MEMOIRS OF THE MANCHESTER LITERARY AND PHILOSOPHICAL SOCIETY.

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NOTE.

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MEMOIRS

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LITERARY AND PHILOSOPHICAL SOCIETY.

I. *Some Novel Phenomena of Chemical Action attending the Efflux from a Capillary Tube.* By R. S. Dale, B.A.

Read December 16th, 1884.

The results obtained in the experiments I propose to describe were the outcome of a desire to know what, if any, mechanical action took place when two solutions capable of forming a precipitate were slowly mixed; next to find the nature of such mechanical action, and latterly, if possible, to measure it. I have made no attempt in the latter direction, but propose describing a series of experiments which have yielded some very novel effects.

No. 1. Solutions of lead acetate and potassium dichromate were allowed to travel in opposite directions along a thread placed in the field of a microscope. At the moment of mixing, very considerable disturbance took place, accompanied with a whirling motion. This method not offering results which could be easily registered, it occurred to me to cause one solution to flow into the other through a capillary tube or syphon. The apparatus used was of the simplest possible description, consisting of a pair of cylinders connected by a capillary syphon, the effluent end of which was bent upwards. One cylinder was raised slightly above the other to ensure a flow. I have a photograph of the general arrangement adopted.

No. 2. Solutions of lead acetate and potassium dichromate were allowed to mix in this manner. The latter salt was passed into the former. The capillary syphon was charged with water, and after this had passed through the heavier fluid a series of vortex rings began to be formed at the point of the tube. Later one attached itself to the tube, and others to this, until a tube was built up *through which* the potassium dichromate was passed, without any chemical action taking place, to the top of the lead acetate. This action continued until the system reached an equilibrium. Fearing that I could not show the experiments before the Society, I photographed some of them, and they show exceedingly well the curious growths of lead chromate which were thus produced. With these two substances to obtain a single tube was most difficult, and only a series could be obtained with anything like certainty.

An experiment was made reversing the fluids.

The same results were obtained, though the growth was less stable, as the potassium dichromate being of much smaller specific gravity, no support was given to the lead chromate formed, and thus the growth continually fell off the point of the syphon.

No. 3. A cold saturated solution of sodium sulphate was passed into a saturated solution of barium chloride. A perfectly straight tube was obtained, which formed with great rapidity and was very stable. This result was most unlooked for, taking into consideration the great density of barium sulphate.

No. 4. A solution of ammonium oxalate was passed into a solution of calcium chloride. These particular solutions were chosen because the amorphous calcium oxalate first produced, on mixing these solutions rapidly, becomes crystalline, and the effect could not be surmised on mixing with a capillary tube. The usual phenomena took place until the tube reached the height of about one inch, when the amorphous calcium oxalate suddenly changed to the crystalline variety, and apparently stopped the action, as no further upward growth took place. On careful examination, however, of the point of the growth, a fluid was noticed to emerge, which had no action on the surrounding calcium chloride, showing that chemical action was still going on. Now, the upward growth having ceased, it was inevitable that the tube should become wider, and this is what really took place. On another experiment I obtained a nearly spherical body about half an inch in diameter.

No. 5. Action of ammonia on ferrous sulphate. A very thick tube of ferrous hydrate was formed, which I am able to show you, as it is by no means fragile. It has, of course, been, since out of the fluid, partially converted into ferric oxide.

No. 6. Sodium carbonate on copper sulphate. In this case a crystalline copper carbonate was obtained of two shades, one a bright blue resembling azurite (if it be not actually that substance), and another a bright green resembling malachite. I am able to show this tube.

No. 7. Ammonium sulphide on copper sulphate. An action closely resembling, in many particulars, the action of ammonia on ferrous sulphate.

No. 8. Sodium carbonate on calcium chloride. The commencement of the action was marked by the formation of a perfectly transparent and highly refractive sheath of calcium carbonate, which did not show any signs of crystallization until about half an inch in length. On examination, after the lapse of about twelve hours, a crystalline tube of calcium carbonate had made its way to the top of the containing cylinder. This tube was composed of minute, but well-defined crystals. I found it impossible to retain it in its perfect shape for inspection here.

No. 9. Sodium carbonate on barium chloride. A very similar action to that mentioned in experiment No. 7, but at no time was a transparent substance noted, the growth being quite opaque and not palpably crystalline.

No. 10. Hydrochloric acid on sodium silicate. Here a well-marked action took place, and a tube of silica was produced, a portion of which I am able to show.

No. 11. Knowing the silica produced by the action of ammonium chloride on sodium silicate was much denser than that obtained in the previous experiment, I caused these substances to act on each other, and succeeded in obtaining a very long tube of silica of considerable thickness. I am able to show this also.

No. 12. Ferrocyanide of potassium on ferrous sulphate. Notwithstanding the extreme lightness of the blue precipitate produced by these solutions, a perfect tube was obtained, which reached the surface of the ferrous sulphate.

Many experiments on the above lines will readily suggest themselves; but I think I have described sufficient to call attention to this, to me, novel method of experiment, and I must leave it to some future occasion to describe such others as may show any peculiarities worth noting. I purposely refrain from making any theoretical deductions, with the one exception that it is pretty certain that these phenomena are inseparably connected with vortex-action, the tubes being undoubtedly built up of a series of vortex-rings.

II. *On the Composition of Projections in Geometry of Two Dimensions.* By JAMES BOTTOMLEY, B.A., D.Sc., F.C.S.

Read January 13th, 1885.

IN previous papers (Proceedings, vol. xxi. page 188 *et seq.*; Memoirs, vol. viii. 3rd series, page 218 *et seq.*) it has been shown how, by the composition of two projections, namely, of that of a line on a line, and of that of a plane on a plane, we may derive from a solid another solid of which the volume bears to the volume of the former the ratio n^2, where n denotes the cosine of the angle between the primitive axis and the fixed axis. The kind of projection there contemplated has its analogue in geometry of two dimensions. The projections to be compounded in this case are those of two lines on two lines. As the simplest case, let Ox, Oy be two fixed rectangular axes, and ABC a rectangle in the plane of these axes; let l and m be the cosines of the angles made by AC with Ox and Oy. Project AB on Ox; then we shall have

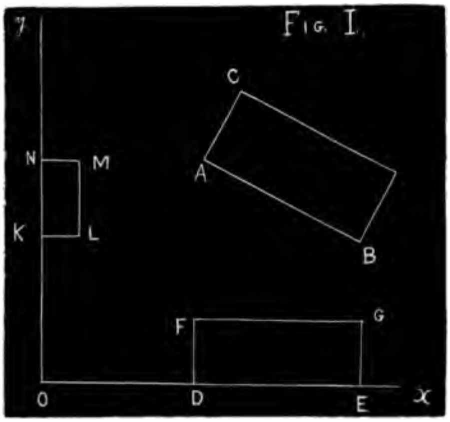

Fig. I.

$$DE = mAB. \qquad \ldots\ldots (1)$$

If AC were projected on Oy, the length of the projection would be mAC; from the point D draw a perpendicular such that

$$DF = mAC, \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and complete the parallelogram. Multiplying together (1) and (2), we get

$$DE \, . \, DF = m^2 AB \, . \, AC;$$

AB . AC is the area of the primitive parallelogram, and FD . DE is the area of the parallelogram FDE. By projecting on the line Oy, we may obtain, in a similar manner, another parallelogram such that

$$NK \, . \, KL = l^2 AB \, . \, AC.$$

Hence A_x and A_y denoting the projected areas, we have

$$A_x + A_y = Al^2 + Am^2,$$
$$= A;$$

for

$$l^2 + m^2 = 1.$$

If the rectangle CAB have any motion of translation, this will affect the positions, but not the magnitudes, of the projections; if the rectangle have a motion of rotation round any axis perpendicular to its plane, each projection will vary in magnitude, but their sum will be constant.

The reasoning of the above simple case may be extended to any plane area bounded by curved lines; for we may suppose the area to be rigidly connected with two straight lines on its plane, and at right angles; then the whole area may be considered as the limit of a series of elementary parallelograms whose sides are parallel to these axes. If a denote the area of one of these elements, its projection a_x on a line parallel to the axis of x, will be m^2a, and summing, we have

$$\Sigma a_x = m^2 \Sigma a;$$

Σa denoting the area of the primitive figure, which we may also write A, and Σa_x denoting the area of some geometrical figure built up by piling one on another the successive projected rectangles. This area we may also denote by A_x. In a similar manner we may pile one on another the projections on lines parallel to the axis of y, and if A_y denote the area of the figure so generated, being the limit of Σa_y, we shall have on addition

$$A_x + A_y = Al^2 + Am^2 = A.$$

Of the two axes rigidly connected with the movable area, one may be termed the primitive axis, and the other the complementary axis. If L be the greatest dimension of the curve parallel to the primitive axis, and if we draw parallel to the axis of x two straight lines distant from each other mL; then, in building up the x-projection, we have some choice in the manner of doing so, provided that none of the curve so generated lie outside the above-bounding lines. In what follows I have proceeded according to the method adopted in projecting a solid, given in a previous paper.

Let the primitive axis AB and complementary axis ED

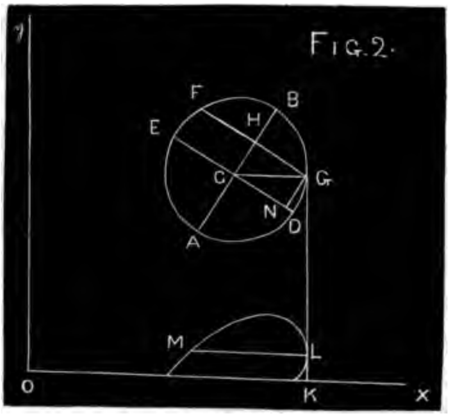
FIG. 2.

intersect in a point C, of which the coordinates are $x=a$, $y=b$. Draw FG parallel to ED, and GK parallel to Oy; on GK take a length KL, so that NG being parallel to AB,

$$\mathrm{KL}=m\mathrm{NG};$$

then L will be a point on the projected curve. If through L we draw parallel to Ox a line LM such that

$$\mathrm{LM}=m\mathrm{FG},$$

then M will be another point on the curve. By proceeding in this manner, the entire curve may be constructed. A curve generated in this manner from the primitive curve may, for brevity, be termed its projectrix.

The equation to the primitive being given, that of its projectrix may be deduced as follows:—

$$\mathrm{NG}=\mathrm{CG}\cos\mathrm{GCH},$$

x and y being coordinates of G, we shall have

$$\cos\mathrm{GCH}=\frac{(x-a)l+(y-b)m}{\mathrm{CG}};$$

therefore

$$\mathrm{NG}=(x-a)l+(y-b)m;$$

and

$$\mathrm{KL}=m\{(x-a)l+(y-b)m\};$$

therefore, if η and ξ be coordinates of the corresponding point on the projectrix, we shall have

$$\xi=\mathrm{OK}=x, \quad \ldots\ldots\ldots \quad (3)$$

$$\eta=m\{l(x-a)+m(y-b)\}, \quad \ldots \quad (4)$$

and if the primitive curve be

$$f(x, y)=0,$$

the projectrix will be

$$\int\left(\xi,\ \frac{\eta}{m^2}-\frac{(\xi-a)l-bm}{m}\right)=0.$$

From the relation between the coordinates, we may infer that the equation to the projectrix will be of the same degree as that of the primitive. Also since $\frac{d^2\eta}{d\xi^2}$ vanishes when $\frac{d^2y}{dx^2}$ vanishes, if the primitive has any singularities, the projectrix will have some singularity at the corresponding points.

That portion of the primitive area lying below the line ED will on projection be situated below the axis of x.

The relation between the areas of the primitive curve and its projectrix may readily be obtained by means of equations (3) and (4) :—

$$A_x=\iint_0^\eta d\eta\,d\xi \quad \text{or} \quad \int\eta\,d\xi\,;$$

by substitution this becomes

$$\begin{aligned}A_x&=\int m\{l(x-a)+(y-b)m\}dx,\\&=m^2\int\left(y-b+\frac{l(x-a)}{m}\right)dx,\\&=m^2\iint_{b-\frac{l}{m}(x-a)}^{y}dx\,dy.\qquad\ldots\ldots\ldots\ (5)\end{aligned}$$

In equation (4) make $\eta=0$, then we obtain

$$(x-a)l+(y-b)m=0.$$

This is the equation to the complementary axis, and the limits in (5) show that the integration is to extend from this axis to all points above; hence, between corresponding limits, we have

$$A_x = m^2 A.$$

Also if $\phi(x)$ be any arbitrary function of x, we may show in a similar manner that

$$\iint_0^\eta \phi(\xi)\, d\xi\, d\eta = m^2 \iint_{b-\frac{l}{m}(x-a)}^{y} \phi(x)\, dx\, dy.$$

As a particular example of the foregoing remarks, suppose the primitive curve to be a circle of radius c, and suppose the primitive axis to be a line through its centre; then

$$(x-a)^2 + (y-b)^2 = c^2.$$

By substitution we obtain for the projectrix

$$m^4(x-a) + \{y - lm(x-a)\}^2 = m^4c^2. \quad . \quad . \quad (6)$$

To simplify this remove the origin to the point $x=a$, $y=0$, and then refer it to new axes, so that θ, the angle between the new and old axes of x, fulfils the following condition:—

$$\tan 2\theta = \frac{2m}{l}; \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

then the equation assumes the form

$$\frac{\dfrac{x^2}{2m^4c^2}}{1+m^2-\sqrt{(1+3m^2)(1-m^2)}} + \frac{\dfrac{y^2}{2m^4c^2}}{1+m^2+\sqrt{(1+3m^2)(1-m^2)}} = 1; \quad (8)$$

this represents an ellipse of which the area is $m^2\pi c^2$.

