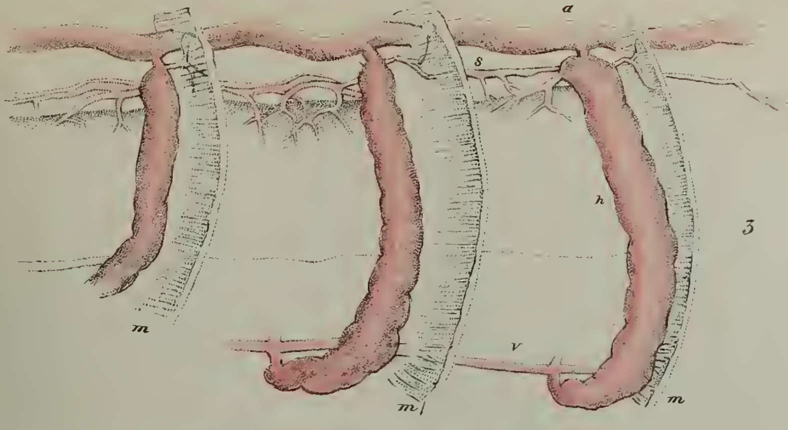
Fig. 12.—Cocoon. Natural size.

Fig. 13.—Transverse section through body wall of embryo on dorsal side. *e*, hypoderm; *t*, transverse muscular coat; *t′*, longitudinal coat.

Fig. 14.—Strip of the skin of young *Pleurochæta*, to show the setæ and their special muscles.

Fig. 15.—Diagrammatic vertical section through *Pleurochæta*, to show arrangement of setæ.

Fig. 16.—Strip of skin from dorsal part of embryo, from the same region as fig. 13.



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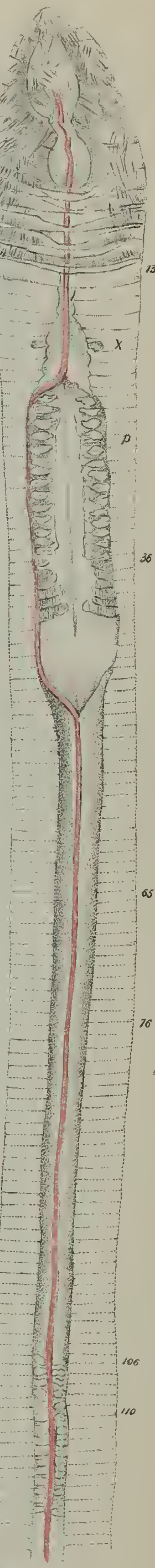

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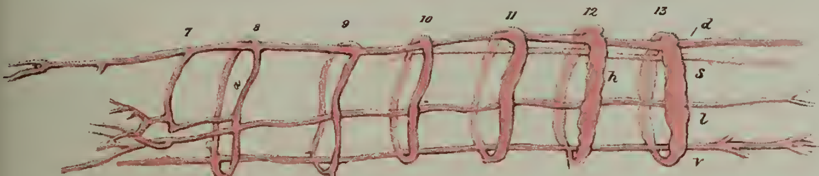

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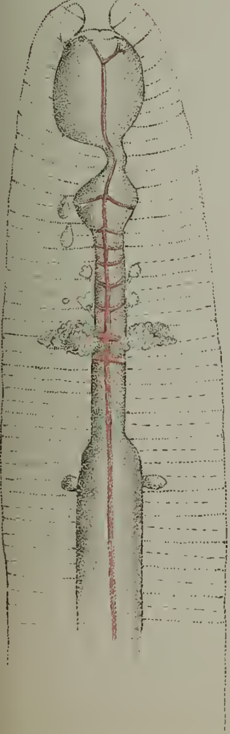

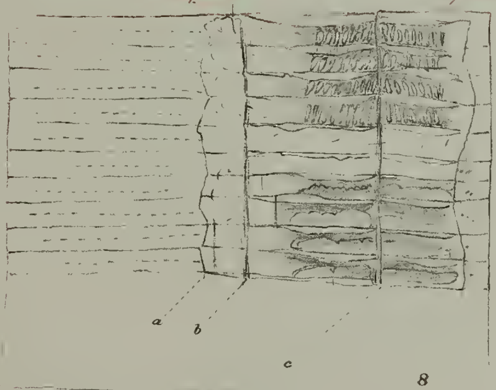

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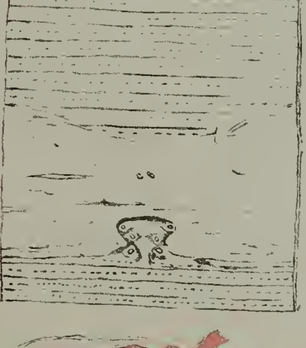

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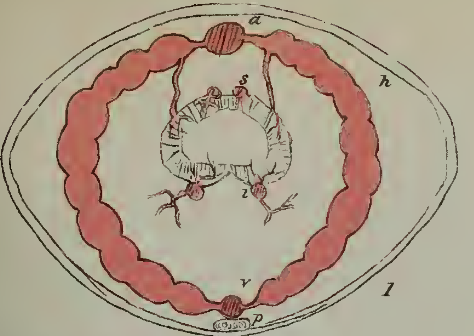

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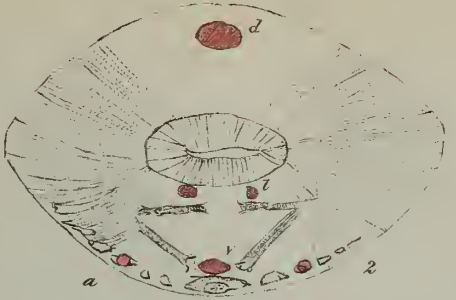

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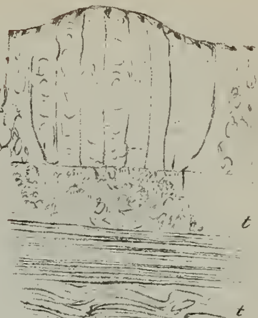

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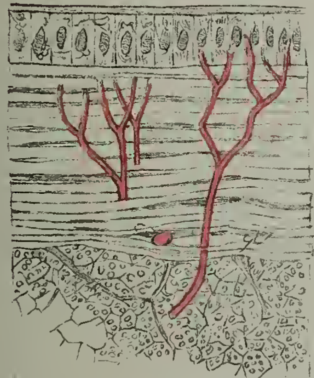

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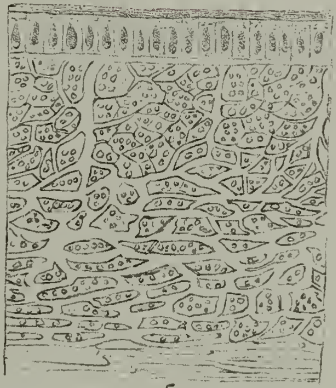

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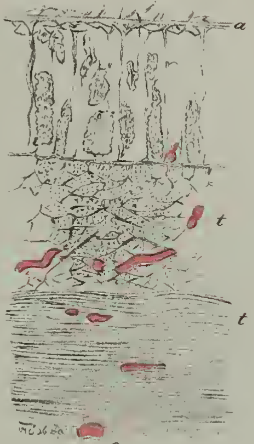

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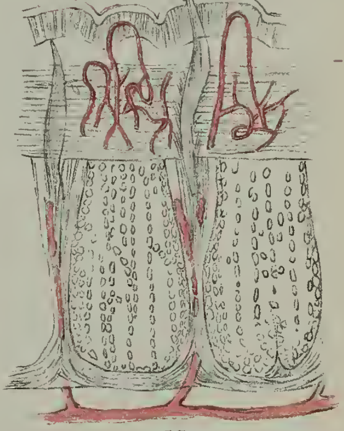

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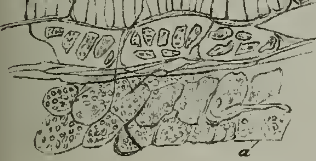

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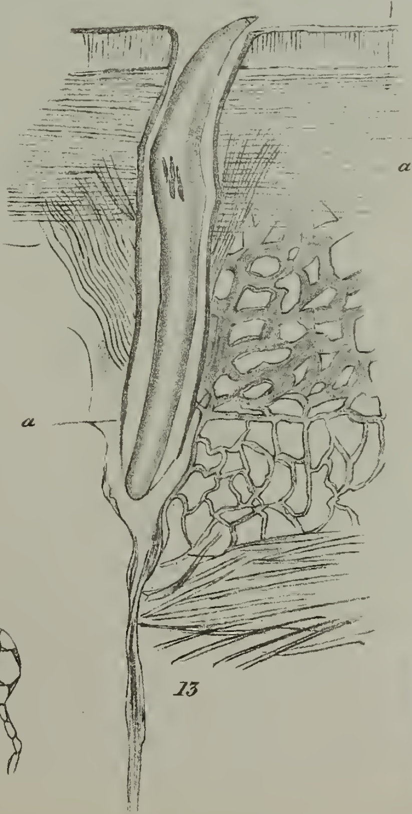

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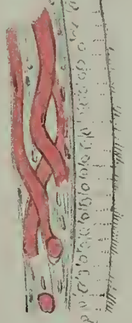

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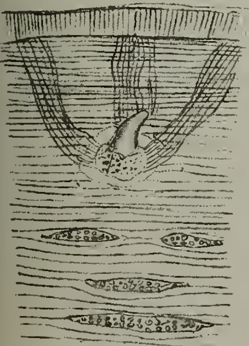

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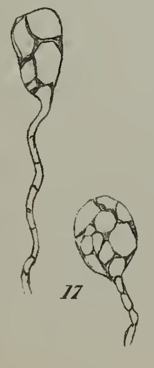

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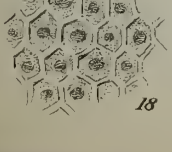

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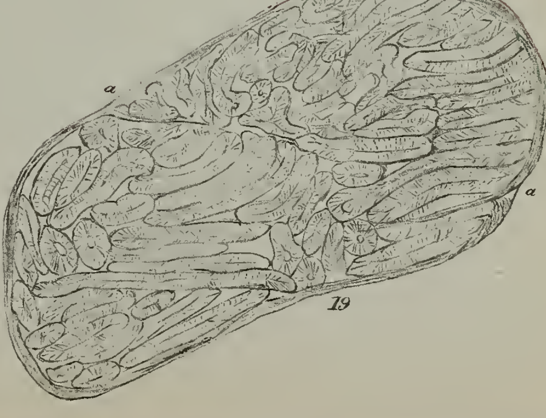

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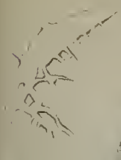

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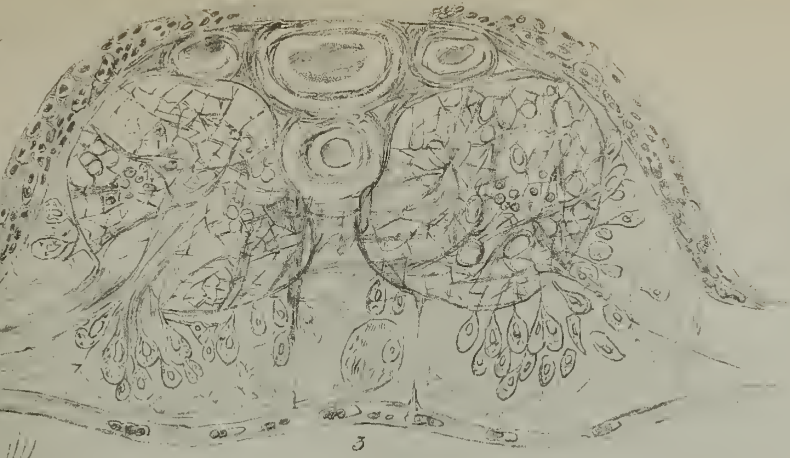

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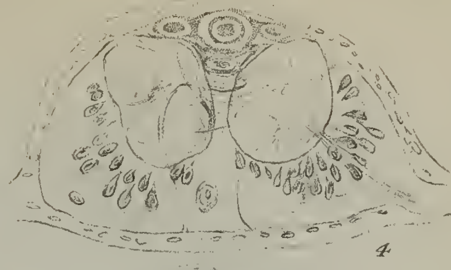

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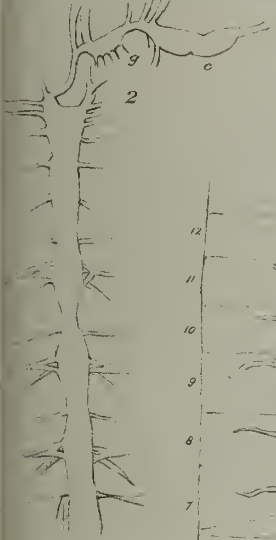

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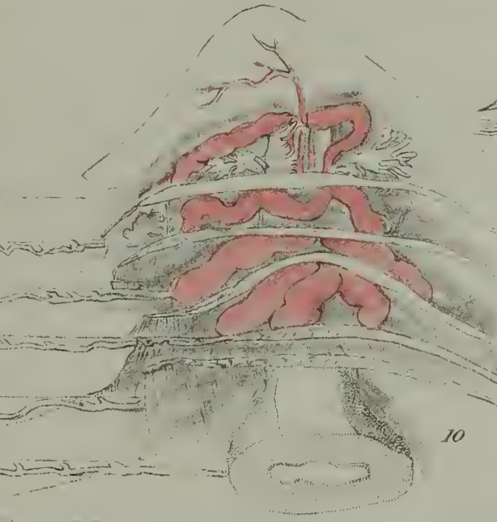

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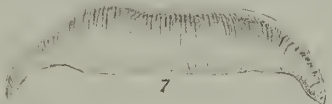

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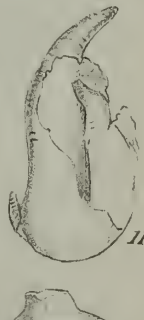

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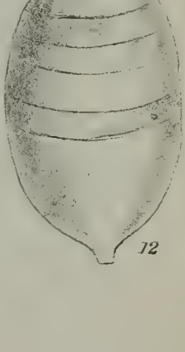

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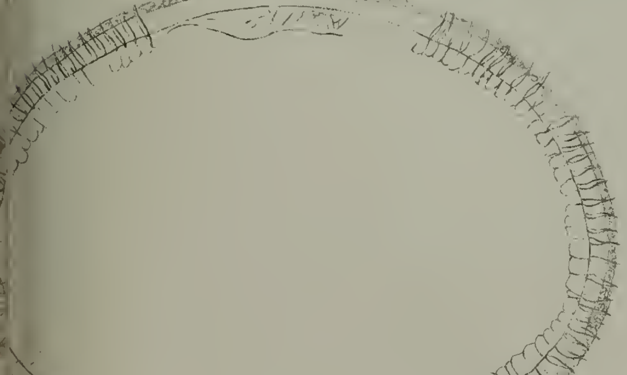

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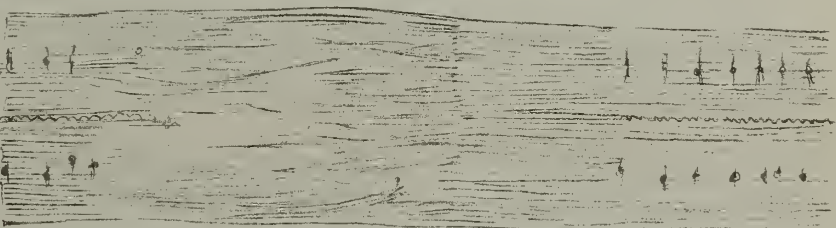

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J. Bartholomew, Edin.

XXI.—*Further Researches among the Crustacea and Arachnida of the Carboniferous Rocks of the Scottish Border.* By B. N. Peach, A.R.S.M., F.R.S.E., of the Geological Survey of Scotland. (Plates XXVIII. and XXIX.) .

(Read 20th March 1882.)

I have again been privileged by Professor A. Geikie, Director-General of the Geological Survey of Great Britain and Ireland, in being allowed to bring before this Society the results of a further study of the Crustacea and Arachnida obtained by the Geological Survey from the Lower Carboniferous rocks of the Scottish Border. Since my former papers on those subjects were read, a considerable amount of fresh material has come to light, which has allowed of many species, which were formerly represented by fragmentary specimens, to be more fully described, and several altogether new to science to be added to our former list.

Class I. CRUSTACEA.

The Crustacea, as formerly, arrange themselves under the orders *Phyllopoda* and *Decapoda.*

Order I. Phyllopoda.

In my former paper I described two species of *Phyllopoda,* which I referred to the genus *Ceratiocaris,* Salter. Since then I have been enabled to study a large suite of these fossils belonging to at least three species, and I now think that, though they are very nearly allied to *Ceratiocaris,* they differ so much from it as to warrant their being erected into a separate genus, for which I propose the name of *Acanthocaris,* or spine-shrimp, from the spine-like telson.

Acanthocaris, gen. nov.

Characters.—Carapace small, and not hinged, produced anteriorly into a blunt snout, and posteriorly into rounded lobes. Body fusiform and long, composed of numerous segments which increase in length backwards, the seven posterior ones being uncovered by the carapace. Third segment from tail tumid, and notched on its ventral surface. Telson long and spiniform, and flanked on each side by a rudimentary spinelet. Test smooth or slightly wrinkled, but not striated longitudinally.

Acanthocaris attenuatus, nov. spec., Pl. XXVIII. figs. 1–1*c*.

Animal small, about 2·6 cm. in length, including telson.

Carapace.—About 6 mm. in length, narrow in front, and broadening posteriorly to about 2 mm. Body 14 mm. long, narrow in front, where it measures ·5 mm., gradually broadening backwards, its greatest breadth being 1 mm. The segments of which the body is composed as well as broadening increase in length backwards, the three last measuring respectively 1·5 mm., 2 mm., and 3 mm. As in the already described species the ventral surface, of the third segment from tail appears gapped by a large notch, which in all probability represents the opening of the generative organs. Telson 6 mm. long by about 1·5 mm. broad at the base, and tapering to a point which is gently curved upwards, ornamented dorsally by a central ridge of small bosses, with a fluting on each side bearing a row of nearly circular raised rings with embossed centres. This ornament is much like that of *Ceratiocaris elongatus*, mihi, but is much larger in proportion to the size of telson than in that species.

Order II. Decapoda.

Genus *Anthrapalæmon*, Salter, 1861.

Anthrapalæmon formosus, mihi, Pl. XXVIII. figs. 3–3*b*.

At the time of the reading of my last paper, this species was known by a single carapace only. Since then the Survey has added to its collection several specimens, which allow of the abdomen being studied. One of these shows a carapace like that described, which is displaced, doubled together, and turned round, so that its anterior end overlaps on to the first segment of the abdomen; but there can be no doubt that the different parts originally belonged to the same individual.

None of the appendages of the cephalo-thorax have been observed.

The abdomen, which varies in different specimens of from 1·8 to 3 cm. in length, consists as usual of six segments, and is in most respects very like that of *A. Etheridgii*, except that it is plainer and more elongated. The first segment is narrow, the second a little deeper, and the third much larger than either, while the sixth is the deepest. The last five are supplied with pointed pleuræ directed backwards. The telson is of the same type as that of *A. Etheridgii*, but more elongated. It is about half the breadth of the sixth segment at its anterior portion, tapers down to about one-third of its breadth, and then expands into an elongated spatulate membranous extremity, strengthened by being slightly corrugated. At its narrowest part the telson has articulated with it two small accessory swimmerets, one on each side. The telson is flanked on each side by the customary two swimmerets set on a single propodite, the modified limbs of the sixth segment. The strengthening portion of each swimmeret is more elongated than in *A. Etheridgii.* The test is everywhere thin and smooth, and devoid of corrugation. Altogether there is a chaste severity in the want of external ornament, and an elegance of form which makes the abdomen a fit accompaniment to the carapace, and deserving of the name it bears.

Anthrapalæmon Etheridgii var. *latus*, nov. var., Pl. XXVIII. figs. 4–4*b*.

Among the many specimens of this species, there appears to be a well-marked variety, which is in all other respects like *A. Etheridgii* described by me, except that it is much broader and shorter in all its proportions. Its breadth compared with its length is as 1 to $2\frac{1}{8}$, while in the latter it is as 1 to 3. Its carapace is broader than long, while that of *A. Etheridgii* is the reverse. It occurs in the Langholm bed associated with the latter form in the relation of about two to every hundred.

Horizon.—Calciferous Sandstone Series.

Collector.—A. MACCONOCHIE.

ROBERT ETHERIDGE, jun., of the British Museum, while acting as Palæontologist to the Scottish Survey, ascribed several carapaces of a decapod crustacean, collected by Mr. MACCONOCHIE from Tweeden Burn, Liddesdale, to the genus *Anthrapalæmon,* under the name of *A. Macconochii,* after the finder. Since Mr. ETHERIDGE left, two specimens were found, which displayed many other parts, and which I described in my former paper. Further search among the Border rocks has brought to light a goodly number of specimens, showing that there are at least two more species with a strong family likeness to that form, and that they so far agree with it in differing from all the other crustaceans that have been looked upon as belonging to the genus. Their chief characteristic is the large size of the carapace compared with the dwindled abdomen, which could be of little use as a propelling organ. In this they remind one of such recent anamorous decapods as Galathea and Procellana. I therefore propose to separate them from Anthrapalæmon by forming the new genus *Pseudo-Galathea,* to include them, though by so doing I would expressly state that I do not believe that our recent Anamoura were more immediately descended from these than from any other of the Carboniferous decapods.

Genus *Pseudo-Galathea,* gen. nov.

Character.—Carapace large, subovate or nearly discoid, produced anteriorly into short stout rostrum, and the posterior angles continued backwards as incurved horns much beyond the middle line of posterior margin. Cervica groove deep. Carapace ridged into three longitudinal crests, besides the thickened margins, all tuberculated. Abdomen short, composed of six narrow highly faceted segments with pointed recurved pleuræ. Telson wide at base, suddenly narrowing, expanding into a rounded and fimbriated termination and supporting two flattened lobes at narrowed part. Swimmerets of tail ovate and directed inwards, so that tail is broader at base than extremity. Body much depressed, so that fossils belonging to this genus are invariably exposed "back up." Test of considerable consistence.

Pseudo-Galathea rotunda, nov. sp., Pl. XXVIII. figs. 6–6*a*.

Small species nearly as broad as long. Length, including rostrum and telson, 2 cm., of which the abdomen only makes up 8 mm. Breadth across widest part of carapace 1·4 cm.

Carapace almost discoid, produced anteriorly into short rostrum and posteriorly into horn-like processes, so that the posterior margin is deeply concave. A deep cervical groove proceeds from near the antero-lateral angles, and passes backwards to near the mid line of the back, dividing off the carapace into two unequal areas. Three lines of ridging, one mesial and two lateral, traverse both areas, being gapped only by the cervical groove. These bear numerous tuberculations, as in *P. Macconochii*, while the thickened lateral margins only bear small tubercles, and are further ornamented by longitudinal lines. Cephalic appendages, as in *P. Macconochii*, consist of large eyes, antennules with broad conical two or three jointed propodites, supporting double short tapering many-jointed setæ, and antennæ made up of long-jointed lashes very thick at base. The nature of the propodite not observed. No basal scale seen. None of the other cephalo-thoracic appendages observed. Abdomen short and narrow between the horns of carapace, and suddenly expanding beyond it, made up of six well-faceted very small terga, which give off small-pointed pleuræ directed back at a considerable angle from the line of the tergum. The telson is broad at base, tapers very suddenly, and again expands into a fimbriated lobe, and supports a small lobe on each side. The appendages of sixth segment in the form of two flattened elongated swimmerets, on each side supported on single propodites. These are usually found in the fossil state with the points directed inwards.

Locality.—River Esk, 4 miles south of Langholm.

Horizon.—Calciferous Sandstone Series.

Collector.—A. MACCONOCHIE.

Pseudo-Galathea ornatissima, mihi, Pl. XXVIII. figs. 7–7*b*.
Anthrapalœmon ornatissimus, ante p. 83, Pl. XXVIII. fig. 7.

The description of this species was obtained from two fragments of carapaces, the anterior portions of which were only visible. From what I saw I presumed they were nearly allied to *P. Macconochii,* and several specimens have been recently added to the Survey Collection, and these fully bear out the surmise. The carapaces are much more elongated than in the *P. rotunda,* and are in most respects like those of *P. Macconochii,* save that the ridges, instead of bearing a single row of large bosses, each carry several rows of minute tuberculations. Eyes and antennules much as in *P. Macconochii.* No basal scale to antennæ observed. The abdomen is intermediate in length between that of the other two species, while the tail is much as in *P. Macconochii.*

As no basal scale has been observed attached to the antennæ of any species of this genus, there is a strong presumption that it never existed, for in those of the carboniferous decapods, which are known to bear it, that part is oftener preserved than the more fragile lash. In this character, and the general arrangement of the tails, these species are similar to *Anthrapalœmon gracilis* of Meek and Worthen, though the posterior angles of the carapace of their species are rounded off, and not produced backwards as in ours.

Genus *Palœocrangon,* Salter, 1861.

Palœocrangon elegans, nov. sp., Pl. XXVIII. figs. 8–8*a*.

A very graceful shrimp-like form, 2–3 cm. in length.

In most respects this species resembles the *P. Eskdalensis,* but differs from it in its more elongated form, and in the pleuræ of the second abdominal somite, which are not so much enlarged, nor do they extend so far forwards. The tergum of the last thoracic somite is not covered by the carapace.

This species occurs sparingly at Langholm along with *P. Eskdalensis,* but at Pathhead Mill, near Dunse, Berwickshire, whole shoals of it are found embedded in the same slab.

Horizon.—Calciferous Sandstone Series.

Collector.—A. Macconochie.

Genus *Palœocaris,* Meek and Worthen, 1865.

Palœocaris Scoticus, mihi, *ante.*

A further contingent of these pretty little fossils from Langholm shows that the eyes were supported on long movable stalks much as in the recent Mysis. One or two specimens show them as bent off at right angles to the direction of the body. This fact, coupled with the arrangements of the antennules, antennæ, and tail, show them to have been lowly decapods in which the parts have not been so much specialised as in their neighbours the Anthrapalæmons.

Dr. WOODWARD has described another species of this genus in the interval between the reading and publishing of my former paper. As his specimens were obtained in 1876, they bear away the priority which I supposed the Eskdale fossils to have enjoyed as having been the first of the genus found in Britain.

Class II. ARACHNIDA.

Under this class I propose to rank a set of animals which have usually been placed among the Crustacea, by what I consider a straining of the comparatively few analogies which exist in common with them and undisputed orders of that class, while the eyes have been shut to the more numerous and conspicuous affinities with the Arachnida through the scorpions. In this I only follow STRAUS-DURCKHEIM, VAN BENEDEN, RAY LANKESTER, and many other naturalists.

Order MEROSOMATA.

Suborder EURYPTERIDA.

Numerous specimens, which would certainly have been ascribed to Eurypterus, have been unearthed by the Survey Collectors from the Carboniferous rocks of the Borders within the last year or so. These, though fragmentary, are sufficient to add some small items of positive evidence in support of the inference that the ancestry of our recent scorpions was through the Eurypterids, and that the Carboniferous Eurypterus was probably a land animal, and therefore distinct from the discovered Silurian and Old Red members of that genus which were aquatic. As some at least of the Carboniferous Eurypterids were supplied with combs and walking feet ending in two claws, undistinguishable from those of scorpions, I propose to erect a genus for the reception of such as bore them.

Genus *Glyptoscorpius*, gen. nov.

Segmented animals with horny integuments sculptured as in Eurypterus, composed of carapace with sub-central simple eyes, and twelve other body segments, and provided with comb-like appendages, as in scorpion, the walking legs having bi-ungulate tips.

Glyptoscorpius peronatus, nov. sp., Pl. XXIX. fig. 16.

The specimen from which the following description is taken, was found by Walter Park, Esq., at Langholm, in the highly fossiliferous bed near that place. Like many of his other treasures obtained from the same source, it has been generously lent to the Survey for description. It exhibits the dorsal view of the posterior part of the left side of the carapace, and a little more than the left halves of five of the body segments still in place. In addition, the interior of a large portion of the sternal organs of the left side have been exposed by the removal of the anterior portion of the carapace, as well as several joints of one of the limbs, and the second joint of another. A narrow stripe along the broken margin gives an insight into the nature of the ventral plates corresponding to the dorsal ones preserved. The animal seems to have been truncated at the fifth body ring, the soft parts decomposed out, and the hollow partially filled in with mud before being entirely embedded. The greatest length of the specimen is 9 cm. (about 3½ inches), and the breadth 8 cm. (3⅛ inches). The carapace measures from the mid line to the posterior lateral angle 6 cm., the breadth of the carapace then must have been about 4¾ inches. From this the body tapers backwards to 8 cm. or 3⅛ inches at the posterior margin of the fifth body segment.

Carapace.—The portion preserved represents part of the hinder end of the head shield extending from the left margin to a little beyond the middle line. It measures from 6 to 7 cm. in breadth, by 2 cm. in depth. The portion which would bear the central eyes is therefore not preserved. At the left side the carapace is doubled under, so that a flange with the ornamented side turned downwards 5 mm. wide, is seen to extend for some distance beyond the portion of the carapace preserved. If the direction of this indicates the shape of the carapace, it should be nearly semicircular, with a radius of about 6 cm. The whole of this part is covered more or less with the characteristic scale-like ornamentation, while the posterior margin is graced with a deep fringe of scollops which have sub-parallel sides and rounded tips, each scollop having a bulging centre and a delicate raised edge, and being separated by grooves like knife cuts from its neighbours. The fringe is deepest near the mid line of the back, and dwindles to less than half that depth towards the sides. Near the lateral edge a different ornament, like the long feathers on a bird's wing, sets in, while on the flange the markings are V-shaped and pointed. Where the test is thickened, especially where two plates overlap, the ornament is considerably marred by the test being blown up with pyritous concretions, which have formed within its thickness. Many of these have decomposed out, leaving lines of honey-combed test, as shown in fig. 16.

Cephalic Appendages.—The interior of four triangular plates, with intervening wrinkled skin, are seen to converge towards the centre of the head shield. The posterior edges of the plates are seen to underlie the anterior edge of the succeeding ones—that is, to overlap them. These are doubtless the coxæ of limbs, portions of which are still attached to their broader ends. The inner or narrower ends are broken off, so that it is impossible to see whether they were used as gnathites. The foremost coxa preserved bears a limb, which is unfortunately in a bad state of preservation. The portion left is 4 cm. long, by 6 mm. broad, and has extended beyond the limit of the stone. It lies bent back at nearly right angles to the coxa, and is again bent forward upon itself so that it must have had several joints, though it is not sufficiently well preserved to make out its component parts. It is covered over with a thick coating of spines and bristles, some of which are curled up, and others are detached and lying loose in the matrix. It is unfortunate that the extremity is broken off. The coxopodite of another limb studded with bristles is also preserved, and this too is bent back, so as to lie alongside the body. No swimming foot observed.

Body Segments.—The dorsal portion of the body segments increase in depth as they decrease in width, for while the first is only 5 mm. the seventh is a little over 7 mm. in depth. The exposed portion of the segments of the specimen vary considerably, as the body rings have been telescoped irregularly into one another. They are all ornamented in a similar manner to that described as occurring on the carapace. The scale-like ornament is smaller near the anterior margin, and increases both in convexity and size towards the posterior margin of each segment. The depth of the fringe of scollops on each segment also increases backwards. On the fifth dorsal plate a symmetrical pattern is produced by the scale-like ornament becoming very much elongated and diverging from a central line, thus allowing of the middle line of the back being easily made out, which can only be seen from the depth of the scolloping on the segments anterior to this one. The lateral margin of the hinder segments have the same V-shaped markings as the flange of the carapace. The ventral aspect of the abdominal plates, corresponding to the dorsal ones described, is seen along a narrow stripe a little to the right of the middle line of the animal. These are all seen to be firmly attached to each other by folded skin, and they bear a similar ornament to that exhibited by the dorsum.

Locality.—River Esk, 4 miles south of Langholm.

Horizon.—Calciferous Sandstone Series.

Glyptoscorpius Caledonicus, Salter, Pl. XXIX. figs. 17–18*a*.

Cycadites Caledonicus, Salter, Mem. Geolog. Survey (*Geology of Eastern Berwickshire*, p. 58), figured in Memoir of Geological Survey, 33, Scotland (*Geology of East Lothian*, p. 72), fig. 22.

About the year 1860, the late RICHARD GIBBS, fossil collector to the Geological Survey, while searching the Calciferous Sandstone beds near Cockburnspath, a few miles to the south of Dunbar, alighted on a peculiar fossil which SALTER described as a new cycadeous plant, under the name of *Cycadites Caledonicus.* For a long time this specimen remained unique. Last spring, however, Mr. MACCONOCHIE, while examining the beds in which the famous Lennel Braes fossil wood occurs, had the good fortune to find magnificent specimens of a like fossil, which proves to be the "comb" organs of an animal nearly allied to scorpion. If my dear old friend and instructor had enjoyed the opportunity of studying the new fossils instead of the one he did, which is preserved in coarse sandstone, there is little doubt he would have seen that they belonged to a Eurypterid, and would have ascribed them to their true position in that animal. Fragments of these comb-like organs with Eurypterus markings have since been found near Langholm; and this year THOMAS STOCK, Esq., of the Museum of Science and Art, Edinburgh, has generously allowed me to study a small one from the Calciferous Sandstones of Tweeden Burn, Liddesdale, which he got there during a visit he paid to the Borders last year, and which he has since presented to the Geological Survey. Professor A. GEIKIE has kindly brought me the original specimen of the *Cycadites Caledonicus* from the Jermyn Street Museum, London, for my inspection, and after carefully comparing it with the Lennel Braes fossils, I have little hesitation in looking upon it as belonging to a smaller individual of perhaps the same species. I therefore retain SALTER's specific name.

Description.—Carapace unknown. It was probably semicircular, with subcentral simple eyes like those of *Eurypterus Scouleri,* Hibbert.

Of the limbs only fragments are preserved, but these are sufficient to show that they have been much more elongated than in the case of the Old Red and Silurian Eurypterus. One fragment, probably the shaft of the third joint, measures 8 cm. in length by 3 cm. in breadth, without showing any articulation, and as it is broken off at each end it may have been considerably longer. That this was the case can be proved, for the lower articulation is preserved on a separate piece of stone, which does not fit on to that on which the larger part occurs. This portion of the limb was in all probability laterally compressed, and bore a fringe of long elegant leaf-like serrations (figs. 17*a*–17*c*); while the body of the shaft is beset with the ordinary scale pattern, the scales being much elongated in the direction of its length. The distal end of the joint seems to be prolonged beyond the articulation with the succeeding one into two triangular projections, down the outside of which the serrated margin is continued, the apex of the triangles being occupied by a blunt-spine just as in other limb-joints to be described. Other portions of equally massive limbs occur on the same slab with the above, and these bear similar markings. A specimen from Coldstream Bridge shows a fringe which must have belonged to a still larger limb than any of the Lennel Braes fossils.

Body Rings.—As regards size, these are in keeping with the limbs; but there are only portions of one or two of them from which to judge of the rest. One fragment of what appears to be the fifth or sixth dorsal plate measures 10·5 cm. from its anterior articular face to its posterior margin, and 15·2 cm. from the central line of ornament on its back to the broken edge of the specimen, which does not show the lateral margin. This plate must therefore have been more than 1 foot across. Another plate, only 4·5 cm. in depth, must have succeeded close to the carapace. It too is broken, and there are no means of judging of its breadth except that the comb organs each measure 17·5 cm. at least. This plate then could not be less than 16 to 18 inches broad. Both these plates and the portions of others more fragmentary still show that they were covered by the scale-ornament. This is small compared with the size of the plates. As in other Eurypterids, the scales are only slightly concave, and most numerous near the anterior margin, becoming larger, deeper, and more scattered as we proceed backwards. The posterior margin of the plates is ornamented with a broad band, and scolloped with small scollops on its edge. The largest plate shows a symmetrical pattern in the mid line, like that observed on the *G. perornatus.*

Combs.—The greater part of both combs are preserved in good condition for study. They must have measured at least 17·5 cm. each from base to tip. They each consist of a broad rachis 1·1 cm. across the broadest part of the specimen measurable, which is at least 8 cm. from the possible base where it was probably broader. They taper gradually to blunt points. From the base they curve backwards very gently at first, and then gradually and increasingly to the tips. They have been attached only by their base, their whole upper margin being quite free. On the lower or concave margin they give attachment to two rows of long flattened hollow leaf-like filaments, which are set obliquely to the long axis of the rachis, and with their exterior margins directed towards its tip. They therefore overlap from within outwards. As well as this, the inner edges of the filaments of the separate rows extend beyond the middle line, and as the leaflets in each row are given off alternately their inner edges interlock (see fig. 18). Those filaments attached near the base appear to be the longest, where they measure 4 to 5 cm. From this they gradually decrease towards the tip, so that the limit of their extremities forms a nearly straight line. They are on an average a little over 1 mm. in breadth, their sides are for a considerable part of their course almost parallel, and they converge gently and increasingly to the tips. All the filaments are set outwards at angles from 45° to 60° to the stem. They are at first straight, and then gently curved outwards towards their points. The rachis is ornamented with pyriform or spine-like embossing arranged in its long direction. The filaments, which are hollow and depressed, have a central plain portion bounded by a raised margin. In addition to this the external edges are serrated with a miniature pattern to that on the limbs. On the internal margin only a few denticles are shown near the tips. On an average eight filaments are given off on each side in a distance of 10 mm., so that a comb 17·5 cm. long would support 280 filaments. In the above specimens the test has been well preserved. It is horny, tough, and elastic, black and opaque where thick, and rich brown and translucent where thin. The rachis in the case of the Lennel Braes specimens is flattened, and conforms to the bedding planes of the stone in which it occurs; but in that from Cockburnspath the "Cycadites," being embedded in sandstone, it is preserved in the round. In it the greater portion is broken away, but there is still a part preserved near the tip, which shows a cross section pyriform in shape, with the broader end downwards, measuring in depth 4·5 mm. and 3 mm. in breadth at its widest end. From this fact it would appear that the comb could not have been hid under an opercular plate, but must have been an external organ. The rachis of this specimen also shows that as well as the downward curve noticed in the Lennel Braes ones, that there was a gentle curving inwards especially near the extremity, just as in the combs of recent scorpions, thus giving us a very good indication of the amount of rotundity or depression of the body of the animal to which it must have conformed itself (see fig. 18).

The specimens again throw light upon the apparent narrowing of the leaflets of the *Cycadites Caledonicus* at their bases, as described by SALTER in the Survey Memoirs. The filaments, which are at first set on obliquely to the rachis, soon bend round so as to lie almost in the same plane as itself, thus giving rise to the deceptive appearance which doubtless misled him.

Horizon.—Calciferous Sandstone Series.

Disjecta Membra of Glyptoscorpius.

Combs.—A portion of a comb similar to those described, though much smaller and differing in ornament from them, was obtained from the Cement-stone Shales at Tarrasfoot, near Langholm. A portion of the rachis, 1·5 cm. long by 5 mm. broad, with about thirteen filaments, the longest of which measures about 1·8 cm., is still seen. These latter are arranged exactly as in the former case, but the serrations on the outer margins of the filaments are much longer in proportion than in *G. Caledonicus.* The rachis is also much thicker in proportion to the filaments (figs. 20 and 20*a*).

Horizon.—Calciferous Sandstone Series.

Collector.—A. MACCONOCHIE.

The comb mentioned as having been found by Mr. STOCK is smaller when compared with the above, but it is essentially of the same character. It is preserved in the round as a cast in sandy shale. The outline of the rachis is visible along the curve for about 3·5 cm., but a portion of about 10 mm. long, near its outer extremity, has the leaflets attached. The rachis is very thick compared with those already described, being from 4 to 5 mm., and tapers off to a blunt point, while the longest leaflet preserved is only 6 mm. The leaflets diminish in length outwards, and overlap each other in the manner of those of *G. Caledonicus.* The fossil being a cast gives no definite ornament, though there is a faint appearance as if the rachis had been embossed. This specimen shows very decidedly that the rachis was not of a nature to allow of its being wedged in between the opercular plates, else it would have been more laterally compressed (see fig. 21).

Locality.—Tweeden Burn, Liddesdale.

Horizon.—Calciferous Sandstone Series.

Collector.—THOMAS STOCK, Esq., of the Museum of Science and Art, Edinburgh.

Single comb filaments have been obtained from the Liddesdale and Langholm beds. They are very apt to be passed over as "Poacites," and might easily be mistaken for Graptolites, as they are of a like horny texture, and have the edges similarly notched. There is a considerable variety in the shape and pattern of these filaments, showing that there are several Eurypterids yet to be described.

Limbs.—A portion of a limb with Eurypterus markings, and having a bi-ungulate tip, has turned up in the collection made by Mr. MACCONOCHIE from Langholm. The specimen measures over 6 cm. (or 2⅜ inches). It is made up of three joints, which correspond exactly to the last three of the recent scorpion limb. The portion of the topmost joint preserved is 2·2 cm. long, and about 6 mm. broad at its narrowest part, while across the articulation it swells out to 10 mm. The tarsus is 1·7 cm. long, narrowest above where it measures only 4·5 mm., and broadening to 9·5 mm. at its articular extremity. Both these joints lie nearly in the same direction. The hand, which is bent upwards at a considerable angle, is 1·3 cm. long, 4 mm. broad at base, and expanding to 7 mm. It supports two stout recurved claws, the tip of one being broken off;* the other is nearly whole, and measures about 10 mm. along its curve. Above the articulation of the claws there is just such a projection of the test as in scorpion, which evidently fitted in between the claws when the animal was alive. From the lower part of each articulation a spine-like projection is given off. This is serrated with the Eurypterus marginal ornamentation.

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* Since the above was written a further examination shows that the rest of the claw is present, but that it passed down into a lower stratum of the matrix.

The tarsus bears a similar marking on its lower margin. Each articulation is edged with the Eurypterus scolloping (see Pl. XXVIII. fig. 11).

A specimen (fig. 11*a*), showing the tarsus and hand with the double claws, and projecting spines at the joint, which in all likelihood belonged to this genus, was obtained from Lennel Braes, and described by me as scorpion in my paper on the Scorpions of the Scottish Border.

Another portion of a limb, apparently a walking leg made on the type of scorpion, comes from Lennel Braes. The shaft of one joint measures 5 cm. from articulation to articulation. It is laterally compressed, has serrations on both margins, is narrowest about its middle, where it measures 11 mm. across, and widens at its lower articulation to 15 mm. It has a gentle upward curve. The upper articulation of this joint is set at an angle of 45° to the long axis of the shaft, and it occupies only about the anterior half of the end on which it is placed, the other half being produced backwards as rounded heel-like projection. The lower extremities of this joint is produced considerably beyond the articular line in the form of two triangular areas down the outside, of which the ornamental serrations are continued, the inner sides being plain. Between these the next joint is wedged, and a portion of it with its serrated anterior edge is seen to be bent off at an angle of 35° towards the posterior margin. The joint first described must then correspond with the third joint in the scorpion's limb, where the leg doubles both ways. Fig. 23 is a representation of this fossil, natural size, with a scorpion's limb drawn for comparison, and the portion of the corresponding joint which exhibits a different sculpturing is shown in fig. 14, also from Lennel Braes. Fig. 15 represents the apical portion of another joint from Langholm, which, in addition to similar triangular projections to those above described, shows the Eurypterus scolloping on the articular portion. As well as the usual fringes, it has a strong ridge bearing serrations on its mid line. It is very much like the third joint of the palpus of a scorpion, which has just such crests of tubercles.

Besides the portion described there are several fragments of more or less interest in the Survey Collection, exhibiting a considerable variety of pattern and sculpturing. Some of these pieces must have belonged to individuals as colossal as the *G. Caledonicus,* and others to mere pigmies; but it would be imprudent to attempt to make species from ornament alone without knowing what part of the body it graced, as the same Eurypterus often exhibits different kinds of decoration on its several parts. Among the fragments obtained from Langholm are the remains of what has been an individual almost as large as the *P. Caledonicus* described from Lennel Braes, and which exhibits an ornamentation somewhat similar to that species. The specimen occurred in such a manner that only fragments of it were procurable by the collectors. One piece is of great interest, as it still holds between the upper and lower plates of the thoraco-abdomen the mummified remains of muscle, which can be teased out so as to exhibit its characters under the microscope. The fibres all lie parallel to each other, and at right angles to the breadth of the plates, that is, in the direction of the length of the body, as they do in the corresponding parts of the recent scorpions.

It is necessary I should say something in defence of my position, in making a genus for the reception of these Eurypterids. The affinities of scorpion with Stylonurus and Pterygotus have often been pointed out, but in all these the cephalic appendages of which have been observed were undoubtedly aquatic. The appendages of the Carboniferous Eurypterus, however, have never before been studied to my knowledge, as that animal has been only known by the carapace and a few of the body segments. From these and the markings it has been inferred that their limbs were like those of the Old Red and Silurian genera. As far as the present evidence goes, this inference entirely breaks down, at least for those individuals that have come under our notice in the Survey Collection. The portions of limbs preserved can better be interpreted by comparison with scorpion, and those with the bi-ungulate foot belonged to undoubted air-breathers. There is little doubt that the comb-like organs occupied the same position as those in scorpion, for they are constructed exactly on the same type. They have been found in the same position in Pterygotus, but attached to the under side of the lateral alæ of the opercular plate, as shown by WOODWARD.* Professor GEIKIE has kindly placed at my disposal for study the specimen figured by WOODWARD, and which belongs to the Jermyn Street Collection. This plainly shows the gills in place. WOODWARD's figures are in the main so truthful that it is unnecessary to make any new sketches to illustrate this paper. It may be as well, however, to say that what might be mistaken as the rachis of the left gill is in reality in a higher stratum than the gill filaments, and that the latter as seen on the specimen pass under it and reappear between it and the larger and unbroken and upturned portion of the left ala. The filaments are quite membranous and highly vascular, and well fitted to perform the function of breathing. In the Carboniferous combs, however, the filaments are not membranous, but are yet preserved as hard, tough, horny and elastic plates, so that it is improbable that they acted as gills, and the rachis is too thick and rounded ever to have been held beneath the thoracic plates. The rachis itself is in all probability the homologue of the lateral alæ of the thoracic plates of Pterygotus and other older Eurypterids, while the "teeth," so to speak, are the gill filaments chitinised and modified to perform some other function.

The integument of the Carboniferous specimens examined are not crustacean in character, but are horny and like that of scorpions and insects. In

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* *Mon. British Fossil Crust. belonging to the Order* Merosomata, by HENRY WOODWARD, LL.D., F.R.S., &c., p. 67, pl. xi. figs. 2*a* and 2*b*.

the thinner parts of the sternal plates it is still quite translucent and almost transparent.

Suborder XYPHOSURA.

Genus *Prestwichia*, Woodward, 1867.

A portion of a thoraco-abdominal buckler of a small Limuloid was obtained by Mr. MACCONOCHIE from Larriston, Upper Liddesdale, some time ago. The recent excavations near Langholm have brought to light several specimens of a large species of the same genus *Prestwitchia,* which, however, are very badly preserved.

Prestwichia alternata, nov. sp., Pl.XXVIII. fig. 10.

Carapace unknown. Thoraco-abdominal buckler about 6 mm. long by 7 mm. broad, irrespective of telson and side spines. Anterior or articular margin not preserved. There is a central area divided off from the broad margins by two deep trenches which proceed from near the anterior part, and after describing arcs of circles converge upon base of the telson. Side branches are given off from this trench inwards, but they only pass a short distance into the central area. All the sulci are merely infoldings of the test, and not articulations. The telson, which is broken off at a distance of ·5 mm. from its insertion at the sulcus, where it is ·5 mm. broad, appears to have been much longer. Six recurved spines are seen on one side, which pass from the sulcus through the border, and are then curved gently backwards. These are alternately longer and shorter, the former on measuring an average 7 mm. and the latter only 3 mm. It it this character which distinguishes it from *Prestwichia anthrax*; which species it closely resembles.

Locality.—Larriston Burn, Upper Liddesdale.

Horizon.—Calciferous Sandstone Series.

Prestwichia rotundata, Woodward, 1867.

Limulus rotundatus, Prestwich, 1840, *Trans. Geol. Soc.*, 2nd series, vol. pl. xli.

Several specimens of a *Limulus*, which may be provisionally referred to the above species, have been obtained from the fossil locality on the Esk near Langholm. They are in a bad state of preservation, owing to their being fossilised in shale, so that the limbs and the gill plates are pressed up through the dorsal shield. In addition, the whole cuticle is usually so much infested with innumerable calculi that it is rendered granular. Owing to these causes the glabella, eyes, and nature of the thoraco-abdominal buckler are not apparent. The general form, however, is easily made out. There is an anterior buckler, the front margin of which describes a little more than a semicircle from 25–40 mm. in radius, and ending at both sides in slightly recurved horns, so that the posterior margin is somewhat hollow, giving the appearance of a saddler's knife. The breadth from tip to tip of horns varies from 2 to 3 inches. Within the semicircle are the arcs of two smaller circles, which intersect at the mid line anteriorly, and divide off a broad horseshoe-shaped plain margin, narrowest in front from a central area, the nature of which cannot be made out for the crushed limbs which are invariably confined within it. The thoraco-abdominal buckler is seen to be fringed with a similar serrated web as in the specimen figured by WOODWARD. In their size and proportions they differ slightly from the *P. rotundata,* though there are not sufficient characters displayed by the specimens to warrant their being made into a separate species.

It is to be hoped that further examples may be obtained, which will throw some light on their character and anatomy.

Locality.—River Esk, 4 miles south of Langholm.

Horizon.—Calciferous Sandstone Series.

Collector.—A. MACCONOCHIE.

Genus *Cyclus,* de Koninck, 1841.

A considerable number of specimens belonging to this genus have been secured during the operations at Langholm. They occur chiefly as flat discs or dome-shaped masses of radiating calculi, which have coalesced into a polygonal mosaic of calcareous plates. They vary from 3 mm. to 10 mm. in diameter. Several specimens are not so badly treated in this way, and in them the test is seen to be chitinous and flexible. Being embedded in shale, they are all more or less flattened, and apparently much in the same condition as the *Cyclus Rankini* described by WOODWARD as having been obtained from the Carboniferous Limestone of Carluke. They appear to belong to one species, which is different in some respects from any yet described. A few of the specimens exhibit the dorsal shield, which is plain and slightly embossed; while others only show the dorsal aspect of the borders, the rest of the upper surface being broken away, exposing the ventral or sternal arches, which radiate much as in the *C. Rankini.* Several large Limuloids and Eurypterids have been obtained from the same beds in which these occur, so that it is just possible they may be larva of the larger animals; but, at the same time, it is quite as probable that they are themselves adult forms. From the fact that several of the Survey specimens exhibit limbs, the radiating lines of the sternum are most probably the divisions between the coxæ, so that I am inclined to differ from WOODWARD, and to look upon the opposite end to what he does as being the anterior one.

Cyclus testudo, nov. spec., Pl. XXVIII. figs. 9–9*d*.

Body discoid or dome-shaped, varying from 3·5 to 10 mm. in length by 2·5 mm. in breadth, and divided into a larger anterior area or carapace, and a smaller posterior area or abdomen. The carapace, which occupies the larger part of the body, is rounded in front, and produced backwards into two horns like *Limulus,* which, however, lie close in to the body, and hold the abdomen wedged as it were between them. The carapace, at least in the crushed specimens at command, is itself divided into two areas, a broad horseshoe-shaped area occupying the whole of the anterior and lateral margins, doubtless due to the infolding of the margin of the carapace as in *Limulus,* and an interior or dome-shaped area, which does not seem to have been subdivided into lobes. The whole of the carapace, as well as the rest of the dorsal portions of the test where not infested by calculi, are minutely pitted or corrugated. In many cases the central area has broken away, so as to expose the interior of the sternal portion of the animal to view. In such specimens six triangular plates on each side, divided from each other by deep sulci, are seen to converge upon an oval sternum; these are smaller in front, and become larger and longer backwards, and the point towards which they converge is situated within the anterior half of the carapace. They do not complete the whole round, for there is a larger median plate behind, which, however, appears to belong to the abdomen. The former plates are the coxæ of limbs, which are seen to pass from the outer sides, beneath the broad horse-shoe band, which is still left on the fossils, and to appear outside it as jointed cylindrical limbs, the tips of which have not been observed.

The abdomen is very small compared with the carapace, and appears to have been buckler-shaped, and to have terminated in a short pointed telson. The nature of its articulation to the carapace, and the character of its appendages cannot be made out from the specimens at command.

Collector.—H. Macconochie.

Locality.—Langholm.

Horizon.—Calciferous Sandstone Series.

EXPLANATION OF PLATES.

Plate XXVIII.

Fig. 1. *Acanthocaris attenuatus*, nat. size.
Fig. 1*a*. *Acanthocaris attenuatus*, nat. size.
Fig. 1*b*. *Acanthocaris attenuatus.* Three last segments and telson of fig. 1 enlarged 6 diameters.
Fig. 1*c*. *Acanthocaris attenuatus.* Portion of telson highly magnified to show ornament.
Fig. 2. *Acanthocaris scirpioides* (*Ceratiocaris scirpioides*). Young specimen nat. size, for comparison with figs. 1 and 1*a* to show difference of proportions.
Fig. 3. *Anthrapalæmon formosus*, nat size. Carapace and abdomen.
Fig. 3*a*. *Anthrapalæmon formosus*, nat. size. Abdomen.
Fig. 3*b*. *Anthrapalæmon formosus*, nat size. Abdomen.
Fig. 4. *Anthrapalæmon Etheridgii*, var. *latus*, nat. size.
Fig. 4*a*. *Anthrapalæmon Etheridgii*, var. *latus.* Carapace nat. size.
Fig. 4*b*. *Anthrapalæmon Etheridgii*, var. *latus.* Carapace nat. size.
Fig. 5. *Anthrapalæmon Etheridgii.* Carapace nat. size, for comparison of proportions with figs 4–4*b*.
Fig. 6. *Pseudo-Galathea rotunda*, nat. size.
Fig. 6*a*. *Pseudo-Galathea rotunda*, nat. size, to show markings on carapace.
Fig. 7. *Pseudo-Galathea ornatissima* (Anthrapalæmon ornatissimus), nat. size.
Fig. 7*a*. *Pseudo-Galathea ornatissima*, nat. size.
Fig. 7*b*. *Pseudo-Galathea ornatissima.* Inside of carapace nat. size.
Fig. 8. *Palæocrangon Elegans*, nat. size.
Fig. 8*a*. *Palæocrangon Elegans*, nat. size.
Fig. 9. *Cyclus testudo.* Magnified nearly two diameters, showing dorsal aspect.
Fig. 9*a*. *Cyclus testudo.* Magnified two diameters, showing central portion of carapace broken away, so as to expose interior of sternum, limbs, &c.
Fig. 9*b*. *Cyclus testudo.* Magnified three diameters, showing carapace broken away as in fig. 9*a*.
Fig. 9*c*. *Cyclus testudo.* Magnified three and a half diameters, in same condition as figs. 9*a* and 9*b*.
Fig. 9*d*. *Cyclus testudo.* Portion of another individual, more highly magnified, to show dorsal surface of abdominal shield.
Fig. 10. *Prestwichia alternata.* Abdominal shield, nat. size.
Fig. 11. Three last joints of walking limb of *Glyptoscorpius* sp., nat. size.
Fig. 11*a*. Two last joints of walking limb of *Glyptoscorpius* ? nat. size.
Fig. 11*b*. Two last joints of walking limb of *Eoscorpius glaber.* Magnified three diameters, to compare with figs. 11 and 11*a*.
Fig. 12. Three last joints of walking limb of a recent scorpion. A little magnified to compare with figs. 11–11*b*.
Fig. 13. Three last joints of walking limb of recent scorpion, nat. size, to compare with figs. 11–11*b*.
Fig. 14. Proximal end of third joint of limb of *Glyptoscorpius* sp. (to show nature of joint), to compare with fig. 22, pl. xxix.
Fig. 15. Distal end of joint of limb of *Glyptoscorpius* sp.

Localities and Horizons.

Figs. 1, 9, 11, 11*b*, and 15. Calciferous Sandstone series, River Esk, 4 miles south of Langholm, Dumfriesshire.
Figs. 11*a* and 14. Calciferous Sandstone series, Lennel Braes, near Coldstream, Berwickshire.
Fig. 10. Calciferous Sandstone series, Thorlieshope, Upper Liddesdale, Roxburghshire.
Fig. 12. Recent, South America.
Fig. 13. Recent, Philippine Islands

PLATE XXIX.

Fig. 16. *Glyptoscorpius perornatus*, nat. size, showing portion of carapace and five body segments.

Fig. 17. *Glyptoscorpius Caledonicus* (*Cycadites Caledonicus*, Salter). Portion of right comb organ, and casts of portions of body segments; nat. size.

Fig. 17*a*. *Glyptoscorpius Caledonicus*. Portion of left comb organ, with some of the filaments hidden by the cast of a limb-like organ with deeply fringed margin ; nat. size.

Fig. 17*b*. *Glyptoscorpius Caledonicus*. Counterpart of portion of 17*a*, showing more of the comb and limb ; nat. size.

Fig. 17*c*. Single filaments of comb represented in fig. 17. Magnified to show serrated edges.

Fig. 18. *Glyptoscorpius Caledonicus*. From specimen figured by Salter, and from which he described the *Cycadites Caledonicus*. Left comb organ ; nat. size, as seen from above, to show the curved rachis, and the manner of attachment of filaments.

Fig. 18*a*. Diagramatic cross section of comb organ, fig. 18, which is partly preserved in the round.

Fig. 19. Enlarged comb of recent scorpion, drawn in the same position as fig. 18, for comparison. After Ray Lankester.

Figs. 20 and 20*a*. Counterparts of portion of comb organ of *Glyptoscorpius* sp., nat. size.

Fig. 21. Comb organ of *Glyptoscorpius* sp., nat. size.

Fig. 22. *Glyptoscorpius* sp. Third, and portion of fourth joint of walking limb ; nat. size, to show nature of articulations.

Fig. 23. Portion of limb of recent scorpion, slightly magnified, for comparison with fig. 22.

Horizon and Localities.

Figs. 17–17*a*, 20 and 20*a*. Calciferous Sandstone series, Lennel Braes, near Coldstream, Berwickshire.

Figs. 18–18*a*. Calciferous Sandstone series, Cockburnspath, Berwickshire.

Fig. 16. Calciferous Sandstone series, River Esk, 4 miles south of Langholm, Dumfriesshire.

Fig. 19. Recent, South America.

The Calciferous Sandstone series of Scotland is now regarded by the Geological Survey as the equivalent of part of the lower portion of the Carboniferous Limestone series of England.

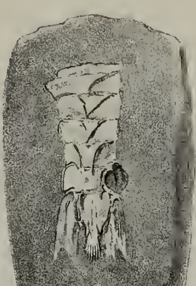

1


1^{b}


1^{a}

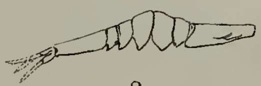

3^{a}


3


3^{b}


2


1^{c}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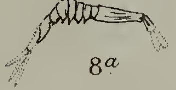
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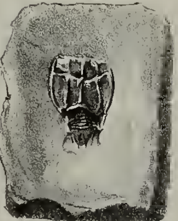
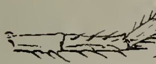
6


6^{a}


11^{b}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13


11

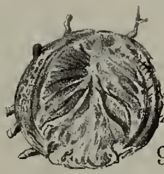

11^{a}


14


15


10


9


9^{b}


9^{c}


9^{a}


7^{b}


9^{d}


4^{a}


7


7^{a}


5


4^{b}


4

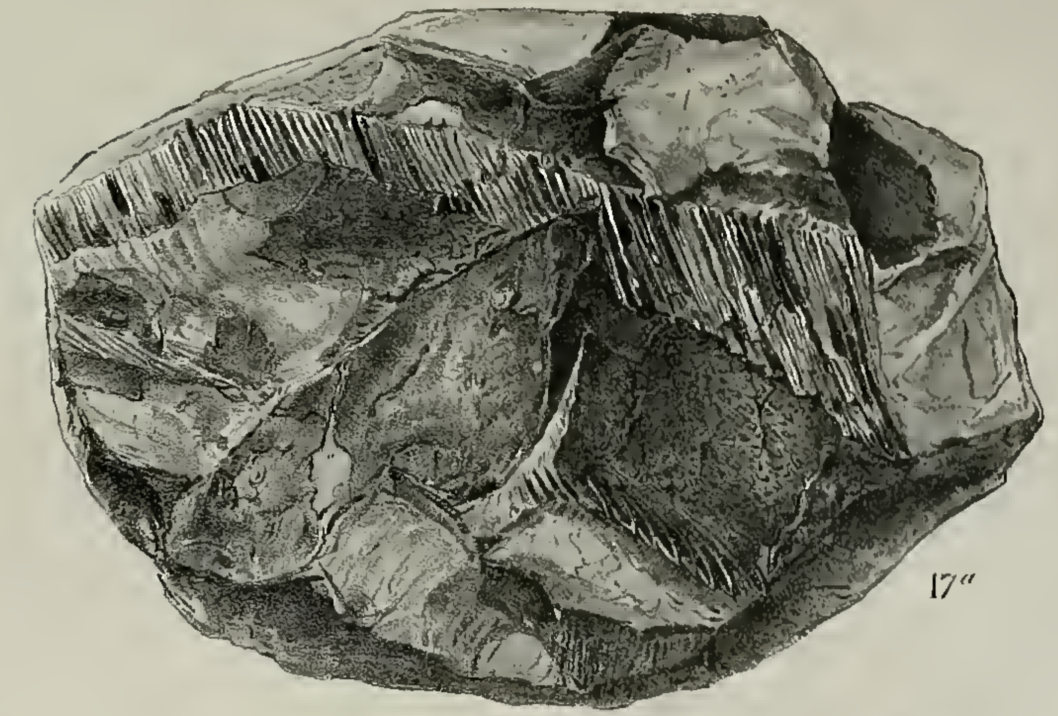
B. N. Peach. delt

McFarlane & Erskine, Lithrs Edinr

17

17^d

23



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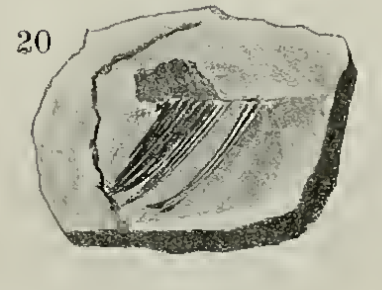
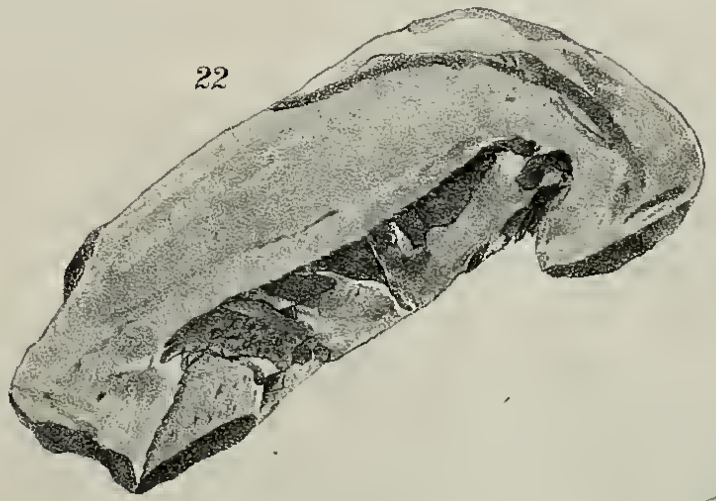


20

20^a

17^c



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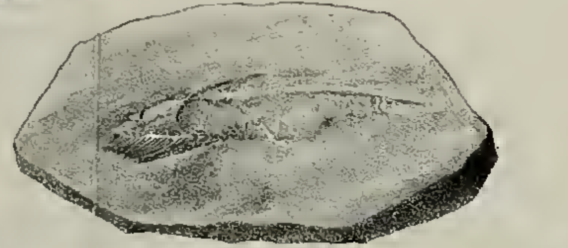

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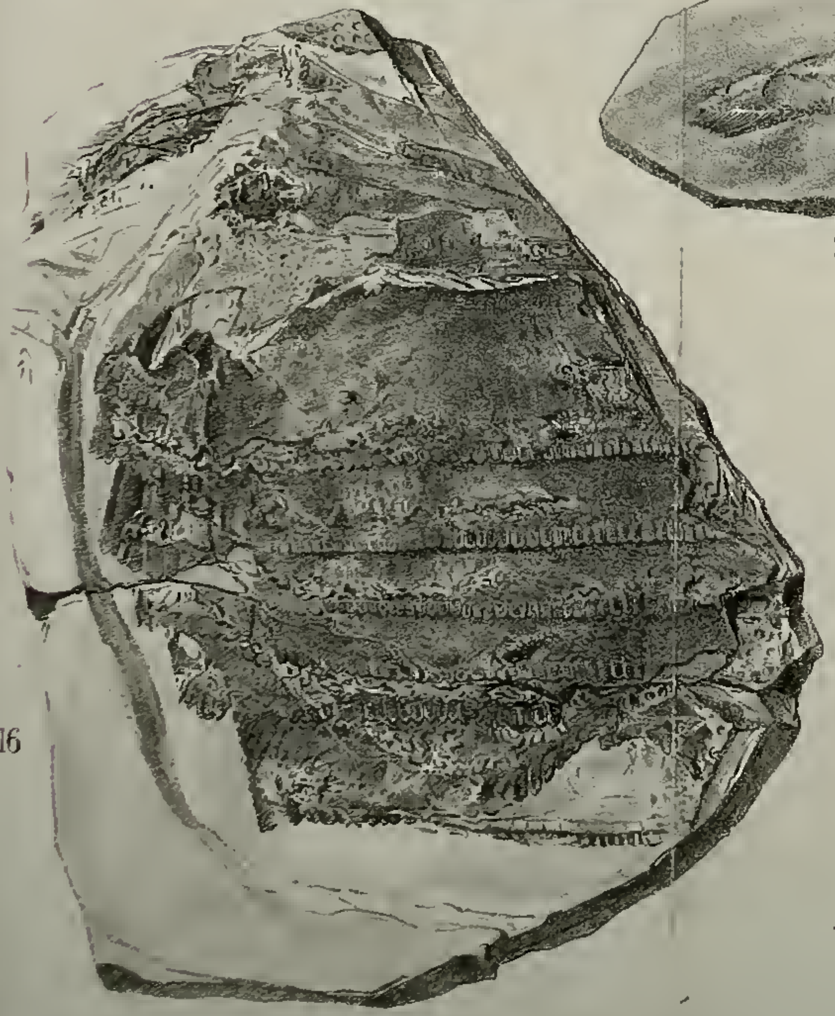

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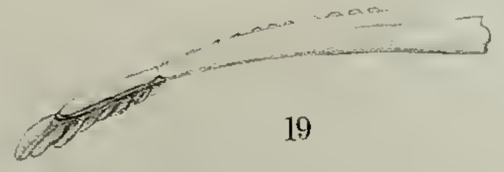
18^a



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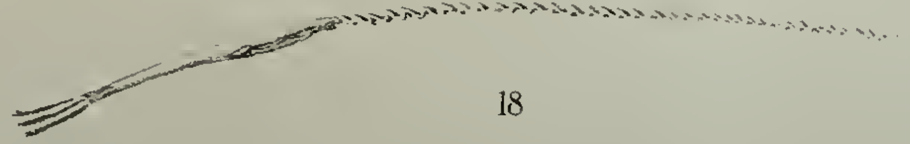

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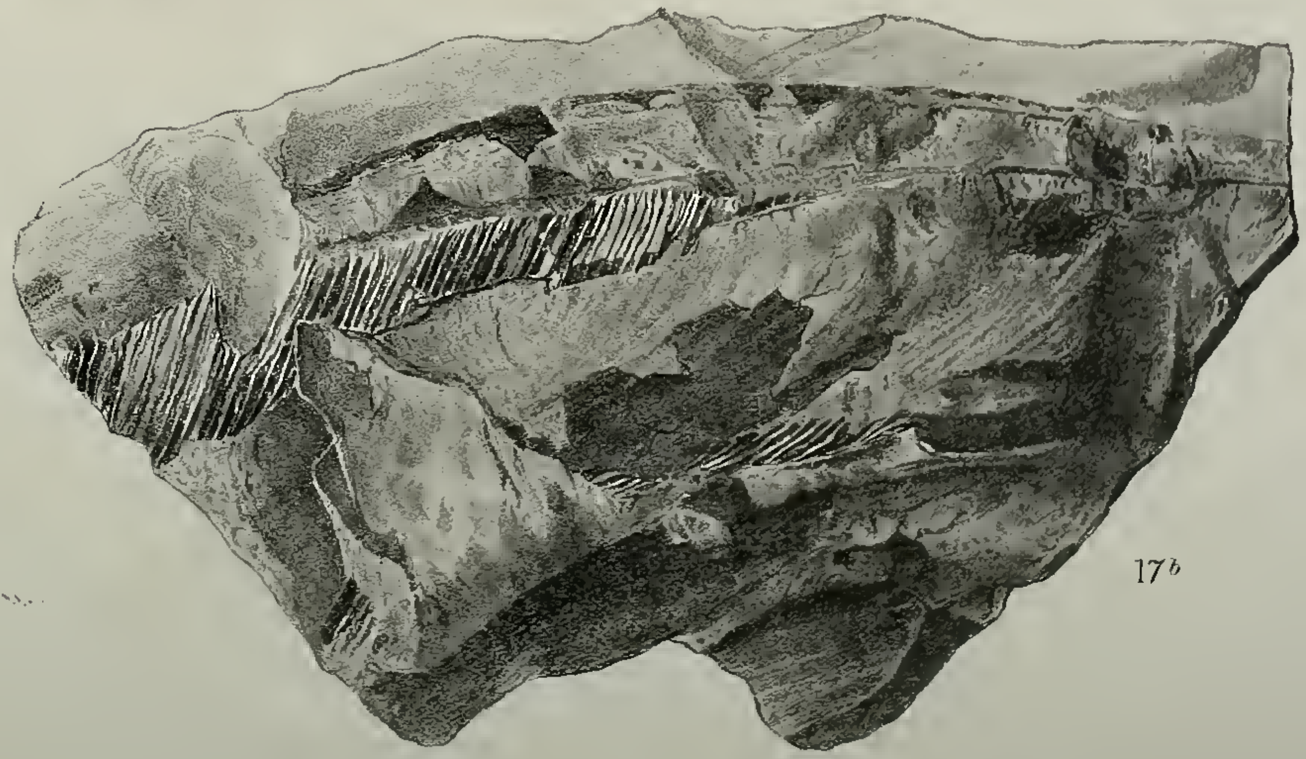

17^b

Report on Fossil Plants, collected by the Geological Survey of Scotland in Eskdale and Liddesdale. By Robert Kidston. (Plates XXX. to XXXII.)

(Read 20th March 1882.)

Through the kindness of Dr. A. Geikie, Director-General of the Geological Survey of Great Britain, I have had the pleasure of examining the fossil plants collected by the Scottish Geological Survey from the Calciferous Sandstones of Eskdale and Liddesdale.

The collection contains about four hundred and fifty specimens, of which considerable numbers were so imperfect and fragmentary, that nothing more than the *genus* could be determined with safety, whilst others were beautifully preserved, showing their most minute details of structure.

Eight of the plants I believe to be new species, and a few, as far as I am aware, are now recorded for the first time as occurring in Scottish rocks.

The specimens were chiefly collected by Mr. Arthur Macconochie, Fossil Collector to the Geological Survey.

The following is a list of the genera and species; those which I consider to be new species are marked *, and those which I believe to be recorded for the first time as belonging to our Scottish Fossil Flora †.

Plants from Eskdale and Liddesdale, exclusive of Canonbie.

THALLOPHYTA.

ALGÆ.

1.**Chondrites plumosa*, Kidst.
2.* ” *simplex*, Kidst.
3.**Crossochorda carbonaria*, Kidst.
4.†*Bythotrephis*, sp.

FILICACEÆ.

Sphenopterideæ.

5. *Sphenopteris linearis*, Brongn.
6. ” *furcata*, Brongn.
7.* ” *Geikiei*, Kidst.
8. ” *bifida*, L. & H.
9. ” *excelsa*, L. & H.
10. ” *Hibberti* var., L. & H.
11. ” *Höninghausi*, Brongn.
12.* ” *decomposita*, Kidst.
13. ” sp.
14. *Staphylopteris Peachii*, Carr.
15.†*Eremopteris erosa*, Morris (?), sp.
16.* ” *Macconochii*, Kidst.
17.†*Rhacophyllum Lactuca*, Sternb.

Palæopterideæ.

18. *Adiantites Londseæformis*, Bunbury.

Neuropterideæ.

19. *Neuropteris cordata*, Brongn.
20.† ” (*Cyclopteris*) *Trichomanoides* (?), Brongn.

Stipes Filicinæ.

21.**Caulopteris minuta*, Kidst.

Equisetaceæ.

22. *Volkmannia*, sp.

Lycopodiaceæ.

23. *Lepidodendron Sternbergii*, Brongn.
24. ” sp.
25. *Lepidostrobus variabilis*, L. & H.
26.* ” *fimbriatus*, Kidst.
27. *Lepidophyllum lanceolatum*, L. & H.
28. *Lycopodiaceous sporangiæ.*
29. *Cordaites*, sp.
30. *Stigmaria ficoides*, Brongn.

Fruits.

31.†*Cardiocarpus apiculatus*, Göpp and Berger.
32. ” sp.
33. *Schutzia*, sp.

CANONBIE PLANTS.

FILICACEÆ.

SPHENOPTERIDEÆ.

1.†*Sphenopteris multifida*, L. & H.
2.† „ *obtusiloba* (?), Brongn.
3. „ sp.
4. *Staphylopteris*, sp.

NEUROPTERIDEÆ.

5. *Neuropteris heterophylla*, Brongn.

ALETHOPTERIDEÆ.

6. *Alethopteris heterophylla*, Sternb.

PECOPTERIDEÆ.

7. *Pecopteris nervosa*, Brongn.
8. „ sp.

EQUISETACEÆ.

9. *Calamites*, sp.

LYCOPODIACEÆ.

10. *Lepidodendron*, sp.
11. *Lepidophyllum lanceolatum*, L. & H.

In comparing the list of the species contained in this collection (except those from Canonbie) with the fossil plants from the Calciferous Sandstone series in the neighbourhood of Edinburgh, their similarity will be at once apparent.

This is remarkable when viewed in relation to the fish and crustacean remains which have been already described from Eskdale and Liddesdale, by R. H. TRAQUAIR, Esq., M.D., F.R.S., and BENJ. PEACH, Esq., F.R.S.E., which, as far as at present known, are mostly peculiar to these districts.

This points to some local physical conditions, which, though favourable for the growth of plants, widely distributed in other parts of Scotland, seem to have favoured the existence of a fauna peculiar to itself.

DESCRIPTION OF GENERA AND SPECIES.

THALLOPHYTA.

ALGÆ.

Chondrites, Göppert.
Fucoides, Brongn.

Chondrites plumosa, sp. nov., Kidston.

Plate XXX. fig. 3, and Plate XXXII. fig. 2.

Description.—Frond much branched, pinnæ about an inch long, densely covered with short filamentous segments. Main and secondary axes threadlike.

Remarks.—None of the specimens of this plant are complete, so its original length cannot be ascertained. It must have been a much-branched species, and attained some inches in length.

The whole plant appears to have been very delicate, and the ultimate divisions of the fronds are clothed with closely-set and very fine filamentous segments about a quarter of an inch long, which give it a plumose appearance.

It is all but impossible to place fossil *Algæ* in a true systematic classification, owing to the imperfect manner in which their remains occur, and the entire absence of fruit.

I have placed this and the following species in *Chondrites,* Stern., but it appears to me that they might have been placed with equal propriety in *Fucoides,* Brongn.

Position and Locality.—Frequent, but mostly in a fragmentary condition, in the Cement-stone group of the Calciferous Sandstone series, Glencartholm, Eskdale.

Chondrites simplex, sp. nov., Kidston.

Plate XXXI. fig. 14.

Description.—Frond filamentous, simple.

Remarks.—This *Alga* appears to have consisted of separate simple filaments, from a thirtieth to the tenth of an inch broad, reminding one of the recent genus *Chorda,* and probably growing in the same tufted manner.

The greater number of the component filaments appear in this specimen to lie in a somewhat confused mass. It is probable that each of the parts was separate when growing, but have assumed the tangled appearance subsequently.

In the larger filaments, neither apex nor base is shown, so an estimate cannot be formed as to the length of the perfect fronds.

Only one specimen of this *Alga* has been obtained.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstones, Glencartholm, Eskdale.

Crossochorda, Schimper.
Crossopodia, MacCoy.
Crossochorda carbonaria, sp. nov., Kidston.

Plate XXX. fig. 4.

Character.—Frond pinnate, segments filamentous, springing laterally from the central axis, from which they bend gently outwards and upwards.

Remarks.—This *Alga* was also probably of considerable length, though the most perfect individual is only two inches long.

In their width the fronds vary considerably, some being fully half an inch, others only the tenth of an inch broad.

The main axis appears as a furrow running down the centre of the frond, from the sides of which the ultimate segments spring, and in their upward bending become somewhat adpressed, giving a plumose appearance to the plant.

The only other species with which this fossil is likely to be mistaken are *Crossochorda* (*Crossopodia*) *Scotica,* MacCoy, and *Cruziana semiplicata,* Salter.*

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* *Mem. of Geo. Survey,* vol. iii. p. 291.

The former is easily distinguished from the present species by its small size and much more delicate structure, and the latter, by the presence of a clear border extending past the "fringe."

It has been suggested that the two genera, *Crossochorda* and *Cruziana,* should be united, as the only generic distinction rests on the presence or absence of the clear border extending past the ultimate segments.*

Several specimens of this plant have been found.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, Liddel Water, near New Castleton, Liddesdale.

Bythotrephis, Hall.

Bythotrephis, sp.

Remarks.—Two specimens of a large *Alga,* which should probably be placed in this genus, occur in Eskdale.

Both are imperfect, but the better example gives a fair idea of the plant.

It appears to have possessed a well-marked dichotomous growth.

The frond measures fully three-quarters of an inch in breadth, immediately below the lowest dichotomy shown in the fossil.

Each dichotomy is accompanied by a slight constriction at the point where it takes place.

The discovery of *Algæ* in Scottish Carboniferous rocks being of rare occurrence, I have inserted a figure of this specimen, natural size, to draw the atten-

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* Schimper and Zittel, *Handb. der Palæontologie,* Band ii. Lief i. p. 52.

tion of geologists to this plant, as more perfect specimens must be secured before it can be satisfactorily determined.

Position and Locality.—Glencartholm, Eskdale, in the Cement-stone group of the Calciferous Sandstone series.

FILICACEÆ.

SPHENOPTERIDEÆ.

Sphenopteris, Brongn.

Sphenopteris linearis, Stern.

Sphenopteris linearis, Brongn., *Hist. d. végét. foss.*, p. 175, tab. liv. fig. 1.
" " Lind. and Hut., *Fossil Flora*, pl. 230.
" " Sternberg, *Flora d. Vorw.*, tab. 42, f. 4.

Remarks.—A few specimens of this fern occur in the collection.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series at Docken Beck, near Langholm; Tinnis Burn, near New Castleton, Liddesdale; and Glencartholm, Eskdale.

Sphenopteris furcata, Brongn.

Sphenopteris furcata, Brongn., *Hist. d. végét. foss.*, pl. xlix. figs. 4, 5.
" " Geinitz, *Steinkohlf. in Sachs*, tab. xxiv. figs. 8–13.
" " L. & H., *Fossil Flora*, pl. 181.

Remarks.—This fern occurs plentifully.

The specimens agree more fully with BRONGNIART'S figure of this plant than with that of LINDLEY and HUTTON in their *Fossil Flora*, which appears to have been a less lax form.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone Series, foot of Tarras Water, Eskdale.

Sphenopteris Geikiei, sp. nov., Kidston.

Plate XXX. fig. 5, and Plate XXXI. fig. 9.

Description.—Frond (?) bipinnate, narrow, linear, tapering suddenly to an acuminate point; pinnæ alternate, rhomboidal, narrow; pinnules finely divided into three or four narrow linear segments; nerves numerous.

Remarks.—This fern can be at once distinguished by its narrow lanceolate form, and its much divided pinnæ, composed of long narrow segments.

As far as I am aware, there is no other fossil fern with which this species could be mistaken.

Of the five specimens of this plant which have been obtained, that figured was the most perfect, but on another the pinnæ were rather larger; all the other examples were much less.

Though the pinnules of this fern in their tripartite segmentation show some points of resemblance to SCHIMPER's genus *Triphyllopteris,* I have placed it in *Sphenopteris,* to which it appears to be more closely related.

It gives me much pleasure to name this species after Dr. A. GEIKIE.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, Glencartholm, Eskdale.

Sphenopteris bifida, L. & H.

Sphenopteris bifida, L. & H., *Fossil Flora,* pl. liii.
,, ,, Hibbert, "Limest. of Burdiehouse," *Roy. Soc. Ed.,* vol. xiii.
,, ,, Miller, *Test. of the Rocks,* p. 423, fig. 129.
Trichomanites bifidus, Gœpp., *Syst. Fil.,* tab. xv. fig. 11.
Todea Lipoldi, Stur., *Culm-Flora,* tab. xi. fig. 8.*

Remarks.—This fern occurs very plentifully in Eskdale and Liddesdale. Among these specimens is one showing its mode of growth very beautifully.

This specimen is nine and a half inches long, but the rachis does not appear to be complete at its lower extremity.

Two inches above the apparent break the stem bifurcates.

On the main axis, below the bifurcation, are a few very small, and what may be regarded as *rudimentary* pinnæ, which gradually increase in size from below upwards, but the largest is only two-fifths of an inch long.

One of the main forks has been broken off about three inches above the bifurcation, but the other is entire.

The portion of the broken fork is of the same size as the corresponding part in the perfect one, so we may reasonably presume they were originally equal. It would appear that this bifurcating of the main axis, a short distance above its base was characteristic of the *Sphenopteris linearis* group (to which group I feel inclined to refer the present species), as in several of the other ferns of this class I have observed the same structure.†

The ultimate segments of the pinnæ consist of little more than a nerve with a very narrow margin of delicate cellullar tissue.

In LINDLEY and HUTTON's figure this narrow cellular margin has been entirely destroyed;‡ and in that of STUR its state of preservation has been little better.§

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* C. W. PEACH on "Fossil Plants from the Calciferous Sandstone around Edinburgh," *Bot. Soc. Ed.,* vol. xiii.

† Mr. C. W. PEACH has shown me young fronds of *S. affinis* in the circinate condition, exhibiting very beautifully the two forks rolled up in a crozier-like manner.

‡ *Fos. Flora,* vol. i. pl. liii.

§ STUR., *Culm-Flora,* tab. xi. fig. 8.

All these forms are shown among the numerous specimens comprised in this collection.

Position and Localities.—From the Cement-stone group of the Calciferous Sandstones at Kershope Burn and Tweeden Burn, Liddesdale; Plashetts Burn, North Tyne, Northumberland; and River Esk, Glencartholm, Eskdale.

Sphenopteris excelsa, L. & H.

Sphenopteris excelsa, L. & H., *Fossil Flora,* pl. ccxii.

Plate XXX. fig. 2, and Plate XXXI. figs. 7 and 8.

Remarks.—This fern is extremely plentiful, and affords a very good example of the latitude which must be allowed for deviation in minor details in the various individuals of a given species.

The type figured by Lindley and Hutton represents what may be regarded as the middle form of the Eskdale specimens.

Departing from this, we have on the one hand a very lax form (Plate XXXI. fig. 8), and on the other a more compact variety (Plate XXX. fig. 2).*

Had these two forms not been connected by a series of specimens, passing from one to the other by almost insensible gradations, it would have been difficult to recognise them as belonging to the same species.

The fronds of this fern must have been large, judging from the size of the pinnæ, probably at least three feet in height. Hence it is extremely likely that the small portions figured held different relative positions on the fronds from which they came.

Lindley and Hutton say of the plant figured by them: "The specimens of this beautiful fern are so imperfect, that we can neither ascertain what the margin was of the leaflets, nor the nature of the veins. . . . . It appears, however, to belong to the genus *Sphenopteris.*"

In the specimens from Eskdale, the veins are well preserved, and show this fern to be a true *Sphenopteris* (Plate XXXI. fig. 7). The outline of the leaflets also, in their figure, agrees with those specimens I have called the middle form.

Sphenopteris cuneolata † of the same authors is perhaps only an ill-preserved specimen of this species, exhibiting a bifurcation of the axis, similar to that shown in Plate XXX. fig. 2. They also say in regard to this plant: "Not a trace of veins could be found in the specimen from which the drawing was made."

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, Glencartholm, Eskdale.

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* This is not so well shown in the small portions figured as in the larger specimens.

† *Fos. Flora,* vol. iii. pl. 214.

Sphenopteris Hibberti, L. & H. (var.)

Sphenopteris Hibberti, L. & H., *Fossil Flora*, pl. clxxvii.

Plate XXX. fig. 1.

Remarks.—Two specimens obtained in Eskdale I have placed under this species.

They are more compact in their mode of growth, and the pinnules less segmented, than in the type of this plant figured in the *Fossil Flora of Great Britain*, pl. clxxvii. These differences, however, appear to be insufficient for the creation of a new species.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, Glencartholm, Eskdale.

Sphenopteris Höninghausi, Brongn.

Sphenopteris Höninghausi, Brongn., *Hist. d. végét. fos.*, tab. liii.
" " Geinitz, *Verst. d. Steink.*, tab. xxiii.
" " Andrœ, *Vorwelt. Pflanz.*, tab. iv., v.
" " Schimper, *Paléont. végét.*, tab. xxix.

Remarks.—The specimens of this species are more similar to Lindley and Hutton's drawing of this plant than to Brongniart's original figure.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, Glencartholm, Eskdale.

Sphenopteris decomposita, sp. nov., Kidston.

Plate XXXII. figs. 1, 1*a*, 4, and 5.

Description.—Frond tripinnate; primary pinnæ, alternate, deltoid, their margins touching or overlapping; secondary pinnæ narrow-deltoid, again divided into pinnæ of the third degree, which bear two or three pairs of cuneate segments with slightly rounded angles, the lower pair notched or divided into three pinnules; veins numerous; rachis thick.

Remarks.—This beautiful fern appears to be very distinct from any species with which I am acquainted. The portion drawn on Plate XXXII. fig. 1 is from the central part of a frond; that at figs. 4 and 5 shows the lower extremity of the rachis, which bears smaller and much less divided pinnæ.

From this it appears that the perfect frond was broadest towards the centre, tapering gradually to each extremity.

In the general appearance of the ultimate segments, this plant has a slight resemblance to *Sphenopteris dilatata*, L. & H.,* but is distinguished from this species by its much-divided pinnæ and the cuneate pinnules, which become attenuated into a small stalk.

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* *Sphenopteris trifoliolata artis*, s.p.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, Glencartholm, Eskdale.

Sphenopteris, sp.

Remarks.—Among the collection are a few *Sphenopteroids*, which, though too imperfect for identification, are, I believe, distinct from any already mentioned.

Position and Localities.—From the Cement-stone group of the Calciferous Sandstone series, at Glencartholm; Docken Beck and foot of Tarras Water, Eskdale; and Liddle Water, Newcastleton, Liddesdale.

Staphylopteris, Presl. (Lesq. 1870).*
Sorocladus, Lesq., 1880.†
Staphylopteris Peachii, Balfour.

Staphylopteris Peachii, Balfour, *Bot. Soc. Ed.*, vol. xii. p. 176.
„ „ C. W. Peach, *Quar. Jour. Geo. Soc.*, vol. xxxiv. pl. viii. p. 133.

Plate XXXI. fig. 6.

Several specimens of this fossil have been obtained. It is extremely probable that the original specimens, on which the species was founded, belong to *Sphenopteris linearis*, Brongn., as this fern, and it alone, most frequently occurs on the same slab. Hence I include *Staphylopteris Peachii* among the *Sphenopteroids.* Through the kindness of Mr. C. W. PEACH, I have been enabled to compare the Eskdale specimens with the original plants in his cabinet, and though on an average they are slightly larger, place them in the same species, as the types vary in size among themselves.‡

In deference to the opinion of certain geologists, who object to the genus *Staphylopteris* being used for the reception of "fructifications of ferns," other than Tertiary species, LESQUEREUX has proposed the name *Sorocladus,* in which to include the Carboniferous forms. Under this name he places species whose "sori have various forms," and presumably belonging to distinct genera. As both these names are at the best of a most provisional nature, the constitution of a new genus, whose only character requires that the specimens be *Carboniferous,* appears to possess no advantage over the older name, hence I retain the original name *Staphylopteris* for these fossils.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, Glencartholm, Eskdale.

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* *Geo. Sur. of Illin.*, vol. iv.

† *Coal Flora of Pennsyl. and U. S.*

‡ I differ from Mr. C. W. PEACH in the identification of his *Sph. affinis,* and prefer calling the form which occurs on the slabs with *Staphylopteris Peachii, Sph. linearis.* What I regard as *Sph. affinis* differs from *S. linearis* in having much smaller pinnules. It is most likely that these two ferns should form only *one* species, and, at the most, *S. affinis* be regarded as a variety of *S. linearis.*

Eremopteris, Schimper.

Eremopteris erosa, Morris.

Sphenopteris erosa, Morris; Murchison, *Geo. of Russia*, ii., pl. C. f. 3.

Position and Locality.—Plentiful in the Cement-stone group of the Calciferous Sandstone series, Glencartholm, Eskdale.

Eremopteris Macconochii, sp. nov., Kidston.

Plate XXXII. figs. 3 and 3*a*.

Description.—Frond bipinnate; pinnæ alternate, lanceolate; pinnules rhomboidal, distinct, margins laciniate or cut into narrow linear segments, dentate at their apices, the pinnæ attached to the rachis by their attenuated decurrent bases; veins numerous.

Remarks.—Only one specimen of this fern has been met with. It is distinguished from *Eremopteris elegans*, Ett., by its regular rhomboidal and distinctly separate pinnules.

These characters and the regular mode of its growth, clearly define this species from the other members of the genus.

I have pleasure in naming this fern after Mr. ARTHUR MACCONOCHIE, who was the chief collector of the Eskdale and Liddesdale fossils.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, Glencartholm, Eskdale.

Rhacophyllum Lactuca (Sternb.), Schimper.

Rhacophyllum Lactuca (Sternb.), Schimper, *Paléont. végét.*, tab. xlvi. f. 1; xlvii. f. 2.
Schizopteris Lactuca, Presl. in Sternb. *Fl. d. Vorw.*, ii. p. 112.
" " Genitz, *Steinkohl. v. Sachs*, tab. xxvi. f. 1; tab. xviii., xix. (specimina speciosissima).
Pachyphyllum Lactuca, Lesq., *Geo. of Pennsyl.*, vol. ii. pl. viii. f. 4, 5.
Hymenopyllites Clarkii, Lesq., *Paléont. of Illinois*, ii. pl. xxxix.

Remarks.—Of this fossil, concerning whose true affinities so many opinions are held, only one specimen has been obtained.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, Docken Beck, Eskdale.

PALÆOPTERIDEÆ.

Adiantites, Brongn.

Adiantites Lindseæformis, Bunbury.

Racopteris Machaneki, Stur., *Culm-Flora*, tab. viii. fig. 4.
(?) " *paniculifera*, Stur., *Culm-Flora*, tab. viii. fig. 3.

Remarks.—This plant is certainly identical with *Racopteris Machaneki*, Stur., and also I think with his *R. paniculifera.* His figure of the former species appears to be the lower part of a frond, that of the latter an upper part, very beautifully showing its mode of fructification.

Among the Eskdale plants are two which exhibit a similar bifurcation of the main axis, as shown in his figure of *R. paniculifera.*

Sphenopteris alciphylla, Phill.,* appears to have been a specimen of this plant, where the ground tissue of the pinnules has been destroyed and the veins only preserved.

Position and Locality.—A few specimens from the Cement-stone group of the Calciferous Sandstone series, Glencartholm, and Foot of Tarras Water, Eskdale.

NEUROPTERIDEÆ.

Neuropteris, Brongn.

Neuropteris cordata, Brongn.

Neuropteris cordata, Brongn., *Hist. de végét. foss.*, pl. lxiv. fig. 5.

Remarks.—One pinnule of this large species has been obtained.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, Glencartholm, Eskdale.

Neuropteris (*Cyclopteris*) *Trichomanoides?* Brongn.

Neuropteris (*Cyclopteris*) *trichomanoides*, Brongn., *Hist. de végét. foss.*, pl. lxi. fig. 4.

Remarks.—A small specimen about an inch broad, and rather less than an inch long, may perhaps belong to this species.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, Glencartholm, Eskdale.

STIPES FILICINÆ.

Caulopteris, L. & H.

Caulopteris minuta, sp. nov., Kidston.

Plate XXXI. figs. 1 and 1*a*.

Description.—Scars oval, somewhat less than the fifth of an inch long, and rather more than the tenth of an inch broad at their greatest diameter. They stand about three-tenths of an inch apart, and are arranged in spiral series. The impression of the vascular bundle forms a narrow oval band, running

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* *Illustrations of Fossil Botany*, G. A. Labour, pl. xxxvii., 1877.

parallel to the contour of the scar, having a sharply inflected notch at its upper extremity.

Remarks.—The specimen is five and a quarter inches long and one inch broad, but appears to have been originally broader.

The upper part of the fossil is covered by a smooth carbonaceous film, which probably represents the outer surface of the bark.

At first sight one would take this plant for a species of *Stigmaria,* but from the form of the scars and the shape of the vascular bundle impression, it must be placed in *Caulopteris,* as that genus is at present defined. Only one specimen has been obtained.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, Kershope Burn, Liddesdale.

EQUISETACEÆ.

Volkmannia, Sternb.

Volkmannia, sp.

I have placed under this name a specimen containing several small cones referable to the *Calamites.*

The cones are an inch and quarter to an inch and three-quarters in length, and about the fifth of an inch in width.

They spring from a common stem, to which they are attached by stalks about three-quarters of an inch long.

The little bracts bearing the sporangia arise from the axis of the cone at right angles, but as to how many bracts may have formed a whorl, I am unable to determine.

These cones resemble *Volkmannia sessilis,* Presl., and *Calamodendron commune* Binney, in the verticillate manner in which they spring from the main stem and in the arrangement of the bracts round the axis of the cone, but differ from them in being longer and proportionately narrower.

These two genera are included by some authors in *Palæostachya,* Weiss, but I have used the genus *Volkmannia* in preference, as it means little more now than the cone of a *Calamite.*

This appears better than placing it in a restricted genus, from which it would probably require to be removed, when more perfect examples have been examined.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, Glencartholm, Eskdale.

Lycopodiaceæ.

Lepidodendron, Sternberg.

Lipidodendron Sternbergii, Brongn.

Lepidodendron Sternbergii, Brongn., *Prodr.*, p. 85.
„ „ Lind. & Hut., *Foss. Flora*, pls. iv. and cxii.
„ „ Schimper, *Paléont. végét.*, pl. lviii.; lix. fig. 2; lx. figs. 3, 4.
„ *obovatum*, Sternb., *Flor. d. Vorw.*, tab. xvi. figs. 3, 4, 5.
„ *elegans*, Brongn., *Hist. d. végét. foss.*, ii. tab. xiv.
„ „ Lind. & Hut., *Foss. Flora*, pl. cxviii.
„ *gracille*, Brongn., *Hist. de végét. foss.*, tab. xv.
„ „ Lind. & Hut., *Foss. Flora*, pl. ix.
„ *acerosum et dilatatum*, Lind. & Hut., *Foss. Flora*, pl. vii. figs. 1, 2.
Sagenaria dichotoma, Sternb., Geintz, *Steinkoh. in Sach.*, tab. iii. figs. 2–12.

Position and Locality.—A few specimens from the Cement-stone group of the Calciferous Sandstones, Glencartholm, Eskdale.

Lepidodendron, sp.

Remarks.—Several other specimens of *Lepidodendra* occur, but are not sufficiently well preserved to admit of determination.

Localities.—Hartsgarth Burn, Liddesdale; and River Esk, Glencartholm, Eskdale.

Lepidostrobus, Brongn.

Lepidostrobus variabilis, L. & H.

Lepidostrobus variabilis, L. & H., *Fossil Flora*, pls. x., xi.
„ *Carruthers*, Coal Plants from Brazil, *Geo. Mag.*, vol. vi., 1869, p. 151.

Remarks.—Of frequent occcurence.

Position and Localities.—From the Cement-stone group of the Calciferous Sandstone series, stream above Saughtree, Liddesdale; and Glencartholm, Eskdale.

Lepidostrobus fimbriatus, sp. nov., Kidston.

Plate XXXI. figs. 2, 3, and 4.

Description.—Scales cordate acuminate, margins of upper portion distinctly fimbriated or produced into regular spiny projections; mid-rib prominent, bearing a sporangium towards its lower extremity.

Remarks.—Of this cone nothing but separate scales have been obtained nearly all of which show the inner surface.

The sporangium occupies the centre of the basal expansion of the scale, its position being indicated by a raised carbonaceous film. It usually shows on each side a small conical elevation, but what this may represent I am unable to determine. From the constancy of their occurrence, I am inclined to regard them as an integral part of the structure.

In some of the specimens, part of the tissue has been destroyed, causing the bract to appear as if composed of a terminal and basal portion (fig. 4). In fig. 2, the missing portion is slightly indicated, while fig. 3 shows a perfect specimen.

Position and Localities.—Frequent in the Cement-stone group of the Calciferous Sandstone series, Lewis Burn, North Tyne, Northumberland; Tweeden Burn, Liddesdale; and Glencartholm, Eskdale.

Lepidophyllum, Brongn.

Lepidophyllum lanceolatum, L. & H.

Lepidophyllum lanceolatum, L. & H., pl. vii. figs. 3, 4.

Position and Localities.—Of frequent occurrence in the Cement-stone group of the Calciferous Sandstone series, Tweeden Burn, Liddesdale; and River Esk, Glencartholm, Eskdale.

Lycopodiaceous sporangia.

Position and Locality.—They occur very plentifully in an impure limestone, in the Cement-stone group of the Calciferous Sandstone series, Tinnis Burn, and Kershope Foot Limestone Quarries, Liddesdale.

Cordaites, Unger.

Pycnophyllum, Brongn.

Cordaites, sp.

Remarks.—Only a few fragmentary specimens of this genus have been obtained.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, Tweeden Burn Foot, Liddesdale.

Stigmaria, Brongn.

Stigmaria ficoides, Brongn.

Stigmaria ficoides, Brongn., *Classif. d. végét. foss.*, tab. i. fig. 7.
" " Lind. & Hut., *Fossil Flora*, pls. xxxi.–xxxvi.
" " Geinitz, *Fl. d. Kohlenf. Hain. Ebersd. u. Flöh. Kohlenbassins*, tab. xi. figs. 1, 2.
" " Goepp., *Foss. flor. d. perm. Form.*, tab. xxxiv.–xxxvii.
" " Schimper, *Paléont. végét.*, lxix. figs. 7–9.

Remarks.—Of frequent occurrence.

Position and Localities.—From the Cement-stone group of the Calciferous Sandstone series, Peel Burn, near Myredykes, Liddelhead, and Saughtree, Liddesdale.

FRUITS.

Cardiocarpus, Brongn.

(?) *Cardiocarpus apiculatus,* Göpp & Berger.

(?) *Cardiocarpus apiculatus,* Göpp. & Berger, *De fruct.*, tab. ii. fig. 32.
(?) „ „ Lesq., *Coal Flora of Pennsyl.*, p. 571.