If we suppose the primitive circle to revolve round an axis perpendicular to its plane, then m becomes a variable quantity, and equation (6) will contain a single variable parameter. Differentiating with regard to m, we obtain the following equation:—

$$\{y-ml(x-a)\}\left\{2y-(x-a)\frac{m}{l}\right\}=0.$$

The condition

$$y-ml(x-a)=0,$$

along with equation (6), gives the condition

$$x=a\pm c;$$

the two lines represented by this equation touch all the ellipses generated by varying m.

The condition

$$2y-(x-a)\frac{m}{l}=0,$$

gives for m and l the values

$$m=\frac{2y}{\sqrt{4y^2+(x-a)^2}},$$

$$l=\frac{x-a}{\sqrt{4y^2+(x-a)^2}}.$$

These values introduced into equation (6) give the following equation:—

$$16y^4+8y^2(x-a)^2+(x-a)^4=16y^2c^2,$$

an equation which is resolvable into the two following:—

$$\left(y-\frac{c}{2}\right)^2+\frac{(x-a)^2}{4}=\frac{c^2}{4},$$

$$\left(y+\frac{c}{2}\right)^2+\frac{(x-a)^2}{4}=\frac{c^2}{4};$$

each of these equations represents an ellipse, of which the major axis is equal to the diameter of the circle, and the minor axis to the radius; both ellipses touch the axis of

x and each other at the point $x=a$, $y=0$, one being situate above the axis and the other below.

Locus of the Extremities of the Major and Minor Axis.—Both the magnitude of the major axis of the projectrix and its inclination to the axis of x are functions of m. If r be the length of the major axis, from equation (8) we have

$$r=\frac{m^2c\sqrt{2}}{\sqrt{1+m^2-\sqrt{(1+3m^2)(1-m^2)}}};$$

eliminating m between this equation and (7), we obtain for the polar equation to the curve traced out by the extremities of the major axis

$$r=\frac{c}{\sqrt{\frac{3}{4}+(\sec^2\theta-\frac{3}{2})^2}}. \quad . \quad . \quad . \quad . \quad (9)$$

From the form of the equation it is evident that the major axis will have a maximum value $\frac{2c}{\sqrt{3}}$, and this will be the case when

$$\cos\theta=\sqrt{\tfrac{2}{3}}.$$

The form of the curve is shown in the annexed figure,

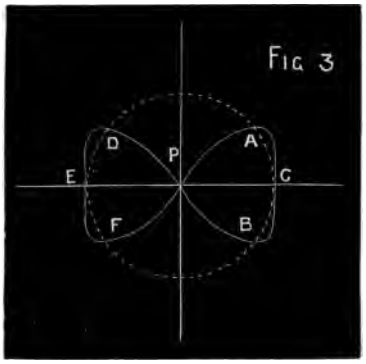
FIG 3

where the dotted curve represents a circle of the dimensions of the primitive circle. The curve cuts the axis of

x at the origin and at the point $x=c$; it cuts the circle at the point $r=c$, $\theta=45°$; at this point the inclination of its tangent is $\tan^{-1}\frac{1}{3}$. Below the axis of x there is a branch PBC similar to the one above the axis, and to the left of the axis of y there is a branch PDEF similar to the one on the right.

The major axis of the ellipse is generally greater than the radius of the circle. But of the curve just described a portion lies within the circle, and for such points the radius is less than c; the connection of this portion of the curve with the axes of the ellipses may be established as follows. Let r_1 be the length of the minor axis of the projectrix; then from (8) we have

$$r_1=\frac{m^2c\sqrt{2}}{\sqrt{1+m^2+\sqrt{(1+3m^2)(1-m^2)}}}.$$

Eliminating m between this equation and (7) we obtain the equation

$$r_1=\frac{c}{\sqrt{\frac{3}{4}+(\operatorname{cosec}^2\theta-\frac{3}{2})^2}}.$$

But if θ_1 be the inclination of the minor axis to the axis of x, measured in the positive direction, we shall have

$$\theta_1=\frac{\pi}{2}+\theta;$$

hence the polar equation to the minor axis is

$$r_1=\frac{c}{\sqrt{\frac{3}{4}+(\sec^2\theta_1-\frac{3}{2})^2}}.$$

This equation is of the same form as (9), but the minor axis is generally less than c; hence it follows that those portions of the curve which lie outside the circle are traced out by the extremities of the major axis, and those portions lying within the circle are traced out by the extremities of the minor axis. By the aid of this curve we may readily obtain any ellipse which may be derived by projection from a given circle—any line through the centre and terminated by the external branches will be a major axis; to obtain the corresponding minor axis, draw a line at right angles, then the portion intercepted between the internal branches will give the magnitude of the minor axis.

The equation to the curve in rectangular coordinates is

$$y^6=x^4(c^2-x^2);$$

its area is two thirds the area of the primitive circle.

As previously stated, we have some choice of method in constructing a projected curved area; in (6) the elementary rectangles have been so piled up that their centres lie on the line

$$y=\frac{m}{l}x-\frac{ma}{l},$$

that is, on a line parallel to the primitive axis. If the locus of the middle points were the line

$$y=-\frac{m}{2l}x+\frac{ma}{2l},$$

we should obtain an equation of the form

$$m^2(x-a)^2+4ml(x-a)y+(4-3m^2)y^2=m^4c^2,$$

representing an ellipse of which the perimeter is equal to the perimeter of the primitive circle. If any line $y=h$ cut this ellipse, the length of the section will be $2\sqrt{m^2c^2-h^2}$; this will also be the length of the section made by the same line with (6).

Inverse Problems in Projection.—In the foregoing remarks it has been supposed that the primitive curve has been given and the projectrix obtained by means of equations (3) and (4); but it is evident that by means of the same equations we may solve inverse problems, viz. given the equation to the projectrix to deduce that of the primitive. If the equation to the projectrix be given in the form

$$f(\xi, \eta) = 0,$$

that of the primitive will be of the form

$$f\big(x, m\{l(x-a)+m(y-b)\}\big).$$

Suppose the projectrix to be the circle

$$y^2+(x-a)^2=c^2,$$

we shall obtain for the primitive the ellipse

$$(x-a)^2(1+m^2l^2)+2m^3l(x-a)(y-b)+m^4(y-b)^2=c^2.$$

The semiaxes of this ellipse are

$$\frac{c\sqrt{2}}{\sqrt{1+m^2+\sqrt{(1+3m^2)(1-m^2)}}}$$

and

$$\frac{c\sqrt{2}}{\sqrt{1+m^2-\sqrt{(1+3m^2)(1-m^2)}}}.$$

Although the projection of this ellipse on the axis of x may be a circle, its projection on the axis of y will not simultaneously be a circle. The projectrix in this case will be

$$\{x-lm(y-b)\}^2+l^2m^2(y-b)^2=l^4c^2,$$

representing an ellipse of which the semiaxes are

$$\frac{cl^2\sqrt{2}}{\sqrt{1+2m^2l^2+\sqrt{4l^2m^2+1}}}$$

and

$$\frac{cl^2\sqrt{2}}{\sqrt{1+2m^2l^2-\sqrt{4m^2l^2+1}}}.$$

Relation of Perimeters of the Primitive and its Projectrices.—In a former paper it was shown that if on a primitive solid we draw any arbitrary curve of length s, and if s_x, s_y, s_z denote the lengths of the curves passing through the corresponding points of the projected solids, then a simple relation can be found amongst the differentials of these quantities. A similar proposition holds in geometry of two dimensions, the relation in this case being between the perimeters of the primitive and its projectrices. Differentiating (3) and (4) and squaring we obtain

$$d\xi^2 = dx^2,$$
$$d\eta^2 = m^2(l\,dx + m\,dy)^2.$$

ξ_1 and η_1 being the corresponding points on the y-projectrix, we shall have

$$\eta_1 = y,$$
$$\xi_1 = l\big((x-a)l + (y-b)m\big),$$

whence

$$d\eta_1^2 = dy^2,$$
$$d\xi_1^2 = l^2(l\,dx + m\,dy)^2.$$

By addition we have

$$d\xi^2 + d\eta^2 + d\xi_1^2 + d\eta_1^2 = dx^2 + dy^2 + (l\,dx + m\,dy)^2. \quad (10)$$

ds being the arc of the perimeter extending from the point x, y to the point $x + dx$, $y + dy$, and ds_x, ds_y being the arcs of the projectrices between corresponding points, we shall have

$$ds^2 = dx^2 + dy^2,$$
$$ds_x^2 = d\xi^2 + d\eta^2,$$
$$ds_y^2 = d\xi_1^2 + d\eta_1^2;$$

also if ϕ be the angle between the direction of the primitive axis and the tangent at any point to the primitive curve, we have

$$\cos\phi = l\frac{dx}{ds} + m\frac{dy}{ds};$$

therefore, by substitution, equation (10) may be put in the form

$$\sqrt{ds_x^2 + ds_y^2} = \sqrt{1 + \cos^2\phi} \, . \, ds.$$

If we suppose the primitive area to revolve round any axis perpendicular to its plane, since the primitive axis is rigidly connected with it, the expression $\int\sqrt{1+\cos^2\phi} \, . \, ds$ will be invariable; replacing it by c, we shall have then

$$\int\sqrt{ds_x^2 + ds_y^2} = c.$$

Relation of Projectrices of Higher Orders.—From a primitive may be derived two projectrices; but each of these may in its turn be regarded as a primitive that may be operated upon in a similar manner; then, on a repetition of the process, we shall obtain four projectrices. The relation of the area of these to that of the primitive may be obtained as follows. A_x being the primary projectrix on the axis of x, the secondary projectrices which may be derived from it may be denoted by $(A_x)_x$ and $(A_x)_y$, and we shall have

$$(A_x)_x = m^4 A, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (11)$$

$$(A_x)_y = m^2 l^2 A. \quad . \quad . \quad . \quad . \quad . \quad . \qquad (12)$$

If $(A_y)_x$ and $(A_y)_y$ denote the secondary projectrices which may be derived from A_y, we shall have

$$(A_y)_x = l^2 m^2 A, \quad . \quad . \quad . \quad . \quad . \quad . \qquad (13)$$

$$(A_y)_y = l^4 A. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (14)$$

By addition of these four equations we obtain

$$(A_x)_x + (A_x)_y + (A_y)_x + (A_y)_y = A(m^4 + 2m^2l^2 + l^4)$$
$$= A(m^2 + l^2)^2 = A.$$

From this it seems likely that if we repeated the operation n times the aggregate of the 2^n areas obtained would be equal to the primitive area, and it may be readily shown that if the proposition be true after n operations, it will be true after $n+1$ operations. But it has been shown to be true when n is equal to 2, therefore when n is equal to 3, therefore when n is equal to 4 &c., and so the proposition is generally true.

III. *On some Undescribed Tracks of Invertebrate Animals from the Yoredale Rocks, and on some Inorganic Phenomena, produced on Tidal Shores, simulating Plant-remains.* By Professor W. C. Williamson, LL.D., F.R.S., President.

Read February 10th, 1885.

[Plates I., II., III., & III′.]

About two years ago I received from the Rev. Isidore Kavannah, of Montreal, then a student of Stonyhurst College in Lancashire, some interesting objects which he had discovered upon some loose blocks of stone strewing the shore of the river Ribble, close to the College. The raised bank of the river, at that point, consists of hard beds of Yoredale rock separated by thin layers of softer material. A careful examination of the locality left no doubt on my mind that the specimens had fallen from the under surface of one of these hard beds. Though we failed at that time to discover any such *in situ*, at a later date Mr. Kavannah was more successful. He then obtained some fine examples from the under surfaces of some of these undisturbed beds, making it certain that the objects immediately to be described belong to the Yoredale division of the Carboniferous strata.

Like so many allied remains obtained from Silurian deposits, these objects stand out in bold relief from the inferior surfaces of the rock-layers, of which their substance is a mere extension. The peculiar sculpturings characterising these convex surfaces are wholly superficial, indicating that they are but casts of concave tracks once existing on the surface of the subjacent stratum. The dimensions of those excavated tracks are faithfully, though invertedly, represented by the prominent configurations of the objects before us.

The specimen (Plate I. fig. 1) represents a slab twice the size of the photograph, upon which are three more or less defined meandering ridges. The longest of these runs from *a* to *a*. A considerable portion of it is almost obliterated; but at each extremity it preserves its characteristic features. At *b* and *c* are two shorter ones, each of which commences in an undefined irregular elevation; *b* near the centre of the slab, and *c* at *d*; but both acquire their peculiar sculpturings at the extremities *b* and *c*. Assuming that the creatures which made these tracks moved towards the lower margin of the specimen, the appearances suggest that in the cases *b* and *c* they terminated their strolls by sinking into the sand, as many recent invertebrates do, on reaching the spots where each of two of the tracks end in an irregular mass, as represented at *d*.

The average diameter of each of these tracks is from five to six tenths of an inch. Their elevation, representing the depth of the original tracks, is sometimes four tenths of an inch; usually, however, they fall short of this depth. A median furrow runs along the entire length of the track in these casts, representing some median abdominal groove in the living organism. Numerous parallel ridges and alternating furrows proceed outwards, downwards, and backwards (?) from this groove, about ten such ridges occurring in each lineal inch. Along the summit of each of these lateral ridges we have a row of small tubercles, about twenty to an inch. These tubercles sometimes appear to be the summits of obtuse elevations which pass obliquely down one side of each ridge, disappearing as they reach the median line of the contiguous furrow, the opposite side of which presents no such appearances. These small sculpturings suggest that the appendages (legs?) of the animal to which the primary and secondary ridges and furrows are due had serrated or crenulated margins. Fig. 2, Plate III., represents the arrangements in question diagrammatically, the appearances being made rather stronger than in reality to illustrate their general features.