Plate XXXI. figs. 13 and 13*a.*

Remarks.—One small slab has been collected thickly covered with these fruits. The individuals differ considerably in general outline, as shown in the two figures. The present specimens are somewhat smaller than those figured by LESQUEREUX.* Their border also appears to be narrower. It approaches, however, so closely to his figures that I have little doubt as to the identity of the species.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, Lewis Burn, North Tyne, Northumberland.

Cardiocarpus, sp.

Plate XXXII. fig. 6.

Remarks.—A single specimen of another species also occurs in Eskdale.

It is rather less than four-tenths of an inch long, and slightly over two-tenths of an inch broad. The marginal border is narrow, and the central portion marked with three ridges.

I have not succeeded in identifying this fossil, but being only represented by a single individual, I am unwilling to raise it to the rank of a new species.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, River Esk, Glencartholm, Eskdale.

Schutzia, Gein.†

Anthodiopsis, Göpp.†

Schutzia, sp.

Plate XXXI. figs. 10, 11, and 12.

Remarks.—Of these curious fossils several specimens have been collected. They usually occur on the slabs in masses, but only in one instance have I been able to detect any attachment of the fruit to a stem (fig. 12).

This species appears to be closely allied to *Schutzia anomala,* Gien.

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* Atlas, *Coal Flora of Pennsyl.*, pl. lxxxiii. figs. 6 and 6*a.*

† *Fos. Flora der Permischen Formation,* Göppert, 1865.

(*Anthodiopsis Beinertiana*, Göpp.), from the Permian of Bohemia and Silesia, but the specimens from Liddesdale are not sufficiently well preserved for satisfactory determination.

The three figures given in Plate B. show the more characteristic forms.

Schimper places this genus among the *Coniferæ*, but Göppert mentions that these fruits occur along with *Næggerathiæ* as well as with *Walchia piniformis*, Sternb. Their association, however, with these two plants he regards rather as accidental, than as throwing any light on their affinities.

The plant originally described as *Schutzia bracteata* by Lesquereux, from the Carboniferous formation of the United States, is a totally different fossil, and has now been placed by its author in a new genus, *Cordianthus*, Lesq.*

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, Tweeden Burn, and Kershope Burn, Liddesdale.

Description of Plants from Canonbie.

FILICINEÆ.

SPHENOPTERIDEÆ.

Sphenopteris multifida, L. & H.

Sphenopteris multifida, L. & H., *Fos. Flora*, pl. cxxiii.

Locality.—Byre Burn, Canonbie, Dumfriesshire.

Only one specimen has been obtained.

Sphenopteris obtusiloba ? Brongn.

Sphenopteris obtusiloba, Brongn., *Hist. d. végét. foss.*, tab. liii. fig. 2.
„ „ Schimper, *Paléont. végét.*, tab. xxx. fig. 1.

Remarks.—One small specimen, though too imperfect for satisfactory determination, probably belongs to this species.

Locality.—Byre Burn, Canonbie, Dumfriesshire.

Sphenopteris, sp.

Locality.—Byre Burn, Canonbie, Dumfriesshire.

Staphylopteris, sp.

Plate XXXI. fig. 5.

Remarks.—Only two small stems of this Staphylopteris have been obtained, but unfortunately on neither of them are any traces of fruit. They are much more robust than *Staphylopteris Peachii.*

Locality.—Archerbeck, Canonbie, Dumfriesshire.

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* *Geo. of Illin.*, vol. iv., Lesq.; and *Coal Flora of Pennsyl.*, Lesq., 1880.

NEUROPTERIDEÆ.

Neuropteris heterophylla, Brongn.

Neuropteris heterophylla, Brongn., *Hist. d. végét. foss.*, tab. lxxi., lxxii. fig. 2.
Gleichenites neuropteroides, Gœpp., *Syst. Fil. foss.*, tab. iii., iv.

Locality.—Of this plant there are only a few imperfect specimens from Archerbeck Rowan Burn, and Byre Burn, Canonbie, Dumfriesshire.

ALETHOPTERIDEÆ.

Alethopteris, Brongn.

Alethopteris lonchitica, Sternb.

Pecopteris lonchitica, Brongn., *Hist. d. végét. foss.*, tab. lxxxiv.
„ *heterophylla*, L. & H., *Fossil Flora*, pl. xxxviii.
„ *urophylla*, Brongn., *Hist. d. végét. Foss.*, tab. lxxxvi.
„ *Mantelli*, Brongn., „ tab. lxxxiii. figs. 3, 4.
„ *Davreuxii*, Brongn., „ tab. lxxxviii.
Alethopteris lonchitidis et vulgatior, Sternb., *Flora d. Vorwelt.*, ii. p. xxi. tab. liii. fig. 2.

Remarks.—Only three specimens of this widely distributed species have been collected.

Localities.—Byre Burn and Rowan Burn, Canonbie, Dumfriesshire.

PECOPTERIDEÆ.

Pecopteris, Brongn.

Pecopteris nervosa, Brongn.

Pecopteris nervosa, Brongn., *Hist. d. végét. foss.*, tab. xcv. figs. 1, 2.
„ *Sauveurii*, Brongn., „ tab. xcv. fig. 5.
„ *nervosa*, L. & H., *Foss. Flora*, tab. xciv.
Alethopteris nervosa, Goepp., *Foss. Farrn.*, p. 312.

Locality.—One specimen from Byre Burn, Canonbie, Dumfriesshire.

Pecopteris, sp.

Locality.—Byre Burn, Canonbie, Dumfriesshire.

EQUISETACEÆ.

Calamites, Suckow.

Calamites, sp.

Locality.—One imperfect specimen from Archerbeck, Canonbie, Dumfriesshire.

LYCOPODIACEÆ.

Lepidodendron, sp.

Locality. Archerbeck, Canonbie, Dumfriesshire.

Lepidostrobus, Brongn.

Lepidostrobus variabilis, L. & H.

Lepidostrobus variabilis, Lind. & Hut., *Fossil Flora*, pls. x., xi.

Locality.—Rowan Burn, Canonbie, Dumfriesshire.

Lepidophyllum, Brongn.

Lepidophyllum lanceolatum, L. & H.

Lepidophyllum lanceolatum, L. & H., pl. vii. figs. 3, 4.

Locality.—Archerbeck, Canonbie, Dumfriesshire.

P.S.—*9th Dec.* 1882.—Since compiling the above list, a few more specimens have been handed to me for examination. Among them were the two following, which must now be added:—

Plants from Eskdale and Liddesdale.

ALGÆ.

Chondrites Targionii, Brongn.

Fucoides Targionii Brongn., *Hist. d. Végét. Fos.* p. 56, tab. iv. fig. 4.
Chondrides Targionii, Schimp., *Traité de Paléon. Végét*, vol. i. p. 170, tab. iii. fig. 7.

A few specimens of this plant have been collected.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, in limestone beds on the shore between the gardener's cottage and Borron Point, Arbigland, Kirkcudbrightshire.

EQUISETACEÆ.

Pothocites, Paterson.

Pothocites Grantonii, Pater.

Pothocites Grantonii, Paterson, *Trans. Bot. Soc. Ed.*, vol. i. pl. iii., 1841.
Pothocites calamitoides, Kidston, On the affinities of the genus Pothocites, *Annals and Mag. of Nat. Hist.*, Nov. 1882.

Of this specimen I have already given a short description. It is the only perfect example that has yet been discovered, and shows that *Pothocites*, Paterson, is not the inflorescence of a monocotyledon, but the fructification of a calamitaceous plant. Since writing the short notice above mentioned, I have compared this specimen with the original type, and find that it is not specifically distinct from *P. Grantonii* (Paterson).

The specimen was collected by Mr T. Stock, by whom it has been kindly submitted to me for examination.

Position and Locality.—From the Cement-stone group of the Calciferous Sandstone series, Glencartholm, Eskdale.

EXPLANATION OF THE PLATES.

Plate XXX.

Fig. 1. *Sphenopteris Hibberti*, var., L. & H.

Fig. 2. *Sphenopteris excelsa*, L. & H. A pinna showing a bifurcation of the axis.

Fig. 3. *Chrondrites plumosa*, Kidston.

Fig. 4. *Crossochorda carbonaria*, Kidston.

Fig. 5. *Sphenopteris Geikiei*, Kidston.

Plate XXXI.

Fig. 1. *Caulopteris minuta*, Kidston.

Fig. 1*a*. „ „ Scar enlarged, showing vascular impression.

Fig. 2. *Lepidostrobus fimbriatus*, Kidston. Cone-scale showing sporangium.

Fig. 3. „ „ „ „

Fig. 4. „ „ „ „

Fig. 5. *Staphylopteris*, sp.

Fig 6. *Staphylopteris Peachii*, Balfour. Small fruiting specimen, showing the sporangia.

Fig. 7. *Sphenopteris excelsa*, L. & H. Two pinnules from the upper portion of a pinna, showing the venation. Enlarged.

Fig. 8. *Sphenopteris excelsa*, L. & H. Pinna of lax form.

Fig. 9. *Sphenopteris Geikiei*, Kidston. Pinnule enlarged.

Figs. 10, 11, 12. *Schutzia*, sp. Three of the more characteristic specimens, in different states of preservation. Natural size.

Figs. 13, 13*a*. *Cardiocarpus apiculatus*, Göpp. & Berger.

Fig. 14. *Chondrite simplex*, Kidston.

Plate XXXII.

Fig. 1. *Sphenopteris decomposita*, Kidston. Portion of a specimen showing pinnæ from the central part of a frond.

Fig. 1*a*. *Sphenopteris decomposita,* Kidston. Small portion enlarged to show the venation.

Fig. 2. *Chondrites plumosa,* Kidston.

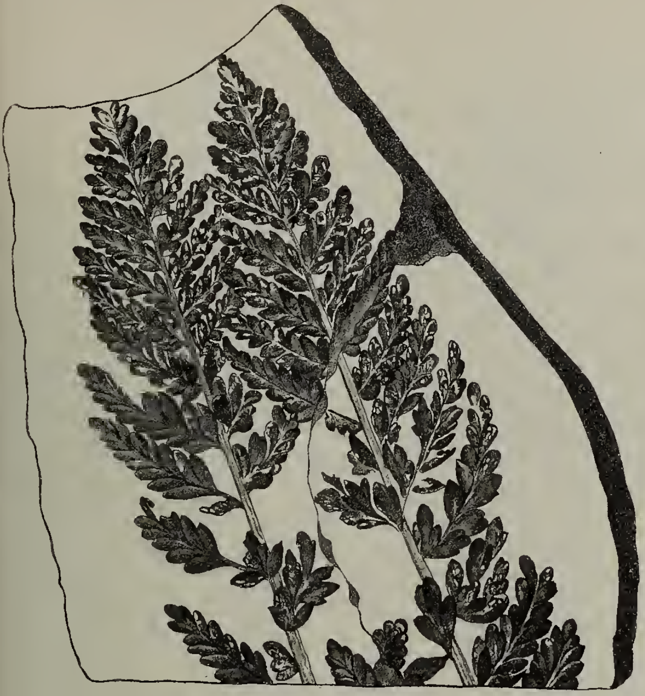
Fig. 3. *Eremopteris Macconochii,* Kidston.

Fig. 3*a*. „ „ Enlarged pinnule, showing venation.

Fig. 4. *Sphenopteris decomposita,* Kidston. Lower extremity of a frond, showing decrease in the size of the pinnæ, and increase in the size of the pinnules.

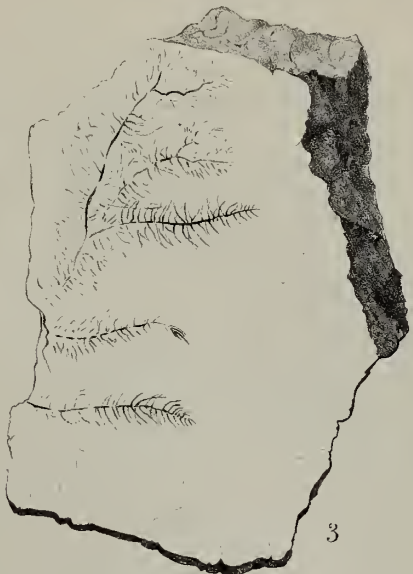
Fig. 5. *Sphenopteris decomposita,* Kidston. Lower extremity of a frond, showing decrease in the size of the pinnæ, and increase in the size of the pinnules.

Fig. 6. *Cardiocarpus,* sp.



1

2



3

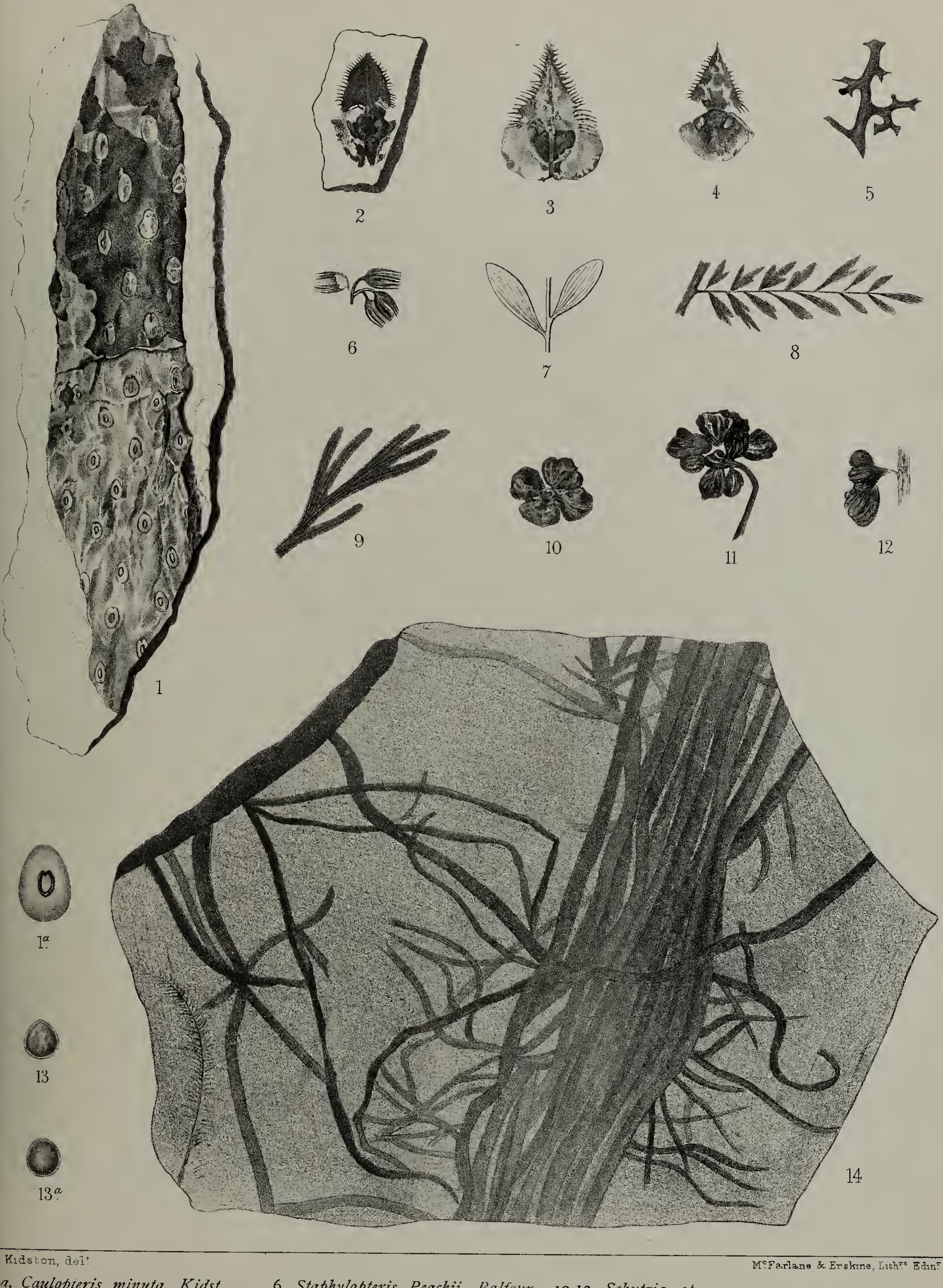
4

5

R. Kidston, delt.

McFarlane & Erskine, Lithrs. Edinr.

1. *Sphen. Hibberti, var. L. & H.*
2. *Sphen. excelsa, L. & H.*
3. *Chondrites plumosa, Kidst.*
4. *Crossochorda carbonaria, Kidst.*
5. *Sphen. Geikiei, Kidst.*

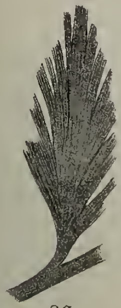


R. Kidston, del^t. McFarlane & Erskine, Lith^rs Edin^r

, 1*a*. *Caulopteris minuta*, *Kidst.*
-4. *Lepidostrobus fimbriatus*, *Kidst.*
. *Staphylopteris*, *sp.*

6. *Staphylopteris Peachii*, *Balfour.*
7, 8. *Sphen. excelsa*, *L. & H.*
9. *Sphen. Geikiei*, *Kidst.*

10-12. *Schutzia*, *sp.*
13, 13*a*. *Cardiocarpus apiculatus*, *Göpp. & Berger.*
14. *Chondrites simplex*, *Kidst.*


3^{a}


1


1^{a}


6


2


4


3


5

R. Kidston, del^{t}

McFarlane & Erskine, Lith^{rs} Edin^{r}

1, 1*a*, 4, 5. *Sphen. decomposita, Kidst.* 2. *Chondrites plumosa, Kidst.* 3, 3*a*. *Eremopteris Macconochii, Kidst.*

XXIII.—*On Mirage.* By Professor TAIT. (Plate XXXIII.)

(Read 5th December 1881.)

I was led to the following investigations while seeking an elementary, and at the same time instructive, application of HAMILTON'S *General Method in Optics.*[*] They were completed in all but a few of their numerical details before I met with the remarkable paper by WOLLASTON,[†] in which the subject of multiple atmospheric images seems first to have been treated by a sound physical method. WOLLASTON'S experiment with a long bar of iron raised to a high temperature suggests undoubtedly the true explanation of at least many of the curious phenomena seen by VINCE,[‡] SCORESBY,[§] and others. But he seems to have thought that sufficient temperature-differences for the natural production of the phenomena could not exist in the atmosphere; and thus the latter part of his paper, in which he tries to explain them by the agency of aqueous vapour, presents a singular contrast to the strength and correctness of the earlier part. A good deal of what follows is implied, if not directly stated, in WOLLASTON'S paper; but I think there is sufficient novelty in what remains to justify my bringing it before the Society.

The subject is one which offers immense facilities for the construction of elegant "Problems," but I have confined myself to the simplest hypotheses which (while enabling me to obtain exact results) promised to throw light upon it:—feeling that anything else would be out of place in endeavouring to explain a class of phenomena which have probably never occurred twice in exactly the same way. I have, however, shown at least the *general* nature of the alterations to which my results would be subject in consequence of modification of the assumptions.

1. Most of the images seen by SCORESBY were inverted, and elevated above the apparent position of the object seen directly, and each series of them (when there were more series than one) can be explained at once by the existence of a horizontal stratum of air in which the rate of diminution of refractive index in ascending is greater than that in the air immediately below. [This is merely the sort of arrangement which, as is perfectly well known, produces the mirage of the desert; but turned upside down.] But the chief phenomenon figured by

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[*] *Trans. R. I. A.*, 1833.

[†] *Phil. Trans.*, 1800.

[‡] *Phil. Trans.*, 1799.

[§] *Greenland*, and *Trans. Roy. Soc. Edin.*, ix. and xi.

VINCE, and also in a few cases by SCORESBY, involves an inverted image with a direct image above it. In some other cases observed by SCORESBY, the direct or the inverted image alone was seen, the object itself being situated far below the horizon. Some excerpts from SCORESBY'S figures (which are themselves *composite*) are given in fig. 1. A comparison of these observations with VINCE'S diagram of the supposed courses of the rays seemed to me to show that a *single* transition stratum may be capable of giving either a single image, direct or inverted according to circumstances, or an inverted image with a direct image above it. As, in at least the greater number of the observations to which I have referred, both the object and the spectator seem to have been *below* the transition stratum which caused the phenomena, I do not think that WOLLASTON'S square bottle with two inter-diffusing liquids presents a fair analogy. For, with that arrangement, the rays enter and emerge from the transition stratum by its ends, and not by its lower side, as, from VINCE'S diagram, they would appear to do in nature.

I propose to return to the consideration of this arrangement of WOLLASTON'S. But meanwhile I will sketch (1) the mode in which I was led to see that, under proper conditions, a simple *continuous* law of refractive index may lead to the formation of three images, (2) how the consideration of the mode in which these are produced in a medium whose refractive index varies to four-fold or more of the minimum value, led me by *necessary* steps to see how they can be produced in the lower atmosphere whose refractive index can vary, even in extreme cases, by only $\frac{1}{40,000}$ or so.

2. To fix the ideas, we will begin with a particular case, which is a thoroughly illustrative one so far as theory is concerned, and is also interesting as it reproduces, with singular accuracy, the exaggerated diagram by which VINCE endeavoured to explain his observations.

The ordinary characteristic of a maximum or minimum is that it differs from neighbouring values of the function by a quantity depending on the *square* of the increment of the independent variable. Assuming then, without any inquiry as to the other physical circumstances, the existence of a medium whose refractive index is represented by the equation

$$\mu^2=a^2+y^2\,,$$

it is clear that $y=0$ is a plane of minimum refractive index.

HAMILTON'S equation for this case is, τ being the characteristic function,

$$\left(\frac{d\tau}{dx}\right)^2+\left(\frac{d\tau}{dy}\right)^2=a^2+y^2 \qquad (1)$$

since it is obvious that the path is in a plane perpendicular to $y=0$.

A complete integral is

$$\tau=\alpha x+\int dy\,\sqrt{a^2+y^2-\alpha^2}\,.$$

Hence the equation of a ray is

$$\mathrm{C}=x-\alpha\int\frac{dy}{\sqrt{a^2+y^2-\alpha^2}}\,. \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

[This result might, of course, have been at once obtained from the corpuscular theory. For its principles give

$$\dot{x}=\alpha\,,\ \dot{y}=\sqrt{a^2+y^2-\alpha^2}\,.]$$

Equation (2) has two distinct forms according as α is greater or less than a. These are separated by the limiting form when $\alpha=a$, viz :—

$$y=\mathrm{C}_1\epsilon^{\frac{x}{a}}\,,$$

a logarithmic curve asymptotic to the axis of x. When α is less than a, the ray *passes through* the plane $y=0$, and we need not consider it further.

We may therefore assume

$$\alpha^2=a^2+\eta^2\,,$$

and it is obvious that y cannot be less than η. With this expression for α, the mere form of the equation (2) shows that the curve has a vertex at the point $y=\eta$, and that it is symmetrical about the ordinate through that point.

We must remark, in passing, that this property of symmetry about an axis, at the extremity of which is a vertex, is common to groups of rays in all media in which the refractive index depends only on the distance from a particular plane :—the groups which possess it being those which either do not reach that plane, or pass through it more than once.

3. Let us now consider only rays which have vertices, and which pass through a particular point $x=0$, $y=b$. Then if ξ be the x-cöordinate of the vertex, equation (2) becomes

$$\xi=\sqrt{a^2+\eta^2}\int_{\eta}^{b}\frac{dy}{\sqrt{y^2-\eta^2}}\,. \quad . \quad . \quad . \quad . \quad . \quad (3).$$

This is the equation of the *Locus of Vertices* of all rays (having vertices) which pass through the point $0,\ b$. We may write it in the form

$$\xi=\sqrt{a^2+\eta^2}\,\log\frac{b+\sqrt{b^2-\eta^2}}{\eta}\,. \quad . \quad . \quad . \quad . \quad . \quad (3).$$

To draw the corresponding curve we may construct, for different values of b, the set of curves

$$\xi' = \log\left(\frac{b}{\eta} + \sqrt{\frac{b^2}{\eta^2} - 1}\right) \quad . \quad . \quad . \quad . \quad . \quad (4),$$

or

$$\frac{2b}{\eta} = \epsilon^{\xi'} + \epsilon^{-\xi'}.$$

The ordinates of these curves are proportional to the reciprocals of those of a common catenary.

Next construct, for the given value of a, the equilateral hyperbola whose equation is

$$\xi'' = \sqrt{a^2 + \eta^2}.$$

Then we have, at once, for any given value of η,

$$\xi = \xi'\xi''.$$

For the purpose of carrying out this process we have tabulated as below, a few rough numerical values:—and by the help of these the curve (4) has been drawn, along with (3), in three forms; for $b=2a$, $b=4a$, and $b=6a$. See fig. 2. In each case (4) is represented by a dotted curve, (3) by the corresponding full curve.

$\frac{\eta}{b}$	$\log\left(\frac{b}{\eta} + \sqrt{\frac{b^2}{\eta^2} - 1}\right)$	$\sqrt{1 - \frac{\eta^2}{b^2}}$	$\sqrt{\frac{1}{4} + \frac{\eta^2}{b^2}}$	(ratio).
0·0	∞	1·0	0·5	0·5
0·05	3·69	0·99	0·51	0·51
0·1	2·99	0·99	0·51	0·51
0·2	2·29	0·98	0·54	0·55
0·3	1·87	0·95	0·58	0·61
0·4	1·57	0·92	0·64	0·70
0·5	1·32	0·87	0·71	0·82
0·6	1·10	0·8	0·78	0·97
0·7	0·89	0·71	0·86	1·20
0·8	0·69	0·6	0·94	1·56
0·9	0·47	0·44	1·03	2·36
1·0	0·0	0·0	1·12	∞

4. Let us digress to consider what we learn, in any case, from the *form* of the Locus of Vertices.

It is obvious that if, instead of the special law of refractive index assumed in the preceding section, we had written quite generally

$$\mu^2 = f(y),$$

(3) would have become

$$\xi = f(\eta) \int_b^\eta \frac{dy}{\sqrt{f(y) - f(\eta)}} \quad . \quad . \quad . \quad . \quad . \quad (3'),$$

while (2) would have been (for rays passing through the point 0, b),

$$0=x-a\int_b^y \frac{dy}{\sqrt{f(y)-a^2}} \quad . \quad . \quad . \quad . \quad . \quad (2').$$

The new *form* of (2′) shows that, for a given value of y, x increases with increase of a; provided no vertex is reached. For the denominator of the differential is less, and the integral is multiplied by a greater factor, than before. Hence two contiguous rays from the same point cannot again intersect till one, at least, has passed its vertex. When the vertex is included within the limits of integration, (2′) may by the symmetry of the ray be written

$$0=x-a\int_b^y \frac{dy}{\sqrt{f(y)-a^2}}-2a\int_y^\eta \frac{dy}{\sqrt{f(y)-a^2}}, \quad \text{or} \quad 0=x+a\int_b^y \frac{dy}{\sqrt{f(y)-a^2}}-2\xi.$$

Now the middle term (as we have seen) is positive, and increases with a, if $y > b$. Hence the second intersection of the rays which have the common point 0, b, is at a point where $y > b$, if and only if, ξ increases as a increases; *i.e.*, if the line, drawn from the vertex of the ray nearer to the minimum plane to that of the other, leans back towards the first common point of the two rays. The converse is easily seen to hold, by taking the second point of intersection as the starting-point and reversing the rays. Hence, if the minimum stratum be horizontal, two neighbouring rays, issuing from a common point below it, and originally directed above the horizon, intersect again *before* they have got back to the level of their former intersection, if their vertices be at a part of the curve of vertices where the tangent leans backwards over the starting-point, and *vice versâ*. This proposition is, in fact, obvious from a mere inspection of the diagram fig. 3, in which the dotted curve is that of vertices, the eye being at E.

To apply it to the case of phenomena such as those observed by VINCE and SCORESBY, suppose the strata of equal refractive index to be horizontal. Then two rays slightly inclined to one another, leaving any point in a common vertical plane, will in general intersect one another before they again reach the level of the starting-point, if, and not unless, the vertex of the higher ray be *horizontally* nearer to the starting-point than that of the lower ray; *i.e.*, if the part of the curve of vertices concerned leans *towards* the starting-point. Also, as is well known, when two rays slightly inclined to one another, cross *once* between the eye and the object, the image formed is an inverted one.

5. Hence the following graphical method for finding the number and characters

of the images of an object situated at the level of the eye. Trace the curve of vertices for all rays leaving the eye in the vertical plane containing the object. Draw also a vertical line midway between the eye and the object. The intersections of this line with the curve of vertices are the vertices of all the paths by which the object can be seen, when the eye is in the assigned position. Or, what comes to the same thing, but (unlike the simpler construction) admits of application to an object at *any* level, draw the curve of the vertices as before, and then draw another for an eye placed *at the object*. Their intersections determine the vertices of the rays giving all possible images.

It is easy to see that, at the intersections with the vertical line midway between eye and object, the curve of vertices, if continuous, must alternately lean from, and towards, the eye, *i.e.*, the images seen are alternately erect and inverted; their number depends of course upon the form of the curve of vertices; which, in its turn, depends not only upon the law of refractive index in terms of level, but also upon the position of the eye. [This alternation of images does not necessarily hold when eye and object are at different levels.]

Thus, as has long been known, the vertices of all the coplanar paths in which a projectile, fired with a given velocity, can move, with different elevations of the piece, lie in an ellipse whose major axis (double the minor axis) is horizontal. The lower half of this ellipse leans *from* the gun, the upper half *towards* it, and these correspond to angles of elevation of the piece, respectively less and greater than 45°. In the former case (when the elevation is less than 45°), a slight increase of elevation increases the range on a horizontal plane, so that the new path is wholly above the old one; which, however, would intersect it *under* the horizon. In the latter case a slight increase of elevation shortens the range, so that the two paths must intersect before reaching the ground.

6. Recurring to the imagined medium in which

$$\mu^2 = a^2 + y^2 ,$$

we see by fig. 3 the paths of the rays by which the three images of AB are seen by an eye placed at E. This figure, as already remarked, is (with the exception of the introduction of the curve of vertices) almost identical with that of VINCE in the *Phil. Trans.* for 1799.

But it is easy to see that, although this shows the possibility of three images in the relative positions observed by VINCE, it is in no way capable of explaining his observation. For the existence of three images, in such a medium, requires (as I have found by an approximate method)* that b be *at*

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* When $\frac{d\xi}{d\eta} = 0$, we have $1 + \frac{a^2}{\eta^2} = \sqrt{1 - \frac{\eta^2}{b^2}} \log\left(\frac{b}{\eta} + \sqrt{\frac{b^2}{\eta^2} - 1}\right)$. Plotting the curves whose ordinates (in terms of η) are expressed by these two quantities, we find that they *touch* when $b = 3{\cdot}68a$.

least$=3{\cdot}68a$. Hence the refractive index at the level of the eye ($\sqrt{a^2+b^2}$) must be at least 3·8 times that in the minimum stratum. And the distance at which an object on the horizon requires to be situated, in order that there may be three images of it, lies within exceedingly narrow limits, unless the refractive index at the level of the eye very greatly exceed this lowest admissible value.

7. The possibility of three images of an object at the level of the eye evidently depends on the existence of three values of y, for the same value of x in the curve of vertices. It is therefore necessary that we should study the question from this point of view.

On thinking of the relative forms of the curves of vertices in fig. 2; the first of which gives only one image, the second and third (in certain cases) three:—I saw that the point of inflexion, on which the triple value of y depends, is due to the gradual diminution of curvature of the ray near the eye (for rays of a given inclination to the vertical) as the eye is placed lower in the medium. Hence any arrangement which lessens the curvature of the lower parts of the rays will increase this effect.

In fact, the portion ABC of the ray OB (fig. 4) is congruent with the ray *abc*, if only the tangents at A and a be parallel. Hence the point B would be shifted to b if the ray Oa were straight (or at all events, less curved than OA) and the angle at a equal to that at A.

Thus it was at once obvious that the curve of vertices (fig. 5) in the stratum above RS, might be made asymptotic to that line towards the right of the figure (the eye being still at O), if only the stratum below it were of uniform refractive index, or at least of a refractive index diminishing so slowly with increased height that a ray from O could intersect RS at a practically infinite distance. This at once showed me the general nature of one mode of explanation. The curve of vertices QPQ′ in the stratum RU will now be asymptotic, towards the right, to both RS and TU, and therefore can be cut in *two* points by a sufficiently distant vertical. These points correspond to VINCE's two upper images, the third and lowest is seen by rays which have not reached the upper stratum, and for which the corresponding branch of the curve of vertices is the horizontal line OM, passing through the eye.

8. To repeat:—the conditions requisite for the production of VINCE's phenomenon, at least in the way conjectured by him, are, a stratum in which the refractive index diminishes upwards to a minimum (or, at all events, nearly to a stationary state); and, below it, a stratum in which the upward diminution is either considerably less or vanishes altogether. The former condition (the

fall to a nearly stationary state) secures the upper erect image, the latter the inverted image. When the former is not present, we have the phenomenon so often observed and figured by SCORESBY. This requires merely a change from a slowly diminishing refractive index to a more quickly diminishing one, and may occur simultaneously in more than one horizontal layer. Turned upside down, this arrangement gives the ordinary mirage of the desert. When this condition is not present, but only the stationary state, we have VINCE's upper erect image without the inverted one. This is figured several times by SCORESBY.

9. If, instead of a plane of minimum, we have a plane of maximum, refractive index, we may assume

$$\mu^2=a^2-y^2\,.$$

An investigation precisely similar to the preceding gives for a ray passing through 0, b the equation

$$x=\sqrt{a^2-\eta^2}\left(\sin^{-1}\frac{y}{\eta}-\sin^{-1}\frac{b}{\eta}\right)\,.$$

Each ray therefore is a harmonic curve, whose level line is in the maximum stratum, and which passes through that stratum an infinite number of times. The locus of vertices is

$$\xi=\sqrt{a^2-\eta^2}\left(\cos^{-1}\frac{b}{\eta}+n\pi\right)\,.$$

Here η is to be taken positive when n (any integer) is even, and negative when it is odd.

The following rough table suffices to determine the general form of this curve in the particular case $a=5b$. It is shown in fig. 6; and it has been foreshortened for convenience of representation.

$\frac{b}{\eta}$	$\frac{2}{\pi}\cos^{-1}\frac{b}{\eta}$	$\frac{\xi}{b}$		
		$n=0$	$n=1$	
1·0	0·0	±0·0	9·8	9·8
0·95	0·2	±0·98	8·8	10·76
0·9	0·29	±1·39	8·35	11·13
0·8	0·41	±1·98	7·70	11·66
0·7	0·51	±2·42	7·16	12·0
0·6	0·59	±2·78	6·64	12·2
0·5	0·67	±3·05	6·11	12·21
0·4	0·74	±3·20	5·46	11·86
0·3	0·80	±2·97	4·47	10·41
0·25	0·84	±1·9	2·5	6·3
0·2	0·87	0·0	0·0	0·0
0·1	0·93	...	...	...
0·0	1·00	...	...	...

The general problem of determining the images is, in this case, a very complicated, though not difficult, one; but it becomes much simplified if we assume as before the object and eye to be at the same level. It is obvious that a vertical line, midway between the eye and the object, will cut the curve of vertices an infinite number of times, both above and below the maximum stratum. Thus there is in such a case an infinite number of images, which are seen by rays which have crossed the maximum stratum an even number of times, in which zero may be included. These must each have one, or some other *odd* number, of vertices between the eye and the object, and the horizontal distance between two such vertices is

$$\pi\sqrt{a^2-\eta^2}\,,$$

which is therefore less for that one of two rays which intersects the maximum plane at the greater angle.

In nature, of course, the number of images depending on a law like this must always be finite, because the utmost percentage change of refractive index in the lower atmosphere is very small. But, independent of equilibrium considerations, there is the farther objection that it cannot be reconciled with the appearances seen by VINCE and SCORESBY. For these were, in the main, very similar to one another for all distances of the object beyond certain limits; while with the present assumption, the appearances presented by an object moving to successively greater distances would exhibit a species of *quasi periodic* change which I have nowhere seen described. And, if we keep to probable changes in the refractive index of the atmosphere, this law will give only one image:—not, of course, in the true direction of the object:—but erect, and therefore not properly coming under the designation of "mirage."

10. After trying a number of assumptions as to the law of refractive index in the transition stratum, I finally chose for detailed examination the following:—

$$\mu^2=a^2+e^2\cos\frac{\pi y}{b}\,.$$

This seemed to me particularly worthy of investigation, for it must be at least a fair approximation to the state of matters near the common boundary of two inter-diffusing fluids, or of two masses of the same fluid at different temperatures. This follows from the facts that:—it gives a stationary state at $y=0$, with a maximum refractive index; and another at $y=b$, with a minimum index. Near $y=\frac{b}{2}$ there is a stratum of greatest rapidity of change of index. This hypothesis has also the advantage of leading to equations which can be treated by the ordinary elliptic integrals.

With this law it follows that, if the eye be in the plane $y=0$, the equation of the curve of vertices is

$$e\xi=\sqrt{a^2+e^2\cos\frac{\pi\eta}{b}}\int_0^\eta\frac{dy}{\sqrt{\cos\frac{\pi y}{b}-\cos\frac{\pi\eta}{b}}}$$

$$=\frac{\surd 2.b}{\pi}\sqrt{a^2+e^2\cos\frac{\pi\eta}{b}}\,\mathrm{F}_1\left(\sin\frac{\pi\eta}{2b}\right)$$

The equation of the path of a ray is

$$ex=\sqrt{a^2+e^2\cos\frac{\pi\eta}{b}}\int_0^y\frac{dy}{\sqrt{\cos\frac{\pi y}{b}-\cos\frac{\pi\eta}{b}}}$$

$$=\frac{\surd 2.b}{\pi}\sqrt{a^2+e^2\cos\frac{\pi\eta}{b}}\,\mathrm{F}\left(\sin\frac{\pi\eta}{2y},\ \phi\right),$$

where
$$\sin\frac{\pi y}{2b}=\sin\frac{\pi\eta}{2b}\sin\phi\,.$$

We have also

$$\frac{dy}{dx}=e\frac{\sqrt{\cos\frac{\pi y}{b}-\cos\frac{\pi\eta}{b}}}{\sqrt{a^2+e^2\cos\frac{\pi\eta}{b}}},$$

and, for $y=0$, this takes the value

$$\frac{\surd 2.e\sin\frac{\pi\eta}{2b}}{\sqrt{a^2+e^2\cos\frac{\pi\eta}{b}}}\,.$$

For the application of these formulæ the following little table has been prepared :—

$\frac{\eta}{b}$	$\frac{1}{k}=\operatorname{cosec}\frac{\pi\eta}{2b}$	$\mathrm{F}_1(k)$	$\frac{\mathrm{E}_1(k)}{1-k^2}$
0·0	∞	$\frac{\pi}{2}$	$\frac{\pi}{2}$
0·1	6·39	1·58	1·60
0·2	3·24	1·61	1·69
0·3	2·20	1·66	1·87
0·4	1·70	1·74	2·18
0·5	1·41	1·85	2·70
0·6	1·24	2·01	3·67
0·7	1·12	2·24	5·74
0·8	1·05	2·60	11·53
0·9	1·012	3·26	42·24
0·95	1·003	3·94	164·17
0·975	1·00077	4·62	650·85
1·0	1·000	∞	∞

The headings explain themselves. The last column is required, as will soon be seen, for the determination of the *magnitudes* of the images, as compared with that of the object when seen (at its true distance) through uniform air.

11. Let us now extend the formulæ of § 4 to the case of a stratum of depth c, in which the refractive index is constant $(=\sqrt{f(c)})$; surmounted by another of thickness b, in which the index is $\sqrt{f(y)}$.

The equation of a ray, passing from the origin, which we now take in the lower surface of the inferior stratum, is

$$x=a\int_0^y \frac{dy}{\sqrt{f(y)-a^2}}.$$

While y is not greater than c, this is the straight line

$$x=\frac{ay}{\sqrt{f(c)-a^2}}.$$

But when y is greater than c, we have

$$x=\frac{ac}{\sqrt{f(c)-a^2}}+a\int_c^y \frac{dy}{\sqrt{f(y)-a^2}} \quad . \quad . \quad . \quad . \quad . \quad (2'').$$

Also, for the branch of the curve of vertices which is in the upper stratum (the other branch being, of course, the axis of x),

$$\xi=\frac{c\sqrt{f(\eta)}}{\sqrt{f(c)-f(\eta)}}+\sqrt{f(\eta)}\int_c^\eta \frac{dy}{\sqrt{f(y)-f(\eta)}}. \quad . \quad . \quad . \quad . \quad (3'').$$

Fig. 5 has been roughly traced from this formula and the curve of fig. 2.

12. In the next following equations, recurring to the form

$$\mu^2=a^2+e^2\cos\frac{\pi y}{b},$$

we will simplify matters by making $a=1$, and altogether neglecting the terms in e^2 when they are added to others not containing e. This will be fully justified, so far as air is concerned, in a subsequent section.

By § 11 the equation of the curve of vertices is

$$e\xi=\frac{c}{\sqrt{2}}\operatorname{cosec}\frac{\pi\eta}{2b}+\frac{b\sqrt{2}}{\pi}\int_\theta^{\frac{\pi}{2}} \frac{d\phi}{\sqrt{1-\sin^2\frac{\pi\eta}{2b}\sin^2\phi}},$$

If we write

$$k=\sin\frac{\pi\eta}{2b}=\frac{\tan\theta}{\sqrt{2}.e},$$

where θ is the inclination of the straight part of the ray, this becomes

$$e\xi=\frac{c}{\sqrt{2}.\pi}\left\{\frac{\pi}{k}+\frac{2b}{c}\mathrm{F}_1(k)\right\}=\frac{c}{\sqrt{2}.\pi}\mathfrak{F}.$$

	$b=10c$		$b=c$		$b=\frac{c}{10}$		$b=\frac{c}{100}$	
$\frac{\eta}{b}$	$\mathfrak{F}$	$\mathfrak{G}$	$\mathfrak{F}$	$\mathfrak{G}$	$\mathfrak{F}$	$\mathfrak{G}$	$\mathfrak{F}$	$\mathfrak{G}$
0·0	∞	− 1	∞	− 1·0	∞	−1·0	∞	− 1·0
0·1	51·7	− 2·63	23·24	− 1·16	20·40	−1·02	20·11	− 1·0
0·2	42·4	− 4·99	13·39	− 1·34	10·49	−1·03	10·20	− 1·0
0·3	40·2	−14·73	10·25	− 1·58	7·25	−1·05	6·95	− 1·01
0·4	40·2	+11·95	8·83	− 1·97	5·69	−1·08	5·38	− 1·01
0·5	41·5	+ 3·32	8·15	− 2·97	4·81	−1·13	4·48	− 1·01
0·6	44·1	+ 1·51	7·91	−13·91	4·29	−1·21	3·92	− 1·02
0·7	48·4	+ 0·73	8·01	+ 2·31	3·97	−1·41	3·57	− 1·03
0·8	55·3	+ 0·32	8·50	+ 0·58	3·82	−2·52	3·36	− 1·07
0·9	68·3	+ 0·09	9·69	+ 0·13	3·83	+0·83	3·25	− 1·35
0·95	81·9	+ 0·026	11·02	+ 0·03	3·94	+0·14	3·23	+60·59
0·975	95·6	+ 0·007	12·39	+ 0·01	4·07	+0·03	3·24	+ 0·33
1·0	∞	0·0	∞	+ 0·0	∞	+0·0	∞	+ 0·0

16. We must now consider, so far as is necessary, the physical properties of air :—and observations which have been made as to actual changes of temperature at different elevations above the earth's surface. There is no necessity for dealing with very exact physical data, because we must make assumptions as to distribution of temperature which cannot, at the best, be more than rough approximations. All that we can attempt to show is, that the observed phenomena are of a character and on a scale compatible with the known properties of air, with observed changes of temperature in the atmosphere, and with the arrangement we have suggested for the production of these phenomena.

Thus, although aqueous vapour diminishes the refractive index of air, the practical effect is so minute at its utmost that we neglect it :—a very slight change in our assumption as to temperature would be sufficient to make up for it.

Assume, then, for air at 0°C. and 760 mm.,

$$\mu_o=1.000294=1+\frac{1}{3400}.$$

Assume farther, what is only approximately true, that the refractive power depends on the density alone, and is proportional to it :—*i.e.*,

$$\mu=1+\frac{1}{3400}\frac{\rho}{\rho_o}.$$

The next assumption :—that the air is practically in hydrostatic equilibrium, when such phenomena are observed :—is probably not far from the truth, except in the case of the mirage of the desert. It gives

$$\frac{dp}{dy}=-g\rho;$$

or, with the laws of BOYLE and CHARLES,

$$\mathrm{R}\frac{d(\rho t)}{dy}=-g\rho.$$

Now if H=26,000 feet, be the "height of the homogeneous atmosphere," we have

$$p_0=\mathrm{R}\rho_0 t_0=g\rho_0\mathrm{H},$$

so that the hydrostatic equation becomes

$$\frac{1}{t_0}\frac{d(\rho t)}{dy}=-\frac{\rho}{\mathrm{H}};$$

or, to a sufficient approximation,

$$\frac{1}{t_,}\frac{dt}{dy}=-\frac{1}{\mathrm{H}}-\frac{1}{\rho_0}\frac{d\rho}{dy}.$$

Instability occurs when $\frac{d\rho}{dy}$ is positive. Hence the greatest rate of fall of temperature, per foot of ascent, which is consistent with stability is

$$\frac{dt}{dy}=-\frac{t_0}{\mathrm{H}}=-\frac{274^\circ}{26{,}000}\mathrm{C.},$$

or $-1^\circ{\cdot}05$ C. per hundred feet.

GLAISHER,[*] in a captive balloon, on two occasions out of twenty-seven, observed the fall of temperature in the first hundred feet to be 1°·8 F. and 1°·9 F. respectively. On other three of these occasions it was 1°·7 F., 1°·5 F. and 1°·3 F. respectively. The first two correspond almost exactly to the 1°·05 C. above computed for a stratum of uniform refractive index. The temperature near the earth's surface was on these occasions 73°·6 F. and 76°·2 F.; or, roughly 24° C. The greatest *rise* of temperature per 100 feet of ascent, which he observed on any of these twenty-seven occasions was 0°·3 F. only. It seems from what follows, therefore, that on none of these occasions would VINCE'S phenomena have been possible.

17. To fix the ideas, let us now assume that the first 50 feet of air is of uniform density, and that next there is a stratum of 50 feet thick in which the refractive index is given by

$$\mu^2=a^2+e^2\cos\frac{\pi(y-50)}{50},$$

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[*] *B. A. Report*, 1869, p. 37.

y being measured from the surface of the earth. Since we may look on μ as practically unity, we have by the formulæ above

$$\frac{1}{\mu}\frac{d\mu}{dy}=\frac{1}{3400}\frac{1}{\rho_0}\frac{d\rho}{dy}=-\frac{1}{3400}\left(\frac{1}{\text{H}}+\frac{1}{t_0}\frac{dt}{dy}\right).$$

Hence, by our assumed law of refractive index,

$$\frac{1}{\text{H}}+\frac{1}{t_0}\frac{dt}{dy}=\frac{3400}{2}\frac{\pi e^2}{50}\sin\frac{\pi(y-50)}{50}.$$

Hence the greatest rate of change of temperature per foot of ascent (at $y=75$ feet) is

$$274\times 34\pi e^2-0{\cdot}0105.$$

The whole change of temperature, from the bottom to the top of the stratum, is

$$274\times 3400e^2-0{\cdot}53.$$

Both of these quantities are in degrees centigrade.

18. To get an idea of the magnitude of e^2, we note that, by SCORESBY's observations, the elevation of the images above the horizon is usually about 10 or 15 minutes of arc at the utmost. Hence, by the value of $\frac{dy}{dx}$ in § 10, we may assume as an upper limit,

$$\sqrt{2}.e=\frac{1}{250},$$

or

$$e^2=0{\cdot}000008.$$

With this, the greatest rate of rise of temperature in the assumed stratum is 0°·22 C. per foot of ascent, and the whole rise is about 6°·9 C. These quantities, moderate as they are, would be greatly diminished by our relinquishing the assumption that the density in the lower stratum is constant.

But even this indicated rise of temperature with elevation has been actually observed. Thus GLAISHER* gives, for July 17th, 1862,

Time.	Altitude.	Temperature.	By Gridiron Thermometer.
10.30 A.M.	19,415 feet.	38°·1 F.	38°·1 F.
10.35 A.M.	19,435 feet.	43°·0 F.	42°·2 F.
10.39 A.M.	19,380 feet.	37°·0 F.	36°·5 F.

The greatest difference here observed is as much as 5° F. in 20 feet; *i.e.*, at the rate of 12°·5 F. or 7° C. per 50 feet, precisely what is required above.

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* *B. A. Report*, 1862.

19. We have another and independent mode of testing whether this value of e accords with observation. For SCORESBY tells us that, only on rare occasions and then only slightly, were objects at four miles' distance affected. The usual distance was 10 to 15 miles. Now, by the table in § 15 we see that the nearest object of which an image can be formed is distant

$$\frac{50\sqrt{2}}{\pi e} 7\cdot9 \text{ feet};$$

or, with the above value of e, about 12 miles.

There is thus a fair agreement, so far at least as these tests can tell us, between the results of our hypothesis and observation.

The table in § 15 shows that, with the same value of e, and the same thickness of the lower stratum, as before, but with the assumption of a transition stratum of a thickness of five feet only; the distance of the nearest object of which an image could be formed would be about six miles only. A still farther reduction of the thickness of the transition stratum reduces this least distance still farther; but it is clear from the table that there is a limit somewhere about five miles. This would be still farther reduced if we supposed the lower uniform stratum to have a depth of less than 50 feet. On the other hand, we see that an increase of thickness of the transition stratum introduces distances greater than are consistent with observation; unless indeed, the thickness of the lower stratum be at the same time reduced. In the table $\mathfrak{F}$ and $\mathfrak{G}$ depend upon the ratio of b to c; ξ is proportional to c.

20. The columns headed $\mathfrak{G}$ in the table of § 15 give, as shown in § 12, the magnitudes of the images relative to that of the object seen directly. They show that the inverted image is always taller than the object. This is consistent with SCORESBY'S observations. When the object is not near the critical distance, however, this magnification is not considerable:—even if we assume a 50-foot transition stratum. On the other hand, the erect image, except when the object is not far beyond the critical distance, is much smaller than the object. Moreover, as is obvious from §§ 12, 15, this image is seen by *converging* rays. No doubt they are so nearly parallel as to be capable of producing distinct vision in a normal eye; but the remark is necessary as showing how different, in some respects, is the phenomenon from one of WOLLASTON'S imitations of it. Both images become infinite:—*i.e.*, there is simply "looming":—when the object is situated at the critical distance. And, as the tables show from the result of § 13, the ratio of the distance between the images to the apparent size of the object seen directly, increases as the object recedes beyond the critical distance. All this seems to accord completely with VINCE'S and SCORESBY'S observations. The only additional remark I need make is that

possibly SCORESBY, from insufficient telescopic power, failed to see (or at least to recognise as part of the phenomenon) the upper erect image, when the object was much beyond the critical distance. The table shows the great rapidity with which its height diminishes as the object recedes. The disparity between the images depends of course upon the fact that we have assumed a law which places the plane of most rapid change in the middle of the stratum. This may often not be the case in nature. It might be useful to work out the whole again, assuming a law (for the transition stratum) which would place the plane of most rapid change considerably out of the middle of the stratum. But I cannot attempt this at present. The results of § 14 seem also to be in complete accord with SCORESBY's observations at Bridlington Quay, which are the only detailed ones I have met with in which the point of view was shifted to or from the transition stratum.

21. For an approximate estimate of the effect of the earth's curvature on these phenomena, let us suppose the same law of density as before; but let the strata be now *level, i.e.*, spheres concentric with the earth. The path of a ray in the lower stratum will still be straight, but the angle at which it meets the transition stratum ($\theta+\psi$, suppose) will now be necessarily greater than its original inclination (θ) to the horizon. See fig. 7.

If R be the radius of the earth, we find to a sufficient approximation,

$$(R+c)\cos\psi-R=R\psi\theta,$$

or

$$\theta=\frac{c}{R\psi}-\frac{\psi}{2}.$$

As θ cannot be negative, the greatest value of ψ is

$$\sqrt{\frac{2c}{R}}=\frac{1}{460}$$

nearly; c being 50 feet, as before. If we write $\frac{1}{p}$ for this quantity, we have

$$2p\theta=\frac{1}{p\psi}-p\psi,$$

whence, by giving $p\psi$ the values 1, 0·9, 0·8, &c., we easily obtain the following table:—

θ	$\theta+\psi$
0·0000	0·0022
0·0002	0·0022
0·0005	0·0022
0·0008	0·0023
0·0012	0·0025
0·0016	0·0027
0·0023	0·0032
0·0033	0·0040
0·0053	0·0057
0·0110	0·0112

Now if we take the value of e as in § 18, we have 0·004 for the greatest value of $\theta+\psi$, which is consistent with the rays not passing *through* the transition stratum. This corresponds to

$$\theta=0·0033=\frac{1}{300}=12' \text{ nearly}.$$

Hence, with this value of e, other assumptions remaining the same, even the upper erect image could not (on account of the earth's curvature) be elevated more than about 12′ above the horizon, and the nearest object of which multiple images could be formed would be at a distance of about 13 miles. Greater values of e might remove this difficulty, but they would introduce greater changes of temperature. This shows, therefore, that the assumption of a lower stratum of uniform density is untenable. If there is to be a *simple* arrangement in that stratum, it must therefore be such that the refractive index diminishes with elevation, but, of course, less rapidly than in the lower half of the transition stratum. The effect of this would be to slightly raise the images, and to reduce the critical distance.

Instead of the upper image, consider the lower one. This would be, at its *farthest*, within the distance of the visible horizon as seen from an elevation of 50 feet. Hence no inverted image of the hull of a vessel could be seen if it were more than 18 miles' distant; and even then it would be seen horizontally. The only ways of reconciling this with SCORESBY's observations are (1) to assume that the lower uniform stratum is much more than 50 feet thick; (2) to assume that it is not uniform, but gives rays a concavity downwards. The former alternative is inadmissible on several of the grounds already mentioned; so we are again forced to assume the latter, which certainly holds if the temperature throughout the lower stratum be constant.

22. In order that the above calculations may be applicable to the phenomena shown by inter-diffusing solutions, it is necessary that the length of the vessel in which the solutions are contained be great enough to allow all rays (by which the images are seen) to enter and escape from the transition-stratum by one of its horizontal surfaces, and not by its ends. By using a vessel nearly 4 feet long, containing a layer of weak brine diffusing into pure water above, I have verified the general accuracy of the results just given. For those rays which enter or escape by an end, the calculation is by no means so simple, and trial shows that the law determining the relative magnitudes of the images is considerably modified. On the other hand, when the vessel is so short and the rays so nearly horizontal, that each ray, while passing through the vessel, may be supposed practically to move in a stratum of uniform rate of change of refractive index, a very simple calculation suffices to give the general nature of the phenomena produced. For the curvature of a ray, in the vessel, may now

be regarded as constant throughout. Here J. THOMSON'S formula* is immediately and usefully applicable. For, if $\theta_1, -\theta_2$, be the angles the ray makes with the horizon just after entering and just before escaping, we have

$$\theta_1+\theta_2=-\frac{t}{\mu}\frac{d\mu}{dy},$$

where t is the length of the vessel. But, if $\theta'_1, -\theta'_2$, be its directions before entering and after escaping, we have approximately,

$$\theta'_1=\mu\theta_1\,,\quad \theta'_2=\mu\theta_2\,.$$

Thus the whole change of direction is

$$\theta'_1+\theta'_2=-t\frac{d\mu}{dy},$$

depending only on the rate of change, not on the value, of the refractive index. Parallel rays, passing nearly horizontally through such a vessel, will all be bent in the direction in which the refractive index increases :--but that which passes through the stratum of most rapid change of index will be the most bent, so that the illuminated portion of a sufficiently distant screen on which the rays fall will be terminated by a spectral band of which the violet is outermost. Measurements of the position of this band, from day to day, from hour to hour, or even (in some cases) from minute to minute, will give an extremely accurate mode of measuring the rate of diffusion. To interpret their indications, however, a determination must be made of the law which connects the refractive index of a mixture of the two fluids with the relative proportions in which they are mixed. And it may not always, or even usually, be the case that the stratum of greatest rapidity of change of refractive index is necessarily coincident with that of most rapid diffusion. From the former, however, the latter can always be found; and, so long as the original layers of the fluids remain in part unaltered by the diffusion, the knowledge of the plane and rate of greatest diffusion is sufficient for the complete determination of the other circumstances. I believe that many important questions connected with diffusion may be speedily and accurately investigated by this very simple method. I propose to give a detailed account of it, with experimental results, to the Society on a future occasion.

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[*] *B. A. Report*, 1870. THOMSON finds by a simple process, for the curvature of a ray in a non-homogeneous medium, the expression

$$\frac{1}{\rho}=\frac{1}{\mu}\frac{d\mu}{dn},$$

where n is measured towards the centre of curvature. The result is seen to follow immediately from the corpuscular theory (in which $\mu=v$) by multiplying both sides by μ^2, for it is thus found to be merely the equation of acceleration of a corpuscle in the direction perpendicular to its path. It is really involved in Prop. I. of WOLLASTON'S paper (*Phil. Trans.*, 1800).

23. In order to calculate roughly the number, position, and dimensions of the images visible to an eye looking through the media nearly horizontally at a distant object, all that is necessary is to draw the caustic, as in fig. 8. It consists, so far as the transition stratum is concerned, of the two (practically) equal and similar curves AB, A′B′; which touch the stratum above and below, and have as common asymptote the path of the most deflected ray. So long as the eye is not within the region BAC, only one image is seen. But from any point within this region two tangents can be drawn to the caustic, and a line can be drawn to the object so as to pass altogether below the stratum. Thus there are three images. In order that the middle one may be distinctly visible, the eye must be 10 inches or so beyond the point of contact of the corresponding ray with the lower caustic. Then the image is an inverted one. The others are always direct. [It may be remarked, in passing, that the intersection of the ray AC with the screen is always definite and measurable.]

Here the upper image is always seen by diverging rays, the middle one by diverging or converging rays according to the position of the eye. Contrast this with the results given in § 20. This middle image changes its direction far more rapidly than the others when the eye is moved vertically. It coincides with the upper image when the eye, gradually moved downwards, reaches the line DB. When they meet, both become blue and then disappear by moving the eye farther down. On moving the eye upwards, the middle image approaches the lower one, and they unite and disappear when the eye reaches the line DC. These results are easily verified by trial, and I have mentioned them only with the view of bearing out my statement, that this form of experiment, unless the tank be long enough, does not give results the same as those of Mirage.

(Read 19th June 1882.)

A few days ago, while finally preparing the above pages for press, I had occasion once more to consult WOLLASTON's paper, and inadvertently took down the wrong volume of the *Phil. Trans.* In it (the vol. for 1803) I found another paper on Mirage by WOLLASTON, in which he speaks of certain articles by WOLTMANN and GRUBER, and regrets his inability to read German. This led me to consult the *Register-band* of *Gilbert's Annalen;* and I thus learned the existence of a very elaborate memoir by BIOT* which I had never seen referred to, and in which the subject of mirage is exhaustively treated both by calcula-

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* *Mém. de l'Institut,* 1809; *Récherches sur les Réfractions extraordinaires qui ont lieu près de l'horizon.* I presume that my having been altogether ignorant of the existence of this memoir is connected with the fact that it is unintelligible without the plates, and that these were not issued along with it. For in each of the three first libraries which I consulted, that of the Society being one, this volume of the *Mém. de l'Institut* is devoid of plates. BIOT's memoir, however, was issued also as a separate volume, and a copy of this, containing the plates, I procured at last from the Cambridge University Library.

tion and by long series of exact measurements of the phenomena as seen by MATHIEU and BIOT at Dunkirk, and by ARAGO and BIOT at Majorca. The previous work of GRUBER, WOLTMANN, BÜSCH, and others, is carefully summarised by GILBERT in vol. xi. of his *Annalen* (1802) in notes to his translation of WOLLASTON'S great paper of 1800. A good deal of BIOT'S work is thus seen to have been anticipated. It may be well to quote here GILBERT'S remark as to the priority of explanation of some of these phenomena—think of it now as we may:—

> "In der That ist WOLLASTON der Erste und Einzige, der die *Spieglung aufwärts* mit Glück zu erklären unternommen hat, ob er gleich auch hierin noch sehr viel zu thun übrig lässt."

BIOT, on the other hand, gives WOLLASTON credit only for the physical, as distinguished from the mathematical, parts of his paper. He says:—

> "Sous le rapport de la physique, son travail ne laisse rien à désirer."

BIOT has considered the subject from a point of view somewhat similar to that which I had adopted, and anticipated of course the great majority of the more general results at which I had arrived. I was occasionally almost startled as I looked through his memoir, to find how closely (even in mode of stating them) I had reproduced some of his main ideas. His whole treatment, for instance, of the ordinary mirage of the desert:—on the assumption that the square of the velocity of a luminous corpuscle is proportional to the height above the ground, but only through a limited stratum, together with the important effects of limitation of the stratum:—is almost the same as mine, except that he (inconveniently I think) uses the caustics in preference to the curve of vertices, though he also notices the latter as the *courbe des minima*. In consequence, I had all but made up my mind to withdraw my paper, before I had looked more than half-way through BIOT'S long memoir; for, though I found here and there statements which I think inaccurate, these are of very small consequence compared with the whole. But it was otherwise when I read farther, where BIOT gives his tentative explanation of VINCE'S observation. There I found our assumptions to be so entirely different in character that, being fairly satisfied with my own, I thought I might still reasonably produce them with their results. My paper, therefore, appears as it was presented to the Society, except in so far as (*a*) a part of the introduction, (*b*) the detailed examination of the ordinary mirage of the desert, (*c*) a discussion of the singular outline sometimes presented by the setting sun, and (*d*) a few minor remarks, are concerned. These parts have been simply struck out, the first as historically imperfect, the others as practically a mere reproduction of what had already been satisfactorily done by BIOT, who had many opportunities of observing and measuring the phenomena. As to the ordinary mirage, however, there can be no doubt that the discovery of the existence of *four* images, when the eye and object are both above the hot stratum, is far more easy by means of the curve of vertices than by the caustics employed by BIOT.

I transcribe some of the more important parts of BIOT'S remarks on VINCE'S phenomenon, premising that it was of course impossible for him to have been acquainted with SCORESBY'S observations, at least at the time when his memoir was written. I fancy that, if he had seen these, he might have felt some doubts as to the accuracy of his inference that the rays, in their course to VINCE'S eye, were probably at first *concave upwards;* and this to such an extent as to make a vessel, which was situated close to the ordinary horizon, show only its top-masts above the apparent horizon. He does not advert to the *certainty* that, had this law held over the nearer parts of the sea, VINCE would have seen inverted images *under* ships within the visible horizon. None such are described. After quoting the passages in question, I shall add a few comments on them. To make them as intelligible as possible, I have reproduced BIOT'S hypothetical figure; it is numbered as fig. 9 in the plate. In many respects the following passages are obscure, but to clear them up (if it can be done at all) would require a thoroughly careful perusal of the whole minute details of BIOT'S volume, and for this I have not been able to find leisure.

Je crois pouvoir expliquer par la même thèorie les phénomènes des triples images observés par M. VINCE et dont j'ai déjà parlé plus haut. Quand je dis expliquer, j'entends ramener ces phénomènes à une même cause, à une même forme de caustique, telle que la disposition des images, et leur marche relative quand elles s' abaissent ou qu'elles s' élèvent, soient des conséquences nécessaires de la forme supposée. Car admettre, comme l'a fait M. VINCE, autant de lois différentes de densité qu'il y a d'images visibles, ne me paroît point une explication satisfaisante, puisque les mouvements respectifs des images restent arbitraires; tandis que, d'après la description qu'il en donne, ces mouvements avoient entre eux des rapports déterminés.

Malheureusement M. VINCE n' a pas observé l'élément le plus nécessaire pour l'explication de ces phénomènes, je veux dire la dépression apparente de l'horizon de la mer. De sorte que l'on ne peut pas affirmer *a priori*, si les trajectoires, dans leur partie inférieure étoient concaves ou convexes vers la surface des eaux. Cependant je crois pouvoir conclure qu'elles étoient convexes d' après plusieurs raisons que je vais développer.

. . . .

Ainsi, pendant l'observation du phénomène, qui se fit depuis 4 heures ½ du soir jusqu' à 8 heures, la température de l'air devoit avoir considérablement diminué, surtout dans les couches supérieures, par l'effet de l'abaissement du soleil. Mais la surface de la mer n'avoit pas dû se refroidir aussi vite. Elle pouvoit donc alors et devoit probablement se trouver plus chaude que l'air, ce qui donne des trajectoires convexes dans leur partie inférieure, et une densité croissante du bas en haut, jusqu' à une petite hauteur; après quoi l'influence de la mer devenant moins sensible, la densité devoit aller de nouveau en diminuant comme à l'ordinaire, et probablement suivant une loi beaucoup plus rapide, tant à cause de l'abaissement subit de la temperature, qu' à cause de la chute des vapeurs aqueuses qui devoit en résulter et qui par leur accumulation et par le froid qu'elles produisoient en se précipitant pouvoient contribuer à augmenter la réfraction dans les couches qu'elles traversoient. Ces conjectures sont confirmées par plusieurs remarques de M. Vince lui-même.

. . . .

Je tire encore des observations mêmes une autre preuve que les trajectoires n' étoient pas convexes dans toute l'étendue de leur cours, comme cela auroit eu lieu s' il n' y avoit eu dans l'air qu'un seul état de densité décroissante de haut en bas. Cette preuve consiste en ce que les deux images supérieures dont la plus haute étoit directe et l'autre renversèe, ont été plusieurs fois complètes, c'est-à-dire que la vaisseau y étoit représenté tout entier depuis le sommet des mâts jusqu' au corps même du bâtiment. Or, d'après les expériences que nous avons faites sur le sable à Dunkerque, si ces deux images eussent été données par des trajectoires entièrement convexes vers la mer, ces trajectoires eussent nécessairement formé une caustique qui se seroit élèvée au-dessus de la surface de la mer à mesure qu'elle s' eloignoit de l'observateur. Cette caustique auroit donc caché de plus en plus les parties inférieures du vaisseau à mesure qu'il s' éloignoit, et par conséquent les deux images de ce vaisseau n' auroient pas été complétes . . . . . On peut encore prouver par les observations de M. Vince que la caustique n' étoit pas formée d' une branche unique, mais de deux branches distinctes réunies par un point de rebroussement et dont la plus basse alloit continuellement en s' approchant de la surface de la mer à mesure qu' elle s' éloignoit de l'observateur. Car puisque M. Vince a vu des images complètes de vaisseaux qui se touchoient par le corps même du bâtiment, il falloit bien qu'alors le vaisseau reposât sur la caustique; et comme il en a vu aussi d'autres qui se touchoient par le sommet des mâts, il falloit bien qu' alors le vaisseau se trouvât sous la caustique et la touchât par le sommet de ses mâts. Enfin, puisque les images d'un même vaisseau données par ces deux branches s' écartoient continuellement l'une de l'autre, à mesure que le vaisseau s' eloignoit, les deux branches de la caustique s' eloignoient donc aussi l'une de l'autre; ce qui indique une forme . . . . . qui seroit donnée par la combinaison de deux décroissemens de densité contraires.

Cette conséquence déduite immédiatement des observations s' accordant avec l'état décroissant de la température, et avec toutes les apparences que nous avons discutées, je crois pouvoir admettre comme une chose trés-probable que, par l'excès de chaleur de la mer, à l'époque où a observé M. Vince, les couches inférieures de l'air se trouvoient dans un état de densité croissante de bas en haut, jusqu' à une petite hauteur, au-dessus de laquelle les densités alloient de nouveau en décroissant par suite de l'abaissement de la température, avec assez de rapidité pour donner des images par en haut. D' après les élévations données par M. Vince, nous devons placer l'observateur dans ces couches supérieures, car il dit avoir observé le phénomène à 25 et à 80 pieds de hauteur. Nous avons déjà examiné précédemment les combinaisons de ces deux états contraires, et l'on a vu qu' elle explique très-aisément les images multiples observées au Desierto de las Palmas et à Cullera, phénomènes qui paroissent avoir le plus grand rapport avec ceux que M. Vince a décrits. Nous supposerons donc conformément à l'endroit cité, que la caustique avoit une forme VRV (fig. 9). . . . . . Soit AMH la circonférence de la terre, O l'observateur, OMV la trajectoire limite tangente à la surface de la mer. Il s' agit d'examiner les phénomènes résultans de cette loi.

. . . .

La supposition que nous venons de faire sur la non-sphéricité des couches n'est point gratuite, car M. Vince rémarque que des vaisseaux également élevés au-dessus de l'horizon apparent présentoient des apparences très-diverses, souvent plusieurs images comme nous

> venons de le dire, quelquefois deux seulement, l'inférieure constamment droite, la supérieure renversée, d'autrefois enfin on n' en apercevoit qu'une seule directe et reposant sur l'horizon. Les côtes de Calais qui présentoient aussi des phénomènes analogues, offroient aussi les mêmes variétés, quelquefois on les voyoit doubles un instant après elles étoient invisibles. Toutes ces apparences sont contraires à l'idée d' une sphéricité parfaite des couches d'air qui produisoient ces phénomènes, et l'on concoit en effet qu'étant le résultat d'une équilibre non stable, ils peuvent difficilement s' accorder avec une forme constante.

On this I would remark, generally, that I think VINCE is here rather hardly treated. It seems to me, on comparing the two explanations, that the reproach of "*autant des lois différentes qu'il y a d'images visibles*" is not merited by VINCE, and would perhaps more justly apply to his censor. It is certainly most unfortunate that VINCE did not note the level of the apparent horizon; though, unless he had done so from a great many different heights above the sea, I fail to see how the observation would have helped to decide between the various possible explanations. BIOT evidently expected a *depression,* for he states as much in reference to the elevated patches of sea and the "heavy fog" which VINCE observed; yet this is inconsistent with his own figure! But the following passage from VINCE's paper (in which I have italicised some words) seems to have escaped the notice of BIOT.

> "The *usual* refraction at the same time was uncommonly great; for the tide was high, and at the very edge of the water I could see the cliffs of Calais a very considerable height above the horizon; whereas they are frequently *not to be seen* in clear weather *from the high lands* about the place. The French coast also appeared both ways, to a much greater distance than I ever observed it at any other time: . . . . . "

Now, one of the most striking of VINCE's observations was that of a ship (hull down) with an inverted image above it, both projected on the confused image of the French cliffs as a background. If BIOT's explanation were correct, this background must have been visible by rays of a truly *schlangenförmig* character (as GILBERT calls them), for they must have been at least *twice* (more probably *thrice*) concave downwards; with a convexity downwards, somewhere between the spectator and the ship (and probably another between the ship and the French coast). It seems much more likely that the ship's hull was really beyond the ordinary horizon, and that the French cliffs were visible by rays originally concave upwards so as to rise up, as it were, behind the ship; and then concave downwards, according to the theory I have propounded, from the ship to the spectator.

BIOT's memoir shows, throughout, the pervading influence of his almost daily observations of rays which were concave upwards, because passing very close to the ground over extensive surfaces of hot sand. If his explanation of VINCE's observation were correct, there would have been an inverted image (of a part of the top-mast) *under* the lowest of the three images, and objects comparatively near hand would have been affected as well as those at a considerable distance.

But there is much more to urge against BIOT's view of the phenomena in question. VINCE expressly states that "the evening was very sultry." As his observations were made at heights above the sea, varying from twenty-five to eighty feet, it is pretty clear that this sultriness was not due to the exceptionally high temperature of the surface of the sea. BIOT, in fact, allows that the effects of this were only sensible "jusqu' à une petite hauteur." But then he assumes (contrary to VINCE's statement) a rapid *descent* of temperature at higher levels. This he looks on as developed, *how* he does not tell us, by the *cold* produced by vapour in condensing! Besides, if this were true, it would make the diminution of density upwards *less*, instead of *greater* than usual, and the optical results of such an arrangement would be in contradiction to his explanation.

It is much to be regretted that VINCE's description, like his drawings, is of the very roughest character. It is quite otherwise with those of SCORESBY. There can be no doubt whatever that BIOT's mode of explanation is altogether inapplicable to the majority of SCORESBY's observations.

I quote a single passage,* which is apparently decisive.

> "A dense appearance in the atmosphere arose to the southward of us . . . . When it came to the S.W. of us, I first noticed that the horizon, under this apparent density, was considerably elevated. . . . . . Two ships lying beset about fourteen miles off, the hulls of which, before the density came on, could not be wholly seen, seemed now from the mast-head not to be above half the distance, as the horizon was visible considerably beyond them."

Had the arrangement of strata here been as BIOT supposes in VINCE's case, only the top-masts would have remained visible, the apparent horizon would have come in front of the hulls, and there would have been inverted images of nearer objects visible *under* the objects themselves.

It will be observed that these observations were taken over a surface of *ice* in which the vessels were "beset." The sun is said to have been "powerful," but the lowest strata of air, in contact with ice or ice-cold water, must have been colder than those above them. The haze, or "density" as SCORESBY calls it, probably consisted of minute drops of water, and would thus be much raised in temperature by the sun. In connection with this I may mention that when a trough, in which brine has been diffusing for some time into water, is suddenly and roughly stirred for a short period, it settles in a few minutes into a large number of strata of different densities. Something similar must hold

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* SCORESBY's *Arctic Regions*, i. 387 (1820).

in the case of air irregularly heated, and thus we have a very probable explanation of the *series* of inverted images figured by SCORESBY. The strata which produced these, in all likelihood produced direct images also, but (except on very rare occasions) so small in vertical dimensions as to have escaped observation. In the absence of wind such strata, once formed, would last for a long time, in consequence of the very small thermal conductivity of air. I might also refer to an interesting case of inverted images seen from a balloon by TISSANDIER.* The height at which the balloon was situated is not stated expressly, but from the context it must have been somewhere about 6000 feet. This, of course, *proves* the existence, at a great elevation, of a stratum in which there was a comparatively rapid diminution of refractive index with increasing height.

I will quote, in conclusion, SCORESBY'S account of his remarkable observation of an isolated inverted image of a ship, which was situated far beyond the horizon. His drawing is reproduced as the second of the series in fig. 1. The obvious and simple explanation of this is what has already been mentioned for TISSANDIER'S observation, though, of course, it could also be accounted for by an infinite number of different laws of refractive index, all of more or less ingenious complexity.

> "The atmosphere, in consequence of the warmth, being in a highly refractive state, a great many curious appearances were presented by the land and icebergs. The most extraordinary effect of this state of the atmosphere, however, was the distinct inverted image of a ship in the clear sky, ... the ship itself being entirely beyond the horizon. . . . . It was so extremely well defined, that when examined with a telescope by DOLLOND, I could distinguish every sail, the general 'rig of the ship,' and its particular character; insomuch that I confidently pronounced it to be my Father's ship, the 'Fame,' which it afterwards proved to be; though, on comparing notes with my Father, I found that our relative position at the time gave our distance from one another very nearly thirty miles, and some leagues beyond the limit of direct vision."†

It seems hard to reconcile the clearness of definition in this case with any other than a stable state of equilibrium of a transition stratum. The mirage of the desert, where the equilibrium is essentially unstable, is always exceedingly unsteady.

BIOT makes a point, to which I have not yet alluded, from VINCE'S statement that the inverted image appeared to rise as the object moved farther away. His mode of explaining this, however, savours of the "*autant des lois différentes,*" &c. ; and, besides, the result follows quite as directly from my ex-

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* GLAISHER'S *Travels in the Air*, p. 297 (1871).

† SCORESBY'S *Journal of a Voyage to the Northern Whale Fishery* (1823), p. 189.

planation as from his. Vince's observations were by no means precise enough to make this point certain ; besides, he speaks of the top-masts and not of the hulls ; and, from the diminution of the image as the distance increases, it may be quite true that the top-masts appear to rise in the inverted image while the hull really sinks. At any rate it is assuredly *not so* in the majority of Scoresby's careful figures. In fig. 1 several examples are shown of multiple images of ships at different distances in nearly the same direction ; and in all it will be observed that the inverted image of the hull is lower as the vessel is farther off. Also that in the upper direct image the hull appears to rise as the vessel recedes.

[*Feb.* 10, 1883.—I have to acknowledge the kindness of Mr. J. W. L. Glaisher in verifying, and in some important instances correcting, the numerical values given in §§ 10 and 15. My own original calculations, made for the most part with four-place logarithms only, were insufficient to give accurately the values of $\mathfrak{G}$ close to the critical point. The reason is obvious from the form of the expression for that quantity as given in § 12, above.]

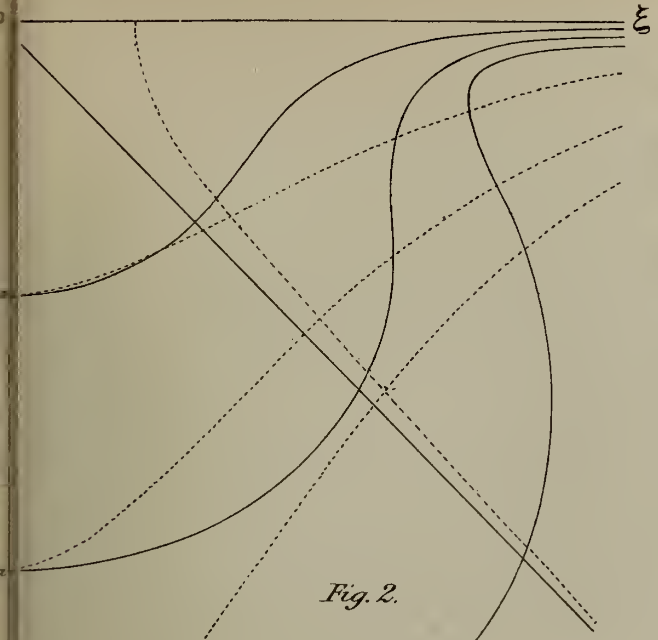


Fig. 2.

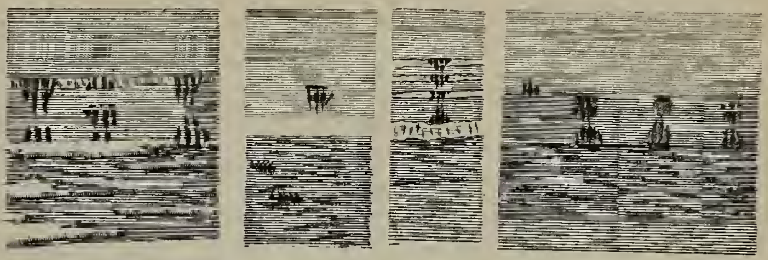


Fig. 1

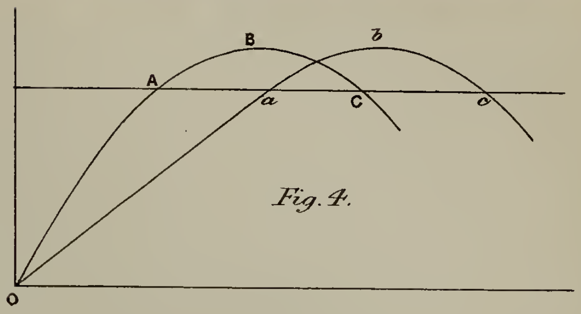


Fig. 4.

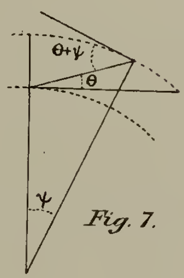


Fig. 7.

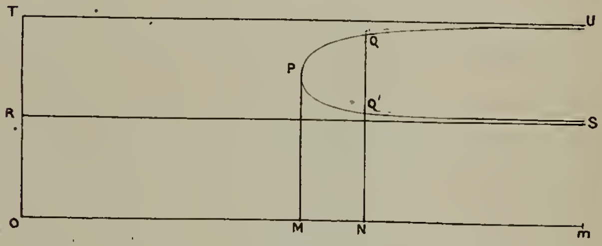
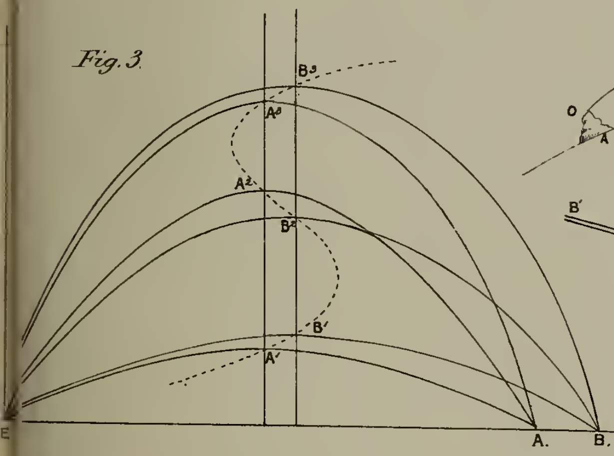


Fig. 5.

Fig. 3.



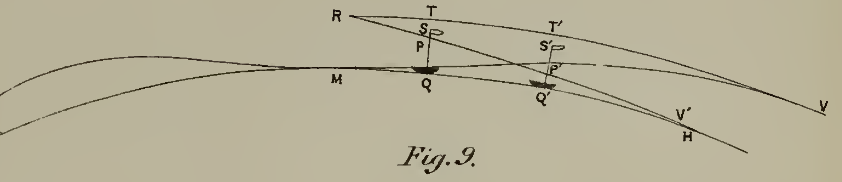


Fig. 9.

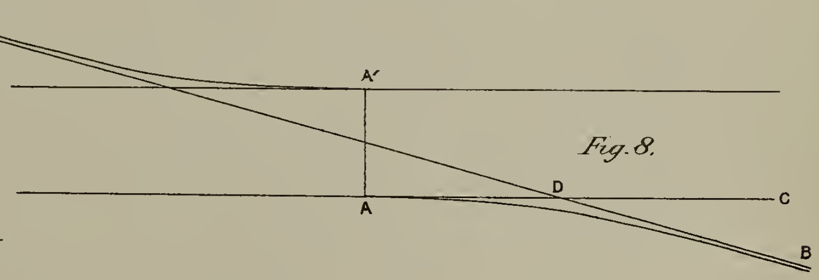


Fig. 8.

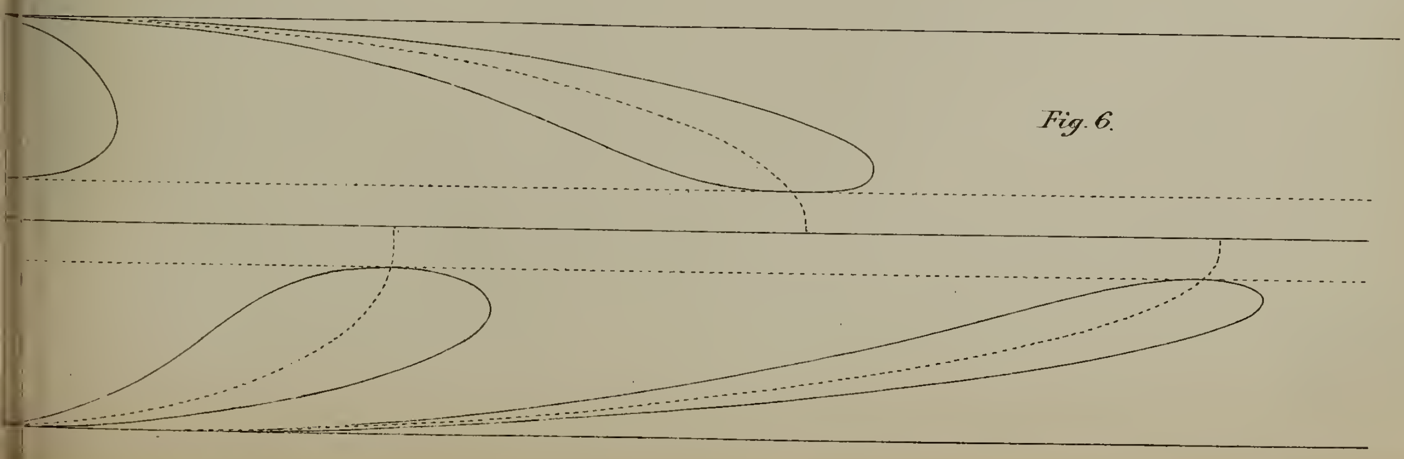


Fig. 6.

J. Bartholomew, Edinr.

XXIV.—*Description of Mimaster, a new Genus of Asteroidea from the Faeröe Channel.* By W. Percy Sladen, F.L.S., F.G.S. (Plate XXXIV.)

(Read May 15, 1882.)

The area lying between the north of Britain and the Faeröe Islands is classical in the annals of Marine Zoology, not only from the fact that the first systematic deep-sea investigations undertaken by this country were carried out there, but also from the number of new and remarkable types of animal life which have been first found in that region. Speaking only of the Echinoderm fauna, in justification of these remarks, it will suffice to mention the discovery of such forms as *Phormosoma* and *Porocidaris* amongst Echinoids, and of *Hymenaster*, *Korethraster* and *Zoroaster* amongst Asteroids.

The object of the present communication is to describe another new and important generic type, which has been added to the last-mentioned group during the dredging operations of H.M. hired ship "Knight Errant," whilst engaged during the autumn of 1880 in further investigating the area referred to. The results of that survey, including the discovery of the "Wyville Thomson" ridge, which was found to form the barrier that separates the "warm" and the "cold" areas, have already been laid before this Society in a detailed account by Staff-Commander Tizard, R.N., and Mr. John Murray.*

I desire to express here my hearty thanks to Mr. Murray for placing the starfishes obtained during the cruise in my hands for determination.

A list of the different species, with notes thereon, is appended to the paper previously cited. The following is a description in detail of the new form.

Genus *Mimaster*, Sladen.

Mimaster, Sladen, 1882, *Proc. Roy. Soc. Edin.*, vol. xi. p. 702.

Marginal contour stellato-pentagonal; dorsal area subject to inflation; ventral area more or less convex. Abactinal floor composed entirely of independent paxillæ, without subjacent calcareous reticulated skeleton. Paxillæ small and compact. Numerous papulæ in the interspaces.

Marginal plates arranged in dorsal and ventral series, small and covered with very numerous spinelets similar to those of the paxillæ.

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* Exploration of the Faeröe Channel during the summer of 1880, in H.M. hired ship "Knight Errant," by Staff-Commander Tizard, R.N., and Mr John Murray; with subsidiary Reports by various scientific men (*Proc. Roy. Soc. Edin.*, vol. xi. pp. 638–719).

Actinal floor extensive, and occupied by imbricating ventral plates, arranged in isolated transverse columns, running from the adambulacral plates to the marginal plates; the whole area covered by a uniform epidermal layer of membrane. Each ventral plate bears a single well-developed naked paxilla.

Adambulacral plates broader than long. Ambulacral spines delicate, taper, numerous, irregular in disposition, forming a group which occupies the surface of the plate, the size of the spines increasing towards the furrow-margin of the plate.

Mouth-plates forming a pointed mouth-angle, superficies prominent, covered with spines similar in form and character to the ambulacral spines, but larger.

Ambulacral sucker-feet with a well-developed fleshy disk, devoid of spicules.

Madreporiform body concealed by paxillæ. No pedicellariæ.

Mimaster Tizardi, Sladen.

Mimaster Tizardi, Sladen, 1882, *Proc. Roy. Soc. Edin.*, vol. xi. p. 702.

Description of an Individual.—Form large and robust; marginal contour stellato-pentagonal. Radii five, short and triangular, tapering continuously from the base to the extremity, the breadth at the base of a ray greater than the lesser radius of the disk, the interbrachial angle being subacute. The lesser radius is in the proportion of 45 per cent., $R=120$ mm., $r=54$ mm.; $R=2{\cdot}2r$; breadth of a ray at the base, 58 mm.

The abactinal surface is high and inflated over the disk, very gibbous at the base of the rays but flattening towards the extremities. A deep furrow is formed along the median interradial line in consequence of the gibbosity, but disappears before reaching the centre of the disk. The actinal surface is more or less convex, but in a regular and comparatively slight degree, although the feature is probably largely emphasized in the specimen under notice by the upward turning of the extremities of the rays, which took place during the *rigor mortis*. Consequent on the curvature of the actinal and abactinal surfaces, the margins are very thin and of small dimensions, and are occupied entirely by the double series of small marginal plates. The thickness or perpendicular height of these two series of marginal plates together is only 4 mm.

The dorsal area is covered with a great number of small, uniform paxillæ, closely and equidistantly placed, and with a well-defined space between each, and presenting no definite order of arrangement, excepting in the immediate neighbourhood of the arm-angle, where a certain amount of obliquely transverse lineal disposition may be observed. The whole of the calcareous portion of the abactinal skeleton is composed entirely of paxillæ, as in *Astropectinidæ.* The paxillæ consist of a cylindrical pedicel, about twice as high as broad, expanding slightly at the base, and with the distal extremity rounded and clavate, and surmounted by a crown of 15 to 20 spinelets, which radiate apart very slightly and produce a compact form of paxilla. The spinelets are short, delicate, and slightly taper, about equal in length to the pedicel, and sometimes less, probably owing, to a certain extent, to abrasion. The base of the paxilla is quite small and thin at the margin, where a faint tendency to develop rudiments of two or three very short radiating processes may be noticed. No calcareous union or connection exists between individual paxillæ. Numerous small papulæ occur in the interspaces, three to five being present in the quadrangle formed by four neighbouring paxillæ. Their membrane is very delicate, and they taper somewhat rapidly towards the tip, which is thickened into a small knob. Owing to the manner in which the papulæ taper, a comparatively swollen appearance is given to their lower part.

The marginal plates are small and subtubercular in appearance, and are arranged in ventral and dorsal series, 37 to 38 plates being present in each, between the interbrachial angle and the extremity of the ray. Each plate is rounded or boss-like externally, and covered with a great number of small spinelets similar to those of the paxillæ, which gives them a prominent, cushion-like appearance. The infero-marginal (or ventro-marginal) plates are the largest, transversely sub-oval in form—the length increasing towards the interbrachial angle—and bear not less than 100 spinelets. The supero-marginal (or dorso-marginal) plates are smaller, usually round, and are placed rather more aborally than the companion plate of the lower series, the pairs standing consequently slightly oblique.

The ventral plates occupy a great space on the actinal surface, and extend up to the very extremity of the ray. The plates are oblong and are arranged in regular transverse and slightly oblique lines between the adambulacral plates and the marginal plates. Each series or column thus formed is isolated, being separated from the neighbouring column by a narrow space; and each plate in a column overlaps or imbricates upon the next innermost plate. The number of the columns corresponds exactly with that of the adambulacral plates, and is not in relation with that of the marginal plates. The whole ventral area is overlaid by a uniform layer of membrane, by which the shape of the individual ventral plates is hidden from superficial observation. Each ventral plate bears a single paxilla near its free extremity, which is rather more robust than those on the dorsal surface, and carries rather fewer spinelets, which are somewhat longer and more widely expanded. The paxillæ, like those on the dorsal area, are naked and not invested in membrane. In consequence of the size and arrangement of the ventral plates, the ventral paxillæ are more widely spaced than the dorsal ones, and are disposed in regular lines which run from the adambulacral plate to the margin, the lines or columns being marked off by straight furrows or wrinkles in the membrane. As the paxillæ are equidistantly spaced in each of these transverse rows, equally regular and uniform longitudinal lines are also traceable along the ray. In the arm-angle nine to ten paxillæ stand in each transverse series, the same number being maintained until about the outer fifth of the furrow.

The adambulacral plates are broader than long, and appear to stand on the furrow margin as the terminal plates of the transverse series of ventral plates; about 75 adambulacral plates may be counted along the furrow. The ambulacral spines are delicate and taper, irregular in number and disposition, forming a compact group, transversely elongate in form, in relation to the direction of the ray, which occupies the whole surface of the plate, and resembles a compressed and enlarged paxilla. There are 15 to 20 spinelets in each group. Two of the spinelets (sometimes three) larger than the rest, slightly flattened and tapering to a point, stand at the margin of the furrow, their relative individual position being generally slightly oblique. The succeeding spinelets are less robust, and pass in gradation to the group of outermost spinelets, which are about equal in size to those of the ventral paxillæ. The five or six innermost adambulacral plates have much larger spinelets than the others.

The united mouth-plates form a sharp angle inwardly, and a large elongately ovoid, sub-tubercular swelling is developed on their superficies,—the whole surface being covered with spinelets arranged in somewhat similar series to the ambulacral spinelets, standing perpendicular, seven to eight along each side of the mouth-angle. The aboral portion of each plate is occupied by a compressed paxilliform group, similar to those on the adambulacral plates. The madreporiform body is obscure and concealed by paxillæ.

The ambulacral sucket-feet are arranged in pairs; they are robust and large, with a well-developed fleshy disk, devoid of spicules.

No traces of any form of pedicellariæ are present.

Remarks.—This magnificent starfish is entirely distinct from any of its northern congeners; and its structure is very remarkable, especially on account of presenting an association of characters which belong to several independent groups of Asteroids.

The arrangement and appearance of the paxillæ, and the numerous papulæ interspersed, recall in a striking manner the habit of *Solaster*. On dissection, however, it is found that this appearance is deceptive and not real; and that the true structural resemblance lies in a very different and unexpected direction. In *Solaster endeca* (Linn.), the form which at first sight is most nearly suggested by the dorsal covering of the new species, the abactinal portion of the skeleton consists of a rather closely reticulated calcareous framework, built up of small imbricating plates, upon certain of which the paxillæ are borne. The skeleton of *Mimaster*, on the other hand, is constructed quite differently; the whole abactinal floor being composed of paxillæ alone, each of the paxillæ consisting of a pedicel, with a slightly expanded base and a rounded clavate extremity, on which the spinelets that form the crown are articulated. The expansion of the base of the paxillæ is very slight, subcircular, or irregular in outline, and usually exhibiting two or three faint prolongations. The bases of the paxillæ are closely placed, and occasionally a trace of overlapping may be found here and there. This structure is identical with that met with in *Astropectinidæ*, and has hitherto been looked upon as specially characteristic of that group.

The adambulacral plates, the ambulacral spines, and the mouth-plates have strictly the characters of the *Goniasteridæ*. The marginal plates are likewise suggestive of the same group, and, notwithstanding their inequality and insignificant development, approach the habit of such forms as *Astrogonium paxillosum* (Gray), from which also the general outline of the body is not far removed.

The ventral plates recall in their character the ventral plates of *Asterinidæ*, whilst their arrangement also approaches in a certain degree that of some of the *Goniasteridæ*.

Possessing such a great complexity of structural character, *Mimaster* naturally stands in a very isolated position. For the present I propose to rank the genus provisionally amongst the *Goniasteridæ*, but reserve any expression of opinion as to its definite position in that group until an opportunity is afforded by a further supply of material for studying more closely the anatomy and general structure. We may even say that the structural formula of the genus does not appear to admit of close association with any form at present known. *Radiaster*, a genus established by M. PERRIER* (from a specimen obtained by the U. S. Coast Survey steamer "Blake," in the dredgings in the Gulf of Mexico and the Carribean Sea), appears to possess characters in common with our form, and may probably prove to be one of its nearest allies. As far as their individual relations are concerned, the description given by M. PERRIER indicates important differences, which separate the forms widely. Without drawing any closer comparison than that afforded by the short description of my learned colleague, the following points may be mentioned. *Radiaster* possesses only one series of marginal plates; each marginal plate carries two separate tufts ("bouquets") of spines, which somewhat resemble those of *Solaster;* dorsal plates are present, and these bear tufts of spines; and the tufts of spines are

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* *Bull. Mus. Comp. Zool.*, Harvard, vol. ix. No. 1, p. 17.

enveloped in membrane. The structure of the abactinal floor and of the marginal girdle is thus quite distinct in the two forms. Respecting the structure of the actinal floor, the description of *Radiaster* does not enable a comparison to be made. It is quite possible that the forms may be even more widely separated than I have supposed.

I have named this very interesting species after Staff-Commander TIZARD, R.N., under whose command the "Knight Errant" cruise was conducted, and to whom science is largely indebted for many valuable services and contributions.

Habitat.—Faeröe Channel, lat. 59° 33′ N., long. 7° 14′ W. ("Knight Errant" Dredging Station No. 4, August 10, 1880.) Depth, 555 fathoms. Bottom temperature, 45°·4 Fahr.; surface temperature, 57° Fahr. Sea bottom, mud. A single example.

DESCRIPTION OF PLATE XXXIV.

Fig. 1. Abactinal aspect of a ray of *Mimaster Tizardi;* natural size.
„ 2. Actinal aspect of the same; natural size.
„ 3. Outline sketch of the whole starfish, seen from above, to show the marginal contour; one-third natural size.
„ 4. Outline sketch of the starfish, seen in profile; one-third natural size.
„ 5. Three adambulacral plates, showing the ambulacral spines, together with a portion of the adjacent ventral plates and their paxillæ; magnified 5 diameters.
„ 6. A portion of the dorsal surface, showing the dorsal paxillæ and papullæ; magnified 5 diameters.
„ 7. A mouth-plate, seen in profile; magnified 5 diameters.

Fig. 5.

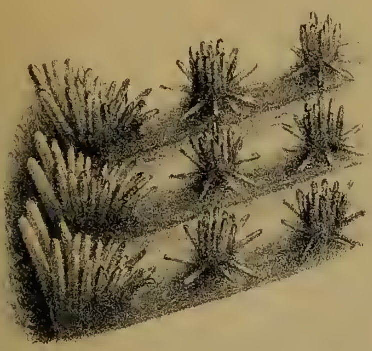


Fig. 7.

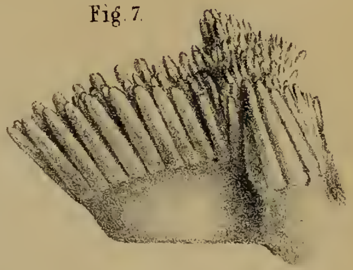


Fig. 1.

Fig. 6.

Fig. 3.

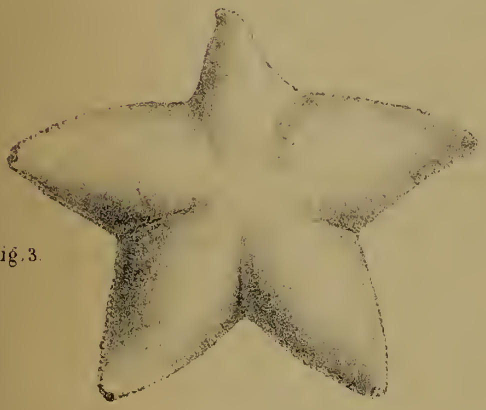
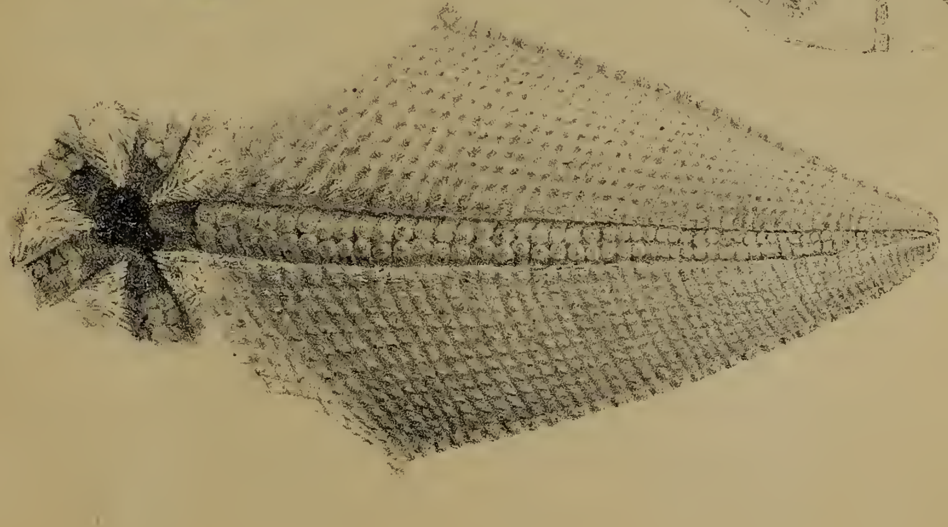


Fig. 4

Fig. 2



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MIMASTER TIZARDI, Sladen

XXV. *Observations on Vegetable and Animal Cells; their Structure, Division, and History.* By J. M. MACFARLANE, B.Sc. (Plate XXXV.)