The surface of the slab (fig. 1) is covered with parallel, rounded ridges and furrows of varying depths and elevations. These may represent drainage-lines, but they also suggest somewhat strongly the idea of a wind-blown surface of sand.

Fig. 3 represents a second fragment, in which the lateral ridges and furrows of one of the two tracks are less uniformly regular, some of them being stronger than in the case of fig. 1; but here again the track is connected at the end on its right with an irregular boss, representing a corresponding depression on the primæval beach.

These objects correspond closely to those supposed vegetable organisms to which Schimper has assigned the name of *Chrossocorda*. Though I am altogether unable to share Schimper's belief in their vegetable origin, I see no objection to retaining his name. So far as I am aware, all the examples of *Chrossochorda* hitherto known have been obtained from strata of much older age than the Yoredale series. But, besides this difference of age, these Carboniferous forms differ from all the older ones in possessing the line of tubercles along the summit of each of the secondary ridges already referred to. These objects may therefore be distinguished as *Chrossochorda tuberculata.*

What animal produced the hollow tracks of which these fossils are casts in relief, we have no means of knowing. There is an obvious resemblance between them and the tracks which Dr. Nathorst obtained by allowing the Crustacean *Corophium longicorne* to walk and swim over prepared mud*. In several similar tracks figured by Dr. Nathorst we find the line of footsteps terminating in enlarged irregular depressions, corresponding to the bosses seen in figs. 1*d* & 3.

Plate I. fig. 4 represents a track of an entirely different kind, from a quarry of Carboniferous flagstones near Hawes†. I presume that in this case we have not the cast, but the actual indented track of the animal that has left its footsteps on the smooth sands. The length of the stone is $17\frac{1}{2}$ inches. Each separate group of impressions consists of four pairs of slightly curved indentations, each octant occupying a square $1\frac{3}{10}$ of an inch from *a* to *b*, $\frac{19}{20}$ of an inch from *c* to *d*, and nearly $\frac{8}{10}$ from *e* to *f* of the accompanying lignograph. The markings suggest the idea of having been made by four pairs of abdominal plates rather than by crustacean limbs. The distances between

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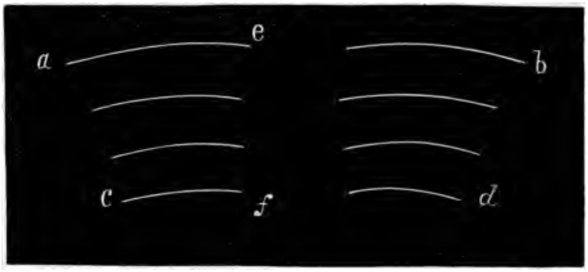
* Om spår af några evertebrerade Djur m. m., och deras paleontologiska betydelse, af A. G. Nathorst. Stockholm, 1881. Tafl. i. figs. 1–2.

† Mr. J. W. Davis says, "The footprints are from a quarry of flagstones and grey slates about a mile from Hawes, on the road to Muker. The horizon is above the Hardrow Limestone."

the anterior pair *a* and *b*, and the corresponding pair *b* and *c* in fig. 4, is exactly $1\frac{2}{10}$ of an inch. There is no trace of any defined median vertical line, but there is a distinct elevation in each of the areas separating the parallel curved grooves, and the vertical median line between each two rows is also faintly raised, as if, in the latter case, a slight concavity existed at the corresponding part of the living animal. What that creature may have been is more than doubtful. Except what appears in the successive octants, no continuous trail of any kind appears on the slab, making it obvious that the creature possessed no Trilobite-like tail or sternal ridge. The object may safely be placed in the genus *Protichnites*, and be distinguished as *P. Davisi*, after my friend J. W. Davis, Esq., F.G.S., of Halifax, by whom the specimen was found, and who has kindly allowed me to describe it in this memoir.



Leaving these two relics of a past age, I would now direct attention to some phenomena of modern origin, which I have recently observed on the sea-shore. Two summers ago my attention was arrested by some remarkable appearances on the sands left bare by the retreating tide at Llanfairfechan in North Wales. Watching the formation of these appearances, it soon became obvious that they were formed by small drainage-streams flowing either towards the sea or towards large temporary depressions in the sand running more or less parallel with the sea-line. The contours produced by many of the smaller tributaries, where they united to form larger streamlets, suggested to my mind the extreme probability that the casts of such sculptured areas would, if found in any of the older strata, be undistinguishable from many of the so-called fossil "Fucoids" found in these strata. Working carefully, I succeeded in obtaining a number of plaster casts of these grooved surfaces, some of which are accurately represented, through the aid of photography, by the several figures 5–11 on Plate II., and figs. 12 & 13 on Plate III. The leaf-like peripheral outline of some of these figures has no significance, it being merely that assumed by the flowing of the semi-fluid plaster of Paris when poured upon the sand; but it is otherwise with the plant-like ramifications revealed on the surface of each cast. Had such specimens been found on the inferior surfaces of ancient flagstones, I have little doubt but that they would have appeared in the pages of Schimper, and other authors with similar views, as Palæozoic Fucoidal forms of plant-life; anyhow their publication may benefit some of our younger and more ardent palæontologists, by suggesting caution ere they give names and places in the annals of Palæophytology, to objects which may be as wholly inorganic as those which I have just described. Nearly all the configurations of this kind which I discovered at Llanfairfechan were of the same character as those represented by figures 5–13 of my Plates. On visiting the sands to the north of Barmouth during the summer of 1884 I made diligent search, in the expectation of finding there *similar* configurations. Products of tidal action and drainage were not wanting, but to my surprise those of the new locality were wholly different from what I found on the Carnarvonshire coast.

Figs. 14 & 15 are photographs of casts made at Barmouth, and represent the results of a double action, viz. the production of ripple-marks, and a subsequent sculpturing by drainage-currents. The ripple-marks, at the point in question, curved diagonally across the lines subsequently followed by the drainage-streamlets. Hence the surface of the sand was cut up into the very regular, diagonally arranged, contours represented in Plate III. fig. 14. We have here two sets of regular ripple-marks, one of which passes from the upper to the lower margin of the figure, from right to left. A second and more sharply defined set crosses these diagonally, *i. e.* from left to right. These lines were, of course, formed under the water. When the tide had retreated sufficiently, drainage-lines began to form; but these pursued their direct course down the sloping sand-bank towards the sea. The result of this triple action was the formation of a series of regularly arranged, acuminate contours, the surfaces of which were characterized by longitudinal flutings, resembling the overlapping scale-leaves of some Cycadean stem. They readily might, and probably would, have been mistaken for such, had they been discovered on some slab of Oolitic sandstone.

Fig. 15 exhibits a slight difference from fig. 14. Here we had only one diagonal series of ripple-marks, followed by the formation of drainage-lines as before. The result is an effect not unlike that of two or three corrugated Laminarian fronds overlapping one another.

I have no doubt that further investigation will bring to light other examples of inorganic configurations simulating organic forms. I am somewhat surprised that so little attention has hitherto been paid to the results of littoral drainage-lines. Sir J. W. Dawson figures an example of one such result, but of very different aspect from those now described, in his memoir on tracks of Invertebrata in Silliman's American Journal, entitled "On the Footprints of *Limulus* as compared with the Protichnites of the Potsdam Sandstone" (1862). But I have not met with any other detailed illustrations of drainage-lines contributing towards the formation of pseudo-organic structures*, still less to the combination of drainage-lines and ripple-marks in producing analogous results; yet the literature of the subject of tracks and pseudo-vegetable forms has now become a very copious one.

In his extremely valuable memoir "On some Tracks of Invertebrate Animals &c., and their Palæontological Import"†, Dr. Nathorst has published a bibliography of the subject treated in his memoir, containing no less than 130 references to writers who have dealt with various aspects of the subject between the years 1823 and 1881 inclusive. Many of these writers have regarded the objects to which they have referred as the tracks or footsteps of various invertebrates left upon the sandy or muddy shores which they frequented; but a large proportion of the authors have referred these objects to the vegetable kingdom, especially to the Fucoidal section of it. The extent to which this has been done is shown in the pages of Schimper's 'Paléontologie Végétale,' where a large number of genera, and a still larger one of species, have been created out of extremely vague and indefinite objects. More recently the Marquis de Saporta has published his volume, entitled 'L'Évolution du Règne Végétale' (Paris, 1881), in which he adopts freely the conclusions of Schimper, and recognizes in these doubtful objects various definite forms of marine Algæ.

The Marquis de Saporta first replied to the memoir of M. Nathorst in a volume entitled 'Les Organismes problématiques des anciennes Mers,' 1882, and two days ago I received from him a second volume, entitled 'A propos

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* My ignorance of the Swedish language has led me to overlook the fact that Dr. Nathorst figures an example of this kind on p. 21 of his memoir supplied to him from Gothland by Professor Lindström (July 25th, 1885).

† Om spår af några evertebrerade Djur m. m., och deras paleontologiska betydelse, af A. G. Nathorst. Stockholm, 1881.

des Algues Fossiles,' having the same object as the preceding one*. These two volumes embody every argument that can be advanced in favour of the vegetable origin of the objects in dispute. Much of the discussion turns upon the point illustrated by figs. 1 & 3 of my present memoir, viz. that nearly all the debated structures stand out in prominent demi-relief from the undersides of the slabs of which they form a part; and that, as is conspicuously the case with my specimens, what ought to represent the substance of the supposed organism is merely an extension of the inorganic rock overlying the sculptured surfaces. M. Saporta takes much pains to show that many unquestionable fossil plants are found in this same condition of demi-relief. This is true; but we find abundance of the same plants in different conditions, in which substance and even structures are equally preserved. Hence we are able to identify the specimens seen only in semi-relief by the aid of the more perfect examples. But in the case of such specimens as my figs. 1 & 3, we have hitherto failed to obtain any trace of either substance or structure. M. Saporta, in his latest memoir, seems to have found some specimens of the genus *Biserites*, in which he can trace what he describes as "le contour entier de la Bilobite." This only shows a possibility that one of the many objects to which the name of Bilobites has been given may have been plants.

These views were attacked in a formidable manner by Dr. Nathorst in the memoir above referred to. This important memoir embodies the results of a series of exact experiments, in which various aquatic animals were allowed to travel under water, leaving behind them very definite tracks in fine mud as they did so. Dr. Nathorst succeeded in obtaining very perfect casts of those tracks, and, in

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* The resemblance of M. Saporta's figure of *Vexillum Desglandi*, on p. 42 of the latter volume, to my fig. 15 on Plate III. is too striking to be overlooked.

order that his representations of them should owe nothing to the imagination of his artist, he employed photography, that unerring delineator, in illustrating his memoir; an example which I have followed on the present occasion.

Examples of what are probably concretionary objects occasionally occur of such a magnitude as to make it improbable in the highest degree that they can have been of vegetable origin. Some of these might be regarded as a huge form of *Dictyonema,* in which the fibres forming the network are six inches in circumference, and the enclosed meshes a foot wide. At the junction of the lowermost beds of the Coralline Oolite with the uppermost beds of the Calcareous Grit at Filey Brig in Yorkshire, acres of the contiguous surfaces of the two rocks are covered with such a huge network of coarse inorganic sandstone, in which the cylindric form is sufficiently perfect; but after prolonged study of these ramifying objects, all that Professor Phillips could say of them is that "they are ramified masses of doubtful origin, which appear like dichotomous cylindrical sponges" *. Thoroughly familiar with these structures, I never for a moment doubted their inorganic character. Such objects can have no weight with the student of Evolution, and until we obtain more definite proofs than we have hitherto obtained of the vegetable nature of most of these dubious "Palæozoic Algæ," we must reject their testimony when framing a pedigree for the vegetable kingdom. At the same time I regard the existence of an abundant marine vegetation during the Palæozoic ages as an inevitable corollary of the fact that the rocks of those ages abound in the remains of Phytophagous animals. But many sources of error surround us when we endeavour to demonstrate that existence by means of the anomalous objects which those rocks have already supplied to us.

* Geology of the Yorkshire Coast, 2nd edition, p. 106.

INDEX TO THE FIGURES.

Plate I.

Fig. 1. Slab of Yoredale rock, with tracks of *Chrossocarda tuberculata*, Will. Half the nat. size.

2. Diagrammatic representation of a portion of one of the above tracks.

3. A second fragment, with two tracks of somewhat more strongly defined contour than those of fig. 1. Nat. size.

4. Track of *Protichnites Davisi*, Will. Two fifths of the natural size.

Plates II. & III.

5–13. Casts of a series of drainage-lines from the coast of North Wales at Llanfairfechan.

Plate III′.

14, 15. Two similar casts from the coast north of Barmouth.

These figures are all copied by an autotype process from photographs, kindly taken for the purpose of illustrating this memoir, by Alfred Brothers, Esq., F.R.A.S., of Manchester.

IV. *On the Structure, the Occurrence in Lancashire, and the probable Source, of* Naias graminea, *Delile, var.* Delilei, *Magnus.* By Charles Bailey, F.L.S.

Read April 29th, 1884.

(Plates IV.–VII.)