PART I.—THE VEGETABLE CELL.

(Communicated by Professor DICKSON.)

In the present paper I propose extending my previous observations "On the Structure and Division of the Vegetable Cell."* I have shown that a nucleolus and nucleolo-nucleus (at Professor Rutherford's suggestion I now propose terming this the *endonucleolus*) are essential, and in most cases evident, parts of every growing vegetable cell, and that the division of the endonucleolus very probably precedes that of the nucleolus, just as division of the latter undoubtedly precedes that of the nucleus, in all the cases investigated.

Chara fragilis, which I will now specially deal with, is eminently suited, in many respects, for confirming the views above stated. Since all the tissues are produced, directly or indirectly, from a single apical cell by repeated division, the complete life-history of each cell can pretty easily be ascertained. My observations have been made principally on specimens prepared by the osmic acid process. Buds especially, prepared in this way and mounted in balsam, have a clear appearance and pleasing effect.

BRAUN,† PRINGSHEIM,‡ THURET,§ DE BARY,|| SACHS,¶ and others, have contributed to our knowledge of the history of *Chara*, while recently STRASBÜRGER ** and JOHOW †† have studied cell division in it. Reference will be made to their results as we proceed.

In all our recent text-books illustrations of the terminal bud of *Chara* are given with great accuracy, if we deal only with cell wall, protoplasm, and nucleus; but when we come to the nucleolus, appearances are figured such as I have never seen in the numerous specimens by me. This is not surprising, if we remember that the nucleolus has generally been regarded as a very doubtful structure, even in spite of laboured protests in the shape of careful observations by NAEGELI and others. It will be seen as we advance that in *Chara* the

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* *Trans. Bot. Soc. Edin.*, vol. xiv. part ii.

† *Monatsberichte der Berliner Akad. der Wiss.*, 1852.

‡ *Jahr. für Wiss. Bot.* 1864, vol. iii.

§ *Annales des Sc. Nat.* 1851, vol. xvi.

|| *Monats. der Ber. Akad.* 1871.

¶ *A Text-book of Botany* (Eng. ed. 1875).

** *Ueber Zellbildung und Zelltheilung* (3rd ed.).

†† *Bot. Zeitung*, 1881.

internode was cut off, its nucleolus showed continued activity, so here also, when the three cells of the cortical node have been formed, the internodal nucleolus may have proliferated once or twice. But the cortical nodal cells themselves do not further multiply. Curiously enough, however, their nucleoli follow the example of that of the internode, though necessarily at a somewhat later period ; the consequence being that the cortical internodal, and soon after the cortical nodal cells, become multinucleolar (figs. 6 and 7) ; and this multiplication of the nucleoli may not unfrequently be succeeded by breaking up of the nucleus.

This remarkable continued activity without new cell formation holds throughout the development of all the vegetative parts.

We turn now to leaf development. Each leaf originates as a lateral outgrowth from the stem node, the first portion cut off from it forming a leaf apical cell, which by repeated transverse divisions forms a row typically of nine cells. Of these, the three terminal, as a rule, do not further divide. Each of the lower six divide into an upper, the nodal, and a lower, the internodal, leaf cells. The nodal cell and its contents proliferate till it forms a peripheral layer of from six to ten cells surrounding an inner central cell. These peripheral cells bulge out, their nucleoli divide, the nuclei then divide, a very delicate spindle or barrel can now and again be detected (fig. 8), and along its centre the new cell wall is deposited. The outer cells thus cut off are the so-called stipules. In succession an inner layer, "the uniting cells" (SACHS), are similarly produced. Lastly, the cells of what may now be called the middle layer divide, first transversely, then longitudinally. The progress of the latter stage is well seen in fig. 9, where, after transverse division, the nucleoli of the cells are in every phase of preparation for it.

But during this time the leaf internodes have been exhibiting the same tendency to continued nucleolar proliferation which we have already noticed in the stem, but in this respect even they have been outstripped by the three terminal cells, whose nuclei, even while the stipules were being developed, have greatly enlarged, and their nucleoli have broken up into many portions. This again is followed at times by breaking up of the nucleus. A little later the internodal leaf cells exhibit similar proliferation (figs. 8 and 9). But just as we found that the nodes of the stem cortex after finishing their tissue-producing work passed into this state, so also the nodal leaf cells exhibit similar phenomena. But in saying so I must except the central, uniting, and stipular cells, which, while becoming always multinucleolar, never, to my knowledge, become multinuclear. The fact of these cells always remaining relatively small, give us a probable explanation of this circumstance.

In tracing the later or multinuclear stages I have found that staining in eosin, &c., with previous decolorising of the preparations, enables me more easily to notice the nuclei than if prepared by the osmic acid process. It is to be understood that while the multinucleolar phase has been seen in all cells, the same cannot be said of the multinuclear phase, except in the internode of the stem, which invariably has a greater or less number of nuclei. Only here and there in the other parts of the plant have I detected multinucleated cells. Whether this be due to imperfect histological examination or to the more common presence of one nucleus only, cannot as yet be fixed.

Having studied *Chara*, I examined the genus *Nitella*, which, while closely allied to the former, is much simpler in structure. The internodal cells both of the stem and leaf elongate greatly after their formation, while the nodal cells scarcely increase at all. Though they all alike become multinucleolar, the internodal cells only progress to the multinuclear condition, but this is of a most pronounced character, since in internodes still elongating I have counted thirty to seventy nuclei.

These observations enable us to understand and group together facts which have been more or less isolated. To do so we will take up the structural parts in detail.

Endonucleolus.—Though I have not been able always to follow the fate of the endonucleolus in *Chara*, owing to many of my preparations being pretty deeply stained, from all that I have seen of it I am led to conclude that division begins with it.

Nucleolus.—The nucleolus has been shown to pass through a most precise and very remarkable series of changes, which force upon us the conclusion that it is a most important part of the cell. But, as Dr HAMILTON has remarked in going over some of these points, a belief in its reality and importance is, to a great extent, a return to former ideas. If we refer to SCHLEIDEN's classic paper on cell structure,* we learn that he regarded it as "a small sharply defined body." But to NAEGELI † is due the merit of pointing out its very wide occurrence and definite nature, for, after an examination of many *Cryptogams* and *Phanerogams*, he is "inclined to set forth generally and to claim as an essential character of the nuclear vesicle, that it contains one or more nucleoli." Again, he says, "as to the structure of the nucleolus, in my opinion, nothing universal or precise can as yet be said. In some cases they appear to be merely accumulations of mucilage. In others a membrane which surrounds them is wholly unmistakable. In every case it is certain that they always appear with a clearly defined margin. This circumstance speaks strongly in favour of the assumption that they, like the nuclei, are enclosed in a utricle. Since if they were merely agglomerated mucilage, we should have nucleoli, the substance of which would pass gradually into the mucilage of the nuclear vesicle, and which

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* MÜLLER's *Archiv.*, part ii., 1838.

† *Ray Society Bot. Papers*, 1845 (Trans.).

would generally possess an irregular periphery. Or, if they originated by deposition of layers from without, this lamellar structure would be perceptible in large and perfect nucleoli."

NAEGELI regarded it functionally as a centre round which protoplasm gathered to form the nucleus. Recent botanical authors have either greatly neglected it or supposed it to result from a firming or segregation of the nucleoplasm.

The conclusions expressed in my previous paper have been amply confirmed in studying *Chara*. *In every active embryonic cell one nucleolus only is present in the resting state.*

In very rare cases, and only where it had attained a large size, have I noticed a clear homogeneous liquid-like globule enclosed. Whether this resulted from degradation of the endonucleolus, or whether the latter was enclosed in it, I cannot definitely say, though, judging from appearances in *Spirogyra*, *Rheum*, &c., the former view seems most probable.

From the action of chemical reagents, and the impression which it gives during division of being thick and viscid, it seems to be a vesicle containing richly differentiated protoplasm.

All reagents used, such as carmine, logwood, iodine solution, osmic acid, eosin, and the various aniline dyes agree in this, that they invariably, or with but few exceptions, stain the nucleolus more deeply than the nucleus.

During division the nucleolus elongates, becomes constricted rather sharply in dumb-bell fashion, but during the whole period retains its dense consistence, and then separates into daughter nucleoli. In *Spirogyra*, even before division, I have pointed out that it is the centre of two opposing forces acting along the length of the cell. The reason of this seems to be that a large nuclear spindle has to be formed in order to bring the daughter nuclei into the middle of the two forming daughter cells. In *Chara* no such necessity exists, so that even if similar forces be acting in it before division, these do not, since they need not, exert themselves in the same pronounced way. But that the daughter nucleoli are new centres of influence, determining greatly the future division of the cell, cannot well be doubted in view of what has been seen to take place.

JOHOW, in regarding the daughter nucleoli of cells as formed from the chromatin granules, states that the latter are at first numerous, but gradually unite to form the nucleoli. We might expect then to find preparations with aggregating masses of four, five, or more. I have never found such in multiplying cells, and further, the idea is opposed to all that we know of cell division where an increase and not a decrease in number occurs.

Nucleus.—I come now to a matter of great importance in view of recent research, viz., the formation of the nuclear spindle or barrel, and the transformations of the nuclear substance during the process. No one could venture to doubt that these are often complex, in view of the beautiful investigations of STRASBÜRGER; but the question is, Do these occur to an equal extent in all plants, and in all the tissues of them? Before answering this, let us ascertain for what end they exist. Setting aside STRASBÜRGER'S nuclear plate and disc phase as something which, though occasionally, is not always present, the study of various plants has convinced me that the spindle or barrel is merely a scaffolding thrown across the space between the halves of the dividing nucleus, the equator of this barrel, as its outward bulging progresses, coming ultimately to span the inner surface of the cell wall. It thus helps the protoplasm in its work of depositing the septum, and its presence is most definite and marked where vacuolation has most occurred. In cells filled with protoplasm, such as those of *Chara*, near the apex, no need exists for a complex structure of this kind, and while STRASBÜRGER figures, and TREUB and SCHMIDT believe in, indirect division, I have, like JOHOW, only seen such an appearance as would result from the separation of a rather viscid body like the nucleus, whose substance is traversed probably by delicate intranuclear threads. There seems undoubtedly to be a fibrous network ramifying through the nuclear substance of vegetable cells, judging from their appearance in the resting state, both when fresh and stained, as also in the dividing state, when these fibres are the most evident parts of the nuclear spindle.

In division they must of necessity be apparent if present, and the less dense the medium by which they are surrounded the more strongly will they stand out to view. Thus we have the very sharply defined spindles in the vacuolated cells of *Equisetum limosum* and *Spirogyra nitida*, but if the enveloping medium be nearly or quite as dense as the fibrils, the less evident will these appear, and as proof of this I would cite the cortical cells at the apex of the stem in *Equisetum limosum*, which are filled with protoplasm, and in which either fresh or stained spindles can be observed, but only by careful shading of the light. In young *Chara* cells this is even more striking, for it is only by skilful adjustment and shading of the light that between two nuclei pretty widely separated, but with no cell wall, or but a mere trace of it, between, delicate radiating striæ could be detected.

PROTOPLASM, CELL WALL.—In the formation of the cellulose septum NAEGELI'S conclusion, long ago expressed, that "the cell membrane is an investment lying upon the surface of the contents, and secreted by them," is being surely verified, though, as we have seen, it may be in a more complicated manner than he imagined, particularly in vacuolated cells.

Multinucleolar and Multinuclear State.—We will now deal with the very peculiar phenomenon, which I hope to show occurs more or less in all plants, but is so strikingly exemplified in *Chara,* of a multinucleolar succeeded by a multinuclear condition.

As we have already seen, it can be said of all the vegetative cells of *Chara,* that sooner or later, after a more or less prolonged period of proliferating activity, further multiplication seems impossible, and the cells, while mostly increasing greatly in length, all pass into a dormant multinucleolar and not infrequently into a multinuclear state. Now, in studying the tissue systems of *Ornithogalum* and *Scilla* (*op. cit.,* pp. 198–99), exactly the same phenomenon, though not so striking in its regularity arrested my attention, causing me to conclude "that the nucleolus, or more probably the nucleolo-nucleus is the centre of germinal activity, and that as we pass outwards to the periphery of the cell, this reproductive activity becomes less and less. Soon after, when studying *Chara,* I was so struck with the similarity of the process, though on a more exaggerated scale, that an examination of many plants, and a wider comparison with other observers, seemed desirable. The result is that in all plants thus examined, after cell formation has ceased, continued division of the cell contents from the endonucleolus outwards goes on, though in a varying degree. Further, not only does this seem true in the vegetable but also in the animal cells, of which more anon.

But to bring out the phenomenon in *Chara* more strongly, if we commence with a sub-apical cell, this, on division, forms a lower internodal cell, which is at once arrested. The upper cell forms the nodal layer of cells which, after giving off the cortical and leaf portions, is also arrested. The latter portions continue to form many cells till, in the leaf, the three terminal cells and leaf internodes are arrested, and in the cortex the internodes. The cells of the cortical nodes and leaf nodes multiply till the former and then the latter are arrested, and with their arrest the series of developmental stages is completed.

We see therefore from this that the general structural peculiarities of *Chara* result from the different cells being arrested at successive periods, the arrest being most complete in the cells as a whole, less so in the nucleus, and least of all in the nucleolus and endonucleolus, which, as we have seen, may undergo proliferation to a large extent unaccompanied by any change in the nucleus or cell as a whole. In this way, two, three, or more nucleoli may soon be formed inside one nucleus. This is the usual condition of plant cells which have lost the power of division. These may serve to some extent for the conveyance of material in the nutritive process, but seem principally to act as a kind of connective tissue through which the fibro-vascular bundles ramify, and outside of which the chlorophyll-bearing cells are borne. But in many plants, recorded by observers or examined by me, the nucleus in turn divides in a few of the cells at least. With such division there is no attempt at the formation of a cell plate, but the nuclear membrane either grows into the nuclear substance till separation into parts is effected, or the nucleus elongates greatly and becomes constricted in the middle, as figured by Johow, one or more nucleoli being enclosed in each part. When the nucleus and nucleolus are large, as in the young growing peduncle of *Hæmanthus coccineus* and stem of *Fritillaria imperialis,* one can trace this ingrowth towards separation with ease; and it is to be noted that the size and number of nucleoli enclosed greatly determine the size of each resulting nucleus. Thus we may get, as ingrowth proceeds, a portion with three well-formed nucleoli being cut off from a smaller portion with two lesser nucleoli, and so on, the nucleoli seeming to act as centres round which the nucleoplasm gathered (fig. 10).

Strasbürger, in terming this breaking up of the nucleus "fragmentation," does not regard the nucleoli as of marked importance. He also holds that it is in old cells that this phenomenon is exhibited; but in very many cases this is not so, since even the second, but usually the fourth or fifth internode from the apex in *Chara,* may have two or three large nuclei, and yet be surrounded by dividing cells which have been derived from the nodal cell that was cut off contemporaneously with the internode under consideration. The same is true in other plants. But while it may form in comparatively young cells, it remains as the permanent condition of old cells; that is, the nuclei formed thus may after a time become dormant, and be found in old cells. This is especially true of those which are elongating to form bast cells in the more succulent plants.

After an examination of many plants, I find that the most gradual transition in this continued activity can be traced. Thus, in *Spirogyra nitida,* one frequently finds two to five endonucleoli, though rarely two nucleoli; but in *S. majuscula* two nucleoli are very common. In the succulent parts of most plants, one nucleus, with two or at most three nucleoli, each enclosing one to two endonucleoli, is the rule. In the elongating cells of the internodes of *Equisetum limosum* the condition is one nucleus with three to six nucleoli, and two to three endonucleoli in each. In a few cells of some succulent plants, as *Diclytra spectabile,* young peduncle of *Hæmanthus coccineus, Orchis mascula,* &c., two to three nuclei each, with one to four nucleoli, can be noticed. But in rather long cells round the fibro-vascular bundles in *Hæmanthus coccineus,* as many as seven nuclei, each with two to three nucleoli, have been detected. *Chara* may have even more, specially in the internodal cells, each filled with dozens of small nucleoli. Again, Hegelmaier has described the multinuclear suspensor cells of some *Leguminosæ* as having thirty or more nuclei, with one or two nucleoli in each. As already stated, thirty to seventy nuclei, each with several nucleoli, is the rule in the internodal cells of *Nitella;* while, according to Schmitz, there may be several hundred in the seaweed *Valonia,* and in other algæ and fungi. Treub observed great numbers in bast cells and laticiferous vessels.

I venture, therefore, to regard it as a general principle *that after cell formation has ceased, the cell contents* (specially the endonucleolus and nucleolus) *persist in their activity for a shorter or longer period.*

In studying these relative progressions, one or two features strike us :—

1. The cell wall is growing rapidly in length.

2. The amount of progression seems to depend greatly on relative nutrition.

(*a*) Those which only become multinucleolar are supplied, as far as can be judged, with a moderate supply of pabulum, and are still able, in their earlier stages at least, to form cells, as proved in *Equisetum limosum, Hæmanthus coccineus,* &c., where there may be three or four nucleoli in a nucleus which is participating in cell division. The multinucleolar (two to seven) is the usual condition of parenchymatous cells after cessation of germinal activity.

(*b*) Those which progress to the multinuclear state have an abundant pabulum; thus, in large cells round the fibro-vascular bundles, in bast cells and laticiferous vessels, there is abundant elaborated material, and I should suppose that the same applies in the suspensor of leguminous plants. In the long cells of *Chara,* whose walls are covered by chlorophyll bodies, as also in *Yalonia,* &c., great nutritive supplies must be ever forming.

3. That wherever we have multinucleated cells these are never forming new cells, but, though helping greatly perhaps in general nutrition, are themselves the consumers of much elaborated material wherewith to increase the area of the cell wall, and to maintain a certain quantity of protoplasm within it.

4. That multinucleolar and multinuclear cells are not the result of pathological change, but ensue naturally when cell formation is stopped, the amount of progression being to some degree proportionate to the nutritive supply. When we say that the change is not pathological, we mean that it neither originates new cells nor destroys old ones, so as to interfere with the normal vital functions of the plant. Further, in stating that the progression is proportionate to the nutritive supply, we do not assert that *nutrition* is the cause of division of the nucleolus or nucleus, but simply that material is provided by which the energy of the nucleolus is kept up.

It will thus be seen that I regard the building up of cells to form a definite plant or the parts of it, as the result of a force radiating from the cell centre, stimulating to division; and either that the energy giving rise to this force is equal to producing only a certain amount of tissue, or that it is inhibited or resisted by some external force, which prevents it forming an excess of tissue when this would tend to pathological change, or to loss of individuality in the plant. Also that the most exalted type of cell is one with abundant protoplasm containing a single nucleus, nucleolus, and endonucleolus; that a cell with vacuolated protoplasm, one nucleus, and two to four nucleoli is less exalted, while the multinuclear state is the most degraded form of cell.

EXPLANATION OF PLATE XXXV.

Fig. 1. Division of the apical cell of *Chara fragilis.*

Figs. 2 and 3. Section of the terminal bud. In fig. 2 the second and third internodal cells have had their nuclei removed in cutting.

Fig. 4. Down-growing cortical lobes, covering in an internodal cell.

Figs. 5, 6, and 7. Further stages in the development of the cortical lobes.

Fig. 8. Upper portion of young leaf. Some of the cells are in process of division, the daughter nuclei exhibiting *very delicate* spindles.

Fig. 9. More advanced leaf development.

Fig. 10. Cell from the rapidly growing peduncle of *Hæmanthus coccineus.* Though cell division has ceased, the nuclei, &c., have continued dividing.

J. M. Macfarlane, del.

McFarlane & Erskine, Lithrs. Edinr.

CHARA FRAGILIS, ETC.

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PRINTED BY NEILL AND COMPANY, EDINBURGH.

1842.

TRANSACTIONS

OF THE

ROYAL SOCIETY OF EDINBURGH.

VOL. XXX. PART III.—FOR THE SESSION 1882–83.

–1884–

CONTENTS.

APPENDIX.

XXVI.—*On the Nature of Solution.* Part I.—*On the Solubility of Chlorine in Water, and in Aqueous Solutions of Soluble Chlorides.* By WILLIAM LAWTON GOODWIN, B.Sc. (London and Edinburgh), Demonstrator of Chemistry in University College, Bristol. Communicated by Dr CRUM BROWN. (Plate XXXVI.)

Thesis for the Degree of Doctor of Science in the University of Edinburgh.

(Read July 17, 1882.)

This research was undertaken with a view to ascertaining if metallic chlorides have any tendency to combine with a further quantity of chlorine. The well-known fact that potassium iodide unites with iodine to form a tri-iodide suggested that potassium chloride might, under suitable conditions, form a similar compound with chlorine. The method of investigation which first presented itself was to expose crystals of various chlorides to the action of dry chlorine gas at low temperatures, when any chemical action taking place would be expected to show itself in changes in the appearance of the crystals. A few experiments were made with no apparent result, and the method finally adopted was to determine the quantity of chlorine absorbed by solutions of the salts. It was thought that in this way quantitative results could be obtained which would reveal any tendency towards the formation of perchlorides. If a body having the formula KCl_3 could be shown to exist, it would strengthen the position of those chemists who contend that the generally accepted ideas regarding atomicity need modifying. The discovery of a compound having the formula KCl_2 would be a still stronger argument. At an early stage, however, the research resolved itself into an investigation of the solubility of chlorine gas in solutions of metallic chlorides in water, the question of the existence of perchlorides becoming a side issue. The influence of salts in solution on the solubility of gases in water is a subject of considerable interest, as throwing light on the nature of solution in general. Of late, certain chemists are inclining to adopt the old view that *solution* should be included under the general head of *Chemical Action.* This view was generally held by chemists about the beginning of this century, and in Thomson's *System of Chemistry* (1817) we read at p. 92 :—

> "The second species of combination into which water enters with solid bodies has been usually termed the *solution* of these bodies in that liquid."

And Berthollet, in his *Statique Chimique* (i. 35), explains solution as follows :—

"Water has obviously an affinity for all those bodies with which it is capable of uniting. But affinity is mutual. We may say with as much propriety that the solid acts on the liquid as that the liquid acts on the solid. Both act upon each other reciprocally, and at the same time; but the force exerted by each will be proportional to its mass. Now, there is this peculiarity in the action of liquids upon solids, that they can only act at the point of contact, or at least near it. Hence, as far as the mass is concerned, it is quite the same thing whether a solid be acted on by a large quantity of liquid or by a small quantity, since the points of contact, and of course the sphere of the liquid's activity, must in both the cases be the same. When a solid body, then, is plunged into a liquid for which it has an affinity, whatever the quantity of liquid may be, the action is always limited to a very small portion. Hence the liquid is not capable at first of destroying the cohesion of the solid; the latter imbibes it and *combines* with it, while new portions of liquid come into contact, and begin to exert their action. If the affinity between the solid and the liquid be weak, the combination proceeds only till the force of affinity is so far weakened by the quantity of water united, that it is no longer able to overcome the cohesion of the particles of the solid, and then it necessarily stops. The compound continues solid. With such solids water is capable only of forming a *hydrate;* it does not dissolve them. If the affinity be strong, new doses of water continue to combine with the atoms of the solid, and thus these atoms are separated farther and farther from each other; but as this distance increases the force of cohesion continually diminishes, while the liquid, by its increased mass, is enabled to act with greater and greater energy. Hence the cohesion of the solid is gradually destroyed; the particles of it are separated to too great a distance, and are dispersed equally through the liquid. *This is what is termed solution.* If we continue to add more of the solid after a portion has been dissolved in this manner by the liquid, it will be dissolved in the same way. But by this new portion the particles of the dissolved solid are brought nearer each other in the solution; their mass is increased in proportion to that of the liquid. Hence they exert a greater force on it, and of course the liquid is enabled to exert only a smaller force upon new portions of the solid. If we continue to add new portions of the solid, a time will come when the action of the liquid will be so much weakened that it will no longer be able to overcome the cohesion of the solid, and it will then refuse to dissolve any more of it. When a liquid has come to this state, it is said to be *saturated* with the solid. Were we to suppose the solution to go on, the particles of the solid in solution would be brought so near each other that their force of cohesion would overbalance the affinity of the liquid for them. They would, in part, cohere, and form again a new portion of the solid. The saturation of a fluid, then, does not mean that its affinity for the solid is satisfied, but that it is not greater than the tendency of the combined particles to cohere. Now, when a liquid is saturated with a solid, if by any means we can abstract part of that liquid, the cohesive force of the particles of the solid must gain the superiority, and the consequence will be, that they will unite and form solid bodies anew, till their number be so diminished that their mutual attraction is again counterbalanced by the attraction of the liquid. Hence the reason that evaporation occasions the crystallisation of those bodies which are held in solution by liquids. If the affinity between water and the solid be not sufficiently great to enable it to overcome any part of the cohesion of the particles of the solid, in that case none of it combines with that body, it only moistens its surface. If the affinity is even weaker than the cohesion of the particles of the liquid, in that case the surface of the solid is not even wetted."

This extremely lucid explanation of the phenomena of solution evidently is based on the assumption that solution in general is a species of chemical action, and in Turner's *Elements of Chemistry* (1842) the same assumption is made. At p. 139, in discussing "affinity," he says:—

> "The most simple instance of the exercise of chemical attraction is afforded by the admixture of two substances. Water and sulphuric acid, or water and alcohol, combine readily. On the contrary, water shows little disposition to unite with ether, still less with oil. . . . . Sugar dissolves very sparingly in alcohol, to any extent in water; while camphor is dissolved in a very small degree by water, and abundantly by alcohol. It appears from these examples that chemical attraction is exerted between different bodies with different degrees of force. . . . . Simple combination of two substances is a common occurrence, of which the solution of salts in water, the combustion of phosphorus in oxygen gas, and the neutralisation of a pure alkali by an acid, are instances."

The opinion at present generally held is thus formulated in Roscoe and Schorlemmer's *Treatise on Chemistry* (vol. i. p. 232):—

> "Concerning the nature of solution, whether of solids, liquids, or gases, we know at present but little. The phenomena of solution differ, however, essentially from those of chemical combination, inasmuch as in the former we have to do with gradual increase up to a given limit, termed the point of saturation, whereas in the latter we observe the occurrence of constant definite proportions in which, and in no others, combination occurs. Solution obeys a law of continuity, chemical combination one of sudden change or discontinuity."

But on closer examination this distinction disappears. A mixture of chlorine gas with *excess* of hydrogen would be a precise analogue of a solution of a salt in excess of water. The chlorine would *combine* with its equivalent of hydrogen, and then the hydrochloric acid so formed would mix with the excess of hydrogen. Similarly, the salt would *dissolve* in its "*equivalent*" of water, and then the saturated solution would mix with the excess of water. This would go on in the one case till *all* the hydrogen had combined with its equivalent of chlorine, when any excess of chlorine added would remain uncombined and show its presence as free chlorine by its colour, &c.; in the other case, till all the water had united with as much salt as it could take up, after which any excess of salt added would remain undissolved. The same continuity appears in the one case as in the other. In one case, excess of gas mixes with combined gases; in the other, excess of salt is visibly separate from the combined salt and liquid, and this constitutes an apparent difference, but that it is apparent only is seen in the fact that solids can be so finely divided as to remain mixed with liquids for an almost indefinite period. And the analogy holds when we compare a compound such as peroxide of hydrogen with a supersaturated solution of a salt. A change of conditions interferes with the stability in both cases. PICKERING has lately shown that basic sulphates of alumina have no definite composition. An essential difference between solution and combination seems at first sight to lie in the fact that solubility is a function of temperature. Thus, the quantity of a salt which will dissolve in water generally increases with the temperature regularly and apparently without a limit. It is possible that at low temperatures the molecules of water are associated together in groups, and that a molecule of salt attaches itself to a whole group. When the temperature is raised these groups are broken up, and molecules of water are broken off and ready to unite with farther molecules of the salt. Or, on the supposition that the molecules of salt occupy the *interspaces,* it is easy to see how a rise of temperature would increase the solubility by increasing the number of interspaces. This supposition is strengthened by the observed decrease of the coefficient of viscosity of water with rise of temperature, and the increased coefficient of solutions of salts. Gases certainly *mix* irrespective of anything like chemical attraction, but when liquids and solids are considered, a different set of phenomena is observed. Some liquids "mix" in all proportions, others only within a limit. If solution is a mere interpenetration of the particles of the two bodies, how can it be explained that oil does not dissolve in water, but does dissolve in ether? It may be that the particles of oil are too large to find their way into the interstices of water, otherwise the kinetic theory is as favourable to interpenetration between oil and water as between alcohol and water. The case of water and ether may be cited as an example of a limit to the solution of each liquid by the other. The molecules of ether must be either very large or very far apart, for with a molecular weight of 74 it has a specific gravity of only ·723. Its great mobility would seem to point to the latter as probable. If this be the case the molecules of water should have no difficulty in finding room among the molecules of ether. It can be generally stated that bodies which are like each other in chemical constitution dissolve in each other, and it seems as if something like chemical action between bodies must be assumed to explain this fact. There is no definite boundary between solutions and chemical compounds.* Alloys occupy a sort of middle-ground, but many of these can be obtained in definite crystals; but this is no more a proof of chemical combination than the production of definite crystals of isomorphous salts. It is probable that there is a gradual progression from simple mixture to the most stable chemical combination, and for any particular case by a change of temperature we may pass from a state of chemical combination to one of simple mixture. Substances resembling each other chemically tend to mix merely,

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* Dr Ramsay has shown (*Jour. Chem. Soc.*, Oct. 1877) that hydrates of alumina and ferric oxide give off their water at a regular rate depending on the temperature, while salts containing water of crystallisation show different rates corresponding to definite hydrates. Something very like this is seen in the phenomena of solution.

but may be made to combine in definite proportions by lowering the temperature or otherwise varying the conditions. Examples of this are seen in the compounds of chlorine, bromine, and iodine with each other. The mixing of water with sulphuric acid, as is well known, gives out decreasing quantities of heat as dilution goes on, and the point at which no more heat is given out on further dilution cannot be determined. We may suppose that the molecules of water are associated together in groups, and that when the first portion of water is added to the sulphuric acid these groups are completely broken up, and each molecule of sulphuric acid attaches to itself a molecule of water to form a monohydrate. If another molecule of water be added, the attraction of the sulphuric acid, being less, can only *partially* disintegrate the groups of molecules. It could be imagined that the former molecule of water prevents the second from getting completely within the sphere of attraction of the molecule of sulphuric acid. A third molecule would be still less attracted, the groups still more incompletely broken up.

Solution probably depends on the kinetic condition of the bodies, on the distances between their molecules, and on the attractions of molecules on each other, or rather chemical action between the bodies.

There are, then, two theories put forward to explain the phenomena of solution—one, that stated by Berthollet, may be called the Chemical Theory, for it assumes a chemical action between the solvent and the body dissolved; the other may be termed the Physical Theory, since it supposes the molecules to "dissolve" by finding their way into the molecular interspaces of the solvent. It is probable that solutions are to be explained by a reference to both theories, that some solutions take place in exactly the same way as the diffusion of gases into each other, but that others require chemical action to bring them about by breaking up congeries of molecules. (The word "solutions" is, of course, not intended to include obvious chemical action.) An examination of the effect of salts in solution on the solubility of gases might throw some light on the subject, if the effect of an *equal number of molecules* of various salts be studied.

The solubility of carbonic acid gas in solutions of salts has been studied by J. J. Mackenzie (*Ann. Chem. Phys.* [2] i. 438), who arrived at the following results:—

1. Saline solutions absorb less carbonic acid than an *equal volume* of water.

2. The volume of the gas absorbed decreases as the concentration of the solution increases.

3. The coefficient of absorption for solution of potassium chloride lies, like its molecular weight, between those of ammonium and sodium chlorides; similarly for strontium, calcium, and barium chlorides.

As salts, in dissolving in water, generally increase the bulk, a volume of saline solution contains less water than an equal volume of pure water. The question then arises, Is the solubility in the water decreased by the presence of the salt ?

SETSCHENOW (*Deut. Chem. Ges. Ber.*, vi. 1461) has examined the effect of magnesium, aluminium, and zinc sulphates on the solubility of carbonic acid. He concludes from his results that in salts of similar structure and amount of water of crystallisation, the chemical equivalents are likewise the absorptiometric equivalents. He has also experimented with sodium salts, and finds that they fall into two groups with regard to their action on the solubility of carbonic acid. (1.) Those which do not combine with carbonic acid, as sodium chloride. Solutions of these absorb the gas according to DALTON's law. (2.) Salts which combine with carbonic acid—for example, phosphate of sodium. With these absorption increases with strength of solution, but is not proportional to pressure.

SETSCHENOW's examination of sulphuric acid (*Peterb. Acad. Bull.*, xxii. 102) gives the following results:—The coefficient of absorption of the pure acid for carbonic acid is almost identical with that of water. On dilution, the coefficient diminishes rapidly till an acid of a strength represented by the formula $H_2SO_4 + H_2O$ is obtained, after which further dilution *slowly* increases the coefficient.

The solubility of *ammonia gas* has been studied by RAOULT (*Compt. Rend.*, lxvii. 1078), who has obtained the following results:—

The coefficient for solutions of caustic potash is less than that for water. Thus, at 16° C. and 760 mm. pressure—

100 c.c. water absorbs 60 gms. ammonia.
„ „ 24·25 per cent. potash solution 30 gms. ammonia.
„ „ saturated potash solution 1 gm. ammonia.

From which it appears that the solvent power of the *water* is decreased by the presence of caustic potash, since 100 c.c. of the 24·25 per cent. solution contains more than 50 c.c. of pure water.

Soda solutions have the same coefficient as potash solutions of the same strength (*equivalent?*).

Solutions of sodium nitrate and of ammonium nitrate absorb the same volume as equal volumes of pure water. On the other hand, dry sodium nitrate absorbs none, while dry ammonium nitrate absorbs a considerable volume. Solution of potassium nitrate absorbs more ammonia than pure water, but there is no ammonia in the evaporated residue. He formulates his results in the general statement: The difference between the coefficient of absorption of ammonia in water and in solutions of a salt is proportional to the weight of the salt in a constant volume measured *before* the absorption of the gas.

The solubility of chlorine gas in saline solutions does not appear to have been heretofore determined, and the following pages give the results of my determination of the coefficients for solutions of chlorides. The solutions were made to contain quantities of salt proportional to the molecular weights of the anhydrous chlorides, so as to secure an equal number of molecules in equal volumes. By this method it was hoped that any influence due to the number of molecules would become apparent.

The method at first adopted was to saturate 10 c.c. of the solution with chlorine, read the temperature of a thermometer placed in the test-tube containing the solution, blow off the atmosphere of chlorine, run in excess of iodide of potassium, and titrate with hyposulphate solution. This method did not give concordant results, owing to the difficulty of getting rid of the superposed atmosphere of chlorine. A slight modification of SCHÖNFELD'S method was then adopted. This chemist has determined the solubility of chlorine in water at temperatures between 10° C. and 40° C. He passed the chlorine through boiled water contained in a flask fitted with a stopper having four holes bored in it—one each for the entrance and exit tubes, one for a thermometer, and a fourth for a bent tube through which the chlorine water was forced out, when required, by stopping the exit of the gas. To estimate the amount of chlorine dissolved at any temperature, a given volume of liquid was drawn off, diluted to a known volume, of which an aliquot part was titrated by the iodometric method (*Ann. Ch. Pharm.*, xcvi. 8). The apparatus employed in the present research is sketched in Plate XXXVI., fig. VIII. Chlorine evolved in A from a mixture of potassium bichromate, and strong hydrochloric acid is washed in B, and led through G into the solution contained in E, thence away by F, a rubber tube, which can be closed at will by a pinch-cock. E was surrounded by a freezing mixture, after the liquid had been saturated at the ordinary temperature, and determinations were made as the temperature rose from the lowest point attained, by closing the tube F and receiving the liquid forced out through D in a specific gravity flask (10 c.c.), which was quickly stoppered, washed, immersed in a solution of potassium iodide, and opened to allow the solution to escape. The iodine set free was titrated with standard solution of sodium thiosulphate. The stream of chlorine was easily regulated by means of a burner under the flask A, and formed a most efficient stirrer for the solution in E. The temperature was accurately marked by a thermometer T, graduated in tenths of a degree.

The solubility in water was first examined. The flask E was partially filled with water, and the chlorine passed through for some time at ordinary temperature. The bath was then filled with ice, and the end of the tube D, which dipped below the surface of the water in E, was loosely plugged with asbestos, to act as a filter for the chlorine hydrate. As soon as the thermometer was steady, 10 c.c. of the solution was drawn off and the chlorine estimated. As the temperature rose, determinations were made as rapidly as possible. After the maximum solubility had been attained and passed, the chlorine was estimated at intervals of 5 to 10 degrees. The temperature was raised above that of the laboratory by pouring hot water into the bath till a thermometer marked a temperature two or three degrees above that required. As soon as the thermometer in E was steady, the chlorine was estimated.

Then, if n represent the number of cubic centimetres of thiosulphate employed, a the equivalent of 1 c.c. in iodine, p the pressure of the atmosphere, and α the coefficient of absorption,

$$\alpha = \frac{na \times 22{\cdot}33 \times 760 \times 100}{254 \times p}$$

The results are tabulated below. H_2O.

I.

Made with a common thermometer, and not so reliable below 12° (part of stem within E) as the other series made with a delicate thermometer.

$t°$	p	c.c. of $Na_2S_2O_3$	α
4	761·9	20·6	1·8717
5		21·0	1·9080
7·5		23·2	2·1079
8·9		26·8	2·4350
9·6		28·7	2·6077
10·3		29·9	2·7104
10·8		32·4	2·9438
11·5		32·9	2·9894
14·3		27·9	2·5350
23·5		23·7	2·1534
32·5		19·1	1·7354
39·0		15·5	1·4083
45·0		12·8	1·1636
50·0		11·9	1·0812

1 c.c. thiosulphate = 0·10537 gm. iodine.

II.

$t°$	p	$Na_2S_2O_3$	α
6·9	750	20·7	2·2931
8·4		23·0	2·5469
9·3		24·5	2·7135
10·2		26·2	2·9012
13·3		26·5	2·9344
15·2		23·6	2·6133
20·9		20·9	2·3143

1 c.c. = 0·01243 gm. iodine.

III.

$t°$	p	$Na_2S_2O_3$	a	a (*Schönfeld*)
10·1	756·2	25·6	2·8741	2·59
11·2		24·3	2·7267	2·53
11·3		24·05	2·7001	2·54
13·7		22·35	2·5079	2·42
21·7		18·2	2·0422	2·21
32·1		14·05	1·5766	1·67
32·2		14·35	1·6111	1·66
36·7		12·3	1·3802	1·48

1 c.c.=0·0127 gm. iodine.

These results are expressed in curves H_2O (1), (2), and (3) of Diagram I. It will be seen that these curves are not identical, but show a regular variation too great to be ascribed to experimental error. Experiment I. was begun when only a small quantity of chlorine hydrate had been formed; in Experiment II. the water was allowed to become semi-solid before beginning the determinations; Experiment III. was begun at 10° without formation of chlorine hydrate. The curves show that the solubility of chlorine in water, or at least the action on potassium iodide, is greater in proportion to the amount of chlorine hydrate previously formed. This applies only to the solubility *after* the decomposition of the hydrate, for several sets of determinations show that the solubility before the maximum point is reached is constant, and represented by the curve H_2O (2), this part of curve H_2O (1) being somewhat irregular on account of a circumstance mentioned above.* An explanation may be found if it is supposed that hydrate of chlorine in decomposing forms a small quantity of hydrochloric or hypochlorous acid. The presence of hydrochloric acid would increase the solubility of chlorine in water (see p. 612). With a view to ascertaining if hydrochloric acid is really formed, the reaction was tested after titration in a series of estimations made for another purpose (p. 603), and found to be neutral until the chlorine hydrate was decomposed, then distinctly acid.

Curve H_2O (Sch.) was drawn from SCHÖNFELD'S numbers, and it appears that the maximum as determined by him is too low, and indeed an initial rapid fall as seen in H_2O (3) is more probable than a gradual descent; for it may be safely assumed that some chlorine hydrate is formed at 10°, but *remains in solution.* Its decomposition between 10° and 15° would produce the sudden descent. If the temperature be reduced below 10° the hydrant crystallises out. The question then arises—Why does the remaining liquid dissolve less chlorine at low than at high temperatures? The answer to this is plain. The ascending part of the curve represents the solubility of a *solid* (chlorine hydrate) in water, and this solubility follows the general law. The descending portion represents the solubility of a *gas* in water, and this solubility as usual decreases with rise of temperature.

Potassium Chloride.—A solution of pure potassium chloride was made, so as to contain 20 gms. salt in 100 c.c. solution. The chloride was recrystallised to insure its purity, and the absence of bromine, iodine, and oxidising agents was proved. When the solution was exposed to a current of chlorine at low temperatures, chlorine hydrate did not appear until the thermometer marked 2°. As the solution had been saturated at the ordinary temperature before cooling, it is evident that the presence of potassium chloride prevents the formation of solid chlorine hydrate between 2° and 10°. The maximum solubility is at 9°, the hydrate beginning to decompose rapidly between 7° and 8°, and disappearing completely at 9°. Potassium chloride in solution then hastens the decomposition of chlorine hydrate, and decreases the solubility of the gas in water. It will be noticed that the ascending part of the curve is almost identical with the prolongation of the corresponding part of the curve for water. In other words, chlorine hydrate has the same solubility in this solution of potassium chloride as in pure water until a temperature of 7° is reached. The descent from the maximum is at first rapid, and then more gradual.

KCl.

$t°$	p	$Na_2S_2O_3$	a
− 3·0	741·0	11·6	1·0812
− 0·7		14·1	1·3142
+ 1·7		17·7	1·6497
2·2		19·1	1·7802
5·5		22·8	2·1251
8·0		23·3	2·1717
− 1·0	735·5	12·9	1·2114
+ 0·0		14·1	1·3243
3·0		19·9	1·8687
4·0		20·1	1·8875
5·2		21·6	2·0283
7·5		22·7	2·1316
10·5		23·5	2·2067
18·0		14·3	1·3428
24·0		10·5	0·9860
31·8		9·5	0·8921
35·0		8·7	0·8170

1 c.c. $Na_2S_2O_3 = 0·010337$ gm. iodine.

Sodium Chloride.—A solution was made containing 15·71 gms. in every 100 c.c., *i.e.*, molecule for molecule with the solution of potassium chloride.

The curve of solubility is almost identical with that of potassium chloride solution.

$NaCl$.

t°	*p*	$Na_2S_2O_3$	*a*
− 3	763·2	10·3	0·9321
− 0·8		14·0	1·2669
+ 2·0		17·3	1·5656
3·0		20·5	1·8371
5·5		21·5	1·9455
6·7		22·6	2·0452
9·2		24·3	2·1990
10·0		21·9	1·9818
15·2		16·1	1·4570
21·0		12·9	1·1674
25·5		10·3	0·9321
29·5		9·4	0·8507

1 c.c. $Na_2S_2O_3$=0·010337 gm. iodine.

Barium Chloride.—On account of its sparing solubility it was necessary to make the solution of this salt only half as strong as the preceding. Its curve therefore appears *above* the curves for potassium and sodium chlorides. Chlorine hydrate formed readily below 10° and decomposed rapidly between 8° and 10°.

$BaCl_2$.

t°	*p*	$Na_2S_2O_3$	*a*
2·0°	766	12·5	1·1651
3·0		15·0	1·3981
3·3		15·6	1·4540
4·2		16·95	1·5799
5·1		17·7	1·6497
6·1		19·4	1·8082
7·2		20·5	1·9107
9·1		21·3	1·9853
10·9		20·3	1·8921
12·0		19·0	1·7131
13·5		16·9	1·5238
17·0		16·0	1·4426
21·0		14·7	1·3254
26·5		12·1	1·0910
34·0		9·5	0·8566

Under *Strontium Chloride* will be found a comparative experiment with that salt, the solution being diluted to half strength. The curve so obtained lies above that for barium chloride.

Strontium Chloride.—With a solution of this salt of an equivalent strength to that of potassium and sodium chlorides, only a very small quantity of chlorine hydrate was formed at about 0°. Determinations were made with a solution diluted to double its volume for comparison with barium chloride.

$SrCl_2$.

I. 1 c.c. = 0·01234.

$t°$	p	$Na_2S_2O_3$	a
0·5	752	9·75	1·0768
2·9		10·5	1·1596
5·0		9·9	1·0933
6·8		9·5	1·0492
11·7		8·4	0·9277
18·8		7·3	0·8062
25·5		6·1	0·6737
32·4		5·6	0·6185
		II. (half strength).	
1·0	750	12·6	1·3915
2·2		13·6	1·5020
4·2		15·0	1·6566
7·0		17·2	1·8966
10·1		18·0	1·9879

An accident here interrupted the experiment. Hydrate formed abundantly at 0°, and began to decompose rapidly at about 9°.

Calcium Chloride.—No chlorine hydrate was formed even at 7°·0, and when the solution at this temperature came in contact with some chlorine hydrate which had formed in the tube delivering the chlorine, decomposition took place with strong effervescence.

$CaCl_2$.

$t°$	p	$Na_2S_2O_3$	a
−5·5	757·7	12·75	1·4279
−3·5		15·45	1·7302
−2·8		15.5	1·7358
−1·0		15·55	1·7414
+0·3		14·55	1·6294
4·2		13·9	1·5567
10·4		11·9	1·3327
15·9		10·8	1·2095
21·4		9·2	1·0303
27·8		7·75	0·8679
35·4		6·2	0·6943

1 c.c. = 0·0127 iodine.

The curve constructed from these results is remarkable for its flat summit. It shows a maximum point, although there is no formation of chlorine hydrate. It might be supposed that this was due to non-saturation, but the same phenomenon appeared in an earlier set of experiments, and indeed the chlorine was in each case passed through the solution for about two hours before any determinations were made. An explanation of this and other maxima, occurring without formation of hydrate, will be suggested further on.

Calcium, strontium, and barium form a series, the solubility of chlorine in solutions of their chlorides decreasing with increase of atomic weight.

Magnesium Chloride.—With this solution no chlorine hydrate was obtained even at – 7°·5, and a maximum of solubility appeared at about 2°.

$MgCl_2$.

t°	p	$Na_2S_2O_3$	a
−7·5	769	11·2	1·0059
−5·6		14·1	1·2664
−4·7		16·2	1·4550
−3·2		17·4	1·5627
−0·8		17·7	1·5897
+1·4		18·1	1·6256
3·5		17·8	1·5987
5·7		17·4	1·5627
8·5		16·2	1·4550
12·8		15·7	1·4101
19·7		13·8	1·2394
26·1		11·9	1·0688
31·3		10·6	0·9520
37·3		8·7	0·7814

1 c.c. = 0·010337 iodine.

Ferric Chloride.—A neutral solution of this salt was obtained by dissolving pure iron wire in hydrochloric acid, keeping the iron in excess, estimating the iron and diluting to the required strength. The solution did not allow the formation of chlorine hydrate, but on the contrary decomposed it when previously formed (*Cf.* Calcium Chloride). As ferric chloride slowly sets free iodine from iodide of potassium, the usual method of estimating the dissolved chlorine was varied. The solution was poured into excess of Mohr's salt, and the excess titrated with permanganate of potash. It was found extremely difficult to prevent loss of chlorine unless an enormously large excess of Mohr's salt was used. The results are, however, sufficiently accurate to show that there is a maximum also in this case, although not very well defined.

Fe_2Cl_6.

t°	a
−6·0	1·2748
−5·4	1·3038
−3·0	1·3328

Fe_2Cl_6.

t°	a
+1·1	1·3618
+2·1	1·3618
+5·2	1·3618
14·9	1·2169
32·0	0·5795
38·1	0·4636

From 1°·1 to 4°·2 the solubility is constant.

Cobalt Chloride.—No chlorine hydrate was formed in this case, and the solution decomposed solid chlorine hydrate with effervescence, but not so quickly as ferric and calcium chlorides.

$CoCl_2$.

t°	p	$Na_2S_2O_3$	a
−5·0°	766·6	13·0	1·4084
−4·0		14·0	1·5167
−1·5		16·1	1·7442
+0·7		16·0	1·7334
1·9		15·9	1·7225
5·5		14·7	1·5925
9·5		13·7	1·4842
15·9		12·0	1·3000
21·2		10·45	1·1312
27·3		9·1	0·9859
35·0		7·4	0·8018

1 c.c. = 0·01243 gm. iodine.

Nickel Chloride.—Chlorine hydrate was formed abundantly at −4°, and decomposed at 0°.

$NiCl_2$.

t°	p	$Na_2S_2O_3$	a
−5·0	754	13·9	1·5643
−1·0		17·1	1·9244
+1·0		19·55	2·2001
3·3		19·95	2·2451
5·1		19·8	2·2283
11·6		18·1	2·0370
15·0		16·3	1·8344
22·2		13·3	1·4968
29·4		9·5	1·0691
35·5		7·8	0·8778

1 c.c. = 0·0127 gm. iodine.

Manganese Chloride.—Chlorine hydrate was formed in small quantity at 5·°0, and a few dark purplish crystals appeared for a short time at the lowest temperature attained. As the temperature rose no peroxide was seen till after the maximum was passed, when small quantities began to form. This renders the numbers rather high between 0° and 30°, although not very much so, as the formation of peroxide ceased shortly after the maximum point was passed. This would seem to show that the formation of peroxide is due to the decomposition of chlorine hydrate, and suggests hypochlorous acid as the oxidising agent. According to SOBRERO and SELMI,* no peroxide of manganese is formed by passing chlorine through a solution of pure manganese chloride ; but evidently the formation of hydrate of chlorine, and its subsequent decomposition in presence of manganese chloride, causes the production of the peroxide.

$MnCl_2$.

t°	p	$Na_2S_2O_3$	a
−5·0	768·6	15·0	1·6208
−0·2		21·9	2·3664
+1·1		21·7	2·3448
2·9		19·7	2·1287
5·7		18·5	1·9990
16·0		14·7	1·5884
24·7		12·8	1·3831
31·4		8·7	0·9401

1 c.c. = 0·01243 gm. iodine.

Cadmium Chloride.—With this solution chlorine hydrate was easily formed, and examined undecomposed up to 8°.

$CdCl_2$.

t°	p	$Na_2S_2O_3$	a
−1·5	769	5·7	0·6156
+1·3		7·4	0·7992
3·2		8·8	0·9509
12·2		12·1	1·3068
16·0		11·35	1·2258
25·4		9·7	1·0476
31·8		8·6	0·9288

1 c.c. = 0·01243 gm. iodine.

Zinc Chloride.—An attempt was made to estimate the solubility in solution of zinc chloride, prepared from carbonate, but it was found that a small quantity of iron was present, and time did not permit purification. A few determinations showed the maximum to be at about 3°.

Lithium Chloride.—Chlorine hydrate appeared in this solution at −5°, and began to decompose between −5° and −4°, disappearing completely below 0°. An inspection of the curve of solubility will show that chlorine dissolves in

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* *Ann. Ch. Phys.* [3], xxxix. 161.

solution of lithium chloride almost as freely as in water, but that the maximum point is nearly 10 degrees lower. Beyond the maximum the solubility greater is than that of any other solution heretofore examined.

LiCl.

t°	*p*	$Na_2S_2O_3$	*a*
−6·3	764·5	20·0	2·1727
−3·5		25·3	2·7484
−0·3		26·0	2·8245
+0·5		24·8	2·6948
5·3		22·9	2·4877
10·5		21·2	2·3030
14·8		17·7	1·9228
20·9		14·2	1·5426
27·4		10·9	1·1841
38·0		9·6	1·0429

1 c.c. = 0·01243 gm. iodine.

Hydrochloric Acid.—A solution of hydrochloric acid was made, of specific gravity 1·046, containing an amount of pure hydrochloric acid per 100 c.c., very nearly equivalent to 20 grammes of potassium chloride. In this case the wash bottle was filled with the same solution, and the flask was cooled down before the stream of chlorine was passed through the solution to be experimented upon. The numbers below show that chlorine is much more soluble in hydrochloric acid solution than in pure water. Of course the results at the higher temperatures are only approximate, owing to the continual weakening of the solution. Chlorine hydrate appeared at 0°, began to decompose at 2°, and had completely disappeared at 7°.

HCl (sp. gr. 1·046).

t	*p*	$Na_2S_2O_3$	*a*
−4·8	752	27·0	2·9819
−3·3		29·4	3·2469
−1·1		34·1	3·7660
+0·5		37·8	4·1746
3·2		41·8	4·6163
4·7		46·4	5·1244
6·9		46·0	5·0801
8·6		38·2	4·2188
16·2		31·5	3·4788
23·6		23·0	2·5403
30·1		17·1	1·8885
37·0		13·0	1·4357
41·0		10·8	1·1927
43·8		9·0	0·9940

1 c.c. = 0·01245 gm. iodine.

Stronger solutions were now tried, and the numbers below show that the solubility increases rapidly with the concentration of the acid.

HCl (sp. gr. 1·080).

t°	p	$Na_2S_2O_3$	a
−5·8	763·7	59·4	6·4596
−4·8		60·2	6·5466
−3·3		59·2	6·4378
−1·4		58·0	6·3073
+1·3		56·1	6·1007
2·5		51·6	5·6113
6·8		45·1	4·9045
15·5		38·1	4·1433
26·0		29·5	3·2080
31·0		21·2	2·3054
35·6		16·7	1·8161
39·6		13·9	1·5116
45·2		12·3	13·376

1 c.c.=0·01243 iodine.

HCl (sp. gr. 1·125).

t°	p	$Na_2S_2O_3$	a
−10·0	763·7	80·9	8·7976
− 5·0		83·1	9·0369
− 2·2		74·5	8·1017
+ 0·8		65·5	7·1229
10·0		57·0	6·1843
20·7		43·8	4·7631

1 c.c.=0·01243 gm. iodine.
No chlorine hydrate was formed.

It will be noticed that the points of maximum solubility occur at lower temperatures with the stronger solutions, and if the summits of the curves be connected so as to form a curve of maxima the latter is found to be very steep, and it was thought that at still lower temperatures chlorine gas might be got to combine with dry hydrochloric acid to form a perchloride of hydrogen. The experiment was tried by passing the dry gases into a flask, cooled down to about −10°, but no result was obtained. The high solubility of chlorine in hydrochloric acid solutions certainly points to the formation of a perchloride, and it is probable that under increased pressure the two gases would combine at low temperatures.

Mixed Chlorides.—It is well known that when chlorine is passed into a solution of lead chloride and sodium chloride it is absorbed in large quantity, and a perchloride of lead is formed. The chloride by itself does not combine with more chlorine, and the formation of a perchloride, in presence of sodium chloride, is no doubt due to the existence of a salt $PbCl_4,2NaCl$, analogous to $PtCl_4,2NaCl$. This led to the hope that other similar double chlorides might be obtained. Accordingly, solutions were made containing two chlorides in molecular proportions, half a molecule of each, taking the solutions used above as containing one molecule.

$\frac{1}{2}(NaCl+KCl)$. Plate XXXVI., Diagram II.

$t°$	p	$Na_2S_2O_3$	a
− 4·0	771·2	10·0	1·0769
0·0		13·0	1·4000
+ 1·0		14·0	1·5076
4·4		17·6	1·8953
7·3		18·1	1·9492
10·6		17·6	1·8953
11·8		17·0	1·8307
15·9		14·2	1·5292
22·1		11·7	1·2600
25·6		10·6	1·1415
31·4		8·7	0·9369

1 c.c. = 0·01243 gm. iodine.

This solution possesses a solubility almost identical with those of the simple salts.

Manganese and Sodium Chlorides.—Chlorine hydrate was obtained easily at 0°. No peroxide of manganese was formed until the chlorine hydrate was decomposed, but its formation was then rapid apparently, for the curve seems to run almost horizontally instead of dipping down rapidly. Unfortunately, an accident stopped the experiment at 11°.

$\frac{1}{2}(NaCl+NmCl)$. Plate XXXVI., Diagram III.

$t°$	p	$Na_2S_2O_3$	a
−2·5	761·7	12·7	1·3843
+1·2		16·3	1·7768
3·5		17·9	1·9512
5·6		18·7	2·0384
7·5		19·0	2·0711
8·8		17·9	1·9512
9·8		17·8	1 9403
11·1		17·4	1·8967

1 c.c. = 0·01243 gm. iodine.

It is to be observed that the curve for the mixed salts takes a course between the curves for its two components, crossing almost exactly at the point where these latter cross each other, thus keeping its mean position on both sides of the maximum point.

Cobalt and Sodium Chlorides.—Chlorine hydrate appeared at −4°, and was completely decomposed at +4°. The curve in this case also runs between those of the single salts, crossing as in the preceding case.

$\frac{1}{2}(NaCl + CoCl_2)$. Plate XXXVI., Diagram IV.

$t°$	p	$Na_2S_2O_3$	a
−3·5	754	12·0	1·3217
−1·5		14·7	1·6191
+1·0		15·6	1·7180
5·0		15·4	1·6963
12·0		13·4	1·4760
16·6		11·3	1·2446
25·4		9·7	1·0687
32·6		8·7	0·9583
38·2		7·2	0·7931

1 c.c. = 0·01243 gm. iodine.

Calcium and Sodium Chlorides.—No chlorine hydrate was formed at −5°, and the solution caused decomposition of the hydrates with effervescence, as in previous cases. The curve lies between those of the single salts, but is below both after passing the maximum.

$\frac{1}{2}(CaCl_2 + NaCl)$. Plate XXXVI., Diagram V.

$t°$	p	$Na_2S_2O_3$	a
−3·0	744·3	12·6	1·4059
+0·5		13·0	1·4506
1·5		12·7	1·4171
4·8		11·85	1·3222
9·9		10·05	1·1214
15·7		8·7	0·9708
22·5		7·9	0·8815
29·1		6·6	0·7364
34·6		5·1	0·5691

1 c.c. = 0·01243 gm. iodine.

Cadmium and Sodium Chlorides.—Hydrate of chlorine formed easily. An accident happened at an early stage, but sufficient results were obtained to show that the curve lies between that of the single salts, at least before the maximum is reached.

$\frac{1}{2}(ClCl_2 + NaCl)$.

t	p	$Na_2S_2O_3$	a
−1·4	745	6·7	0·7842
−0·5		7·3	0·8160
+2·4		9·1	1·0172
5·8		11·4	1·2473

1 cc. = 0·0127 gm. iodine.

Nickel and Sodium Chlorides.—Chlorine hydrate appeared at 2°. The curve falls between those of the two single salts on both sides of the maximum, but lies nearer the curve for sodium chloride. It shows the flat top characteristic of the nickel chloride curve.

$\frac{1}{2}(NiCl_2 + NaCl)$. Plate XXXVI., Diagram VI.

$t°$	p	$Na_2S_2O_3$	a
−1·5	764·6	11·85	1·3151
−0·3		12·4	1·3761
+1·3		14·1	1·5648
3·5		17·9	1·9865
8·0		17·6 (?)	1·9532
11·3		17·8	1·9754
16·0		14·8	1·6425
24·5		11·3	1·2541
29·0		8·3	0·9211

1 c.c = 0·0127 gm. iodine.

Strontium and Sodium Chlorides.—Chlorine hydrate appeared at −3°, began to decompose at 2°·6, and had completely disappeared at 5°·6. The curve lies above those of the single salts before the maximum, afterwards falls between them.

$\frac{1}{2}(SrCl_2 + NaCl)$.

$t°$	p	$Na_2S_1O_3$	a
−3·0	766·7	11·6	1·2838
−1·6		11·9	1·3170
0·0		13·6	1·5052
+2·6		14·7	1·6269
5·6		16·5	1·8261
7·0		15·0	1·6601
9·5		12·7	1·4056
14·3		10·5	1·1621
22·8		8·5	0·9407
28·7		7·2	0·7968
37·3		5·6	0·6198

Discussion of Results.—In discussing these results it must be premised that the curves are not strictly comparable after the maximum point is passed in the case of those solutions which allowed the formation of chlorine hydrate; for water was thus retained in the flask while a stronger solution was drawn off, so that the solution became weaker than it was originally, after the chlorine hydrate was decomposed. It is proposed to determine the solubilities of such solutions at a later date, without previous formation of hydrate, so that the second part of the curves may be strictly comparable. The principal object in the present research has been to determine the first part of each curve, and fix the maximum points.

The salts which prevent the formation of chlorine hydrate are chlorides of magnesium, calcium, iron, cobalt, and strontium (almost entirely).

On referring to the curves it will be found that those for these salts form a well-defined group, having the following characteristics:—

1. The maximum point is at a temperature lower than that for water by from 10 to 15 degrees.
2. The tops of the curves are flat, and the descent is very gradual.

The occurrence of maxima in the case of these salts is not to be explained in the same way as in cases where solid chlorine hydrate appears. In seeking for an explanation it is to be noticed that all of these chlorides have a strong attraction for water, and tend to form definite hydrates. The anhydrous chlorides unite with water very readily, forming definite crystalline hydrates stable at higher temperatures than have been employed in this research.

It may be supposed that two forces come into play to determine the amount of chlorine in the solution—(1) the solubility of chlorine in the "free" water, and (2) the attraction of calcium chloride for water, determining the amount of "free" water. It is a case where chemical combination is a function of the temperature. As the temperature falls the amount of free water decreases, but at the same time its coefficient of absorption increases, and at a quicker rate than the decrease of free water. Therefore, on the whole, the solubility increases as the temperature falls. But as the temperature continues to fall the rate at which the chloride goes on attaching the water increases, until it overtakes the rate of increase of solubility, and a maximum is reached. From this point onwards the chloride keeps and increases its ascendancy and the solubility decreases. The gradual rise and fall of the curves favour this theory. There is no sudden descent from the maximum, as in the case of those salts permitting the formation of the hydrate.

The curves for the remaining solutions do not admit of classification, but there seems a general tendency for a strong attraction for water to coincide with a maximum at a low temperature, except in the case of cadmium chloride where the maximum appears at 10°, very near that for water. There is also to be remarked in the curves for those chlorides which permit the formation of chlorine hydrate, a generally steep ascent to the maximum and rapid fall after passing that point.

The coefficients in the foregoing results express the volumes of chlorine measured at 0° and 760 millimetres pressure absorbed by unit volume of the solution measured at the temperatures of estimation. Probably new relations would appear if they were stated as weights of chlorine absorbed by unit weight of the salt and its accompanying water. The data necessary for this are—(1) amounts of chlorine absorbed at particular temperatures, and (2) the specific gravity of the solutions containing chlorine at those temperatures. The weight of chlorine being known, the weight of chloride could be easily found.

In a second research on this subject, it is proposed to follow the course indicated. Such determinations were made for water, and it was found that the absorption of chlorine increases the specific gravity of water, as the following numbers will show :—

	Sp. gr. of Chl. Water.	Sp. gr. of Pure Water.
2°·5	1·00406	0·999980
8°·0	1·00494	0·999886
16°·3	1·00424	0·998954
23°·0	1·00264	0·997601
29°·0	1·00069	0·996051
25°·5	0·99984	0·994247

Taking a general survey of the curves as grouped in the diagrams, the following facts are remarked :—

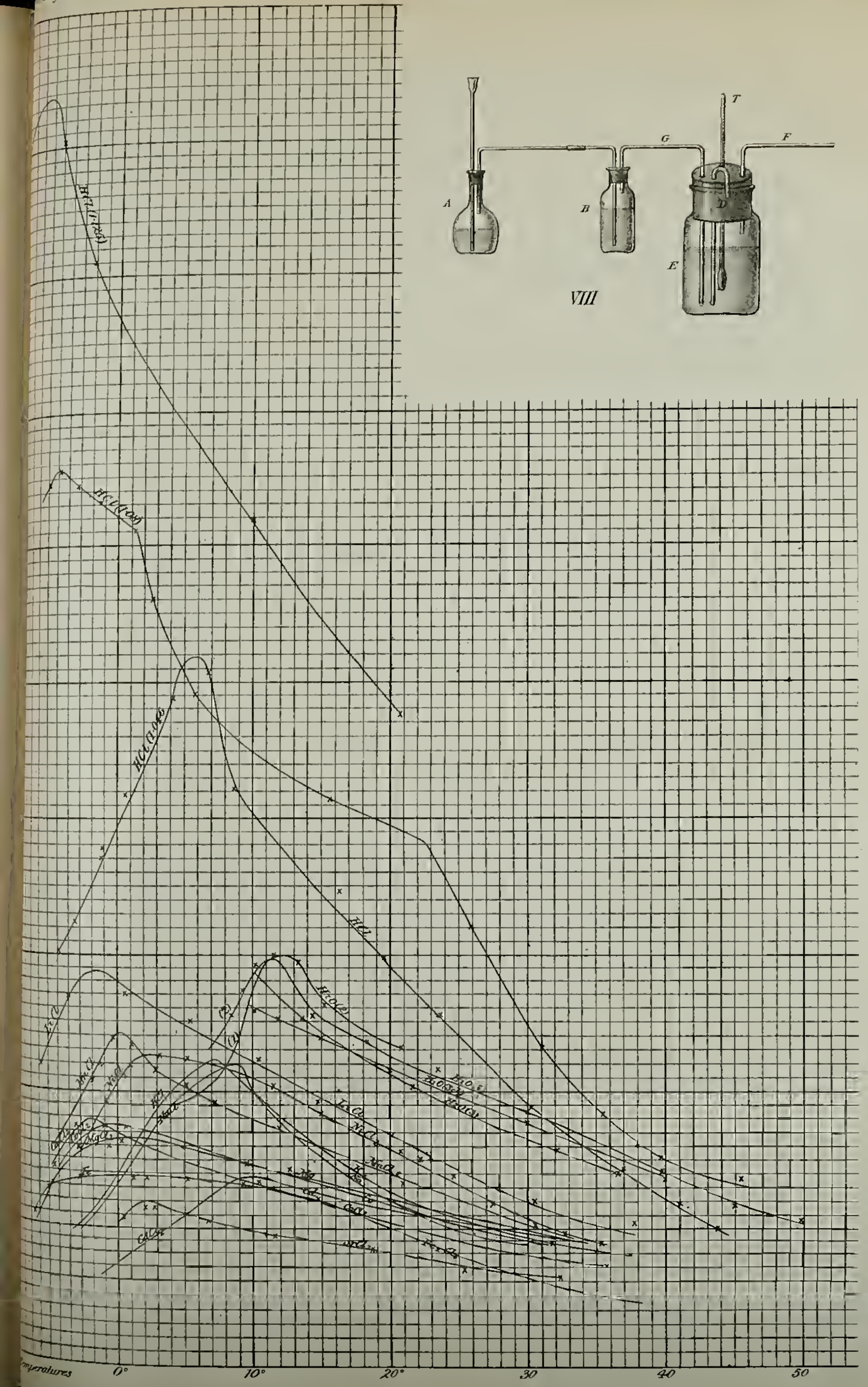
1. There is a general tendency towards coincidence at high temperatures (Plate XXXVI., Diagram I.).

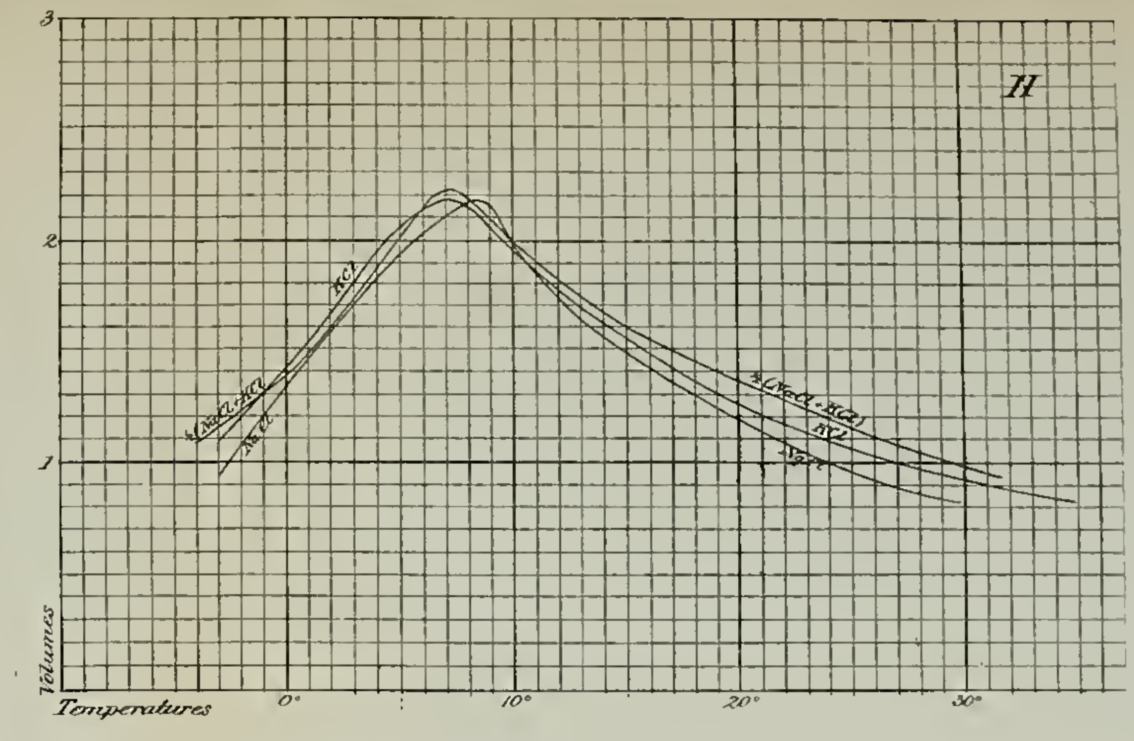
2. The curves for the mixed chlorides, where chlorine hydrate is formed with both single chlorides, follow a mean course very closely ; in cases where one of the chlorides only prevents the formation of the hydrate, the curve does not always follow such a mean course between the curves for the single chlorides (Plate XXXVI., Diagrams II., III., IV., V., VI., and VII.).

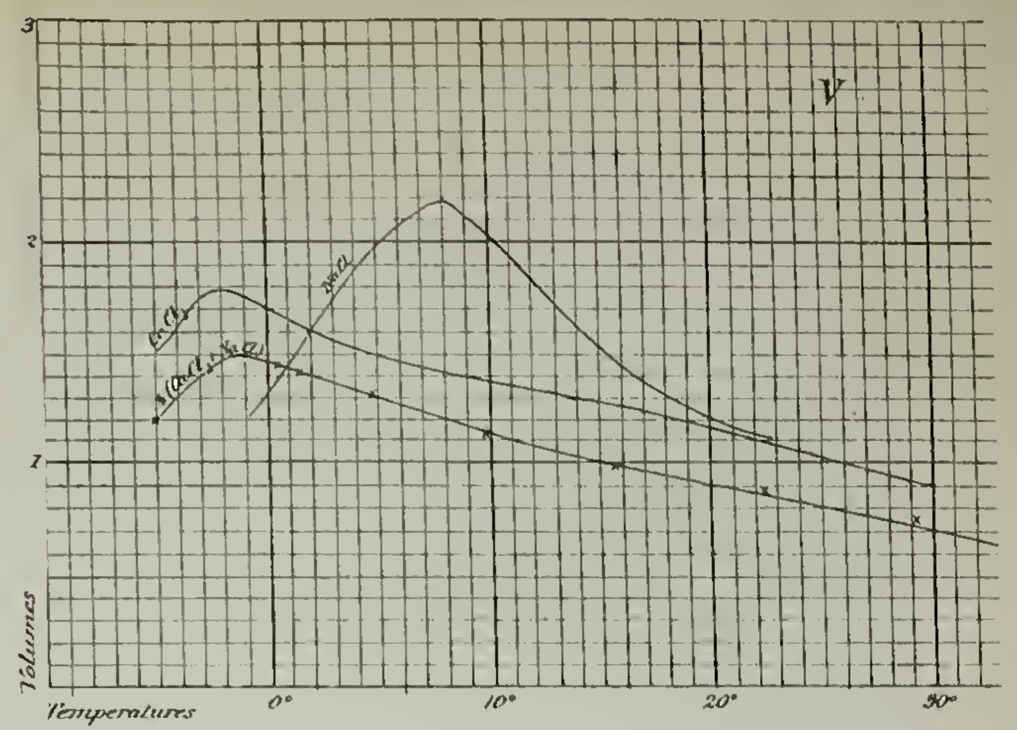
3. The solubility of chlorine in water is increased by the presence of lithium chloride, hydric chloride, and, perhaps, manganese chloride (Plate XXXVI., Diagram I.).

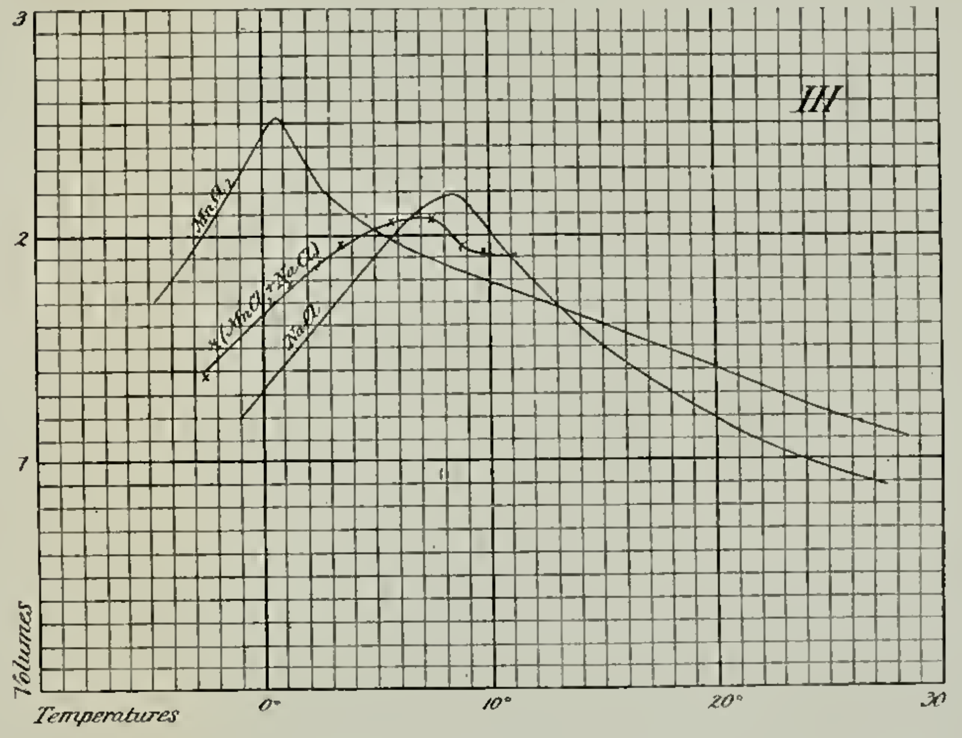
4. The presence of chlorides affects the solubility of chlorine in water *chemically* at *low*, but *mechanically* at *high*, temperatures.

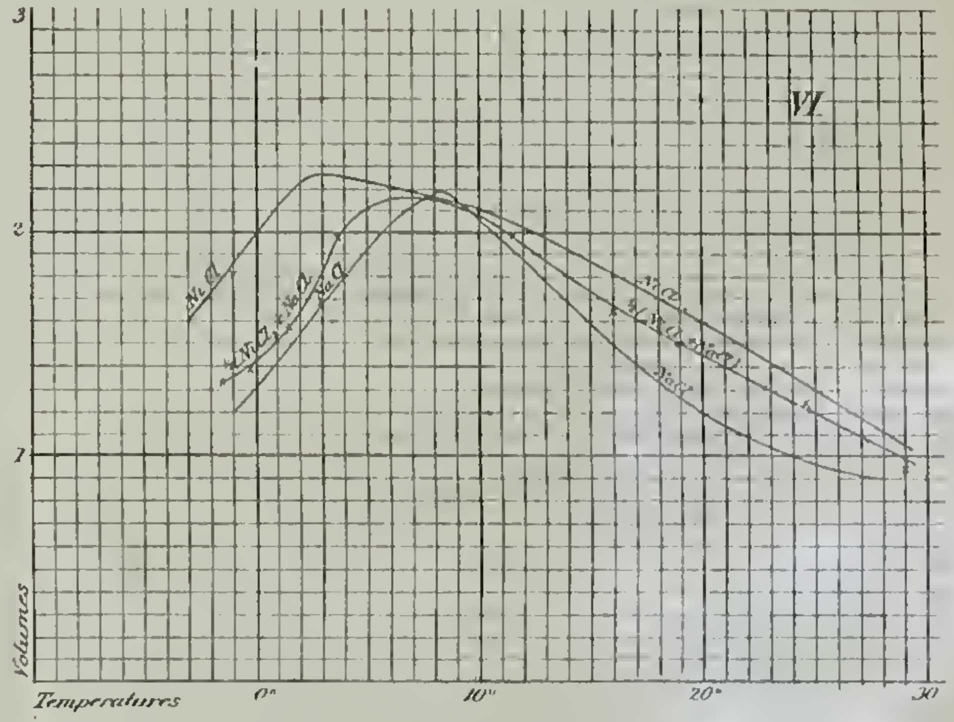
This research was carried on in the Chemical Laboratory of University College, Bristol, during the first six months of 1882, and I have to thank Professor Ramsay for many valuable suggestions.

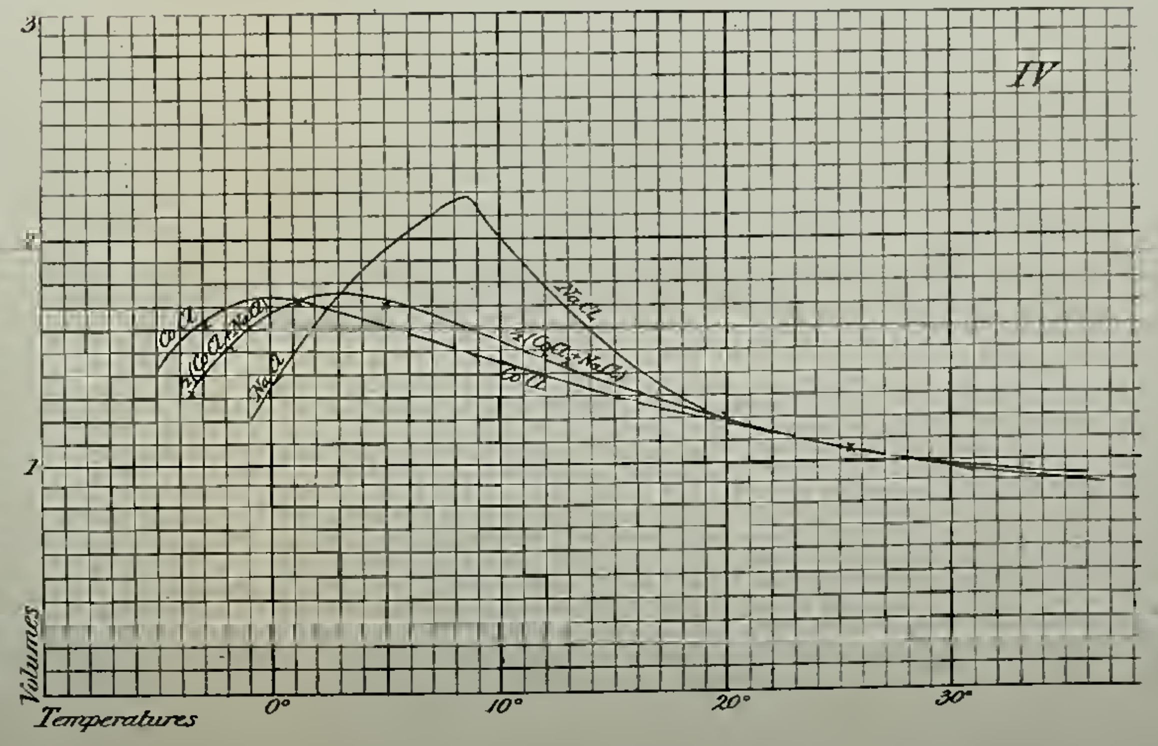


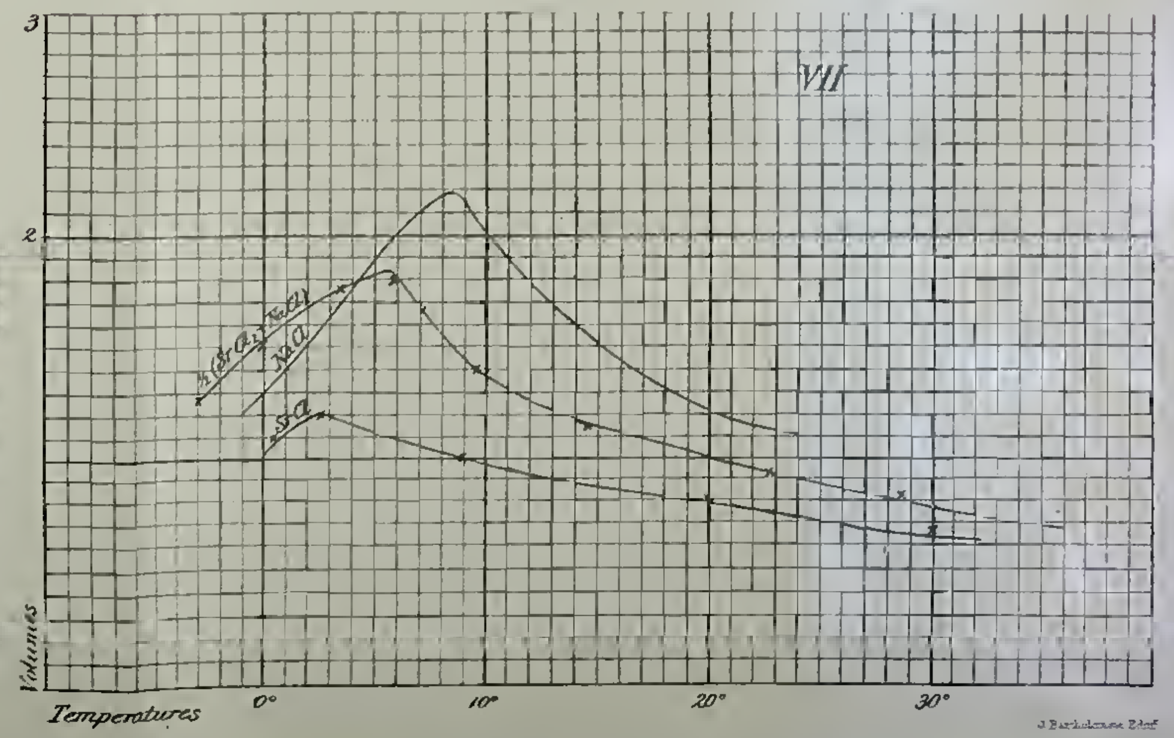












J. Bartholomew, Edin^r.

XXVII.—*The Dragon's Blood Tree of Socotra* (Dracæna Cinnabari, *Balf. fil.*). By Bayley Balfour, Sc.D., M.B., Regius Professor of Botany, University of Glasgow.

The following remarks on the dragon's blood tree of Socotra are intended to serve as introduction to Dr Dobbie's and Mr Henderson's paper on the red resin obtained from the tree, and to furnish a technical description of the plant which has not hitherto appeared. In my account of the Botany of Socotra, which will shortly be published by the Society, further remarks upon this interesting tree will be found, along with a figure.

Resina draconis (dragon's blood resin), now only used as a varnish, has been known as a commercial product for many centuries. Under the name κιννάβαρι, Disocorides[*] mentions a costly pigment brought from Africa, and under the same designation the author of the Periplus of the Erythrean Sea[†] speaks of a product of the island of Dioscorida, the modern Socotra. This κιννάβαρι is undoubtedly the resin dragon's blood, or rather one of the resins at present in commerce under that name. Pliny[‡] also mentions this produce. Various of the early Arabian geographers and European travellers speak of dragon's blood as one of the commodities exported from the region of the incense country about the Gulf of Aden, and we have, in the narratives of explorers of this century, references to the production of the resin both on the Arabian and on the African coasts of that neighbourhood.

But dragon's blood resin has also been long known as a product of other parts of the globe. The fame of the dragon's blood tree of Orotava, in Teneriffe, is world wide, and the resin of the Canary Islands tree was in former times exported in large quantities.

Then from Sumatra and Borneo, and other islands of the Eastern Archipelago, a dragon's blood resin is an article of trade, though no records of its export at an early period are extant.

In the West Indies, and also in Mexico, substances are obtained which bear the name dragon's blood, but, according to Flückiger and Hanbury, they are not met with in European commerce.

The substances from these different regions, though bearing the same name,

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[*] Op. lib. v., cap. cix.

[†] Voyage of Nearchus and Periplus of the Erythrean Sea, translated by Vincent, Oxford, 1809, 90.

[‡] Hist. Nat., xxxiii. 38.1.

are not of the same character, nor are they derived from the same, or in all cases from allied plants.

We may dismiss here the West Indian and the Mexican resins with the remark that the former is the exudation of a leguminous plant,—*Pterocarpus Draco,* Linn.,— and is, according to FLÜCKIGER and HANBURY, of the nature of kino, whilst the latter is got from the euphorbiaceous *Croton Draco,* Schlecht. I have not been able to obtain specimens of the resins of these.

An East Indian resin is at the present day the most common commercial resin of dragon's blood. It is procured from the fruits of a rotang palm, *Calamus Draco,* Willd. The resin which exudes on the fruits is separated by beating these in a sac, and then sifting out the fruit scales and other refuse. The resin is next softened by exposure to the sun, or warming in a vessel plunged in hot water, and then moulded into sticks or balls, which are wrapped in a piece of palm leaf. An inferior kind is obtained by boiling the pounded fruits. Two kinds are exported, "Reed" and "Lump," of which the former is the finer.*

Another East Indian plant, one of the Leguminosæ—*Ecastaphyllum Monetaria*—found in Surinam, is said to yield a resin like dragon's blood, but of it I know nothing.

The dragon's blood resins from Arabia, Africa, Socotra, and the Canary Islands are furnished by species of the liliaceous genus Dracæna; but although it is of these resins that we have the earliest records, yet the specific source of the resin, with the exception of that from the Canary Islands, has until quite a recent date remained unknown. The productive species are branching trees, with large trunks, and form a very marked section of the genus.

The Canary Island tree, *Dracæna Draco,* Linn., has been long known, and frequently and fully described. The large Orotava plant was 60 feet in height and 15 feet in diameter when it was destroyed by a hurricane in 1867. The resin is apparently not largely exported at the present time, but there is evidence that it was formerly an article of much trade, besides being used in early times by the Guanchos for the purposes of embalming.

Amongst the botanical results of Miss TINNE'S expedition to Bahr-el-Ghazal river and its affluents in Nubia, was the discovery in the vicinity of Suakim of a tree about 24 feet high, which yields a dragon's blood. KOTSCHY and PEYRITSCH † describe the plant under the name *Dracæna Ombet,*—"ombet" meaning Mother of Earth, being the native name for it. A figure of the plant is given in a landscape heading to the letterpress. Both description and figure leave much to be desired. Fortunately SCHWEINFURTH, in his Abyssinian tour, found the same plant at an elevation of 2000 feet, growing over a few square

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* See *Pharmacographia,* FLÜCKIGER and HANBURY, 2nd edition (1879), p. 672.

† *Plantæ Tinneanæ,* p. 47.

miles of country near Suakim, and he gives a representation of the tree in one of the woodcut illustrations of his travels.[*] The leaf specimens sent by him to Kew with KOTSCHY and PEYRITSCH'S description and figure were not sufficient to permit Mr BAKER, in his revision of "Asparageæ,"[†] to take up the species, and of it he merely remarks, under the species *D. Draco*, "e montibus Indiæ et verisimiliter Socotræ insulæ incola ex datis notis non potui segregare." But recently Dr SCHWEINFURTH has sent to Kew a portion of the panicle of this tree, which enables me to form a more decided opinion regarding it, and shows that the Nubian plant is a distinct species. Fruits are still wanted, and of the resin I have seen no account, nor have I succeeded in obtaining any of it.

In 1877 HILDEBRANDT found on the hills of Somali Land a tree attaining a height of 24 feet, and known to the inhabitants as "moli," which is said to supply a dragon's blood resin. It is a Dracæna, and specimens sent to Kew, though imperfect, there being only portions of flower panicles, showing specific differences from others before known, Mr BAKER described it[‡] as *D. Schizantha*. Regarding it we have as yet but little information, and of its resin nothing is known.

Our expedition in the spring of 1880 to Socotra has cleared up all doubts as to the source and character of the dragon's blood of that island. As I have noted above, the tree has been previously supposed to be identical with the Nubian plant. But though very nearly allied to it, there are differences between them which have led me to regard the Socotran plant as distinct from it.

On Socotra, the dragon's blood tree to which I, for obvious reasons, have given the name *Dracæna Cinnabari*, forms a small tree, attaining sometimes a height of about 30 feet. The trunk reaches considerable dimensions. One I measured on the Haghier hills, near the Adona Pass, at an elevation of 4000 feet, was 5 feet 3 inches in circumference at 3 feet from the ground; another near it was 6 feet 5 inches at 2 feet; whilst at Homhill, near the eastern end of the island, I found one at an elevation of 1100 feet, which had a circumference of 9 feet at 3 feet from the ground, and a spread of branches 29 feet 6 inches in diameter. The tree grows only on the higher regions of the island. Nowhere did we see it below 1000 feet elevation. It grows frequently in small groves, and the trees branch freely and form when well grown a dome-shaped crown, exhibiting the feature so characteristic of screw pines. There is but one species on the island. It has been hinted that there are two. HUNTER[§] records that the inhabitants recognise two distinct forms, which they speak of as being of

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[*] *Heart of Africa*, Eng. trans., i. p. 22.

[†] In *Jour. Linn. Soc. Lond.*, xiv. (1875), p. 527.

[‡] In *Trim. Jour. Bot.*, vi. (1877), p. 71.

[§] *Manuscript Journal of a Visit to Socotra in* 1876.

different sexes. But all the forms assumed by the tree—and it does vary much both with habitat and with age—are referable, we consider, to the one species. The young plant has always much longer and broader leaves than the older plants, and in these latter the inflorescences are shorter and more compact. In unsheltered localities, too, as might be expected, the tree is frequently of a more dwarfed size than when well protected.

The resin exudes naturally through cracks and rents in the stem, and these are increased in size by the collector. The amount of resin produced varies with their situation. The mode of collection is very simple. Holding below the seat of exudation a small piece of goatskin about a foot square, the gatherer chips with a knife the resin from the stem, and catches it on the skin. The time for collecting is immediately after the rains, and there are therefore two gatherings in the year, and the resin is exported immediately after collecting to Makullah, the Persian Gulf, and elsewhere, the Sultan taking tithe of all export. The trees over the island are, I understand, farmed out to the inhabitants, but the Sultan retains for himself a certain district.

To the tree the inhabitants give the name "kharya," and the resin they call "edah." WELLSTED[*] states that the Arabic name for the resin is "dum khoheil." One also reads that the Arabic name for it is "kätir."

Of the resin there are three kinds—

(*a*) "Edah amsello" (WELLSTED calls it "moselle"), the tears, many of them an inch in diameter, as they exude. 2½ lbs. of this are said to fetch a dollar. It is the purest and most valuable kind.

(*b*) "Edah dukkah" is the second best kind. It consists of the small chips and fragments of the tears which have been broken off in separating them from the tree, or by attrition. The fragments present a dull red powdery aspect. It sells at one dollar for 4 lbs.

(*c*) "Edah mukdehah" is the cheapest kind, is very impure, and brings a dollar for 5 lbs. It is in the form of small flat-sided masses, and consists of fragments of the resin and refuse of the gatherings melted together into a flat cake, which is then broken up into small portions.

We obtained a considerable supply of all these kinds of resin; and as it appeared a matter of some interest to have an analysis made of such authentic specimens, my friend Dr DOBBIE kindly undertook the investigation, in which he has been assisted by Mr HENDERSON. They have extended their research to the comparative analyses of the several kinds of dragon's blood; and through the kindness of Sir JOSEPH HOOKER, and those in authority at Kew, I have been able to obtain samples of most of the resins labelled dragon's blood in the Kew Collection, and Mr E. M. HOLMES, curator of the Pharmaceutical Society's Museum, has kindly supplied samples of like resins in the Society's Museum.

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[*] In *Jour. Roy. Geol. Soc.*, v. (1835) 198.

These have been turned to good account, but much still remains to be cleared up. Certain it is that red resins of different composition, and therefore probably derived from different sources, are in commerce, at least have found their way into our Museums, under the name dragon's blood, and do not appear to be distinguished from one another. But I must leave Dr DOBBIE and Mr HENDERSON to tell their own story, and conclude this brief note with a technical description of the Socotran tree.

Dracæna Cinnabari, *Balf. fil.* Arbor 25–pedalis trunco crassitiem 3 ped. attingente apice copiose ramoso; foliis 1–2 ped. longis 1–1¼ poll. latis ¼–½ poll. crassis sessilibus in apicem ramorum validorum confertis patenti-erectis firmis sed in juvenilibus sæpe subrecurvis basi amplexicaulibus ad similitudinem piscis caudæ expansis ibique 4 poll. latis rubescentibus, versus apicem gradatim attenuatis, supra concavis infra jugo medio prominulo convexo extremitate trigonis obtuse punctatis, ecostatis, glauco-viridibus margine concoloribus; paniculis glabris pseudo-terminalibus multiramosis 1–2½ ped. longis, ramis ramulisque divaricatis strictis, antepenultimis 9–12 poll. longis, penultimis contractis 2–4–floris, pedicellis validis ⅕ poll. longis supra medium articulatis; bracteolis membranaceis longis acuminatis; perianthio sordido ¼ poll. longo, segmentis oblongis vix connatis, apice uncinatis; genitalibus inclusis, filamentis subulatis antheris oblongis duplo-longioribus; ovario oblongo stylum æquanti, stigmate trilobato; baccis aurantiacis ½ poll. diam. nitidis.

NOM. VERN. Arboris—Kharya; Resinæ draconis—Edah.

Socotra, per insulam totam in montibus ultra 1000 ped. alt. crescens. B.C.S. No. 80. Schweinf. No. 550. Perry.

The Nubian *D. Ombet* is separated from the Socotran plant by its less robust habit, more slender and shorter antepenultimate branches of the panicle, longer pedicels, non-acuminate bracteoles, and more delicate perianth, with commonly a stipitate ovary.

D. Schizantha, from Somali Land, is easily diagnosed by its downy panicles.

D. Draco, from the Canary Islands, differs in having compressed ensiform leaves, smaller bracteoles, greenish perianth, the segments of which are not uncinate at the apex, anthers relatively to the filament shorter, ovary commonly stipitate, and stigma capitate.

XXVIII.—*On a Red Resin from* Dracæna Cinnabari (*Balf. fil.*), *Socotra.* By J. J. Dobbie, M.A., D.Sc., Assistant to the Professor of Chemistry, University of Glasgow; and G. G. Henderson, B.Sc.

The resin to which the following paper refers was obtained by Professor Bayley Balfour from a species of Dracæna which he discovered in Socotra during his visit to that island in the year 1880, and to which he has given the name of *Dracæna Cinnabari.* In outward appearance and in general physical properties the resin differs from the varieties known commercially under the name of dragon's blood. With the view of ascertaining if these differences depend upon difference of chemical composition, we undertook, at Professor Balfour's request, to make an examination of the resin.

The resin is in the form of large drops or tears of a deep red colour; when ground it is of the same colour as some varieties of cinnabar. At ordinary temperatures it is brittle, and breaks with a clean fracture into transparent fragments which transmit rich ruby-red light. It begins to soften between 50° and 60° C, and melts at about 60°; when heated to its decomposing point it gives off aromatic and irritating fumes. The specimens given us were exceedingly pure, leaving, after solution in ether, a residue of only 3·4 per cent., which appears to consist entirely of fragments of vegetable tissue. The resin is soluble to a slight extent in boiling water, the solution being acid. It dissolves entirely in alcohol, ether, and oil of cloves. The alcoholic solution is of a fine blood-red colour, and has a strongly acid reaction. It is atmost entirely insoluble in chloroform, benzene, carbon bisulphide, and petroleum ether. It contains no benzoic acid; at all events it yields up no extract to petroleum ether, in which benzoic acid is fully soluble. Neither does cinnamic acid appear to be present, because, when the resin is heated to a temperature above that at which cinnamic acid sublimes, no trace of that acid is obtained. As much discussion has taken place regarding the presence of cinnamic or benzoic acid in red resins, we made artificial mixtures containing only 1 per cent. of these acids, in order to determine whether or not they can be detected by sublimation when present in very small quantity. On heating, in sublimation tubes, quantities of the mixture containing not more than one-twentieth of a grain of acid, we found that it could be detected with certainty, whereas a much larger quantity of the resin to which no acid had been added, gave no sublimate. Again, on digesting the artificial mixture with benzene and with chloroform, in both of which cinnamic and benzoic acids are soluble, we obtained an extract which was almost entirely sublimable, while no sublimate was given by the extract obtained by digesting the resin to which no acid had been added. In the latter case the extract, which is very small, appears to consist of a trace of oily matter and a little resin. The resin, indeed, is soluble in these and in nearly every other reagent, with the exception of petroleum ether, to a very slight extent. When heated the resin loses somewhat in weight, the loss being due to the expulsion of moisture.

Caustic potash and soda completely dissolve the resin to an orange-red coloured solution; aqueous ammonia and lime water have nearly the same action upon it. Cold sodium carbonate dissolves it to a blood-red solution, which changes to orange red on boiling. Acetate of lead precipitates from the alcoholic solution a mauve coloured salt, which is insoluble in boiling water but readily soluble in alcohol. Three analyses of this salt gave the following numbers:—(1) 25·33, (2) 25·27, and (3) 25·17 per cent. of lead. The first of these determinations was made by simply treating the salt with strong sulphuric acid, evaporating down and igniting, the other two by acting upon the salt with strong nitric acid, and precipitating the lead with sulphuric acid. This is the only definite salt that we have as yet succeeded in preparing. Nitric acid completely decomposes the resin. Hydrochloric acid dissolves it to a slight extent, ammonia reprecipitating it. Acetic acid, in which it dissolves abundantly, gives an orange-red solution, from which also the resin can be reprecipitated by ammonia. Having carefully purified the resin by repeated solution in ether, we burned it, with the following results:—

	(1)	(2)	(3)	(4)
C . .	71·22	72·80	70·28	72·02
H . .	5·94	6·02	5·93	6·43
O . .	22·84	21·18	23·79	21·55
	100·00	100·00	100·00	100·00

The average of these four analyses is C 71·58, H 6·08, and O 22·34.

Owing to the great difficulty in thoroughly purifying resinous bodies these numbers can only be regarded as approximately accurate; they correspond very closely, however, with the formula $C_{18}H_{18}O_4$. A substance having this formula would contain 72·48 per cent. of carbon, 6·04 per cent. of hydrogen, and 21·47 per cent. of oxygen, and would have a combining weight of 298. This agrees very closely with the results obtained by the analysis of the lead salt. Assuming the acid to be monobasic, the composition of this salt would be $(C_{18}H_{17}O_4)_2Pb$, and a salt having this composition would contain 25·84 per cent. of lead. The percentage of lead actually found, taking the mean of three experiments, was 25·25.