I. Introduction.

Naias graminea, Del. (Plate IV. fig. 1), and *Chara Braunii*, Gmel., were first reported as occurring in a natural state in England at the Meeting of the British Association at Southport in September 1883. Their addition to the flora of South Lancashire and of Britain is due to the Biological Society of Ashton, and to Mr. John Whitehead, of Dukinfield. They were discovered during the exploration of the Ashton-under-Lyne district in acquiring the necessary material for the compilation of a fauna and flora of the neighbourhood, for presentation to the Biological Section of the British Association. An abstract of this communication, made by Mr. J. R. Byrom, of Ashton, is printed on pp. 541–543 of the 'Report of the Fifty-third Meeting of the British Association.'

Few portions of Great Britain are so well known, botanically, as most of the northern counties of England, and yet a concerted systematic examination of so well-worked a district as Ashton has brought to light many novelties, besides two, if not three, plants not previously known to be British. To those who know what a large number of practical botanists there are in the north of England, and with what zest so many of their number pursue botanical studies in their hard-earned leisure, it has always seemed a matter for regret that so little of their accumulated knowledge finds its way into print; and the instance of what has been done by the Ashton botanists should stimulate other local societies to make similar efforts.

The actual discoverer of the *Naias* was Mr. James Lee, of Denton; he brought it to Mr. Whitehead, who sent it to me early in September of last year as a possible *Naias*, and, from plants which I afterwards gathered *in situ* with the discoverer and Messrs. Whitehead and Byrom, it was finally determined by Mr. H. N. Ridley, of the British Museum, to be *Naias graminea*, Del., or *Caulinia alagnensis*, Pollini. Subsequently Dr. Magnus, of Berlin, has given it the varietal name of *Delilei,* on account of a structural peculiarity referred to on pages 46 and 69.

II. The Genus and its Divisions.

The genus gives its name to the natural order Naiadaceæ, which is allied to the Potamogetonaceæ, but systematists are by no means agreed as to the respective limits of either family. Willdenow separated the group to which *N. graminea* belongs from *Naias* proper, under the generic name of *Caulinia**, on account of the male flowers not having the quadrifid perianth of *Naias* proper; but Robert Brown reunited the two groups of *Naias* and *Caulinia* into *Naias,* Linn. There is no doubt, however, that each of these divisions forms a very natural group sharply separated from the other by well-marked characters drawn from the leaf, stem, and fruit. All these points have been carefully worked out by Dr. P. Magnus in a work which he modestly entitled 'Beiträge zur Kenntniss der Gattung *Najas,* L.' (Berlin, 1870); and no one can investigate the morphology and anatomy of a plant of this genus without admiring the minute and conscientious investigations of this author. In preparing the following notes I have referred again and again to this memoir, and I cannot speak too highly of the help derived from it.

Dr. Magnus gives the following diagnoses of the two subdivisions of the genus, viz.:—

"§ Eunajas, Asch.—Spine-teeth chiefly on the stem and backs of the leaves. Flowers diœcious (? in all). Anther four-chambered (? always). Seed-shell consisting of a many-layered stony parenchyma. Conducting bundles of the stem divided from the intercellular spaces by two to three layers of parenchyma-cells. Leaf furnished with a

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* 'Mémoires de l'Académie Royale des Sciences de Berlin, 1798, classe de Philosophie Expérimentale,' page 87.

small-celled epiderm, which rises very sharply from the large parenchyma-cells of the leaf.

"§ CAULINIA, Willd.—Spine-teeth absent from the stem and backs of leaves. Flowers in most species monœcious (? in all). Anther one- to four-chambered. Seed-shell formed of three layers of cellular tissue. Conducting bundles of the stem divided from the intercellular spaces by a layer of parenchyma-cells; leaf without the small-celled epiderm."—*Beiträge*, pp. 55, 56.

The plant which forms the subject of this notice belongs to the section *Caulinia*, and its synonymy and principal book-references are the following:—

III. SYNONYMY OF THE PLANT.

Najas graminea, Delile, Flore de l'Egypte; Mémoire sur les plantes qui croissent spontanément en Egypte, par Alire Raffeneau Delile, p. 1; Floræ Ægyptiacæ illustratio No. 874, p. 75; Explication des planches, p. 282, pl. 50. fig. 3.

Chamisso, Aquaticæ quædam diversæ affinitatis; Linnæa, vol. iv. 1829, pp. 502, 503.

Kunth, Enumeratio Plantarum. &c., tom. iii. p. 115.

Boissier, Flora Orientalis, vol. v. p. 28.

Compendio della Flora Italiana compilato per cura dei Professori V. Cesati, G. Passerini, e G. Gibelli, par. i. p. 205.

Najas alagnensis, Pollini, Hort. et provinc. Veron. pl. nov. vel min. cogn. p. 26; Flora Veronensis quam in prodromum Floræ Italiæ septentrionalis exhibit Cyrus Pollinius, tom. iii. p. 49 (1824).

L. Reichenbach, Flora Germanica Excursoria, No. 920, p. 151.

Chamisso, Aquaticæ quædam diversæ affinitatis; Linnæa, vol. iv. p. 502 (1829).

Antonii Bertolonii, M.D., Flora Italica sistens plantas in Italia et in insulis circumstantibus sponte nascentes, tom. x. fasc. iii. p. 296.

Naias serristipula, Nocc. et Balb. Ic. Fl. Ticin. tab. 15 ex specim. sicc. delineata.

Naias tenuifolia, Aschers., Atti della Società Italiana di Scienze naturali, pp. 267 & 268; non R. Br.

Najas graminea, Del., var. *Delilei*, Magnus, Berichte der deutschen botanischen Gesellschaft, Band i. Heft 10, Jahrg. 1883, pp. 522 & 523.

Caulinia alagnensis, Pollini, Plant. Veron. 26.

Diar. Brugnatelli Giorn. ann. 1816, t. ix. p. 175.

Bluff et Fingerhuth, Compendium Floræ Germaniæ, sectio i. ed. alt. ii. p. 585.
Flora Italiana, ... di Filippo Parlatore, vol. iii. pp. 665, 666.
Caulinia intermedia, Balb. Elench. recentium stirpium, quas Pedemontanæ floræ addendas censet &c.; in Mem. della R. Accad. di Tor. ann. 1818, tom. 23. p. 105.
Balb. et Nocca, Flor. Ticin. tom. ii. p. 163, tab. 15.
Nocca, Clav. ii. p. 91.
Caulinia microphylla, Nocc. et Balb. Flor. Ticin. tom. ii. p. 163, tab. 16.

It still remains a question whether this plant should bear Delile's name or Pollini's name, according as the one or the other had priority in publication, as has been pointed out by Prof. Ascherson in 'Atti della Società Italiana,' vol. x. p. 267, where he shows that the description of the plant of Pollini was certainly published in 1814; whilst the Memoir of Delile, although perhaps printed in 1813, was not published until some later year. I cannot elucidate this point further, as my copy of Delile has no titlepage, and my edition of Pollini's 'Flora Veronensis' is that of 1824. Pollini's herbarium-specimen of the Italian plant is preserved among the possessions of the Society of Naturalists of Rhenish Westphalia, in Bonn.

The Italian plant is not the same as Robert Brown's *Naias tenuifolia*, Prodr. Fl. Nov. Holland. p. 545, published in 1810, on account of the entirely different structure of the male flower (see Plate VI. fig. 15); otherwise the name would have taken precedence of Pollini's and Delile's.

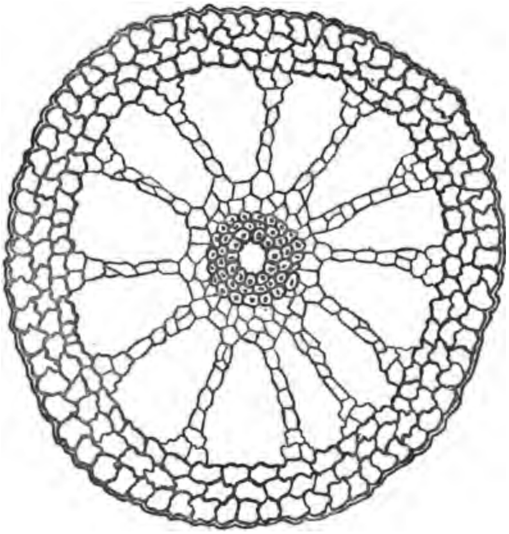
Whether the plant found in Japan, at Yokohama, is identical with *Naias graminea*, Del., is uncertain; but the description of it by Herr C. J. Maximowicz may stand for the Lancashire plant:—" Mollis elongata, foliis verticillatis patentibus rectis argute spinoso-serrulatis, apice 2–3 cuspidatis, dentibus incurvis 1-cellulosis minutis; stipulis distinctissimis lanceolatis foliaceis folii ad instar serrulatis;

fructu lineari-oblongo, granulato. Nippon, in fossis circa Yokohamam semel inveni fructiferam"*.

IV. The Stem.

The stems vary in length from a few inches to upwards of two feet, and they have many branches. Considering the large number of leaves which they support, the stems are comparatively weak; they do not vary much in diameter from the base to the summit; vertical sections of the upper internodes are not quite so circular as those of the lower internodes.

Fig. 42.



If we examine one of these internodes we find that the centre of the shaft consists of a small channel, surrounded by two or three layers of elongate cells somewhat closely

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[*] Diagnoses breves plantarum novarum Japoniæ et Mandshuriæ, in Bulletin de l'Acad. Imp. des Sciences de St. Pétersbourg, vol. xii. pp. 71, 72 (1868).

aggregated; surrounding these is a layer of much larger cells, hexagonal in outline, and having thinner walls than those which protect the central channel. From this central mass radiates a series of from eight to twelve prolongations of the central hexagonal cells, meeting as many outgrowths from the tissue which forms the circumference of the internode, and arranged like the spokes of a wheel. See fig. 42.

The rays enclose an equal number of large intercellular cavities, each cavity being bounded by the central and peripheral parenchyma at either end. The cavities occur in every internode, whatever its age, but they are limited in the direction of the axis by the node. The rays consist of a single row of cells, except at the points where they join the circumference and centre; they are not always as regular as they are drawn in fig. 42, as they occasionally branch at each end so as to enclose a smaller intercellular cavity.

The circumferential tissue of each internode consists of three or four rows of elongate cells having a hexagonal outline, with sinuous edges. The cells are all uniform in size, the outermost layer not being smaller than the rest, as it is in *Naias flexilis*. The external edge of the outer row of cells is slightly thickened, but I cannot detect any epidermal cells.

In the posthumous work of Prof. Parlatore, entitled 'Tavole per una "Anatomia delle piante aquatiche,"' a drawing is given of the transverse section of the Italian *Naias graminea*; but it differs from my drawing (fig. 42) in showing an epidermis of distinct square-shaped cells. The central bundle is also made to consist of about half a dozen rows of cells, smaller in size than I find them in the Reddish plant. I reproduce Parlatore's figure on Plate VII. fig. 36.

Chatin, in his valuable but incomplete work, 'Anatomie comparée des Végétaux,' did not quite reach the Naiadaceæ in the volume devoted to aquatic plants, or his drawings would have been useful for comparison; it is much to be desired that this fine work had been completed, as well for the parasitic plants as for the aquatic. The Naiadæ are not yet figured by Reichenbach in his 'Icones Floræ Germanicæ et Helveticæ,' &c.

V. The Leaves.

The leaves grow in tufts at the side of each internode, and they are rather more lateral than they are represented in Delile's figure, reproduced two thirds the original size in Plate V. fig. 3. In the living state, as seen in the water from above, they have a light olive-green shade, much duller than that of the bright green leaves of *Naias flexilis*. In the dried state they become much darker, particularly in the older leaves, but the younger tufts retain the light green colour of the living plant.

Fig. 43.

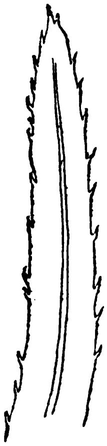
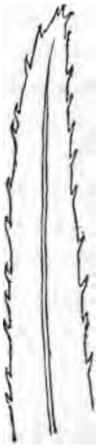


Fig. 44.



In shape the leaves are linear, broadly channelled in their lower portion (figs. 64 & 65), thickened in the region of the midrib (figs. 60–63), and slightly keeled on their lower surface; in length they vary from $\frac{1}{2}$ inch to $1\frac{3}{4}$ inch, and they are $\frac{1}{24}$ inch broad or less (see Plate IV. fig. 2). The sides of the fully-developed leaf are parallel for the greater portion of their length, but at their base they widen out into a broad sheath bearing two upright auricles applied to the stem and half-clasping it (figs. 52–55). The extremity of the leaf is gradually attenuated, and ends in from one to three spines (fig. 43); the extremities are frequently truncate, so that the spines give it a cuspidate character (fig. 44).

The margins of the sides, sheath, and free extremity are studded with erect, unicellular, yellowish-brown spines (figs. 47–49), whose colour presents a contrast to the transparent marginal cell-walls, and to the green contents of the cells of the lamina of the leaf. The spines are acuminate, slightly curved, and gradually narrowed from the base to the sharp point.

VI. The Leaf-spines.

The form of the spine, or tooth, on the margin of the leaf furnishes good discriminating characters between the various species of *Naias*, as was long ago pointed out by the late Al. Braun in the 'Journal of Botany,' vol. ii. 1864, pp. 274–279.

The simplest form of tooth is that of *N. flexilis*, where, in Dr. Boswell's Loch-Cluny specimens, the base of the spine is in the same plane as the leaf-margin. The spine springs from a dilatation between two of the marginal leaf-cells (fig. 45), each of which nearly equally supports the spine to the extent of one third its length, rarely more. Sometimes the two marginal cells are separated from each other by the spine (see fig. 46).