Having ascertained the properties and ultimate composition of the resin from *Dracæna Cinnabari,* we proceeded to compare it with other varieties of red resins. We soon discovered, however, that much uncertainty prevails as to the source of these substances, several distinct varieties of resin being described under one name. All the published accounts of the chemical properties of dragon's blood refer to dragon's blood supposed to be derived from *Calamus Draco,* but it is obvious from the discrepancies in the statements of different writers that some of them must have had in hand resins from other sources. To place our comparison upon a sound basis, we collected specimens of as many varieties of red resin as possible. Through the kindness of Professor BALFOUR we obtained a number of specimens from Kew Gardens and from the museum of the Pharmaceutical Society. Some of these specimens marked "Calamus" have characters widely different from those ascribed by FLÜCKIGER and HANBURY to the red resin from *Calamus Draco.* Beside the Socotra variety we had for examination sixteen specimens. We found that all these specimens admit of classification according to solubility and other characters into four groups. In the first we place those resins which are entirely soluble in chloroform, carbon bisulphide, and benzene. This group includes two of the Kew specimens, one marked "*Calamus Draco,*" the other "Sumatra," the species not being given, and one of the Pharmaceutical Museum specimens, also marked "Sumatra." In our second group the resins are soluble in chloroform, but insoluble in carbon bisulphide and benzene. This group includes two Pharmaceutical Museum specimens, one marked "Dutch East Indies," the other "Pontianak, Dutch East Indies," the source not being indicated. The third group contains resins soluble in chloroform and benzene, and partially soluble in carbon bisulphide. To this group belong three Kew specimens, marked respectively "Singapore," "Penang," and "Calamus Species." The fourth group includes those resins which are insoluble in chloroform, carbon bisulphide, and benzine. To it belong three Kew specimens, marked respectively "*Calamus Draco,* Bombay," "Punjab," and "Indian Museum," and two Pharmaceutical Museum specimens, one marked "Probably from Calamus," the other "*Dracæna Draco.*" The source of the last mentioned specimen is well authenticated. The resins in the first group have the characters ascribed by FLÜCKIGER and HANBURY to the resin from *Calamus Draco.* The resins in the fourth group agree in properties with that from *Dracæna Cinnabari.* All the Kew specimens are believed to have been obtained from species of Calamus, but it is obvious from an examination of the above list that some of them must have a different origin, unless, indeed, as is very improbable, the same species yield different resins in different localities, or at different seasons. Possibly, as suggested by Mr HOLMS, of the Pharmaceutical Society's Museum, some resins exported from Bombay were imported in the first instance from the East Coast of Africa, and not from the East Indies. Thus it is easy to understand how resins derived from widely different sources might come to be confounded with one another.

We shall now give a brief account of the chemical character of the resins belonging to each class. The resins of all the groups are abundantly soluble in alcohol, ether, and oil of cloves,—the insoluble residue, which in some cases is considerable, consisting chiefly of vegetable fibre

The resins of Group I. are, when powdered, of a brick-red colour,—the colour of hæmatite rather than of cinnabar,—and transmit in thin splinters ruby-red light. They melt about 80° C, or nearly 20° above the Socotra resin. Heated to their decomposing point they give off highly irritating red coloured fumes. The alcoholic solution is orange-red rather than blood-red in colour, but has, like that of the Socotra resin, an acid reaction. The resin of this class, which we subjected to a more particular examination, namely, a specimen from the Kew collection marked "*Calamus Draco*, Singapore," contains cinnamic acid, which it yields up readily on heating in a sublimation tube. That it is not benzoic acid is clear from the form of crystal, as well as from the fact that it gives no extract to petroleum ether, which readily dissolves out benzoic acid from an artificial mixture. It ought to be mentioned that cinnamic acid is only very slightly soluble in petroleum ether. This resin is soluble only to a slight extent in strong caustic soda, and dissolves with difficulty even on heating, giving an orange-red coloured solution. It is hardly at all soluble in cold ammonia and lime water, and only to a slight extent on boiling in these reagents. It is insoluble in cold sodium carbonate, and dissolves with difficulty on boiling to a reddish-yellow fluid, giving off a smell like rhubarb. In its behaviour, therefore, with all these reagents, it differs in a marked manner from the Socotra resin. With acetate of lead it gives a brownish-red coloured precipitate, soluble in alcohol, but insoluble in boiling water. It is very slightly soluble in boiling hydrochloric acid to an orange-yellow solution, from which it is reprecipitated by ammonia. It is also reprecipitated by ammonia from solution in acetic acid. It is decomposed by strong nitric acid. The ultimate composition of this resin is very nearly the same as, if not identical with, that of the Socotra resin. Two analyses give the following numbers :—

	(1)	(2)	(Mean.)
C . .	71·03	70·08	70·55
H . .	6·46	6·42	6·44
O . .	22·51	23·50	23·01
	100·00	100·00	100·00

These numbers agree very closely with those given by Johnstone.

The resins of Class II. differ still more widely from the Socotra resin, both as regards their physical and chemical characters. The specimens of the resin which we had to work with were exceedingly pure. This variety of resin is of a beautiful carmine-red colour, and in thin splinters transmits ruby-red light.

The melting point of the specimen marked "Pontianak, Dutch East Indies, probably Calamus," is only slightly under 100° C, nearly 40° above that of the Socotra resin, and 20° above that of *Calamus Draco.* When decomposed by heat it gives off non-irritating fumes. The alcoholic solution is of a pink-red colour, and has an acid reaction. Benzoic acid and cinnamic acid are absent. In cold strong caustic soda it dissolves with a magnificent purple colour, which changes on heating or dilution to an orange-yellow. It is readily soluble in ammonia, giving the same colour as with soda. It is also much more soluble than either the Socotra resin or that from *Calamus Draco* in lime water. In cold sodium carbonate it dissolves with effervescence to a beautiful purple-pink or mauve-pink solution, which changes to orange-red on boiling. Acetate of lead gives a lilac coloured precipitate, soluble in alcohol and apparently slightly soluble in boiling water. This resin is much more soluble in hydrochloric acid than either of the preceding, and is reprecipitated from this solution, as well as from its solution in acetic acid, on neutralisation with ammonia. It is decomposed by strong nitric acid. Two combustions gave the following results :—

	(1)	(2)	(Mean.)
C . .	68·18	68·22	68·20
H . .	6·01	6·05	6·02
O . .	25·81	25·74	25·78
	100 00	100·00	100·00

This resin therefore appears to contain a somewhat lower percentage of carbon than the preceding, and would correspond better with the formula $C_{17}H_{18}O_5$ than with that which we have assigned to the Socotra resin. A substance having the above formula would contain 67·54 per cent. of carbon, 5·96 per cent. of hydrogen, and 26·52 per cent. of oxygen, and would have a combining weight of 302. Owing to the very small quantity of this resin we had to work upon, we were not able to confirm these results by the analysis of any salts.

The resins belonging to our third class are peculiar. We selected for examination one of the Kew specimens marked "Penang." In common with the other resins which we have placed in this class it is soluble for the most part in chloroform, benzene, and carbon bisulphide. A portion, however, persistently remains undissolved by the carbon bisulphide, and carbon bisulphide gives a precipitate when added to the solution in chloroform. These resins therefore would appear to be composed of a mixture of two resins, one soluble in chloroform, benzene, and carbon bisulphide, the other soluble in chloroform and benzene, but insoluble in carbon bisulphide. This conclusion is confirmed by the varying results obtained by combustion. The part of the resin soluble in chloroform, benzene, and carbon bisulphide corresponds very closely in all its properties with the resin from *Calamus Draco,* and like that resin gives a sublimate of cinnamic acid. We have not yet examined the other portion, which is undoubtedly a distinct resin.

In describing the Socotra resin we have already enumerated fully the characters of the resins of Class IV. We compared carefully with the Socotra resin the specimen from the Kew collection marked "*Calamus Draco,* Bombay," and found them to be in all points identical. Combustion gave C 71·89, H 6·17, and O 21·74 as the ultimate composition of the Kew specimen. The specimen from *Dracæna Draco* belongs, as already mentioned, to our fourth class, and as its source is well authenticated, we thought it would be interesting to compare it also more carefully with the resin from *Dracæna Cinnabari,* with the view of ascertaining if there was any difference in properties answering to the difference in species. After a very thorough examination we have come to the conclusion that the two resins are identical, or at all events so closely allied as not to admit of discrimination by their physical properties. The only considerable difference which we could detect was a greater solubility of the resin from *Dracæna Draco* in boiling water.

The result of our work so far as it has gone has been to prove (1) that there are several distinct and well defined varieties of resin known under the name of dragon's blood; (2) that probably each variety is derived from a different genus; and (3) that there is probably no difference in resins derived from different species of the same genus. Little has as yet been done towards the examination of the chemical constitution of these substances. Hlasiwetz and Barth, by oxidising with caustic potash dragon's blood, derived presumably from *Calamus Draco,* obtained a variety of aromatic products, including benzoic acid, paraoxybenzoic acid, phloroglucin, &c. We propose to extend our investigation in this direction with a view to ascertain if the resins of the different classes yield different oxidation products, and in this way hope to gain some insight into their chemical constitution.

APPENDIX.

TRANSACTIONS

OF THE

ROYAL SOCIETY OF EDINBURGH.

1882-83.

CONTENTS.

THE COUNCIL
OF
THE ROYAL SOCIETY OF EDINBURGH,
NOVEMBER 1883.

The Right Hon. Lord MONCREIFF OF TULLIBOLE,
Lord Justice-Clerk, LL.D., President.

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GENERAL SECRETARY.

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TREASURER.

ADAM GILLIES SMITH, C.A.

CURATOR OF LIBRARY AND MUSEUM.

ALEXANDER BUCHAN, M.A., Secretary to the Scottish Meteorological Society.

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Professor T. R. FRASER, M.D., Dean of the Medical Faculty in the University of Edinburgh.

ALPHABETICAL LIST

OF

THE ORDINARY FELLOWS OF THE SOCIETY,

CORRECTED TO NOVEMBER 1883.

N.B.—*Those marked * are Annual Contributors.*

B. prefixed to a name indicates that the Fellow has received a Makdougall-Brisbane Medal.
K. ,, ,, ,, Keith Medal.
N. , ,, ,, Neill Medal.
P. ,, , ,, contributed one or more Papers to the *Transactions.*

Date of Election.			
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1871		* Agnew, Stair A., M.A., Advocate, Registrar-General, 22 Buckingham Terrace	
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1875		* Bain, Sir James, 3 Park Terrace, Glasgow	20
1843		Balfour, Colonel David, of Balfour and Trenabie, Balfour Castle, Kirkwall	

Date of Election.			
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1883		* Barclay, G.W.W., M.A., 40 Princes Street, Edinburgh	
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1876		* Belcombe, Rev. F. E., 14 Merchiston Avenue	
1875		Bernstein, Ludwik Stanthorpe, M.D., Lismore, Queensland, Australia	
1881		* Berry, Walter, Danish Consul General, 11 Atholl Crescent, Edinburgh	
1880		* Birch, De Burgh, M.D., The Dispensary, Newcastle-upon-Tyne	
1850		Blackburn, Hugh, M.A., Emeritus Professor of Mathematics in the University of Glasgow, Roshven, Fort-William	40
1863	P.	* Blackie, John S., Emeritus Professor of Greek in the University of Edinburgh, 9 Douglas Crescent	
1862		* Blaikie, The Rev. W. Garden, M.A., D.D., LL.D., Professor of Apologetics and Pastoral Theology, New College, Edinburgh, 9 Palmerston Road	
1878	P.	* Blyth, James, M.A., Professor of Natural Philosophy in Anderson's College, Glasgow	
1872		* Bottomley, James Thomson, M.A., Lecturer on Natural Philosophy in the University of Glasgow	
1869		* Bow, Robert Henry, C.E., 7 South Gray Street	45
1871		* Boyd, Sir Thomas J., President of the Scottish Fishery Board, 41 Moray Place	
1873		* Boyd, William, M.A., Peterhead	
1877		* Broadrick, George, Memb. Inst. C.E., Claremont Cottage, Leith	
1864	K. B. P.	* Brown, Alex. Crum, M.D., D.Sc., F.R.C.P.E., F.R.S. (SECRETARY), Professor of Chemistry in the University of Edinburgh, 8 Belgrave Crescent	
1881		* Brown, J. A. Harvie, of Quarter, Dunipace House, Larbert, Stirlingshire	50
1883		* Brown, J. Graham, M.D , C.M., F.R.C.P.E., 16 Ainslie Place, Edinburgh	
1861	P.	* Brown, Rev. Thomas, 16 Carlton Street	
1835		Brown, William, F.R.C.S.E., 25 Dublin Street	
1870		Browne, James Crichton, M.D., LL.D., 7 Cumberland Terrace, Regent's Park, London, N.W.	
1883		* Bruce, Alexander, M.A., M.B., M.R.C.P.E., 16 Alva Street, Edinburgh	55
1878		Brunlees, James, President Inst. C.E., 5 Victoria Street, Westminster	
1867		* Bryce, A. H., D.C.L., LL.D., 42 Moray Place	
1833		Buccleuch, His Grace the Duke of, K.G., LL.D., D.C.L., F.R.S., F.L.S., Dalkeith Palace	
1869	B. P.	* Buchan, Alexander, M.A., Secretary to the Scottish Meteorological Society (CURATOR OF LIBRARY), 72 Northumberland Street	
1870	P.	* Buchanan, John Young, M.A., 10 Moray Place	60
1882		* Buchanan, T. Ryburn, M.A., M.P. for the City of Edinburgh, 10 Moray Place	

Date of Election.			
1883		* Butcher, S. H., M.A., Professor of Greek in the University of Edinburgh, 27 Palmerston Place	
1869		* Calderwood, Rev. H., LL.D., Professor of Moral Philosophy in the University of Edinburgh, Napier Road, Merchiston	
1879		* Calderwood, John, F.I.C., Battersea, London	
1881		Cameron, Augustus J. D., Memb. Inst. C.E., 9 Victoria Chambers, Westminster, S.W.	65
1878		Campbell, John Archibald, M.D., Garland's Asylum, Carlisle	
1874		Carrington, Benjamin, M.D., Eccles, Lancashire	
1882		* Cay, W. Dyce, Memb. Inst. C.E., 107A Princes Street, Edinburgh	
1876		* Cazenove, The Rev. John Gibson, M.A., D.D., 22 Alva Street, Chancellor of St Mary's Cathedral, Edinburgh	
1866		* Chalmers, David, Redhall, Slateford	70
1874		* Chiene, John, M.D., F.R.C.S.E., Professor of Surgery in the University of Edinburgh, 21 Ainslie Place	
1875		* Christie, John, 19 Buckingham Terrace	
1872		Christie, Thomas B., M.D., F.R.C.P.E., Royal India Asylum, Ealing, London	
1880	K. P.	* Chrystal, George, M.A., Professor of Mathematics in the University of Edinburgh, 5 Belgrave Crescent	
1875		* Clark, Robert, 7 Learmonth Terrace	75
1863	P.	Cleghorn, Hugh F. C., of Stravithie, M.D., F.L.S., St Andrews	
1875		* Clouston, T. S., M.D., F.R.C.P.E., Tipperlin House, Morningside	
1882		* Coats, Sir Peter, of Auchendrane, President of the Glasgow and West of Scotland Horticultural Society, Auchendrane, Ayr	
1872		* Constable, Archibald, 11 Thistle Street	
1872		* Cotterill, The Right Rev. Bishop, D.D., 10 North Manor Place	80
1863		Cowan, Charles, of Westerlea, Murrayfield, Edinburgh	
1879		* Cox, Robert, of Gorgie, M.A., Gorgie House, Murrayfield	
1830		Craig, J. T. Gibson-, W.S., 24 York Place	
1875		* Craig, William, M.D., F.R.C.S.E., 7 Lothian Road	
1873		* Crawford, Donald, M.A., Advocate, 18 Melville Street	85
1878		* Cunningham, Daniel John, M.D., Professor of Anatomy in Trinity College, Dublin	
1877		* Cunningham, George, 2 Ainslie Place	
1871		* Cunynghame, R. J. Blair, M.D., 6 Walker Street	
1841	P.	Dalmahoy, James, 9 Forres Street, Edinburgh	
1878		* Dalziel, John Grahame, 2 Melville Terrace, Pollokshields, Glasgow	90
1867		* Davidson, David, Somerset Lodge, Wimbledon Common, Wimbledon	
1848		Davidson, Henry, Muirhouse, Davidson's Mains	
1870		* Day, St John Vincent, C.E., 115 St Vincent Street, Glasgow	
1876		* Denny, Peter, Memb. Inst. C.E., Dumbarton	
1879		* Denny, William, Bellfield Dumbarton	95
1869	P.	* Dewar, James, M.A., F.R.S., Jacksonian Professor of Natural and Experimental Philosodhy in the University of Cambridge, and Fullerian Professor of Chemistry at the Royal Institution of Great Britain, London	
1869	P.	* Dickson, Alex., M.D., Professor of Botany in the University of Edinburgh, 11 Royal Circus	
1876	P.	* Dickson, J. D. Hamilton, M.A., Fellow and Tutor, St Peter's College, Cambridge	
1869		* Dickson, William, 38 York Place	
1863		* Dittmar, W., F.R.S., Lecturer on Chemistry, Anderson's College, Glasgow	100

Date of Election.			
1881		* Dobbin, Leonard, Ph.D., 4 Oxford Street, Edinburgh	
1867	P.	* Donaldson, J., M.A., LL.D., Regius Professor of Humanity in the University of Aberdeen	
1882		* Dott, D. B., Memb. Pharm. Soc., 24 Castle Street, Edinburgh	
1866		* Douglas, David, 22 Drummond Place	
1839		Douglas, Francis Brown, Advocate, 21 Moray Place	105
1878		Drew, Samuel, M.D., D.Sc., Chapelton, near Sheffield	
1880		* Drummond, Henry, F.G.S., Free Church College, Glasgow	
1860	P.	* Dudgeon, Patrick, of Cargen, Dumfries	
1863		Duncan, J. Matthews, M.A., M.D., F.R.C.P.E., LL.D., 71 Brook Street, London	
1870		* Duncan, John, M.D., F.R.C.P.E., F.R.C.S.E., 8 Ainslie Place	110
1876		* Duncan, James, of Benmore, Kilmun, 9 Mincing Lane, London, E.	
1878		* Duncanson, J. J. Kirk, M.D., F.R.C.P.E., 22 Drumsheugh Gardens	
1859		Duns, Rev. Professor, D.D., New College, Edinburgh, 14 Greenhill Place	
1866		* Dunsmure, James, M.D., F.R.C.S.E., 53 Queen Street	
1874		* Durham, William, Corebank, Portobello	115
1869		* Elder, George, Knock Castle, Wemyss Bay, Greenock	
1875		Elliot, Daniel G., New York	
1880		* Elliot, T. Armstrong, M.A., Fettes College, Edinburgh	
1856		Ellis, W. Mitchell, 49 Minto Street, Edinburgh	
1855		Etheridge, Robert, F.R.S., Assistant-Keeper of the Geological Department at the British Museum of Natural History, 19 Halsey Street, Cadogan Place, Chelsea, London	120
1863	P.	Everett, J. D., M.A., D.C.L., F.R.S., Professor of Natural Philosophy, Queen's College, Belfast	
1879		* Ewart, James Cossar, M.D., F.R.C.S.E., Professor of Natural History, University of Edin.	
1878	P.	* Ewing, James Alfred, B.Sc., Professor of Engineering and Drawing in University College, Dundee	
1875		Fairley, Thomas, Lecturer on Chemistry, 8 Newton Grove, Leeds	
1866		* Falshaw, Sir James, Bart., Assoc. Inst. C.E., 14 Belgrave Crescent	125
1859		Fayrer, Sir Joseph, K.C.S.I., M.D., F.R.C.P.L., F.R.C.S.L. and E., LL.D., F.R.S., Honorary Physician to the Queen, 53 Wimpole Street, London, W.	
1883		* Felkin, Robert W., F.R.G.S., Fellow of the Anthropological Society of Berlin, 5 Marchhall Crescent, Edinburgh	
1868		* Ferguson, Robert M., Ph.D., 12 Moray Place	
1874		* Ferguson, William, of Kinmundy, F.L.S., F.G.S., Vice-President of the Geological and Royal Physical Societies of Edinburgh, and Deputy-Lieutenant of Aberdeenshire, 21 Manor Place	
1858		Field, Frederick, Chili	130
1852		Fleming, Andrew, M.D., Deputy Surgeon-General, 3 Napier Road	
1876		* Fleming, J. S., 16 Grosvenor Crescent	
1880		* Flint, Robert, D.D., Corresponding Member of Institute of France, Professor of Divinity in the University of Edinburgh, Johnstone Terrace, Craigmillar Park	
1872		* Forbes, G., Professor, M.A., F.R.A.S., M.S.T.E. and E., 34 Great George Street, Westminster	
1859		Forlong, Major-Gen. J. G., 11 Douglas Crescent, F.R.G.S., R.A.S., Assoc. C.E., &c.	135
1828		Foster, John, Liverpool	

Date of Election.		
1858		Fraser, A. Campbell, M.A., D.C.L. Oxon., LL.D., Professor of Logic and Metaphysics in the University of Edinburgh, 20 Chester Street
1867	B. P.	* Fraser, Thomas R., M.D., F.R.C.P.E., F.R.S., Professor of Materia Medica in the University of Edinburgh, 37 Melville Street
1878		* Galloway, R. K., B.A., Advocate, 42 Northumberland Street
1867		Gayner, Charles, M.D., Oxford 140
1868		Gamgee, J. Samson, Birmingham
1880	P.	* Geddes, Patrick, Assistant to the Professor of Botany in the University of Edinburgh, and Lecturer on Zoology at Minto House, 81A Princes Street
1861	B. P.	* Geikie, Archibald, LL.D., F.R.S., F.G.S., Director of the Geological Surveys of Great Britain, and Head of the Geological Museum, 28 Jermyn Street, London
1871	P.	* Geikie, James, F.R.S., F.G.S., Professor of Geology in the University of Edinburgh, 10 Bright Crescent, Newington
1881		* Gibson, G. A., D.Sc., M.B., F.R.C.P.E., F.G.S., 1 Randolph Cliff 145
1877		* Gibson, John, Ph.D., 10 Ethel Terrace
1870		* Gifford, Hon. Lord, late one of the Senators of the College of Justice, Granton House
1879		* Gilray, Thomas, M.A.. Professor of English Language and Literature and Modern History in University College, Dundee
1880		* Gilruth, George Ritchie, 67 York Place, Edinburgh
1850		Gosset, Major-General W. D., R.E., 70 Edith Road, West Kensington, London 150
1867		* Graham, Andrew, M.D., R.N., Army and Navy Club, 36 Pall Mall, London, S.W.
1880		* Graham, James, 195 Bath Street, Glasgow
1869		* Grant, Sir Alexander, Bart., M.A., LL.D., Principal of the University of Edinburgh, 21 Lansdowne Crescent
1851		Grant, The Rev. James, D.D., D.C.L., 15 Palmerston Place
1883		* Gray, Andrew, M.A., Chief Assistant to the Professor of Natural Philosophy in the University of Glasgow, 21 Hayburn Crescent, Partick 155
1875		* Gray, Robert, Secretary to the Royal Physical Society (VICE-PRESIDENT), Bank of Scotland House, Edinburgh
1880	P.	Gray, Thomas, B.Sc., 17 Hayburn Crescent, Partick Hill, Glasgow
1872		* Grieve, David, Lockharton Gardens, Colinton Road, Slateford, Edinburgh
1883		Gunning, R. H., M.D., 28 Bloomfield Road, Shepherd's Bush, London
1860	P.	* Guthrie, Frederick, M.A., Ph.D., F.R.S., Professor of Physics, Science School, South Kensington, London, W. 160
1867		* Haldane, D. R., M.D., Vice-President of the Royal College of Physicians, 22 Charlotte Square
1867		* Hallen, James H. B., F.R.P.S.E., Inspecting Veterinary Surgeon in H.M. Indian Army, 1 Lauriston Gardens, Edinburgh
1833		Hamilton, Alexander, LL.B., W.S., The Elms, Whitehouse Loan
1881	P.	* Hamilton, D. J., M.B., F.R.C.S.E., Professor of Pathological Anatomy in the University of Aberdeen, 1A Albyn Place, Aberdeen
1876	P.	* Hannay, J. Ballantyne, Cove Castle, Loch Long, N.B. 165
1869		Hartley, Sir Charles A., Memb. Inst. C.E., 26 Pall Mall, London
1877		Hartley, Walter Noel, Professor of Chemistry, Royal College of Science for Ireland, Dublin
1870		* Harvey, Thomas, M.A., LL.D., Rector of the Edinburgh Academy, 32 George Square
1880	P.	* Haycraft, J. Berry, M.B., B.Sc., Professor of Physiology in Sir Josiah Mason's Science College, Birmingham

Date of Election.			
1875		Hawkshaw, Sir John, Memb. Inst. C.E., F.R.S., F.G.S., 33 Great George Street, Westminster	170
1870		Heathfield, W. E., Alexandra Villa, Brighton	
1862		* Hector, James, C.M.G., M.D., F.R.S., Director of the Geological Survey, Wellington, New Zealand	
1876	K. P.	* Heddle, M. Forster, M.D., Professor of Chemistry in the University of St Andrews	
1869		* Henry, Isaac Anderson-, of Woodend, Hay Lodge, Trinity	
1881	P.	* Herdman, W. A., D.Sc., Professor of Natural History in University College, Liverpool	175
1871		Higgins, Charles Hayes, LL.D., Alfred House, Birkenhead	
1859		Hills, John, Lieutenant-Colonel, Bombay Engineers, C.B., United Service Club, London	
1879		Hislop, John, Secretary to the Department of Education, Wellington, New Zealand	
1828	P.	Home, David Milne, of Milne Graden, LL.D., F.G.S., President of the Geological Society of Edinburgh, 10 York Place	
1879		* Hood, Thomas H. Cockburn, F.G.S., Walton Hall, Kelso	180
1881		* Horne, John, F.G.S., Palæontologist to Geological Survey of Scotland, Huntly, Aberdeenshire	
1869		* Howe, Alexander, W.S., 17 Moray Place	
1883	P.	* Hoyle, William Evans, M.A., M.R.C.S., Office of Challenger Commission, 32 Queen Street, Edinburgh	
1872		* Hunter, Captain Charles, Pläs Cöch, Anglesea, and 17 St George's Square, London, S.W.	
1864		* Hutchison, Robert (Carlowrie Castle), and 29 Chester Street	185
1855		Inglis, Right Hon. John, LL.D., D.C.L., Lord Justice-General of Scotland, and Chancellor of the University of Edinburgh, 30 Abercromby Place	
1882		* Inglis, J. W., Memb. Inst. C.E., Myrtle Bank, Trinity	
1874		* Irvine, Alex. Forbes, of Drum, Advocate, Sheriff of Argyll (VICE-PRESIDENT), 25 Castle Terrace	
1875		Jack, William, M.A., Professor of Mathematics in the University of Glasgow	
1882		* Jamieson, A., Assoc. Memb. Inst. C.E., Principal of College of Science and Arts, Glasgow	190
1860		* Jamieson, George A., 24 St Andrew Square	
1880		Japp, A. H., LL.D., 13 Albion Square, Dalston, London	
1869	K. P.	* Jenkin, H. C. Fleeming, F.R.S., Memb. Inst. C.E., Professor of Engineering in the University of Edinburgh (VICE-PRESIDENT), 3 Great Stuart Street	
1865		* Jenner, Charles, Easter Duddingston Lodge	
1869		Johnston, John Wilson, M.D., Bengal	195
1867		* Johnston, T. B., F.R.G.S., 9 Claremont Crescent	
1874		Jones, Francis, Lecturer on Chemistry, Monton Place, Manchester	
1877		* Jolly, William, H.M. Inspector of Schools, F.G.S., Ardgowan, Pollokshields	
1866		* Keiller, Alexander, M.D., F.R.C.P.E., 21 Queen Street	
1877		* King, James, of Campsie, Dean of Faculty of Glasgow University, 12 Claremont Terrace, Glasgow	200
1880		* King, W. F., Lonend, Trinity, Edinburgh	
1883		* Kinnear, the Hon. Lord, one of the Senators of the College of Justice, 2 Moray Place	
1878		* Kintore, the Right Hon. the Earl of, M.A. Cantab., Keith Hall, Inverurie, Aberdeenshire	
1875		* Kirkwood, Anderson, LL.D., 7 Melville Terrace, Stirling	
1880	P.	* Knott, C. G., D.Sc., Professor of Natural Philosophy in the Imperial University of Tokio, Japan	205

Date of Election.			
1868		* Laidlay, J. W., of Seacliffe, North Berwick	
1875		* L'Amy, John Ramsay, of Dunkenny, Forfarshire, 107 Cromwell Road, London, S.W.	
1878		* Lang, P. R. Scott, M.A., B.Sc., Professor of Mathematics in the University of St Andrews	
1870		* Laurie, Simon S., M.A., Professor of Education in the University of Edinburgh, Nairn Lodge, Duddingston	
1881		* Lawson, Robert, M.D., Deputy-Commissioner in Lunacy, 33 Drumearn Ter., Grange Loans	210
1872		* Lee, Alexander H., C.E., Blairhoyle, Stirling	
1872		* Lee, the Hon. Lord, one of the Senators of the College of Justice, 26 Charlotte Square	
1882		* Leslie, Alexander, Memb. Inst. C.E., 12 Greenhill Terrace, Edinburgh	
1883		* Leslie George, M.B., C.M.Ed., Old Manse, Falkirk	
1863		* Leslie, Hon. G. Waldegrave, Leslie House, Leslie	215
1858		Leslie, James, Memb. Inst. C.E., 2 Charlotte Square	
1874	P.	* Letts, E. A., Ph.D., F.I.C., F.C.S., Professor of Chemistry, Queen's College, Belfast	
1864		* Lindsay, William, Hermitage-Hill House, Leith	
1870	B. P.	* Lister, Sir Joseph, Bart., M.D., F.R.C.S.L., F.R.C.S.E., LL.D., F.R.S., Professor of Clinical Surgery, King's College, Surgeon Extraordinary to the Queen, 12 Park Crescent, Portland Place, London, N.W.	
1882		* Livingston, Josiah, 4 Minto Street	220
1871		* Logie, Cosmo Gordon, M.D., Deputy Surgeon-General, Royal Horse Guards, 47 Queensborough Terrace, Kensington Gardens, London, W.	
1861	P.	* Lorimer, James, M.A., Advocate, Professor of Public Law in the University of Edinburgh, 1 Bruntsfield Crescent	
1849		Lowe, W. H., M.D., F.R.C.P.E., Woodcote, Inner Park, Wimbledon	
1855		Macadam, Stevenson, Ph.D., Lecturer on Chemistry, Surgeons' Hall, Edinburgh, 11 East Brighton Crescent, Portobello	
1883		* M'Bride, P., M.D., F.R.C.P.Ed., 16 Chester Street	225
1867		* M'Candlish, John M., W.S., 27 Drumsheugh Gardens	
1871		* Macdonald, Angus, M.D., F.R.C.P.E., F.R.C.S.E., 29 Charlotte Square	
1847		Macdonald, W. Macdonald, of St Martin's, Perth	
1878		* MacDougall, Alan, Memb. Inst. C.E., Mail Building, 52 King Street West, Toronto, Canada	
1878	P.	* Macfarlane, Alexander, M.A., D.Sc., Examiner in Mathematics in the University of Edinburgh, 4 Gladstone Terrace	230
1877		* Macfie, Robert A., Dreghorn Castle, Colinton	
1878		* M'Gowan, George, F.I.C., 22 East Claremont Street	
1880	P.	MacGregor, J. Gordon, M.A., D.Sc., Professor of Physics in Dalhousie College, Halifax, Nova Scotia	
1879		* M'Grigor, Alexander Bennett, LL.D., 19 Woodside Terrace, Glasgow	
1869	N. P.	* M'Intosh, William Carmichael, M.D., LL.D., F.R.S., F.L.S., Professor of Natural History in the University of St Andrews, 2 Abbotsford Crescent, St Andrews	235
1882		* Mackay, John Sturgeon, M.A., Mathematical Master in the Edinburgh Academy	
1873	P.	* M'Kendrick, John G., M.D., F.R.C.P.E., Professor of the Institutes of Medicine in the University of Glasgow	
1840		Mackenzie, John, New Club, Princes Street	
1843	P.	Maclagan, Douglas, M.D., F.R.C.P.E. and F.R.C.S.E., Professor of Medical Jurisprudence in the University of Edinburgh, 28 Heriot Row	
1853		Maclagan, General R., Royal Engineers, 37 Lexham Gardens, Kensington, W.	240

Date of Election.			
1869		* Maclagan, R. Craig, M.D., 5 Coates Crescent	
1864		* M'Lagan, Peter, of Pumpherston, M.P., Clifton Hall, Ratho	
1869		* M'Laren, The Hon. Lord, one of the Senators of the College of Justice, 46 Moray Place	
1870		* Macleod, George H. B., M.D., F.R.C.S.E., Regius, Professor of Surgery in the University of Glasgow, and Surgeon in Ordinary to the Queen in Scotland, 10 Woodside Crescent, Glasgow	
1876		* Macleod, Rev. Norman, 7 Royal Circus	245
1883		* Macleod, W. Bowman, L.D.S., 43 George Square, Edinburgh	
1872		* Macmillan, Rev. Hugh, D.D., LL.D., Seafield, Greenock	
1876		* Macmillan, John, M.A., B.Sc., Mathematical Master, Perth Academy	
1866		* Macnair, John, 33 Moray Place	
1883		* M'Roberts, George, F.C.S., Ardeer, Stevenston	250
1858		Malcolm, R. B., M.D., F.R.C.P.E., 126 George Street	
1880	P.	Marsden, R. Sydney, D.Sc., F.I.C., F.C.S., South-Gate House, Eckington, near Chesterfield, Derbyshire, and 14 Lothian Road, Edinburgh	
1882	P.	Marshall, D. H., M.A., Professor of Physics in Queen's University and College, Kingston, Ontario, Canada	
1869		Marshall, Henry, M.D., Clifton, Bristol	
1864		* Marwick, James David, LL.D., Town-Clerk, Glasgow	255
1866		* Masson, David, LL.D., Professor of Rhetoric and English Literature in the University of Edinburgh, 58 Great King Street	
1883		* Matthews, James Duncan, 10 Lonsdale Terrace, Edinburgh	
1853		Mercer, Græme Reid, of Gorthie, Ceylon Civil Service	
1875		* Millar, C. H., of Blaircastle, 5 Palmerston Place	
1852		Miller, Thomas, M.A., LL.D., Emeritus Rector of Perth Academy, Inchbank House, Perth	260
1833		Milne, Admiral Sir Alexander, Bart., G.C.B., Inveresk	
1878		* Milne, John, Trinity Grove, Edinburgh	
1875		* Milroy, John, C.E., Torsonce, Stow	
1866		* Mitchell, Arthur, M.A., M.D., LL.D., Commissioner in Lunacy, 34 Drummond Place	
1843		Mitchell, Joseph, Memb. Inst. C.E., Viewhill, Inverness	265
1879		* Moinet, Francis W., M.D., F.R.C.P.E., 13 Alva Street	
1865		* Moir, John J. A., M.D., F.R.C.P.E., 52 Castle Street	
1870		* Moncreiff, the Right Hon. Lord, of Tullibole, Lord Justice-Clerk, LL.D. (PRESIDENT), 15 Great Stuart Street	
1871		* Moncrieff, Rev. William Scott, of Fossaway, Bishop-Wearmouth, Sunderland	
1868		* Montgomery, Very Rev. Dean, M.A., D.D., 17 Atholl Crescent	270
1879		* Morrison, J. B. Brown, of Finderlie and Murie, Perthshire	
1877	P.	* Morrison, Robert Milner, D.Sc., F.I.C., Senior Demonstrator of Chemistry in the University of Edinburgh, 20 Pentland Terrace	
1873		* Muir, M. M. Pattison, Prælector on Chemistry, Caius College, Cambridge	
1874	P.	* Muir, Thomas, M.A., High School, Glasgow	
1870		* Munn, David, M.A., Mathematical Master, Royal High School, Edinburgh	275
1857		Murray, John Ivor, 8 Huntriss Row, Scarborough	
1877	N. P.	* Murray, John, Director of the Challenger Expedition Commission, 32 Queen Street, and United Service Club, Edinburgh	
1877		* Napier, John, 23 Portman Square, London	
1874		* Napier, James, Maryfield House, Bothwell	
1866		* Nelson, Thomas, St Leonard's, Dalkeith Road	280

Date of Election.			
1883		* Newcombe, Henry, F.R.C.S.E., 5 Dalrymple Crescent, Edinburgh	
1880	P.	* Nicol, W. W. J., M.A., B.Sc., Lecturer on Chemistry, Mason College, Birmingham	
1878		Norris, Richard, M.D., Professor of Physiology, Queen's College, Birmingham	
1877		Panton, George A., 95 Colmore Row, Birmingham	
1881	P.	* Peach, B. N., F.G.S., Acting Palæontologist of the Geological Survey of Scotland, 8 Annandale Street	285
1863		* Peddie, Alexander, M.D., F.R.C.P.E., 15 Rutland Street	
1868		* Peddie, John Dick, M.P., Architect, 33 Buckingham Terrace	
1869		Pender, John, M.P., Manchester	
1883		Phillips, Charles D. F., M.D., 10 Henrietta Street, Cavendish Square, London, W.	
1859	P.	Playfair, The Right Hon. Sir Lyon, C.B., LL.D., F.R.S., M.P. for the Universities of Edinburgh and St Andrews, 68 Onslow Gardens, London	290
1877		Pole, William, Memb. Inst. C.E., F.R.S., Mus. Doc., 31 Parliament Street, Westminster, S.W.	
1874		Powell, Baden Henry Baden-, Forest Department, India	
1852		Powell, Eyre B., C.S.I., M.A., Victoria Villa, Weston Road, Bath	
1880		* Prentice, Charles, C.A., Actuary, 8 St Bernard's Crescent	
1875		Prevost, E. W., Ph.D., Ellesmere, Salop	295
1849		Primrose, Hon. B. F., C.B., 22 Moray Place	
1882		* Pryde, David, M.A., LL.D., Head Master of the Ladies' College, 10 Fettes Row, Edinburgh	
1880		* Pullar, Robert, Tayside, Perth	
1882		* Rattray, James Clerk, M.D., 61 Grange Loan, Edinburgh	
1869		Raven, Rev. Thomas Milville, M.A., The Vicarage, Crakehall, Bedale	300
1883		* Readman, J. B., 9 Moray Place, Edinburgh	
1865		* Redford, Rev. Francis, M.A., The Rectory, Silloth	
1875		* Richardson, Ralph, W.S., Vice-Pres. of the Geological Society, 10 Magdala Place	
1872		Ricarde-Seaver, Major F. Ignacio, Conservative Club, St James' Street, London, S.W., and 2 Rue Lafitte, Boulevard des Italiens, Paris	
1883		* Ritchie, R. Peel, M.D., F.R.C.P.E., 1 Melville Crescent	305
1877		* Roberton, James, LL.D., Professor of Conveyancing in the University of Glasgow, 1 Park Terrace East, Glasgow	
1880		Roberts, D. Lloyd, M.D., F.R.C.P.L., 23 St John Street, Manchester	
1879		* Robertson, Major-General A. Cuningham, 86 Great King Street	
1872		* Robertson, D. M. C. L. Argyll, M.D., F.R.C.S.E., 18 Charlotte Square	
1859		Robertson, George, Memb. Inst. C.E., 47 Albany Street	310
1877	P.	* Robinson, George Carr, F.I.C., Lecturer on Chemistry in the Royal Institution, Hull	
1881		* Rogerson, John Johnston, B.A., LL.B., Merchiston Castle Academy, Edinburgh	
1862	P.	* Ronalds, Edmund, LL.D., Bonnington House, Bonnington Road, Edinburgh	
1881		Rosebery, The Right Hon. the Earl of, LL.D., Dalmeny	
1880		Rowland, L. L., M.A., M.D., President of the Oregon State Medical Society, and Professor of Physiology and Microscopy in Williamette University, Salem, Oregon	315
1852		Russell, Alexander James, C.S., 9 Shandwick Place	
1880		* Russell, J. A., M.A., B.Sc., M.B., Woodville, Canaan Lane, Edinburgh	
1869	P.	* Rutherford, Wm., M.D., F.R.C.P.E., F.R.S., Professor of the Institutes of Medicine in the University of Edinburgh, 14 Douglas Crescent	

Date of Election			
1863		* Sanderson, James, Deputy Inspector-General of Hospitals, F.R.C.S.E., 41 Manor Place	
1864		Sandford, The Right Rev. D. F., LL.D., Bishop of Tasmania	320
1849	P.	Sang, Edward, C.E., LL.D., Secretary to the Royal Scottish Society of Arts (VICE-PRESIDENT), 6 Mollendo Terrace	
1846		Schmitz, Leonard, LL.D., 26 Belsize Park Gardens, London, N.W.	
1880		Scott, J. H., M.B., C.M., M.R.C.S., Professor of Anatomy in the University of Otago, New Zealand	
1875		Scott, Michael, Memb. Inst. C.E., 9 Great Queen Street, Westminster, London	
1864		* Sellar, W. Y., M.A., LL.D., Professor of Humanity in the University of Edinburgh, 15 Buckingham Terrace	325
1872		* Seton, George, M.A., Advocate, 42 Greenhill Gardens	
1872		* Sibbald, John, M.D., Commissioner in Lunacy, 3 St Margaret's Road, Whitehouse Loan	
1870		* Sime, James, M.A., South Park, Fountainhall Road, Edinburgh	
1871		* Simpson, A. R., M.D., F.R.C.P.E., Professor of Midwifery in the University of Edinburgh, 52 Queen Street	
1859	P.	Skene, Wm. F., W.S., LL.D., D.C.L., Historiographer-Royal for Scotland, 27 Inverleith Row	330
1876		* Skinner, William, W.S., Town-Clerk of Edinburgh, 35 George Square	
1868		* Smith, Adam Gillies, C.A. (TREASURER), 64 Princes Street	
1882	P	Smith, C. Michie, B.Sc., Professor of Physical Science, Christian College, Madras, India	
1883		Smith, James Greig, M.A., M.B., 16 Victoria Square, Clifton	
1871		* Smith, John, M.D., F.R.C.S.E., President of the Royal College of Surgeons, Edinburgh, 11 Wemyss Place	335
1855		Smith, R. M., 4 Bellevue Crescent	
1871	P.	* Smith, Rev. W. Robertson, M.A., LL.D., Lord Almoner's Professor of Arabic in the University of Cambridge, 20 Duke Street, Edinburgh	
1880		Smith, W. Robert, M.D., Bayshill Villa, Cheltenham	
1846	K.B. P.	Smyth, Piazzi, Professor of Practical Astronomy in the University of Edinburgh, and Astronomer-Royal for Scotland, 15 Royal Terrace	
1880		Sollas, W. J., M.A., Fellow of St John's College, Cambridge, and Professor of Geology and Zoology in University College, Bristol	340
1882		* Sorley, James, F.F.A., C.A., 26 George Street, Edinburgh	
1874	P.	* Sprague, T. B., M.A., 29 Buckingham Terrace	
1850	P.	Stark, James, M.D., F.R.C.P.E., of Huntfield, Underwood, Bridge of Allan	
1844		Stevenson, David, Memb. Inst. C.E., 45 Melville Street	
1877		* Stevenson, James, F.R.G.S., 4 Woodside Crescent, Glasgow	345
1868		Stevenson, John J., Red House, Bayswater Hill, London, W.	
1848	P.	Stevenson, Thomas, Memb. Inst. C.E., F.G.S. (VICE-PRESIDENT), 84 George Street	
1868		Stewart, Colonel J. H. M. Shaw, Royal Engineers, Madras	
1878		* Stewart, James R., M.A., 10 Minto Street	
1866		* Stewart, T. Grainger, M.D., F.R.C.P.E., Professor of the Practice of Physic in the University of Edinburgh, 19 Charlotte Square	350
1873		* Stewart, Walter, 22 Torphichen Street	
1848		Stirling, Patrick J., LL.D., Kippendavie House, Dunblane	
1877		* Stirling, William, M.D., Sc.D., Professor of Institutes of Medicine in the University of Aberdeen	
1823		Stuart, Captain T. D., H.M.I.S.	
1870		* Swan, Patrick Don, Provost of Kirkcaldy	355

Date of Election.			
1848	P.	Swan, Wm., LL.D., Emeritus Professor of Natural Philosophy in the University of St Andrews, President of the Royal Scottish Society of Arts, Ardchapel, Helensburgh	
1844		Swinton, A. Campbell, of Kimmerghame, LL.D., Dunse	
1875		* Syme, James, 10 Buckingham Terrace	
1872		Tait, the Rev. A., LL.D., Canon of Tuam, Moylough Rectory, Ballinasloe, Ireland	
1861	K.P.	* Tait, P. Guthrie, M.A., Professor of Natural Philosophy in the University of Edinburgh (General Secretary), 38 George Square	360
1870		* Tatlock, Robert R., City Analyst's Office, 138 Bath Street, Glasgow	
1872		* Teape, Rev. Charles R., M.A., Ph.D., 15 Findhorn Place	
1873		* Tennent, Robert, 23 Buckingham Terrace	
1843		Thomson, Allen, M.D., F.R.C.S.E., F.R.S., Emeritus Professor of Anatomy in the University of Glasgow, 66 Palace Garden Terrace, London, W.	
1870		* Thomson, Rev. Andrew, D.D., 63 Northumberland Street	365
1875		* Thomson, James, LL.D., F.R.S., Professor of Engineering in the University of Glasgow, 2 Florentine Gardens, Hillhead, Glasgow	
1880		Thomson, John Millar, King's College, London, W.C.	
1863		* Thomson, Murray, M.D., Professor of Chemistry, Thomason College, Roorkee, India	
1870		* Thomson, Spencer C., Actuary, 10 Chester Street	
1847	K.P.	Thomson, Sir William, LL.D., D.C.L., F.R.S. (Hon. Vice-President), Regius Professor of Natural Philosophy in Univ. of Glasgow, Foreign Associate of Institute of France	370
1882		Thomson, William, M.A., B.Sc., Professor of Mathematics in University College, Stellenbosch, Cape Colony	
1870		* Thomson, William Burns, F.R.C.P.E., F.R.C.S.E., Maison Flory, Route de Grasse, Cannes, France	
1876		Thomson, William, Royal Institution, Manchester	
1878		Thorburn, Robert Macfie, Uddevalla, Sweden	
1874	N.P.	* Traquair, R. H., M.D., F.R.S., F.G.S., Keeper of the Natural History Collections in the Museum of Science and Art, Edinburgh, 8 Dean Park Crescent	375
1874		* Tuke, J. Batty, M.D., F.R.C.P.E., 20 Charlotte Square	
1879		* Turnbull, John, of Abbey St Bathans, W.S., 49 George Square	
1867		* Turnbull, William, Menslaws, Jedburgh	
1861	N.P.	* Turner, William, M.B., F.R.C.S.E., F.R.S., Professor of Anatomy in the University of Edinburgh (Secretary), 6 Eton Terrace	
1877		* Underhill, Charles E., B.A., M.B., F.R.C.P.E., F.R.C.S.E., 8 Coates Crescent	380
1875		Vincent, Charles Wilson, Royal Institution, Albemarle Street, London	
1867		* Waddell, Peter, 5 Claremont Park, Leith	
1873		* Walker, Robert, M.A., University, Aberdeen	
1864		* Wallace, William, Ph.D., City Analyst's Office, 138 Bath Street, Glasgow	
1883		* Watson, Charles, Redhall, Slateford	385
1870		* Watson, James, C.A., 45 Charlotte Square	
1866		* Watson, John K., 14 Blackford Road	
1873	P.	* Watson, Morrison, M.D., F.R.C.P.E., Professor of Anatomy, Owens College, Manchester	
1866		* Watson, Patrick Heron, M.D., F.R.C.P.E., F.R.C.S.E., 16 Charlotte Square	
1862	P.	Watson, Rev. Robert Boog, B.A., Free Church Manse, Cardross, Dumbartonshire	390

Date of Election.		
1877	Weldon, Walter, F.C.S., Rede Hall, Burstow, Surrey	
1873	Welsh, David, Major-General, R.E., R.A., 1 Barton Terrace, Dawlish	
1840	Welwood, Allan A. Maconochie, LL.D., of Meadowbank and Garvoch, Kirknewton	
1882	* Wenley, James, Treasurer of the Bank of Scotland, 5 Drumsheugh Gardens	
1876	White, Rev. Francis Le Grix, M.A., F.G.S., Leaming-on-Ulleswater, Penrith	395
1881	Whitehead, Walter, F.R.C.S.E., 202 Oxford Road, Manchester	
1883	Wickham, R. H. B., F.R.C.S.E., Borough Lunatic Asylum, Newcastle-on-Tyne	
1879	* Will, John Charles Ogilvie, M.D., 12 Union Terrace, Aberdeen	
1868	* Williams, W., Principal and Professor of Veterinary Medicine and Surgery, New Veterinary College, Gayfield House	
1858	Williamson, Thomas, M.D., F.R.C.S.E., 28 Charlotte Street, Leith	400
1879	* Wilson, Andrew, Ph.D., Lecturer on Zoology and Comparative Anatomy in the Edinburgh Medical School, 118 Gilmore Place	
1877	* Wilson, Charles E., M.A., LL.D., H. M. Senior Inspector of Schools for Scotland, 19 Palmerston Place	
1878	* Wilson, Rev. John, M.A., Bannockburn Academy	
1875	Wilson, Daniel, LL.D., President of the University of Toronto, and Professor of English Literature in that University	
1882	Wilson, George, M.A., M.D., 23 Claremont Road, Leamington	405
1834	Wilson, Isaac, M.D.	
1847	Wilson, John, Professor of Agriculture in the University of Edinburgh	
1870	Winzer, John, Chief Surveyor, Civil Service, Ceylon, 7 Dryden Place, Newington, Edinburgh	
1880	* Wise, Thomas Alexander, M.D., F.R.C.P.E., Inchrye Abbey, Newburgh, Fife	
1864	* Wood, Alexander, M.D., F.R.C.P.E., 12 Strathearn Place	410
1855	Wright, Thomas, M.D., F.R.S., Cheltenham	
1864	* Wyld, Robert S., LL.D , 19 Inverleith Row	
1882	* Young, Andrew, 22 Elm Row	
1882	* Young, Frank W., F.C.S., Lecturer on Natural Science, High School, Dundee, 4 Airlie Terrace, Dundee	
1882	* Young, Thomas Graham, Limefield, West Calder	415

LIST OF HONORARY FELLOWS

AT NOVEMBER 1883.