In *Naias graminea* the type of spine is similar, but it differs from that of *N. flexilis* in having a bi-celled base whose sides unequally support the spine. The lowermost of the two basal cells diverges, at its upper end, from the line of the leaf-margin, so as to wholly support the lower end of the spine (see fig. 47). The uppermost cell, on the other hand, acts as a support to the inner side of the spine for fully one half its length; it also partially underlies the upper end of the lowermost basal cell, and thus its three-sided profile fills up the axil of the spine and adds considerably to its rigidity, as compared with the arrangement in *N. flexilis* (comp. fig. 45). Occasionally a third cell makes its appearance, as shown in fig. 48, and not infrequently there is an auxiliary spine between the upper supporting cell and the original spine (see fig. 49). In all these cases, however, the axillary, or uppermost, basal cell distinguishes the type of tooth from the characteristic tooth of *N. flexilis*. Cesati gives figures of the dentition of these two species in plate ii. of 'Linnæa,' vol. xxxvi.;

Fig. 45.

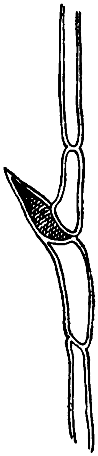


Fig. 46.

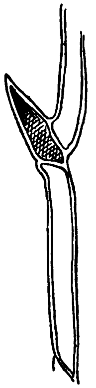


Fig. 47.

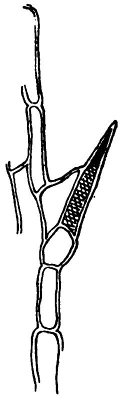
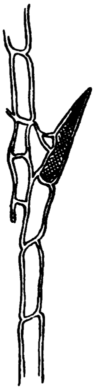


Fig. 48.



but he makes that of *N. alaganensis* much nearer to that of *N. flexilis* than I find it to be in the Manchester plant.

A third type of spine is furnished by *Naias minor,* All. (*Caulinia fragilis,* W.). This shows an advance upon the basal arrangement of the spines of *N. flexilis* and *N. graminea,* in being formed of more than three cells (see fig. 50). The entire tooth stands much above the line of cells which forms the margin of the leaf.

Fig. 49.

Fig. 50.

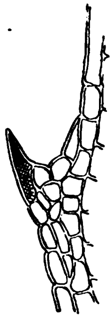
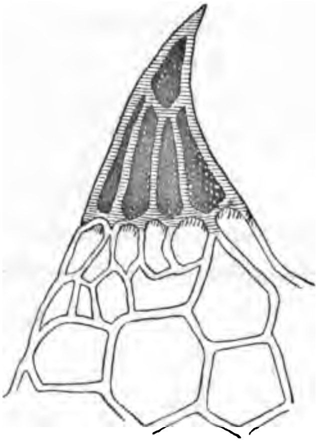


Fig. 51.



Upon comparing these figures (which I have carefully made from typical specimens) with those given by Braun on p. 275, vol. ii. of the 'Journal of Botany' (1864), it will be seen that my drawings present considerable variation from his, particularly in *N. flexilis.* It is possible that Braun's figures were meant to be diagrammatic, and representative of groups rather than of species; for convenience of reference I have reproduced them in Plate VI. figs. 6–8.

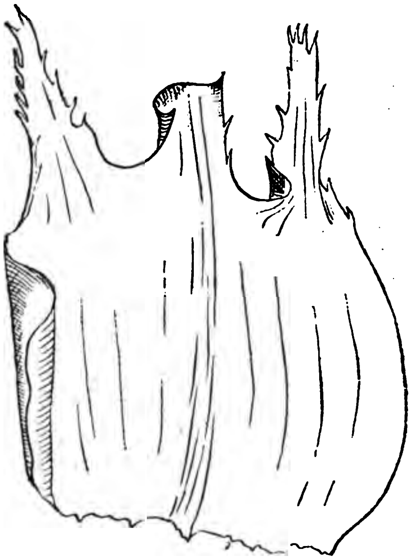
The other end of the series of types of spines is represented by the tooth of *N. major,* where there is not only a multicellular base, but the spine itself is compound; one terminal dark brown cell resting upon several elongate dark brown cells, the whole forming a very conspicuous tooth standing well out from the plane of the leaf-margin. Fig. 51 gives a tooth of this species from one of the late Dr. Wirtgen's specimens from the mouth of the Moselle, near Coblentz.

In *N. graminea* the spines are situated on the leaf-margins only (never on the midrib) at intervals equal to from one half to the whole breadth of the leaf. Figs. 47–49 have been drawn from spines on the edge of the middle portion of the leaf. Their shape is constant on the sides of the lamina, but they become longer on the sheath and at the apex of the leaf.

VII. The Leaf-sheath.

The leaf-sheath is another important character in distinguishing the species of Naiadæ, the extent of the dilatation,

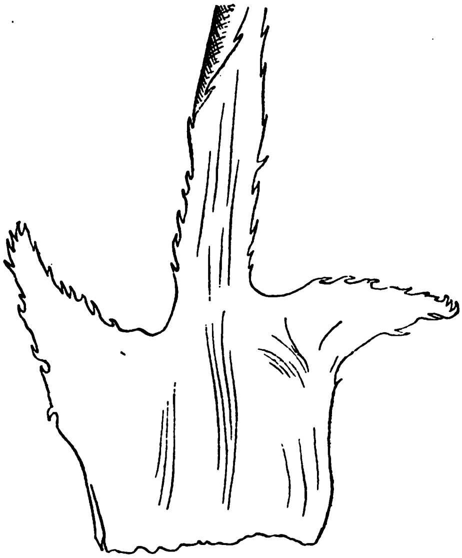
Fig. 52.



and the form of the auricle when present, furnishing useful marks of discrimination. The types given by Braun in the 'Journal of Botany,' vol. ii. p. 274, are redrawn on Plate VI. figs. 10–14, but, as will be seen from what follows, the Reddish plant differs considerably from Braun's figure of *N. graminea,* unless he meant it to serve as a general figure of the type of sheath in his super-species *N. tenuifolia.*

In the English *Naias graminea* the base of the lamina of the outermost pair of leaves suddenly dilates into a pair of upright auricles or ears, which are continued below so as to form a more or less ample sheath (see fig. 52); the size of the sheath presents considerable variations, according to the age and the position of the leaf to which it belongs (see figs. 52–55). I see no trace of any intravaginal scales (squamulæ) at the base of the leaf-sheath, such as are found in *Naias major* and in the allied genus

Fig. 53.



Phucagrostis. Fig. 29, Plate VI., shows the scales of *Naias major in situ;* one of the scales is drawn separately in fig. 30 on the same Plate.

The auricles in their turn vary in shape and size, but I have not met with them so regularly oval nor so acute as they are represented in Braun's figure (fig. 14, Plate VI.); on the contrary, I never find them acute, and, though somewhat parallel-sided, they gradually taper from their base to their elongate truncate apex (see figs. 52 & 54). More often than not the auricle is larger on one side than the other, as in figs. 54 & 55. The auricles are confined principally to the first pair of leaves of each fascicle, and the sheaths of the pair embrace the leaf; most often these are the only leaves in the fascicle which possess auricles (see Delile's figure on Plate V. fig. 4). The next pair of leaves has auricles which, when present, form a more acute sinus with the lamina (fig. 55); but as we approach the

Fig. 54.

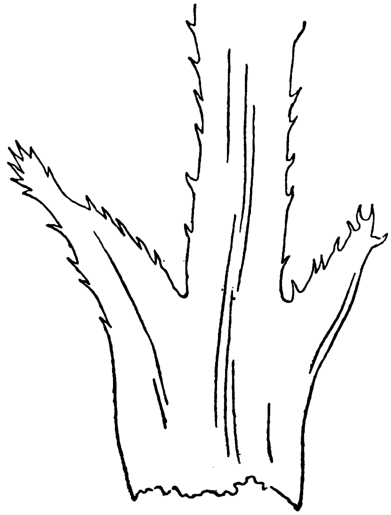
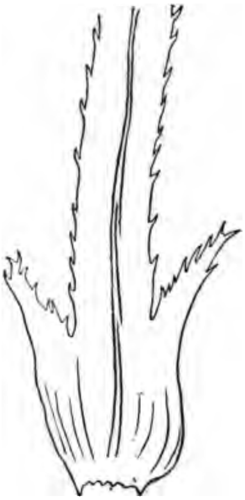


Fig. 55.



centre of each fascicle the leaves are destitute of auricles, and pass into short lanceolate bracts, in the midst of which we find the flowers.

In Scotch specimens of *Naias flexilis* the leaf-sheath is of another type; the base of the limb widens out into a sheath more than twice the breadth of the limb, and at an angle of about 45°; but there is no approach to an auricle on either side. The shoulders of the sheath are crowded with teeth, but they are infrequent on the sides. See figs. 56 & 57, and compare them with the slightly different figure of Braun on Plate VI. fig. 10.

Fig. 56.

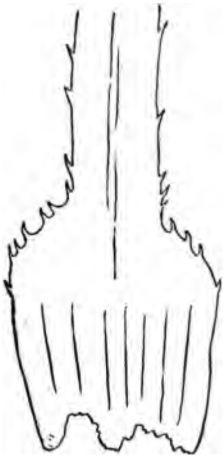
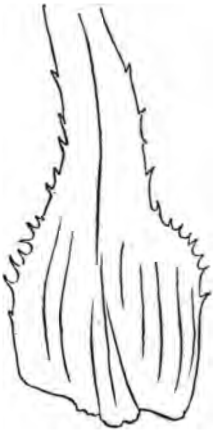


Fig. 57.



For drawings of the leaf-sheaths of *Naias minor* and *N. major*, see Plate VI. figs. 9 & 29, and compare the former with Braun's figure, Plate VI. fig. 11.

The margins of the auricles of *N. graminea*, and more particularly their free extremities and inner sides, are crowded with strong, spiny, tawny-brown cells, similar to those on the lamina; but they occur at much shorter intervals, and the cells at the base of the spines are more loosely aggregated (see fig. 58), so that there is no well-defined series of marginal cells as in the lamina. The basal cells which support the spines have their longest diameter in the direction of the spine.

Fig. 58.

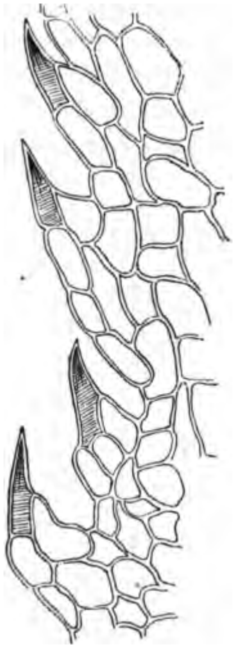


Fig. 59.

In *N. flexilis* (fig. 59) the cells are more loosely aggregated also, but the line of marginal cells, though not so well defined as in the lamina, is more clearly apparent than it is in *N. graminea*. The cells of the sheath, as well as the marginal cells of the lamina, of *N. flexilis* are larger and longer than they are in *N. graminea*; but the two species may be distinguished by the length of the imbedded portion of the spine, which, in *N. flexilis*, is less, and in *N. graminea* is more, than one third of its free length. The leaf-cells of *N. flexilis* generally are larger than those of *N. graminea* (compare figs. 45 & 46 with figs. 47–49, and fig. 58 with fig. 59, all of which are drawn to the same scale).

VIII. Leaf-structure.

The anatomy of the leaves of *N. graminea* is simple. The margins of the lamina to the extent of one third the breadth are composed of two layers of cells (see figs. 63 & 65), which, in the Reddish specimens, do not present that contrast in the size of the cells of the superior and inferior layers which Dr. Magnus mentions on p. 51 of his 'Beiträge.' No doubt the cells of the convex side of the lamina are slightly the smaller, but the difference is not so marked as represented in Plate VII. figs. 31–33, which are copied from the figures given by Dr. Magnus.

There are no stomata on the leaves and no epidermis; but the surface-cells in all parts of the plant have intermixed with them reddish-pink pigment-cells, which become brown with age. They are probably resinous, as they are the last to decay; similar cells occur in other species of *Naias*.

The central portion of the leaf is much thicker than the sides, because at this point the two layers of the lamina diverge from each other so as to enclose a central bundle of small-sized cells, surrounded by a layer of six or eight larger-sized cells. On either side of this central tissue are two intercellular cavities, which greatly exceed in size the cells which bound them (see figs. 60–65).

Fig. 60.

Fig. 61.

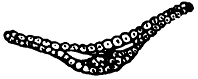


Fig. 62.

Fig. 63.

Fig. 64.

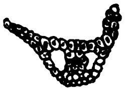
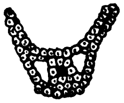


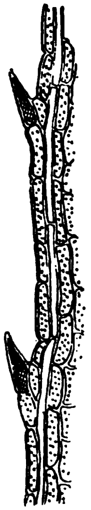
Fig. 65.



In his 'Beiträge,' pp. 51 & 52, Magnus describes *Naias graminea* as possessing bast-cells in certain fixed positions in the leaf, namely, close to the margin, and immediately above and below the central bundle on the upper and lower surfaces of the leaf (see figs. 31–33 on Plate VII.). These bast-cells I cannot discover, after prolonged search, in any portion of the Reddish plants; but as Magnus states (p. 52) that Damietta specimens collected by Ehrenberg, and Cairo specimens collected by Schweinfurth, also have these bast-cells wanting, it is clear that the Reddish plant corresponds in this particular with the plants from Lower Egypt.

On the other hand, the plant from the Italian stations possesses bast-cells. I found them clearly marked in specimens in my herbarium collected by Signor Malinverni, "in stagnis fossis et oryzetis circa Quintum Vercellensis ditionis pagum æstate 1875;" the accompanying figure has been drawn from the leaf of one of these plants (fig. 66).

Fig. 66.



The line of libriform cells is the central one of the three series which I have drawn; it is most clearly apparent, when viewed as a transparent object, from the circumstance that its cells do not contain chlorophyll, and hence it is visible as a transparent colourless line in the midst of green tissue.

An isolated bast-cell is given in fig. 34 on Plate VII., and their position in the leaf is shown in figs. 31–33 on the same Plate at the points marked *b*. In the upper part of fig. 32 the single cell seems to have been multiplied into three, but, as Dr. Magnus explains in his memoir, these long Y-shaped cells are arranged in a single linear series at the edge of the leaf; the bifurcating end of one cell encloses the solitary attenuated end of the one next to it; a section at such a junction severs the three interlocked ends of two contiguous cells.

The absence of this libriform tissue in the Lancashire plant has a bearing in determining its source, as will be noticed further on.

Between the Italian and the Lancashire plants I notice one other point of difference, which may be due to the period of growth. Above and below the central bundle of the leaf, but particularly on the lower surface, the external cells of Malinverni's specimens from Vercelli are densely packed with starch-grains, very similar to what is met with in the external membrane of the fruit. Although starch-granules are present in the membrane of the fruits of the Lancashire plant, I have failed to discover a single instance of their occurring in quantity in the leaves.

All the cells of the leaf exhibit a very striking circulation of their contents against the cell-walls; the chlorophyllean granules and other protoplasmic bodies being very large, and the cell-walls being very transparent, the plant furnishes a splendid illustration of circulation, more than any plant which I have examined.

IX. The Inflorescence.

The construction of the flowers of the genus *Naias* and their morphology have been minutely studied by Dr. Magnus, and the results given in his 'Beiträge,' pp. 26–33. In referring to the development of a side-shoot of *N. graminea,* he says that many of the internodes are suppressed, and that from three to five pairs of leaves spring from the axis before we reach the flowers, which occur to the number of from two to four all in one node.

He adds that it is worthy of notice that the male flowers are found on those parts of the shoots which have long internodes, while the female flowers occur only on those shoots where the internodes are suppressed.

This was not the structure in the Lancashire plant. Quite as often as not pistilliferous flowers were found in the axil of the first pair of leaves of the tuft. Antheriferous and pistilliferous flowers are found side by side (see figs. 67 & 68) in the axil of the same leaf. Both kinds of flowers are also found in all stages of development, quite young ones lying side-by-side with those more developed.

Fig. 67.

Fig. 68.

The great majority of the plants produced fully-developed flowers, both male and female, the latter being much the more numerous. The species is monœcious; even in those instances in which I found only female flowers on the individual branch, I could not be sure that male flowers had not been produced, or would not have been produced later on. It was not usual, though by no means infrequent, to find both sexes in the same fascicle, at equal stages of development (figs. 67 & 68), and mature and immature flowers enclosed by the same bract (see figs. 81 & 86).

Fig. 69.

The flowers begin to occur immediately within the axil of the first pair of leaves in each fascicle, but there is frequently an outlying pair of leaves below the fascicle which does not contain flowers. The oldest flowers are always at the base of the fascicle. When mature, the fruits are plainly visible to the naked eye (see Delile's figure on Plate V. fig. 4), but they can be detected, when present, by the touch. The female flowers are rarely solitary, but occur in twos, threes, or fours; in the earlier stages of development they are sometimes more numerous. The male flowers are more often solitary. In the centre of the fascicle are the youngest flowers (see figs. 68 & 69).

In appearance the flowers look as if they were ordinary anthers and pistils, *i. e.* as if they possessed no perianth; but Dr. Magnus has shown that their outermost covering is really a perianth which more or less closely invests the anthers and pistils. In fig. 16 on Plate VI. the perianth has been drawn back from the exposed anther of *N. major*. Figs. 22, 24, 25, and 28 show the natural reflexion of the perianth-leaves in the male flower of *N. major*.

All the flowers are sessile, and I have endeavoured to convey, in the accompanying figures, accurate representations of each.

X. The Pistilliferous Flower.

The female flower consists of an elongate flask-shaped body, with a long neck which bifurcates at its free end (figs. 68 & 70), like the bifid stigma of a *Carex*, such as *C. ovalis*. The outer covering is the perianth; the body which it encloses is the pistil.

In its early stage the lower, or flask-shaped, portion consists of a globose or ovate body, surmounted by a flat parallel-sided band, of nearly the same breadth as the lower portion (fig. 67). The upper portion, or neck of the flask, divides about halfway up into two divisions, like the stigma of an ordinary flowering plant (see fig. 71). This stigmatoid portion attains its maximum length very early. The basal portion contains a single anatropous ovule, and it enlarges both outwards and upwards until it is twice the length of the style-like portion (see fig. 70).

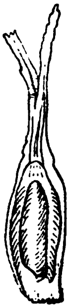
The investing membrane (fig. 88), which can be removed like the calyptra of a *Polytrichum*, is made up of one or two layers of cells, which vary in shape according to their position. The portion which covers the ovule consists of elongate cells with truncate ends, and these cells are densely packed with rounded grains of starch very uniform in size. The starch makes its appearance in the later stages of the growth of the membrane. The portion which covers the long neck of the flask-shaped body is also mostly composed of long cells; but the cells which occur on the margins of the stigmatoid divisions of the free ends are only one third the length of the central cells, and their outer ends are somewhat enlarged, so as to make the edge of the stigmatoid divisions minutely papillate, as if to afford better attachment for the grains of pollen (fig. 72). The cells of the base of the neck are much broader than any of those in other parts of the investing membrane, and they are also more loosely aggregated at that point.

Fig. 70.

Fig. 71.

Fig. 72.

Fig. 73.



A central canal runs throughout the narrow portion which simulates the style, and at the point where it reaches the chamber which contains the ovule it becomes slightly constricted (fig. 71); but immediately below the constriction it widens out into a cupola-shaped cavity, whose upper portion, or roof, is lined with a few unicellular hairs (figs. 72 & 73). Below this cavity is the ovule. The accompanying drawings (figs. 67–73) illustrate the female flower in some of its stages of development.

No portion of the pistilliferous flower bears any spines similar to those which occur on the bracts and leaves; such spines are present in some of the species of *Naias*.

XI. THE ANTHERIFEROUS FLOWER.

The male flowers are not so numerous as the female flowers, and they grow intermixed with them. Although I have frequently found plants of *Naias graminea* in which none but pistilliferous flowers could be detected at the period of examination, such tendency towards diœcism never showed itself when anther-bearing flowers were present. When the latter occurred on a plant pistilliferous flowers were invariably present, and oftener than not side by side with them (see figs. 67 & 68).

My observations of the anther do not quite coincide with the descriptions and figure given by Dr. Magnus; I have consequently given a larger number of illustrative drawings of this organ. The drawing of Dr. Magnus is reproduced on Plate VII. in fig. 35.

When young they are oval-shaped bodies borne upon a very short stalk (see figs. 74 & 76). So much do they resemble the anther of an ordinary flowering-plant that I was a long time in realizing that the outer body which I was examining was the membrane which formed the perianth. The perianth closely invests the anther throughout all its stages of growth, and, from all that I have seen, it keeps pace uniformly with the growth of the membrane of the anther.

The anthers of this genus, according to Dr. Magnus, are axis-growths which, when ripening, are pushed through the perianth, rupturing that membrane somewhat irregularly, and they finally dehisce at their apex. That the anthers of the Reddish plant dehisce at the apex there is no doubt, but I have seen no trace of the rupturing of the outer perianth-membrane through the emergence of the anther proper; on the contrary, the summit of the flower presents a regularity of parts for which Dr. Magnus's observations did not prepare me. The rupturing of the perianth in *N. major* is shown in figs. 22 & 28 on Plate VI.

Fig. 74.

Fig. 75.

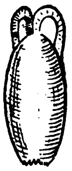
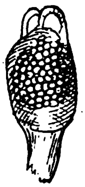


Fig. 76.



In an early stage the antheriferous flower of *N. graminea* has its outer membrane prolonged into two erect rounded ears, which are continued down the sides as keels or ridges (figs. 67 & 75). The young pollen at this stage is distinctly seen through the membranes of the flower and of the anther (fig. 76). The anther then becomes more elongate by its upward growth; a slight groove makes its appearance longitudinally, corresponding with the principal dissepiment of the anther (fig. 68); the upright ears and the keels lose their prominence, and the separate pollen-grains are not so distinguishable (fig. 77). Finally, the mature quadrilocular anther is an ovoid cylindrical body having two narrow parallel ridges passing over the summit, and descending about halfway down the covering of the flower (fig. 78). For comparison, see an antheriferous flower of *N. minor* in Plate VI. fig. 17; a transverse section of *N. major* in fig. 18; a vertical section of *N. major* in fig. 23; a vertical section of *N. minor* in fig. 27; and a vertical section of *N. major* in fig. 21.

Fig. 77.

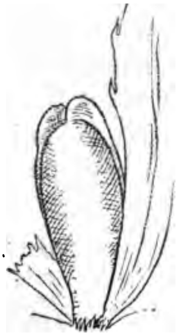
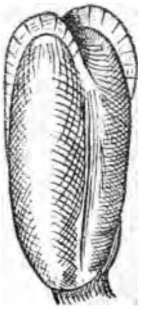


Fig. 78.



The membrane which invests the anther is formed of close-ranked, elongate, translucent cells, six to twelve times as long as broad, and tinged with a beautiful rose-colour; the superposition of this rosy membrane over the lemon-coloured pollen of the anther gives the flower a tawny-orange appearance, which readily attracts notice, even without the aid of a lens. The cells which compose the ridges in the upper half of the flower are larger and broader than those of the rest of the membrane.

Robert Brown's *N. tenuifolia* has considerable affinity with the Manchester plant, but, independent of other differences, the anther is very dissimilar on account of its external tunic terminating in a narrow elongate beak, which bears a number of brown spiny teeth at its free end (see fig. 15, Plate VI.). At the period of dehiscence the internal tunic which contains the pollen separates itself from the external membrane, but, instead of its emerging through the summit of the beak of the perianth, it is thrust through a rupture in the side.

In *N. graminea* the external membrane closely invests the inner membrane, but it is not projected beyond it in the form of a beak; and I have not seen a vestige of a brown spiny cell on any portion of the male flower.

XII. The Pollen.

The pollen of the various species of *Naias* does not seem to have been much noticed by observers. Magnus does not allude to it, nor give any figures of pollen-grains for any of the species; and contradictory statements are made by some authors. Thus the drawings of Braun, engraved in fasc. x. plate i. of the 'Genera plantarum floræ germanicæ' of Nees ab Esenbeck, show a globose pollen for *Naias minor* (*Caulinia fragilis*) *in situ*, and for *Naias major* in separate grains (see Pl. VI. fig. 19), and in his diagnosis of the genus (*Caulinia*) he specifies "pollen globosum, magnum." This statement seems to be the foundation for the similar statement in the works of later authors, one of the most recent being given in the 'Genera plantarum' of Bentham and Hooker, vol. iii. p. 1018, viz. "pollen globosum." In the 'Compendio della Flora Italiana' of Cesati, Passerini, and Gibelli, part 1, p. 204, tab. xxvii. fig. 1, the pollen of *N. major* is elliptico-cylindrical, like a grain of rice, say from two to three times longer than broad (see Pl. VI. fig. 26). In the 'Flora Danica,' plate 2121, the pollen of *Najas marina* (*Caulinia fragilis*) is of an elliptical form, not quite twice as long as broad.

This divergence of form in the pollen-grain of *Naias major* suggests, at first sight, inaccuracy of observation but I have found both globose and elongate pollen in the anthers of the Lancashire *Naias graminea*. The globular form is represented in fig. 79, and the elliptical form is given in fig. 80, both drawn to the same scale. Undoubtedly the pollen is globular in its early stages, but, after selecting what appeared to be perfectly mature anthers just at the period of dehiscence, the pollen which emerged was found to be globose, as drawn, in one anther, and elliptico-cylindrical in another anther. Whether the globose pollen ultimately passes into the elliptical form, and thus the latter represents the mature pollen, or whether there is a dimorphism in the pollen-grain, I cannot pronounce; I can only certify to the occurrence of both forms in plants from the same station, and that the globose form is much the rarer of the two.

Fig. 79.

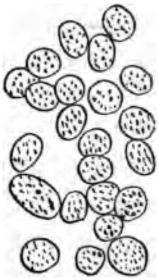
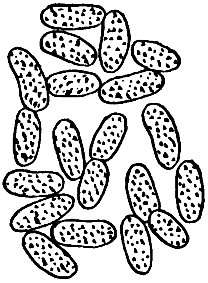


Fig. 80.



In its fresh state the pollen-grain is of a pale yellow colour, and its contents are granular. It must be produced in great abundance, as I have frequently found it in a free state in the water of the glass jars which have held the living plant during these investigations; grains also occur floating about in the chloride of calcium solution which I use for mounting the dissections of the plant for permanent microscopic examination.