His Royal Highness The PRINCE OF WALES.

FOREIGNERS (LIMITED TO THIRTY-SIX BY LAW X.).

Elected.		
1864	Robert Wilhelm Bunsen,	*Heidelberg.*
1867	Michel Eugène Chevreul,	*Paris.*
1858	James D. Dana,	*New Haven, Conn., United States.*
1877	Alphonse De Candolle,	*Geneva.*
1883	Luigi Cremona,	*Rome.*
1879	Franz Cornelius Donders,	*Utrecht.*
1855	Jean Baptiste Dumas,	*Paris.*
1877	Carl Gegenbaur,	*Heidelberg.*
1879	Asa Gray,	*Harvard University, United States.*
1883	Julius Hann,	*Vienna.*
1864	Hermann Ludwig Ferdinand Helmholtz,	*Berlin.*
1879	Jules Janssen,	*Paris.*
1875	August Kekulé,	*Bonn.*
1868	Gustav Robert Kirchhoff,	*Berlin.*
1875	Hermann Kolbe,	*Leipzig.*
1864	Albert Kölliker,	*Würzburg.*
1875	Ernst Eduard Kummer,	*Berlin.*
1864	Richard Lepsius,	*Berlin.*
1876	Ferdinand de Lesseps,	*Paris.*
1864	Rudolph Leuckart,	*Leipzig.*
1881	Sven Lovén,	*Stockholm.*
1876	Carl Ludwig,	*Leipzig.*
1878	J. N. Madvig,	*Copenhagen.*
1855	Henry Milne-Edwards,	*Paris.*
1864	Theodore Mommsen,	*Berlin.*
1881	Simon Newcomb,	*Washington.*
1874	Louis Pasteur,	*Paris.*
1864	Karl Theodor von Siebold,	*Munich.*
1881	Johannes Iapetus Smith Steenstrup,	*Copenhagen*
1878	Otto Wilhelm Struve,	*Pulkowa.*
1855	Bernard Studer,	*Bern.*
1874	Otto Torell,	*Lund.*
1868	Rudolph Virchow,	*Berlin.*
1874	Wilhelm Eduard Weber,	*Göttingen.*
1883	Charles Adolphe Wurtz,	*Paris.*

Total, 35.

BRITISH SUBJECTS (LIMITED TO TWENTY BY LAW X.).

Elected.		
1849	John Couch Adams, LL.D., F.R.S., Corresp. Mem. Inst. France,	*Cambridge.*
1835	Sir George Biddell Airy, K.C.B., M.A., LL.D., D.C.L., F.R.S., Foreign Associate Inst., France,	*Greenwich.*
1870	Thomas Andrews, M.D., LL.D., F.R.S.,	*Belfast.*
1865	Arthur Cayley, LL.D., F.R.S., Corresp. Mem. Inst. France,	*Cambridge.*
1874	John Anthony Froude, LL.D.,	*London.*
1881	The Hon. Justice Sir William Robert Grove, M.A., LL.D., D.C.L., F.R.S.,	*London.*
1883	Sir Joseph Dalton Hooker, K.C.S.I., C.B., M.D., D.C.L., LL.D., F.R.S., F.G.S., Corresp. Mem. Inst. France, Director of the Royal Gardens, Kew,	*London.*
1876	Thomas Henry Huxley, LL.D., D.C.L., President of the Royal Society, F.L.S., F.Z.S., F.G.S., Corresp. Mem. Inst. France,	*London.*
1867	James Prescott Joule, LL.D., D.C.L., F.R.S., Corresp. Mem. Inst. France,	*Manchester*
1845	Richard Owen, C.B., M.D., LL.D., D.C.L., F.R.S., Foreign Associate Inst. France,	*London.*
1881	The Rev. George Salmon, D.D., LL.D., D.C.L., F.R.S.,	*Dublin.*
1878	Balfour Stewart, M.A., LL.D., F.R.S.,	*Manchester.*
1864	George Gabriel Stokes, M.A., LL.D., D.C.L., Sec. R.S., Corresp. Mem. Inst. France,	*Cambridge.*
1874	James Joseph Sylvester, M.A., LL.D., F.R.S., Corresp. Mem. Inst. France,	*Baltimore.*
1864	Alfred Tennyson, D.C.L., F.R.S., Poet Laureate,	*Isle of Wight.*
1883	Alexander William Williamson, LL.D., F.R.S., V.P.C.S., Corresp. Mem. Inst. France,	*London.*
1883	Colonel Henry Yule, C.B., Member of the Council of India,	*London.*

Total, 17.

LIST OF ORDINARY FELLOWS.

Elected during SESSION 1880–81, arranged according to the Date of their Election.

6th December 1880.

Thomas Alexander Wise, M.D. (*re-admitted*).
Thomas Gray, B.Sc.

3d January 1881.

G. A. Gibson, D.Sc., F.R.C.P.E.

7th February 1881.

Walter Whitehead, F.R.C.S.E.
A. H. Anglin, M.A., M.R.I.A.
J. A. Harvie Brown, of Quarter.
W. A. Herdman, D.Sc.
Thomas William Rumble, Memb. Inst. C.E.
Robert Lawson, M.B.

7th March 1881.

John Horne, F.G.S.
B. N. Peach, F.G.S

4th April 1881.

Leonard Dobbin, Ph.D.
D. J. Hamilton, M.B. Prof. of Pathology, Univ. of Aberdeen.

6th June 1881.

The Right Hon. the Earl of Rosebery, LL.D.
Augustus J. D. Cameron, Memb. Inst. C.E.
Walter Berry, Danish Consul-General.
John Johnston Rogerson, A.B., LL.B.
J. E. Tierney Aitchison, M.D.

Elected during SESSION 1881–82.

5th December 1881.

Sir Peter Coats.
Andrew Young.

16th January 1882.

D. B. Dott.
James Clerk Rattray, M.D.

6th February 1882.

Alexander Leslie, Memb. Inst. C.E.
John Sturgeon Mackay, M.A.
Henry Barnes, M.D.

6th March 1882.

James Sorley, Actuary.
William Thomson, M.A.
Thomas Graham Young.
W. Dyce Cay, Memb. Inst. C.E.

3d April 1882.

J. A. Dixon.
Prof. C. Michie Smith, B.Sc.
D. H. Marshall, M.A.
Josiah Livingston.

1st May 1882.

David Pryde, M.A., LL.D.
J. W. Inglis, Memb. Inst. C.E.
Frank W. Young, F.C.S.
T. R. Buchanan, M.A., M.P.

5th June 1882.

George Wilson, M.A., M.D.
Frank E. Beddard, B.A.

3d July 1882.

Andrew Jamieson, Memb. Inst. C.E.
J. A. Wenley, Treasurer, Bank of Scotland.

ELECTED DURING SESSION 1882–83.

4th December 1882.

R H. Gunning, M.D.
Alexander Bruce, M.A., M.B.
Charles D. F. Phillips, M.D.

15th January 1883.

R. Peel Ritchie, M.D.

5th February 1883.

The Hon. Lord Kinnear.
W. Bowman Macleod, L.D.S.
R. H. B. Wickham, F.R.C.S. Ed.

5th March 1883.

William E. Hoyle, M.A., M.R.C.S.
James Duncan Matthews.
James Greig Smith, M.A., M.B.
John Archibald, M.B., C.M.
Robert Rowand Anderson.
Andrew Gray, M.A.

2d April 1883.

P. M'Bride, M.D.
G. W. W. Barclay, M.A.
Thomas Andrews, F.C.S.

7th May 1883.

Professor S. H. Butcher, M.A.
George M'Roberts, F.C.S.
Robert W. Felkin, F.R.G.S.
George Leslie, M.B., C.M.

4th June 1883.

J. R. Readman.
Henry Newcombe, F.R.C.S.E.
Charles Watson.

2d July 1883.

J. Graham Brown, M.D.

ELECTIONS OF HONORARY FELLOWS.

BRITISH HONORARY FELLOWS.

Elected from November 1880 *to November* 1881.

The Hon. Justice Sir William Robert Grove, M.A., D.C.L., LL.D.,	*London.*
The Rev. George Salmon, D.D., D.C.L., LL.D., Reg. Prof. of Divinity, Trinity College,	*Dublin.*

Elected from November 1882 *to November* 1883.

Sir Joseph Dalton Hooker, K.C.S.I., M.D., D.C.L., LL.D., Director of the Royal Gardens, Kew, Corresp. Mem. Inst. France,	*London.*
William Spottiswoode, D.C.L., LL.D., Pres. Royal Society, Corresp. Mem. Inst. France,	*London.*
Alexander William Williamson, LL.D., Corresp. Mem. Inst. France,	*London.*
Colonel Henry Yule, C.B., Member of Council of India,	*London.*

FOREIGN HONORARY FELLOWS.

Elected from November 1878 *to November* 1879.

Frank Cornelius Donders, Professor of Physiology,	*Utrecht.*
Asa Gray, Professor of Botany,	*Cambridge, U.S.*
Jules Janssen, Director of the Observatory, Meudon	*Paris.*
Johann Benedict Listing, Professor of Natural Philosophy,	*Göttingen.*

Elected from November 1880 *to November* 1881.

Sven Lovén, Professor of Physiology,	*Stockholm.*
Simon Newcomb, Professor of Astronomy,	*Washington.*
Emile Plantamour, Professor of Astronomy,	*Geneva.*
Johannes Japetus Smith Steenstrup, Professor of Zoology,	*Copenhagen.*

Elected from November 1882 *to November* 1883.

Luigi Cremona, Professor of Mathematics,	*Rome.*
Julius Hann, Director of Meteorological Institute,	*Vienna*
Charles Adolphe Wurtz, Professor of Chemistry,	*Paris.*

LIST OF FELLOWS DECEASED, RESIGNED, AND CANCELLED.

HONORARY FELLOWS (BRITISH) DECEASED.

From November 1880 to November 1881.

Thomas Carlyle.

HONORARY FELLOWS (BRITISH) DECEASED.

From November 1881 to November 1882.

Dr Charles Darwin, F.R.S.
Rev. Dr Romney Robinson.

From November 1882 to November 1883.

Dr Henry John Stephen Smith, F.R.S.
Dr William Spottiswoode, P.R.S.
General Sir Edward Sabine, R.A., F.R.S.

HONORARY FELLOWS (FOREIGN) DECEASED.

From November 1880 to November 1882.

Joseph Liouville.
Émile Plantamour.
Friedrich Wöhler.

From November 1882 to November 1883.

Johann Benedict Listing.

ORDINARY FELLOWS DECEASED.

From November 1880 to November 1881.

Dr John Hill Burton.
Dr John Cumming.
Dr Handyside.
Dr Lauder Lindsay.
Professor Sanders.
David Smith.
Sir Alexander Taylor, M.D.
James Walker, W.S.
Dr J. G. Wilson.
Dr Andrew Wood.

From November 1881 to November 1882.

David Anderson of Moredun.
Charles Davidson Bell.
Dr John Brown.
Sir Robert Christison, M.D.
Sir John Rose Cormack, M.D.
Joseph Anthony Dixon.
Sheriff Frederick Hallard.
William King.
John M'Culloch.
Sir Daniel MacNee.
Charles Morehead, M.D.
Dr John Muir.
Richard Parnell.
Samuel Raleigh, C.A.
William Robertson, M.D.
John Scott Russell.
Professor Spence.
Sir Wyville Thomson.
Robert Wilson.

From November 1882 to November 1883.

Warren Hastings Anderson (death only intimated in November 1883).
Dr William Chambers.
Dr James Scarth Combe.
William Jamieson, Surgeon-Major (death only intimated in February 1883).
David Maclagan, F.S.A., Actuary.
Right Hon. Sir John M'Neill, G.C.B.
John Miller, Memb. Inst. C.E.
Professor Pirrie.
Andrew Pritchard.
David Rhind.
Donald Ross, M.A.
Thomas William Rumble, Memb. Inst. C.E.
John Alexander Smith, M.D.
William Thomas Thomson, Actuary.
James Young of Kellie, F.R.S.

FELLOWS RESIGNED.

During Session 1879–80.

Dr A. Bruce Bremner.
David MacGibbon.
Professor J. Bell Pettigrew, F.R.S.

During Session 1880–81.

The Rev. Joseph Goodsir.

During Session 1882–83.

James Blaikie, M.A.
Professor H. Alleyne Nicholson.

FELLOWS CANCELLED.

During Session 1880–81.

G. W. Hay.
James Powrie.

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,, Part 2.	1 5 0	1 1 0
,, Part 3.	0 18 0	0 13 6
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XXXII. Part 1.	1 0 0	0 16 0

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TRANSACTIONS

OF THE

ROYAL SOCIETY OF EDINBURGH.

VOL. XXX. PART IV.—FOR THE SESSION 1882–83.

CONTENTS.

LAWS

OF THE

ROYAL SOCIETY OF EDINBURGH,

AS REVISED 20th FEBRUARY 1882.

LAWS.

[By the Charter of the Society (printed in the *Transactions*, Vol. VI. p. 5), the Laws cannot be altered, except at a Meeting held one month after that at which the Motion for alteration shall have been proposed.]

I.

THE ROYAL SOCIETY OF EDINBURGH shall consist of Ordinary and Honorary Fellows. Title.

II.

Every Ordinary Fellow, within three months after his election, shall pay Two Guineas as the fee of admission, and Three Guineas as his contribution for the Session in which he has been elected; and annually at the commencement of every Session, Three Guineas into the hands of the Treasurer. This annual contribution shall continue for ten years after his admission, and it shall be limited to Two Guineas for fifteen years thereafter.* The fees of Ordinary Fellows residing in Scotland.

III.

All Fellows who shall have paid Twenty-five years' annual contribution shall be exempted from farther payment. Payment to cease after 25 years.

IV.

The fees of admission of an Ordinary Non-Resident Fellow shall be £26, 5s., payable on his admission; and in case of any Non-Resident Fellow coming to reside at any time in Scotland, he shall, during each year of his residence, pay the usual annual contribution of £3, 3s., payable by each Resident Fellow; but after payment of such annual contribution for eight years, he shall be exempt Fees of Non-Resident Ordinary Fellows.

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* A modification of this rule, in certain cases, was agreed to at a Meeting of the Society held on the 3rd January 1831.

At the Meeting of the Society, on the 5th January 1857, when the reduction of the Contributions from £3, 3s. to £2, 2s., from the 11th to the 25th year of membership, was adopted, it was resolved that the existing Members shall share in this reduction, so far as regards their future annual Contributions.

Fellows
g Non-
t.

from any farther payment. In the case of any Resident Fellow ceasing to reside in Scotland, and wishing to continue a Fellow of the Society, it shall be in the power of the Council to determine on what terms, in the circumstances of each case, the privilege of remaining a Fellow of the Society shall be continued to such Fellow while out of Scotland.

V.

ers.

Members failing to pay their contributions for three successive years (due application having been made to them by the Treasurer) shall be reported to the Council, and, if they see fit, shall be declared from that period to be no longer Fellows, and the legal means for recovering such arrears shall be employed.

VI.

es of
y Fellows.

None but Ordinary Fellows shall bear any office in the Society, or vote in the choice of Fellows or Office-Bearers, or interfere in the patrimonial interests of the Society.

VII.

's Un-

The number of Ordinary Fellows shall be unlimited.

VIII.

entitled
sactions.

The Ordinary Fellows, upon producing an order from the Treasurer, shall be entitled to receive from the Publisher, gratis, the Parts of the Society's Transactions which shall be published subsequent to their admission.

IX.

f Recom-
g Ordinary
.

Candidates for admission as Ordinary Fellows shall make an application in writing, and shall produce along with it a certificate of recommendation to the purport below,* signed by at least *four* Ordinary Fellows, two of whom shall certify their recommendation from personal knowledge. This recommendation shall be delivered to the Secretary, and by him laid before the Council, and shall afterwards be printed in the circulars for three Ordinary Meetings of the Society, previous to the day of election, and shall lie upon the table during that time.

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* "A. B., a gentleman well versed in Science (*or Polite Literature, as the case may be*), being " to our knowledge desirous of becoming a Fellow of the Royal Society of Edinburgh, we hereby " recommend him as deserving of that honour, and as likely to prove a useful and valuable Member."

X.

Honorary Fellows shall not be subject to any contribution. This class shall consist of persons eminently distinguished for science or literature. Its number shall not exceed Fifty-six, of whom Twenty may be British subjects, and Thirty-six may be subjects of foreign states.

Honorary Fellows, British and Foreign.

XI.

Personages of Royal Blood may be elected Honorary Fellows, without regard to the limitation of numbers specified in Law X.

Royal Personages.

XII.

Honorary Fellows may be proposed by the Council, or by a recommendation (in the form given below*) subscribed by three Ordinary Fellows; and in case the Council shall decline to bring this recommendation before the Society, it shall be competent for the proposers to bring the same before a General Meeting. The election shall be by ballot, after the proposal has been communicated *viva voce* from the Chair at one meeting, and printed in the circulars for two ordinary meetings of the Society, previous to the day of election.

Recommendation of Honorary Fellows.

Mode of Election.

XIII.

The election of Ordinary Fellows shall only take place at the first Ordinary Meeting of each month during the Session. The election shall be by ballot, and shall be determined by a majority of at least two-thirds of the votes, provided Twenty-four Fellows be present and vote.

Election of Ordinary Fellows.

XIV.

The Ordinary Meetings shall be held on the first and third Mondays of every month from December to July inclusively; excepting when there are five Mondays in January, in which case the Meetings for that month shall be held on its third and fifth Mondays. Regular Minutes shall be kept of the proceedings, and the Secretaries shall do the duty alternately, or according to such agreement as they may find it convenient to make.

Ordinary Meetings.

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* We hereby recommend ______________________________
for the distinction of being made an Honorary Fellow of this Society, declaring that each of us from our own knowledge of his services to (*Literature or Science, as the case may be*) believe him to be worthy of that honour.

(To be signed by three Ordinary Fellows.)

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To the President and Council of the Royal Society
of Edinburgh.

XV.

actions.

The Society shall from time to time publish its Transactions and Proceedings. For this purpose the Council shall select and arrange the papers which they shall deem it expedient to publish in the *Transactions* of the Society, and shall superintend the printing of the same.

The Council shall have power to regulate the private business of the Society. At any Meeting of the Council the Chairman shall have a casting as well as a deliberative vote.

XVI.

ished.

The Transactions shall be published in parts or *Fasciculi* at the close of each Session, and the expense shall be defrayed by the Society.

XVII.

cil.

That there shall be formed a Council, consisting—First, of such gentlemen as may have filled the office of President; and Secondly, of the following to be annually elected, viz.:—a President, Six Vice-Presidents (two at least of whom shall be resident), Twelve Ordinary Fellows as Councillors, a General Secretary, Two Secretaries to the Ordinary Meetings, a Treasurer, and a Curator of the Museum and Library.

XVIII.

Council-

Four Councillors shall go out annually, to be taken according to the order in which they stand on the list of the Council.

XIX.

of Office-

An Extraordinary Meeting for the Election of Office-Bearers shall be held on the fourth Monday of November annually.

XX.

Meetings;
d.

Special Meetings of the Society may be called by the Secretary, by direction of the Council; or on a requisition signed by six or more Ordinary Fellows. Notice of not less than two days must be given of such Meetings.

XXI.

r's Duties.

The Treasurer shall receive and disburse the money belonging to the Society, granting the necessary receipts, and collecting the money when due.

He shall keep regular accounts of all the cash received and expended, which shall be made up and balanced annually; and at the Extraordinary Meeting in November, he shall present the accounts for the preceding year, duly audited.

At this Meeting, the Treasurer shall also lay before the Council a list of all arrears due above two years, and the Council shall thereupon give such directions as they may deem necessary for recovery thereof.

XXII.

Auditor.

At the Extraordinary Meeting in November, a professional accountant shall be chosen to audit the Treasurer's accounts for that year, and to give the necessary discharge of his intromissions.

XXIII.

General Secretary's Duties.

The General Secretary shall keep Minutes of the Extraordinary Meetings of the Society, and of the Meetings of the Council, in two distinct books. He shall, under the direction of the Council, conduct the correspondence of the Society, and superintend its publications. For these purposes he shall, when necessary, employ a clerk, to be paid by the Society.

XXIV.

Secretaries to Ordinary Meetings.

The Secretaries to the Ordinary Meetings shall keep a regular Minute-book, in which a full account of the proceedings of these Meetings shall be entered; they shall specify all the Donations received, and furnish a list of them, and of the Donors' names, to the Curator of the Library and Museum; they shall likewise furnish the Treasurer with notes of all admissions of Ordinary Fellows. They shall assist the General Secretary in superintending the publications, and in his absence shall take his duty.

XXV.

Curator of Museum and Library.

The Curator of the Museum and Library shall have the custody and charge of all the Books, Manuscripts, objects of Natural History, Scientific Productions, and other articles of a similar description belonging to the Society; he shall take an account of these when received, and keep a regular catalogue of the whole, which shall lie in the Hall, for the inspection of the Fellows.

XXVI.

Use of Museum and Library.

All Articles of the above description shall be open to the inspection of the Fellows at the Hall of the Society, at such times and under such regulations, as the Council from time to time shall appoint.

XXVII.

Register Book.

A Register shall be kept, in which the names of the Fellows shall be enrolled at their admission, with the date.

THE KEITH, BRISBANE, AND NEILL PRIZES.

The above Prizes will be awarded by the Council in the following manner :—

I. KEITH PRIZE.

The Keith Prize, consisting of a Gold Medal and from £40 to £50 in Money, will be awarded in the Session 1881–82 for the "best communication on a scientific subject, communicated, in the first instance, to the Royal Society during the Sessions 1879–80 and 1880–81." Preference will be given to a paper containing a discovery.

II. MAKDOUGALL-BRISBANE PRIZE.

This Prize is to be awarded biennially by the Council of the Royal Society of Edinburgh to such person, for such purposes, for such objects, and in such manner as shall appear to them the most conducive to the promotion of the interests of science; with the *proviso* that the Council shall not be compelled to award the Prize unless there shall be some individual engaged in scientific pursuit, or some paper written on a scientific subject, or some discovery in science made during the biennial period, of sufficient merit or importance in the opinion of the Council to be entitled to the Prize.

1. The Prize, consisting of a Gold Medal and a sum of Money, will be awarded at the commencement of the Session 1882–83, for an Essay or Paper having reference to any branch of scientific inquiry, whether Material or Mental.

2. Competing Essays to be addressed to the Secretary of the Society, and transmitted not later than 1st June 1882.

3. The Competition is open to all men of science.

4. The Essays may be either anonymous or otherwise. In the former case, they must be distinguished by mottoes, with corresponding sealed billets, superscribed with the same motto, and containing the name of the Author.

5. The Council impose no restriction as to the length of the Essays, which may be, at the discretion of the Council, read at the Ordinary Meetings of the Society. They wish also to leave the property and free disposal of the manuscripts to the Authors; a copy, however, being deposited in the Archives of the Society, unless the paper shall be published in the Transactions.

6. In awarding the Prize, the Council will also take into consideration any scientific papers presented to the Society during the Sessions 1882–83 and 1883–84, whether they may have been given in with a view to the prize or not.

III. NEILL PRIZE.

The Council of the Royal Society of Edinburgh having received the bequest of the late Dr Patrick Neill of the sum of £500, for the purpose of "the interest thereof being applied in furnishing a Medal or other reward every second or third year to any distinguished Scottish Naturalist, according as such Medal or reward shall be voted by the Council of the said Society," hereby intimate,

1. The Neill Prize, consisting of a Gold Medal and a sum of Money, will be awarded during the Session 1883–84.

2. The Prize will be given for a Paper of distinguished merit, on a subject of Natural History, by a Scottish Naturalist, which shall have been presented to the Society during the three years preceding the 1st May 1883,—or failing presentation of a paper sufficiently meritorious, it will be awarded for a work or publication by some distinguished Scottish Naturalist, on some branch of Natural History, bearing date within five years of the time of award.

AWARDS OF THE KEITH, MAKDOUGALL-BRISBANE, AND NEILL PRIZES, FROM 1827 TO 1879.

I. KEITH PRIZE.

1st Biennial Period, 1827–29.—Dr Brewster, for his papers "on his Discovery of Two New Immiscible Fluids in the Cavities of certain Minerals," published in the Transactions of the Society.

2nd Biennial Period, 1829–31.—Dr Brewster, for his paper "on a New Analysis of Solar Light," published in the Transactions of the Society.

3rd Biennial Period, 1831–33.—Thomas Graham, Esq., for his paper "on the Law of the Diffusion of Gases," published in the Transactions of the Society.

4th Biennial Period, 1833–35.—Professor J. D. Forbes, for his paper "on the Refraction and Polarization of Heat," published in the Transactions of tho Society.

5th Biennial Period, 1835–37.—John Scott Russell, Esq., for his Researches "on Hydrodynamics," published in the Transactions of the Society.

6th Biennial Period, 1837–39.—Mr John Shaw, for his experiments "on the Development and Growth of the Salmon," published in the Transactions of the Society.

7th Biennial Period, 1839–41.—Not awarded.

8th Biennial Period, 1841–43.—Professor James David Forbes, for his Papers "on Glaciers," published in the Proceedings of the Society.

9th Biennial Period, 1843–45.—Not awarded.

10th Biennial Period, 1845–47.—General Sir Thomas Brisbane, Bart., for the Makerstoun Observations on Magnetic Phenomena, made at his expense, and published in the Transactions of the Society.

11th Biennial Period, 1847–49.—Not awarded.

12th Biennial Period, 1849–51.—Professor Kelland, for his papers "on General Differentiation, including his more recent communication on a process of the Differential Calculus, and its application to the solution of certain Differential Equations," published in the Transactions of the Society.

13th Biennial Period, 1851–53.—W. J. Macquorn Rankine, Esq., for his series of papers "on the Mechanical Action of Heat," published in the Transactions of the Society.

14th Biennial Period, 1853–55.—Dr Thomas Anderson, for his papers "on the Crystalline Constituents of Opium, and on the Products of the Destructive Distillation of Animal Substances," published in the Transactions of the Society.

15th Biennial Period, 1855–57.—Professor Boole, for his Memoir "on the Application of the Theory of Probabilities to Questions of the Combination of Testimonies and Judgments," published in the Transactions of the Society.

16th Biennial Period, 1857–59.—Not awarded.

17th Biennial Period, 1859–61.—John Allan Broun, Esq., F.R.S., Director of the Trevandrum Observatory, for his papers "on tho Horizontal Force of the Earth's Magnetism, on the Correction of the Bifilar Magnetometer, and on Terrestrial Magnetism generally," published in the Transactions of the Society.

18th Biennial Period, 1861–63.—Professor William Thomson, of the University of Glasgow, for his Communication "on some Kinematical and Dynamical Theorems."

19th Biennial Period, 1863–65.—Principal Forbes, St Andrews, for his "Experimental Inquiry into the Laws of Conduction of Heat in Iron Bars," published in the Transactions of the Society,

20th Biennial Period, 1865–67.—Professor C. Piazzi Smyth, for his paper "on Recent Measures at the Great Pyramid," published in the Transactions of the Society.

21st Biennial Period, 1867–69.—Professor P. G. Tait, for his paper "on the Rotation of a Rigid Body about a Fixed Point," published in the Transactions of the Society.

22nd Biennial Period, 1869–71.—Professor Clerk Maxwell, for his paper "on Figures, Frames, and Diagrams of Forces," published in the Transactions of the Society.

23rd Biennial Period, 1871–73.—Professor P. G. Tait for his paper entitled "First Approximation to a Thermo-electric Diagram," published in the Transactions of the Society.

24th Biennial Period, 1873–75.—Professor Crum Brown, for his Researches "on the sense of Rotation, and on the Anatomical Relations of the Semicircular Canals of the Internal Ear."

25th Biennial Period, 1875–77.—Professor M. Forster Heddle, for his papers "on the Rhombohedral Carbonates," and "on the Felspars of Scotland," published in the Transactions of the Society.

26th Biennial Period, 1877–79.—Professor H. C. Fleeming Jenkin, for his paper "on the Application of Graphic Methods to the Determination of the Efficiency of Machinery," published in the Transactions of the Society; Part II. having appeared in the volume for 1877–78.

27th Biennial Period, 1879–81.—Professor George Chrystal, for his paper "on the Differential Telephone," published in the Transactions of the Society.

28th Biennial Period, 1881–83.—Thomas Muir, Esq., LL.D., for his "Researches into the Theory of Determinants and Continued Fractions," published in the Proceedings of the Society.

II. MAKDOUGALL-BRISBANE PRIZE.

1st Biennial Period, 1859.—Sir Roderick Impey Murchison, on account of his Contributions to the Geology of Scotland.

2nd Biennial Period, 1860–62.—William Seller, M.D., F.R.C.P.E., for his "Memoir of the Life and Writings of Dr Robert Whytt," published in the Transactions of the Society.

3rd Biennial Period, 1862–64.—John Denis Macdonald, Esq., R.N., F.R.S., Surgeon of H.M.S. "Icarus," for his paper "on the Representative Relationships of the Fixed and Free Tunicata, regarded as Two Sub-classes of equivalent value; with some General Remarks on their Morphology," published in the Transactions of the Society.

4th Biennial Period, 1864–66.—Not awarded.

5th Biennial Period, 1866–68.—Dr Alexander Crum Brown and Dr Thomas Richard Fraser, for their conjoint paper "on the Connection between Chemical Constitution and Physiological Action," published in the Transactions of the Society.

6th Biennial Period, 1868–70.—Not awarded.

7th Biennial Period, 1870–72.—George James Allman, M.D., F.R.S., Emeritus Professor of Natural History, for his paper "on the Homological Relations of the Cœlenterata," published in the Transactions, which forms a leading chapter of his Monograph of Gymnoblastic or Tubularian Hydroids—since published.

8th Biennial Period, 1872–74.—Professor Lister, for his paper "on the Germ Theory of Putrefaction and the Fermentive Changes," communicated to the Society, 7th April 1873.

9th Biennial Period, 1874–76.—Alexander Buchan, A.M., for his paper "on the Diurnal Oscillation of the Barometer," published in the Transactions of the Society.

10th Biennial Period, 1876–78.—Professor Archibald Geikie, for his paper "on the Old Red Sandstone of Western Europe," published in the Transactions of the Society.

11th Biennial Period, 1878–80.—Professor Piazzi Smythe, Astronomer-Royal for Scotland, for his paper "on the Solar Spectrum in 1877–78, with some Practical Idea of its probable Temperature of Origination," published in the Transactions of the Society.

12th Biennial Period, 1880–82.—Professor James Geikie, for his "Contributions to the Geology of the North-West of Europe," including his paper "on the Geology of the Faröes," published in the Transactions of the Society.

III. THE NEILL PRIZE.

1st Triennial Period, 1856–59.—Dr W. Lauder Lindsay, for his paper "on the Spermogones and Pycnides of Filamentous, Fruticulose, and Foliaceous Lichens," published in the Transactions of the Society.

2nd Triennial Period, 1859–62.—Robert Kaye Greville, LL.D., for his Contributions to Scottish Natural History, more especially in the department of Cryptogamic Botany, including his recent papers on Diatomaceæ.

3rd Triennial Period, 1862–65.—Andrew Crombie Ramsay, F.R.S., Professor of Geology in the Government School of Mines, and Local Director of the Geological Survey of Great Britain, for his various works and Memoirs published during the last five years, in which he has applied the large experience acquired by him in the Direction of the ardous work of the Geographical Survey of Great Britain to the elucidation of important questions bearing on Geological Science.

4th Triennial Period, 1865–68.—Dr William Carmichael M'Intosh, for his paper "on the Structure of the British Nemerteans, and on some New British Annelids," published in the Transactions of the Society.

5th Triennial Period, 1868–71.—Professor William Turner, for his papers "on the great Finner Whale; and on the Gravid Uterus, and the Arrangement of the Fœtal Membranes in the Cetacea," published in the Transactions of the Society.

6th Triennial Period, 1871–74.—Charles William Peach, for his Contributions to Scottish Zoology and Geology, and for his recent contributions to Fossil Botany.

7th Triennial Period, 1874–77.—Dr Ramsay H. Traquair, for his paper "on the Structure and Affinities of *Tristichopterus alatus* (Egerton)," published in the Transactions of the Society, and also for his contributions to the Knowledge of the Structure of Recent and Fossil Fishes.

8th Triennial Period, 1877–80.—John Murray, for his paper "on the Structure and Origin of Coral Reefs and Islands," published (in abstract) in the Proceedings of the Society.

9th Triennial Period, 1880–83.—Professor Herdman, for his papers "on the Tunicata," published in the Proceedings and Transactions of the Society.

PROCEEDINGS

OF THE

STATUTORY GENERAL MEETINGS,

AND

LIST OF MEMBERS ELECTED AT THE ORDINARY MEETINGS

FROM NOVEMBER 1881 TO NOVEMBER 1882.

STATUTORY MEETINGS.

NINETY-NINTH SESSION.

Monday, 28th November 1881.

At a Statutory Meeting, Professor Maclagan, Vice-President, in the Chair, the Minutes of last General Statutory Meeting of 22nd November 1880 were read, approved, and signed.

The Ballot for the new Council was then taken, Messrs Tennant and Macculloch being requested to act as Scrutineers. The following Council was elected:—

The Right Hon. Lord Moncreiff, President.
David Milne Home, LL.D.
Sir C. Wyville Thomson, LL.D.
Professor Douglas Maclagan, M.D.
Professor H. C. Fleeming Jenkin, F.R.S.
Rev. W. Lindsay Alexander, D.D.
J. H. Balfour, M.D., F.R.S.
Vice-Presidents.
Professor Tait, General Secretary.
Professor Turner, F.R.S.
Professor Crum Brown, F.R.S.
Secretaries to Ordinary Meetings.
Adam Gillies Smith, C.A., Treasurer.
Alexander Buchan, M.A., Curator of Library and Museum.

COUNCILLORS.

Professor Campbell Fraser.
Professor Geikie, F.R.S.
Rev. Dr Cazenove.
David Stevenson.
Professor Chrystal.
Sheriff Forbes Irvine, of Drum.
Professor A. Dickson.
The Right Rev. Bishop Cotterill.
The Rev. Professor Duns.
Dr Ramsay Traquair, F.R.S.
John Murray.
William Ferguson, of Kinmundy.

The Treasurer's Accounts were submitted and approved.

On the motion of Professor Tait, seconded by Mr Macculloch, the Auditor was re-appointed.

Professor Crum Brown gave notice of the following motion for alteration of a part of the Laws, viz., To change in Law XIV. the words "*November to June*" into "*December to July.*"

HUNDREDTH SESSION.

Monday, 27th November 1882.

At a Statutory Meeting, Professor Maclagan, Vice-President, in the Chair, the Minutes of last General Statutory Meeting of 28th November 1881 were read, approved, and signed.

The Ballot for the new Council was then taken, Professor Swan and Professor Dickson being requested to act as Scrutineers. The following Council was elected:—

The Right Hon. Lord Moncreiff, President.	
Professor Douglas Maclagan, M.D.	Vice-Presidents.
Professor H. C. Fleeming Jenkin, F.R.S.	
The Rev. W. Lindsay Alexander, D.D.	
J. H. Balfour, M.D.	
Thomas Stevenson, M.Inst. C.E.	
Robert Gray, Sec. Roy. Phys. Soc.	
Professor Tait, M.A., General Secretary.	
Professor Turner, F.R.S.	Secretaries to Ordinary Meetings.
Professor Crum Brown, F.R.S.,	
Adam Gillies Smith, C.A., Treasurer.	
Alexander Buchan, M.A., Curator of Library and Museum.	

COUNCILLORS.

Professor George Chrystal, M.A.
Alexander Forbes Irvine, of Drum.
Professor Alexander Dickson, M.D.
The Right Rev. Bishop Cotterill, D.D.
The Rev. Professor Duns.
Ramsay H. Traquair, M.D., F.R.S.
John Murray, Director of "Challenger" Commission.
William Ferguson, of Kinmundy.
Professor James Cossar Ewart, M.D.
Professor James Geikie, F.R.S.
Professor William Robertson Smith, LL.D.
Stair A. Agnew, M.A.

Read Letter from the Treasurer apologising for absence on account of illness, and explaining the apparent surplus shown by the Financial Statement.

The Auditor's Report on the Treasurer's Accounts was read and approved.

On the motion of Dr Crum Brown, the Auditor was reappointed.

The following Public Institutions and Individuals are entitled to receive Copies of the Transactions and Proceedings of the Royal Society of Edinburgh:—

London, British Museum.
- ... Royal Society, Burlington House, London.
- ... Anthropological Institute of Great Britain and Ireland, 3 Hanover Square, London.
- ... British Association for the Advancement of Science, 22 Albemarle Street, London.
- ... Society of Antiquaries, Burlington House.
- ... Royal Astronomical Society, Burlington House.
- ... Royal Asiatic Society, 22 Albemarle Street.
- ... Society of Arts, John Street, Adelphi.
- ... Athenæum Club.
- ... Chemical Society, Burlington House.
- ... Institution of Civil Engineers, 25 Great George Street.
- ... Royal Geographical Society, Burlington Gardens.
- ... Geological Society, Burlington House.
- ... Royal Horticultural Society, South Kensington.
- ... Hydrographic Office, Admiralty.
- ... Royal Institution, Albemarle Street, W.
- ... Linnean Society, Burlington House.
- ... Royal Society of Literature, 4 St Martin's Place.
- ... Medical and Chirurgical Society, 53 Berners Street, Oxford Street.
- ... Royal Microscopical Society, King's College.
- ... Museum of Economic Geology, Jermyn Street.
- ... Royal Observatory, Greenwich.
- ... Pathological Society, 53 Berners Street.
- ... Statistical Society, 9 Adelphi Terrace, Strand, London.
- ... Royal College of Surgeons of England, 40 Lincoln's Inn Fields.

London, United Service Institution, Whitehall Yard.
- ... University College, Gower Street, London.
- ... Zoological Society, 11 Hanover Square.
- ... The Editor of *Nature*, 29 Bedford Street, Covent Garden.
- ... The Editor of the *Electrician*, 396 Strand.

Cambridge Philosophical Society.
- ... University Library.

Historic Society of Lancashire and Cheshire.
Leeds Philosophical and Literary Society.
Manchester Literary and Philosophical Society.
Oxford, Bodleian Library.
Yorkshire Philosophical Society.

SCOTLAND.

Edinburgh, Advocates Library.
- ... University Library.
- ... College of Physicians.
- ... Highland and Agricultural Society.
- ... Royal Medical Society, 7 Melbourne Place, Edinburgh.
- ... Royal Physical Society, 40 Castle Street.
- ... Royal Scottish Society of Arts, 117 George Street.
- ... Royal Botanic Garden, Inverleith Row.

Aberdeen, University Library.
Dundee, University College Library.
Glasgow, University Library.
- ... Philosophical Society, 207 Bath Street.

St Andrews, University Library.

IRELAND.

Royal Dublin Society.
Royal Irish Academy, 19 Dawson Street, Dublin.
Library of Trinity College, Dublin.

COLONIES, DEPENDENCIES, &c.

Bombay, Royal Asiatic Society.
Calcutta, Asiatic Society of Bengal.
Madras, Literary Society.
Canada, Library of Geological Survey.
... Queen's University, Kingston.
... Montreal, Royal Society of Canada.
... Quebec, Literary and Philosophical Society.
... Toronto, Literary and Historical Society.
... ... The Canadian Institute.
Cape of Good Hope, The Observatory.
Melbourne, University Library.
Sydney, University Library.
... Linnean Society of New South Wales.
... Royal Society of New South Wales.
Wellington, New Zealand Institute.

CONTINENT OF EUROPE.

Amsterdam, De Koninklijke Akademie van Wetenschappen
... Koninklijk Zoologisch Genootschap.
Basle, Die Schweizerische Naturforschende Gesellschaft.
Bergen, Museum.
Berlin, Königliche Akademie der Wissenschaften.
... Physicalische Gessellschaft.
Bern, Allgemeine Schweizerische Gesellschaft für die gesammten Naturwissenschaften.
Bologna, Accademia delle Scienze dell' Istituto.
Bordeaux, Société des Sciences Physiques et Naturelles.
Brussels, Académie Royale des Sciences, des Lettres et des Beaux-arts.
... L'Observatoire Royal.
... La Société Scientifique.
Bucharest, Academia Romana.
Buda, A Magyar Tudós Tarsasag—Die Ungarische Akademie der Wissenschaften.
... Königliche Ungarische Naturwissenschaftlische Gesellschaft.
Catania, Accademia Gioenia di Scienze Naturali.
Christiania, University Library.
... Meteorological Institute.
Coimbra, University Library.
Copenhagen, Royal Academy of Sciences.
Danzig, Naturforschende Gesellschaft
Dorpat, University Library.
Ekatherinebourg, La Société Ouralienne d'Amateurs des Sciences Naturelles.
Erlangen, University Library.
Frankfurt-am-Main, Senckenbergische Naturforschende Gesellschaft.
Geneva, Société de Physique et d' Histoire Naturelle.
Genoa, Museo Civico di Storia Naturale
Giessen, University Library.
Göttingen, Königliche Gesellschaft der Wissenschaften.
Graz, Naturwissenschaftlicher Verein für Steiermark
Haarlem, Société Hollandaise des Sciences Exactes et Naturelles.
... Musée Teyler.
Halle, Kaiserliche Leopoldino - Carolinische deutsche Akademie der Naturforscher.
Halle, Naturforschende Gesellschaft.
Helsingfors, Sällskapet pro Fauna et Flora Fennica.
... Societas Scientiarum Fennica (Société des Sciences de Finlande).
Jena, Medicinisch-Naturwissenschaftliche Gesellschaft.
Kasan, University Library.
Kiel, University Library.
... Ministerial-Kommission zur Untersuchung der Deutschen Meere.
Kiev, University of St Vladimir.
Leyden, Tijdschrift der Neerlandsch Dierkundige Vereeniging
... The University Library.
Leipzig, Prof. Wiedemann, Königliche Sächsische Akademie.
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Lisbon, Academia Real das Sciencias de Lisboa.
... Sociedade de Geographia.
Louvain, University Library.
Lucca, M. Michelotti.
Lund, University Library.
Lyons, Académie des Sciences, Belles Lettres et Arts.
... Musée Guimet.
... Société d'Agriculture.
Madrid, Real Academia de Ciencias.
... Comision del Mapa Geologico de España.

Milan, Reale Istituto Lombardo di Scienze, Lettere, ed
Modena, Regia Accademia di Scienze, Lettere, ed Arti.
Montpellier, Académie des Sciences et Lettres.
Moscow, Société Impériale des Naturalistes de Moscou.
... Société Impériale des Amis d'Histoire Naturelle, d'Anthropologie et d'Ethnographie.
... L'Observatoire Impérial.
Munich, Königlich-Bayerische Akademie der Wissenschaften (2 copies).
Naples, Zoological Station, Dr Anton Dohrn.
... Societa Reale di Napoli—Accademia delle Scienze Fisiche e Matematiche.
Neufchatel, Société des Sciences Naturelles.
Palermo, Signor Agostino Todaro, Giardino Botanico.
... Società di Scienze Naturali ed Economiche.
Paris, Académie des Sciences de l'Institut.
... Académie des Inscriptions et Belles Lettres de l'Institut.
Paris, Association Scientifique de France.
... Société d'Agriculture, 18 Rue de Bellechasse.
... Société Nationale des Antiquaires de France.
... Société de Géographie, 184 Boulevard St Germain.
... Société Géologique de France, 7 Rue des Grands Augustins.
... Société d'Encouragement pour l'Industrie Nationale.
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... Dépôt de la Marine.
... Société Mathématique, 7 Rue des Grands Augustins.
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... L'Observatoire.
... École Normale Supérieure, Rue d'Ulm.
... Société Française de Physique.
... École Polytechnique.
... Société Zoologique de France, 7 Rue des Grands Augustins.
Paris, Revue Scientifique, et Revue Littéraire et Politique.
Prague, Königliche Sternwarte.
... Königlich-Böhmische Gesellschaft der Wissenschaften.
Rome, Accademia dei Lincei.
... Società Italiana delle Scienze detta dei XL.
... Società degli Spettroscopisti Italiani.
... Comitato Geologico.
Rotterdam, Bataafsch Genootschap der Proefondervindelijke Wijsbegeerte.
St Petersburg, Académie Impériale des Sciences.
... Commission Impérial Archéologique.
... Comité Géologique.
... L'Observatoire Impérial de Pulkowa.
... Physikalisches Central-Observatorium.
... Physico-Chemical Society of the University of St Petersburg.
Stockholm, Kongliga Svenska Vetenskaps-Academien.
Strasbourg, University Library.
Stuttgart, Verein für Vaterländische Naturkunde zu Würtemberg.
Thronddjem Videnskabernes Selskab.
Turin, Reale Accademia delle Scienze.
Upsala, Kongliga Vetenskaps-Societeten.
Venice, Reale Istituto Veneto di Scienze, Lettere ed Arti.
Vienna, Kaiserliche Akademie der Wissenschaften.
... Novara Commission.
... Oesterreichische Gesellschaft für Meteorologie, Hohe Warte, Wien.
... Geologische Reichsanstalt.
... Zoologisch-Botanischer Verein.
Zurich, University Library.
... Commission Géologique Suisse.

ASIA.

Java, Bataviaasch Genootschap van Kunsten en Wetenschappen.
... The Observatory.
Japan, The University of Tokio.

UNITED STATES OF AMERICA.

American Association for the Advancement of Science.
Baltimore, Johns Hopkins University.
Boston, the Bowditch Library.
... American Academy of Arts and Sciences, Beacon Street, Boston.
... Society of Natural History.
Cambridge, Mass., Harvard University.
... Harvard College Observatory.
Chicago Observatory.
Clinton, Litchfield Observatory, Hamilton College.
Concord, Editor of Journal of Speculative Philosophy.
New York, State Library.
Philadelphia, American Philosophical Society.
... Academy of Natural Sciences.
Salem, The Peabody Academy of Science.
St Louis, Academy of Sciences.
Washington, United States Coast Survey.
Washington, United States Fishery Commission.
... United States Naval Observatory.
... United States Geological Survey of the Territories.
... United States Signal Office.
... The Smithsonian Institution.
Wisconsin, University (Washborn Observatory), Madison.
Yale College, Newhaven, Connecticut.

MEXICO.

Mexico, Observatorio Meteorologico Central.

SOUTH AMERICA.

Buenos Ayres, Public Museum, per Dr Burmeister.
Corduba, Argentine Republic, Academia Nacional de Ciencias.
... The Observatory.
Rio de Janeiro, The Astronomical Observatory.

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... Meteorological Office, 116 Victoria Street.
... The Meteorological Society, 25 Great George Street, Westminster.
... *Nautical Almanac* Office, 3 Verulam Buildings, Gray's Inn.
... The Editor of the Illustrated Science Monthly, 3 St Martin's Place, Trafalgar Square, London.
Birmingham Philosophical Society, King Edward's Grammar School.
Cornwall, Geological Society.
Epping Forest and County of Essex Naturalists' Field Club.
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Norfolk and Norwich Naturalists' Society, The Museum, Norwich.
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Geological Society of Edinburgh, 5 St Andrew Square.
Scottish Meteorological Society, 122 George Street.
Geological Society of Glasgow (Anderson's College).
The Glasgow University Observatory.

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Bordeaux, Société de la Géographie Commerciale.
Brunswick, Verein für Naturwissenschaft.
Bucharest, Academia Romana.
Cassel, Verein für Naturkunde.
Chemnitz, Naturwissenschaftliche Gesellschaft.
Cherbourg, Société Nationale des Sciences Naturelles.
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Halle, Verein für Erdkunde.
Hamburg, Verein für Naturwissenschaftliche Unterhaltung.
Lausanne, Société Vaudoise des Sciences Naturelles.
Leipzig, Naturforschende Gesellschaft.
Lille, Société Géologique du Nord.
Luxembourg, Société des Sciences Naturelles.
Lyons, Société Botanique.
... Société Linnéenne, Place Sathonay.
Marseilles, Société Scientifique Industrielle, 61 Rue Paradis.
Milan, Società Crittogamologica Italiana.
Modena, Società dei Naturalisti.
Nijmegen, Nederlandsche Botanische Vereeniging.
Oberpfalz und Regensburg, Historischer Verein.
Paris, Société d'Anthropologie (4 Rue Antoine Dubois).
... Société de Biologie.
... Société Philomathique.
... Bureau des Ponts et Chaussées.
Pisa, Nuovo Cimento.
St Petersburg, Imperatorskoe Russkoe Geographicheskoe Obtshéstvo.
Tiflis, Physical Observatory
Toulouse, Académie des Sciences.
Trieste, Società Adriatica di Scienze Naturali.
Tromsö, The Museum.
Utrecht, Provinciaal Genootschap van Kunsten en Wetenschappen.
Zurich, Naturforschende Gesellschaft.

ASIA.

China, Shanghai, North China Branch of the Royal Asiatic Society.
Japan, Tokio, The Seismological Society.
... Yokohama, Deutsche Gesellschaft für Natur- und Völkerkunde Ostasiens
Java, Batavia, Koninklijke Natuurkundije Vereeniging.

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Annapolis, Maryland, St John's College.
California, State Mining Bureau, Sacramento.
Cincinnati, Observatory.
... Society of Natural History.
Cincinnati, Ohio Mechanics' Institute.
Connecticut, Academy of Arts and Sciences.
Davenport, Academy of Natural Sciences.
New York, The American Museum of Natural History.
... The American Geographical and Statistical Society.
Salem, The Essex Institute.
San Francisco, The Lick Observatory.
Washington, Philosophical Society.
... American Museum of Natural History, Central Park.
Wisconsin, Academy of Sciences, Arts, and Letters.

SOUTH AMERICA.

Rio de Janeiro, Museu Nacional.

MEXICO.

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