XIII. FERTILIZATION.

The pollination of *Naias graminea* is entirely effected in the water, as there is no provision for an elongation of the peduncle to raise the pistilliferous flowers up to the surface of the water, as in *Potamogeton Zizii*, *Valisneria*, *Anacharis*, and other aquatic plants. The structure of the inflorescence forbids its being considered a cleistogamous flower; whether it is an aquatic type of an anemophilous or an entomophilous plant I cannot determine.

Some observations I have noted for recording here are of some interest, as they suggest that pollination is effected in two ways. In the station in which the *Naias* occurs near Manchester the very slight natural flow of the water in the canal towards the locks is quite sufficient for the transport of the pollen, and, though I have not purposely taken any of the canal water to see if it contained free pollen, my home observations leave me no doubt that pollen is carried to the pistilliferous flowers by the current; in such case the plant would be hydrophilous. While, however, examining portions of a living plant on which were ripe anthers, I noticed a colony of Vorticellidæ attached to one of the fascicles of leaves; the grace and activity of its movements led me to watch it for a considerable time, and whilst so watching it I witnessed grains of pollen whirled in all directions, or drawn into the vortex of the animal by its marginal cilia. The alternate contraction and elongation of the elastic and thread-like pedicles of the colony kept the pollen-grains in constant motion, which left me no doubt that at times the grains would be directly borne to the stigmatoid appendages of the pistilliferous flowers.

The canal-water is most prolific in animal life; beetles, molluscs, leeches, rotifers, polyps, larvæ of insects, &c.,

must surely prove potent factors in transporting pollen not only in the tepid water of the Reddish canal, but in the still water of pools and ditches. If we carefully look for instances of their intervention we cannot fail to find distinctive protozophilous plants, dependent for their fertilization upon animal life in the aqueous world, in much the same way as we find entomophilous plants in the aërial world.

It is a very happy circumstance that Sir Joseph Hooker should have indicated, in the new edition of his 'Student's Flora' recently published, the forms of pollination which prevail in many of our native plants, where known. Sprengel, Darwin, Müller, Lubbock, Kerner, and many others have largely increased our knowledge of this subject for terrestrial plants, but its extent after all is very limited; we have but ascended a few steps leading up to the vestibule, whilst the great temple of truth is beyond; while, as regards aquatic plants, and particularly those which are wholly submersed throughout their lives, like *Naias graminea*, *Stratiotes*, &c., our knowledge is even more limited. Hence Sir Joseph Hooker has earned the thanks of British botanists by bringing into prominence this important feature in the economy of our native plants.

XIV. THE FRUIT.

Up to the time of the fertilization of the ovule the outer membrane of the flower—the perianth—and the investing membrane of the ovule contained within the perianth, both remain transparent or semitransparent. After pollination has taken place the membrane of the ovule becomes turbid and thickens, while the ovule itself enlarges and becomes a mature fruit, covered with a testa formed of thick-walled cells (figs. 81–83).

The fruit is sculptured with a network of raised ridges, which thus produce depressions in the shell; this sculpture seems to have its seat in one of the inner membranes of the shell, since it cannot always be distinguished through the most external layer. As far as I have been able to make it out, it is somewhat after the character of the accompanying fig. 84; but this must be looked upon as a diagrammatic interpretation of what is supposed to be seen, rather than an actual representation of fact. In the same way I have drawn the testa of *Naias flexilis* in fig. 85 from a single mature fruit in one of Dr. Boswell's Loch-Cluny specimens; I am more sure of the correctness of this figure than of that of *N. graminea*, but it represents what is seen in a single fruit only. It would there-

Fig. 81.

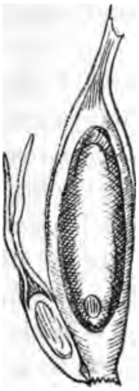


Fig. 83.

Fig. 82.

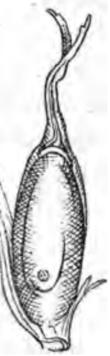


Fig. 84.

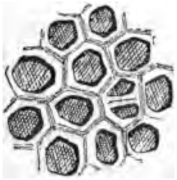


Fig. 85.

fore appear that the sculpture of *N. flexilis* is quadrangular, while that of *N. graminea* is hexagonal; but too much must not be made of observations founded on such a limited basis.

According to the observations of Cesati* the fruits of the Italian *N. alaganensis* are granulose-punctate, which fairly well describes the appearance of the outer covering of the Manchester plant; but Cesati's figure in 'Linnæa,' *l. c.* table ii. fig. 2*d*, makes the fruit much more papillate than I find it in the Lancashire form. On the other hand, this same observer makes the fruit of *N. flexilis* shining and obscurely angular, and he so draws it in his plate.

The explanation of this difference in the form of sculpturing is probably due to the fact that the external membrane more or less obscures the underlying layer, and thus the latter is seen by observers according as the transparency of the outer layer admits of it. For the further elucidation of this point, I have reproduced the figures of Dr. Magnus in Plate VII., where figs. 40 & 41 show the arrangement of the coats of the fruit of *N. graminea* from Cairo, and figs. 37–39 those of *N. flexilis*.

At Reddish mature fruits of *N. graminea* are produced in great abundance; scarcely a plant occurred without fruits. In the many hundred plants which I have examined I have not seen a single instance where the beak of the fruit was other than bifid, unless it had broken off altogether, as represented in figs. 81 & 83, and in the middle fruit of fig. 86. This division of the beak into two branches is a constant character, and very clearly distinguishes it from the four-rayed beak of *Naias flexilis* (fig. 87).

One other point of differentiation between *Naias graminea* and *N. flexilis* rests in the shape of the fruit. In

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* "Die Pflanzwelt im Gebiete zwischen dem Tessin, dem Po, der Sesia und den Alpen" (Linnæa, vol. xxxii. 1863, pages 259 & 260).

the former the ends are more abruptly narrowed into the base and the beak than they are in the latter, which has gradually narrowing ends; compare figs. 86 & 87. Cesati's figures in 'Linnæa,' xxxii. plate 2, confirm this conclusion.

Fig. 86.

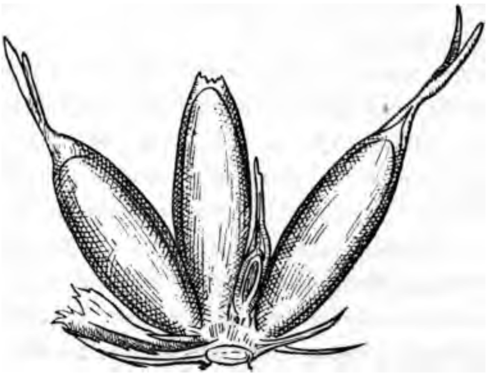


Fig. 87.

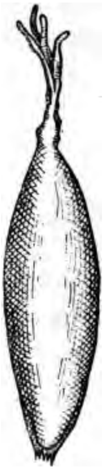
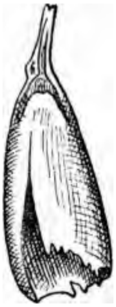


Fig. 88.



The perianth easily separates from the fruit; it is represented in fig. 88. The portion which covers the body of the fruit consists of a single layer of cells.

XV. The Roots.

The roots are of great length, creeping in the soft black mud of the bed of the canal; they are given off from the nodes in verticils. They are capillary, uniform in diameter, even when nine inches long, tawny-orange in colour, and I have not seen them branch.

In internal structure they bear some resemblance to the stems. There is a central channel surrounded by a mass of elongate cells hexagonal in outline, smaller in size, and with thinner walls than those of the rest of the cells within the cylinder. Outside this area is a row of cells whose walls are darker coloured than any of the others (except the cells which form the exterior of the cylinder), and they so arrange themselves as to form a sheath round the central cells; from this row of cells numerous short branches are given off which enclose intracellular cavities similar to those in the stem, but much smaller and more circular (see fig. 89). These cavities are regularly arranged in one series round the central mass, as in the stem, but there are occasionally outlying cavities in the neighbourhood of the external orange-coloured cells, as shown in

Fig. 89.

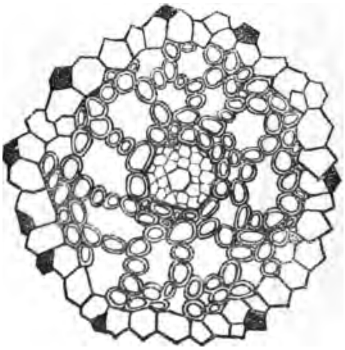


fig. 89. Enclosing the whole is a layer of larger-sized cells of a dark brown colour, and more angular in outline than any of the other cells. In the midst of these cells, but on the outermost side, are a few cells filled with a rich tawny-brown pigment. The walls of the circumferential cells are all very thin, and they have the rich colour of the pigment-cells.

In addition to the roots proper the plant gives off adventitious roots from the stem-nodes, as represented in Plate IV. These are generally given off singly from between the first pair of leaves of the fascicle; occasionally two proceed from the same node, but in such case the second root emerges on the opposite side of the node. In the lower portions of the stem the adventitious roots become more numerous from each node, and they begin to acquire the orange colour of the roots proper. They attain a length of from half an inch to six inches or more, and they have a similar internal structure to that of the roots proper; the peripheral cells, however, do not possess the angular character nor the tawny colour of the outer layer in the lower roots. The tissue is more loosely aggregated; the intracellular cavities are fewer in number and smaller, scarcely exceeding the size of the cells which surround them. The central cavity is present, as well as the surrounding sheath, but the cells of the latter are fewer than they are in the root proper. The external cells do not differ much from the inner cells either in shape or in colour, the rich pigment of the corresponding layer in the root being absent.

XVI. The Lancashire Locality.

The occurrence of a *Naias* in Lancashire was so unexpected a circumstance that I was pleased, through Mr. Whitehead's kindness, to have the opportunity of seeing the plant in its station in the canal at Reddish, near Manchester. The precise locality was not intended to be published, but as the station seems to be well known to so many local botanists, there is no further need to suppress it.

When I first visited the canal, on the 14th September, 1883, the *Naias* grew in an area of about a quarter of a mile in length; in some portions of this space it was the prevailing plant, wholly covering the canal-bed, while in other portions it was intermixed with *Potamogeton rufescens, P. obtusifolius, P. crispus, P. pusillus, Myriophyllum,* and *Anacharis*. Except in so far that the station, like most canals, was an artificial one artificially supported, there seemed nothing in the accompanying vegetation to suggest that the *Naias* was not aboriginal. All the other plants were of the prevailing canal character, the non-native *Anacharis* being as much at home as any of them.

The temperature of the canal water is, however, artificially raised by the discharge of hot water from boilers and condensing-tanks attached to the cotton-mills and other works which are erected on the banks of the canal. In the declining evening of my first visit the water was quite warm, say about 90° Fahr. This abnormal temperature must be looked upon as the important factor in the struggle for existence maintained by this plant. In subsequent visits to the canal the temperature of the water was not met with so high as it was found on the first occasion; still, with the fitful discharge of hot water into the canal at many points, its average temperature must be many degrees above the normal point for the neighbourhood. It might have been expected that the vegetation which grows in this tepid body of water would have shown signs of luxuriance, but such does not appear to be the case. The most striking variation is met with in *Pota-*

mogeton crispus, which becomes dwarfed, particularly in stations where there is an inflowing stream of warm water.

Two other plants which grow in the same canal ought to be noticed in this connection. The first of these is the *Chara Braunii*, Gmel., which the Messrs. Groves figured and described in the 'Journal of Botany' for January 1884, t. 242, p. 3. This plant affects the edges of the canal, but it also occurs in the deeper water of the centre, where it is more liable to be cut down by the passing barges. Another interesting plant grows with the *Chara*, whose identity is by no means settled, and it may prove worthy of a more detailed notice, viz. a species of *Zannichellia*.

Mr. Whitehead had mentioned to me, on the occasion of our joint visit, that *Z. palustris* had been recently found in the canal, and, as it was an infrequent plant in the district surrounding Manchester, I was anxious to procure specimens, although it involved a moonlight search. It was while hunting for this plant that, unknown to myself or to my companions, I collected the *Chara* in the darkness; the specimens were very fragmentary, but from them Mr. Arthur Bennett determined the plant to be the *Chara Braunii*, new to the British Flora. In justice to Mr. Whitehead it ought to be stated that he and Mr. Armitage had collected it in the same station a fortnight or so prior to my visit.

The *Zannichellia* grows in the soft mud, in the shallower parts of the canal, with *Chara Braunii* and *Potamogeton pusillus*; it also occurs in places where the water scarcely covers it. It would appear to flower and fruit in the mud as well as in the water, but the fruits which are produced in mud are of a very pale yellow-green, on account of their imperfect exposure to the light. From the dwarf creeping habit of the plant it seems to have an affinity with the form of *Z. palustris,* named *Z. repens,* Bœnningh. The characters of the Reddish plant agree with the description of *Z. repens* in essential points, but the stigma is not usually more enlarged than in *Z. palustris,* whereas this feature is a decided character, both in the diagnosis and in Reichenbach's plate*. In the spring and early summer it has large reserve-buds of the size of peas, from which the shoots take their rise.

One of its peculiarities is, that it has four or five rows of spines or protuberances on the dorsal and ventral edges of many of its carpels, and much more prominent than they are in *Z. pedunculata*, *Z. gibberosa,* and *Z. polycarpa.*

Delile reports † finding *Zannichellia palustris* in a lake near to Fâreskour in Lower Egypt, along with *Naias muricata.* It would be interesting to determine whether the form is the same as that which occurs in the canal at Reddish. Local botanists also ought to keep an eye upon the possible occurrence of the rare *Naias muricata,* figured and described by Delile; so far, it has only been recorded for Egypt and Arabia.

The locality which produces such an extra-anglican species as *Naias graminea* must be worth exploring for the animal life which is fostered by the same high temperature which has sustained the *Chara* and the *Naias.*

XVII. GEOGRAPHICAL DISTRIBUTION.

Naias graminea is distributed over a wide area. It occurs in a natural state in the northern and central parts of Africa, in Syria (Plain of Sharon: 'Memoirs of the Palestine Exploration Fund,' Fauna and Flora, p. 416), and Persia, in the Indian Archipelago and other warm

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* 'Icones Floræ Germanicæ,' &c., vol. vii. fig. 20, pl. xvi.

† 'Flore de l'Egypte,' vol. ii. p. 281, and also on page 75 under No. 872.

regions of Asia, and probably in Japan. It does not occur in Europe except as a colonist, it having been introduced (according to the Italian botanists) with East-Indian rice, into districts where that cereal is cultivated, as in the plains of Lombardy and Venice; the Italian localities are given in Cesati's 'Compendio della Flora Italiana,' as Alagna in Novara, Balzola between Vercelli and Casale, Merlato near Milan, Upper Vercellese, Strasoldo nel Friuli near Palmanavo. It has also been reported from the extreme north-eastern portion of Austria; but it is not native in any of its European stations, and it is an introduction in Lancashire. It becomes, therefore, an interesting question to account for its appearance in a country which does not grow the rice which it consumes.

XVIII. Its probable Source.

When this plant was exhibited at the British Association at Southport, in September 1883, I expressed the opinion in the Biological Section that it had probably been introduced into the Reddish locality with Egyptian cotton. This class of cotton is not one of the staple articles of consumption in the Stockport district, but there is one mill on the banks of the canal (Houldsworth's) which consumes Egyptian cotton largely, and from it, if not from others, the fruits of the *Naias* may have been transported to the canal. Last autumn Mr. J. Cosmo Melvill and myself carefully examined the large condensing-tank in the yard of this mill, but we could not find a trace of the plant; the water was of a high temperature, and little vegetation was found in it, but its depth was beyond our means of properly exploring it.

Alire Raffenau Delile* gives an account of the culture

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* 'Mémoire sur les plantes qui croissent spontanément en Egypte,' vol. ii. pp. 16, 17.

of rice in Egypt, and shows that the water used for the young plants is drawn from the Nile by fixed machines during the principal part of the year; but in times of inundation, during the rising of the river, the water is naturally distributed, its particular course being regulated by the embankments which protect the fields. He states that the *Naias graminea* grows in the canals of the rice-fields at Rosetta and in the Delta, but he considered it only a variety of *Naias fragilis*, which grows in the same waters.

The irrigation of modern Egyptian cotton-plantations will be effected by much the same means, the Nile, with its artificial ramifications, being the chief water-supply of the country. Fruits of the *Naias* may reach Egypt from Abyssinia, or from the great lakes of Equatorial Africa; the Nile water supplied to the growing cotton-plant will be accompanied by these fruits, some of which would be left dry upon the surface after the water had percolated through the upper soil, but they would not germinate there. Either by the agency of the wind, or through accidental contact with the soil, they become mixed with the cotton exported to England. When the bales of cotton reach the Lancashire mills, the fruits of the *Naias* would be removed in the blowing-room, or by the carding-engines. The refuse is turned out of the mill into the yard, whence the wind and other agencies transport the fruits into the tepid water of the canal; here they meet with a suitable nidus for germination and growth, and the result is the appearance of an alien in our flora.

If these surmises have any substratum of truth, the *Naias* may occur in any mill-pond connected with works where Egyptian cotton is used, and where the water is raised to a permanently high temperature by the condensation of steam from the boiler. As Egyptian cotton is largely used in Bolton, the mill-ponds and canals of that neighbourhood may be expected to contain *Naias graminea* and other Egyptian aquatic plants, as *Naias muricata,* Del., *Chara Braunii,* Gmel., &c.

The Egyptian origin of the plant is to some extent confirmed by the form of *Chara Braunii* which grows at Reddish being very near the form of that species which occurs in Northern Africa. Whether there is anything showing an affinity to the Egyptian plant in the peculiar form of *Zannichellia* which grows in the same canal, I have not the means of determining; but both it and the *Chara Braunii* are so often associated together as to give a strong colour to the surmise of their common origin. There is nothing in the recorded distribution of *Chara Braunii,* however, to forbid its being ultimately shown to be aboriginal; but until it is recorded from other British stations, with fewer doubtful surroundings than it has in the Manchester station, it can only be looked upon as a colonist.

XIX. A HISTOLOGICAL PECULIARITY.

A strong proof of its Egyptian extraction is furnished from the histological side. This part of the case has been dealt with by Dr. Magnus, in a paper read to the German Botanical Association at Berlin, December 11th, 1883, and I make no apology for reproducing here the substance of this interesting communication. In describing the structure of the leaves of *Naias graminea* on page 46, I mentioned that there were two forms of the plant—one possessing peculiar libriform cells near the margin of the leaf; the other destitute of these bast-cells. This latter form Dr. Magnus names the var. *Delilei,* and he states that the English specimens belong to this variety, and indubitably prove their Egyptian source. The following are some extracts from the paper of Dr. Magnus, published in the 'Berichte der deutsch. botanischen Gesellschaft,' Jahrg. 1883, Band i. Heft 10 :—

"I have examined the specimens of *Najas graminea* collected by Delile in the rice-fields near Rosetta, as also those obtained by Schweinfurth near Benha-el-assl in the Nile Delta, and have found them to be without bast-nerves. They are also wanting in a specimen collected by Gaillardet, near Saida in Syria, which has been kindly communicated to me by M. Boissier. I was further enabled, through the kind communication of Professor Ascherson, to examine specimens of *Najas graminea,* Del., collected by him during his travels in the Libyan Desert, in the Oasis of Dachl, as also specimens collected by Schweinfurth in the Great Oasis (Chargeh). From this it would appear that the *Najas graminea,* Del., collected in a brook at Aïn-Scherif near Kasr Dachl, as well as those collected by Ascherson near El Chargeh, likewise have leaves without libriform cells, like the plants of Lower Egypt. On the other hand, the *N. graminea* collected some weeks later in the same ditches in Aïn-Scherif by Ascherson, as well as from a warm spring-hole in Kasr Dachl, as also the specimens collected by Schweinfurth near Chargeh, have all well-developed bast-nerves, similar to the plants of Cordofan, Djur, Algeria, Celebes, &c. . . .

"The absence of these bast-nerves in a variety of *Najas graminea* is the more peculiar, as through the construction of the male flower of *N. tenuifolia,* R. Br. [see fig. 15, Plate VI.], from Australia, which differs so materially, has precisely the same bast-nerves in exactly the same shaped libriform cells on the leaves; consequently these bast-nerves represent the distinctive character of a group of allied species, but still subject to variations. . . . .

"I have mentioned above that the one set of specimens from Kasr-Dachl and Chargeh had leaves without bast-nerves, and that another set had them; that is, that the one set belong to the var. *Delilei*, while the other agrees with the form which appears in Cordofan, Djur, Algiers, &c. This would appear to be a clear proof that the oases of the Libyan Desert have received their flora from Egypt as well as from Central Africa. This agrees with the results of the investigations which Ascherson furnished to the 'Botanische Zeitung' for 1874, pages 641–644.

"These explanations would, however, seem to be somewhat contradictory, seeing that the English specimens are remarkable for their great length of leaf, whereas the leaves of *N. graminea* from Cairo and Damietta are very short. But a minute examination of form teaches us that we must not attach much importance to the question of the length of leaves, which is influenced, as in most water-plants, by the depth, current, bed, and temperature of the water. Thus we find that the specimens collected by Professor Ascherson in the Dachl Oasis, from the deeper pools (half a metre deep), have long leaves as well as bast-nerves, and yet the English specimens have longer leaves without bast-nerves; while the Egyptian specimens have shorter leaves without bast-nerves. Thus, again, we find the *N. graminea*, Del., growing in the shallow ditches of the rice-fields of the plains of Lombardy, has short leaves with bast-nerves, whereas the *Najas graminea* from Celebes has very long leaves with bast-nerves. In short, we see that the length or shortness of the leaves has nothing whatever to do with the formation of the variety, and nothing to do with the histological formation of the leaf-tissue.

"It is nevertheless possible that the var. *Delilei*, deprived of the bast-nerves, has been developed in the quiet stagnant waters of the overflowed Nile, as in these stagnant waters the mechanical cells would become deprived of their functions. Thus we find Schwendener, in his exhaustive work, 'The Mechanical Principle in the Anatomical Construction of Monocotyledons,' Leipzig, 1874, page 122, remarking that *Potamogeton fluitans* in its customary habitat of running water has a developed system of bark-bundles, whereas the var. *β stagnalis*, Koch, is completely deprived of same.

"The var. *Delilei*, found in the stagnant waters of the overflowed Nile, is a most persistent and constant one, as during a period of a hundred years it has been indubitably collected by Delile, Schweinfurth, and Ehrenberg in Lower Egypt. Its unaltered appearance in England and in the oases shows its constancy and total independence of habitats, whilst its formation has probably been caused by the same."

It now only remains to me to tender my acknowledgments to Mr. Ridley, Mr. Arthur Bennett, Dr. Magnus, Professor Ascherson, Mr. Beeby, and Mr. James Britten, for their kind assistance during the preparation of this paper.

XX. EXPLANATION OF THE FIGURES.

PLATE IV.

Fig. 1. The upper portion of a branch of *N. graminea*, from Reddish; nat. size.

2. Two of the leaves from same, drawn rather broader than the natural size, the sheaths and auricles flattened out.

PLATE V.

3. Upper portion of a branch of *N. graminea* from Lower Egypt. Copied from Delile's drawing in his 'Flore de l'Egypte,' but reduced to two thirds original size.
4. Base of a leaf-fascicle, showing leaf-auricles, fruits, &c.; slightly enlarged. From Delile's 'Flore de l'Egypte.'
5. Section of fruit; enlarged. From Delile's 'Flore de l'Egypte.'

Plate VI.

Figs. 6–8. Arrangement of the cells of the marginal spines on the leaf of:—(6) *N. flexilis*, (7) *N. graminea*, (8) *N. minor* and *N. arguta*. From Dr. Alexander Braun's sketches in 'Journal of Botany,' 1864, vol. ii. p. 275.

9. Form of sheath at base of leaf of *N. minor*. From 'Compendio della Flora Italiana' of Cesati, Passerini, and Gibelli, tav. xxviii. fig. 1 *n*.

10–14. Form of sheath at base of leaf of:—(10) *N. flexilis*, (11) *N. minor*, (12) *N. minor*, var. *setacea*, (13) *N. falciculata*, and (14) *N. graminea*. All copied from Dr. A. Braun's woodcuts in 'Journal of Botany,' 1864, vol. ii. p. 274.

15. Male flower of *N. tenuifolia*, R. Br.; enlarged $\frac{16}{1}$. From Magnus's 'Beiträge,' plate iv. fig. 5.

16. Anther of *N. major*, with the perianth reflexed; enlarged. From 'Genera Plantarum Floræ Germanicæ,' Th. Fr. Lud. Nees ab Esenbeck, fasc. vi. *Naias*, fig. 5.

17. Male flower of *N. minor*; enlarged. Nees ab Esenbeck, *l. c.* fig. 24.

18. Transverse section of male flower of *N. major*. Nees ab Esenbeck, *l. c.* fig. 7.

19. Pollen of *N. major*; enlarged. Nees ab Esenbeck, *l. c.* fig. 8.

20. Male flower of *N. major*, with the perianth drawn back; enlarged. From 'Iconographia familiarum naturalium regni vegetabilis,' Dr. Adalbert Schnizlein, Heft v. pl. 71. fig. 4.

21. Vertical section of male flower of *N. major*; enlarged. Schnizlein, *l. c.* fig. 6.

22. Male flower of *N. major*, showing the separation of the perianth from the anther; enlarged. Schnizlein, *l. c.* fig. 7.

23. Vertical section of a male flower of *N. major*. From 'Compendio della Flora Italiana,' *l. c.* fig. 1 *b*.

24 & 25. Dehiscence of the perianth of *N. major*, after the observations of Braun; enlarged. Nees ab Esenbeck, *l. c.* figs. 9 & 10.

26. Grains of pollen of *N. major*, with fovilla; enlarged $\frac{200}{1}$. From 'Compend. Fl. It.' *l. c.* fig. 1 *d*.

27. Vertical section of a male flower of *N. minor*, All.; enlarged. 'Compend. Fl. It.' *l. c.* fig. 1 *e*.

28. Male flower of *N. major*; enlarged $\frac{4}{1}$. 'Compend. Fl. It.' *l. c.* fig. 1 *a*.

29. Base of leaf of *N. major*, with the sheath opened. Intravaginal scales at the base of the sheath, one on each side; enlarged $\frac{3}{1}$. 'Compend. Fl. It.' *l. c.* fig. 1 *m*.

30. Intravaginal scale of *N. major*; enlarged $\frac{5}{1}$. 'Compend. Fl. It.' *l. c.* fig. 1 *o*.

Plate VII.

31. Transverse section of the middle of the leaf of *N. graminea*, Del. enlarged $\frac{152}{1}$. Magnus, 'Beiträge,' pl. vi. fig. 3.

Fig. 32. Transverse section of the side of the leaf of *N. graminea*, Del., from Celebes; enlarged $\frac{235}{1}$. Magnus, 'Beiträge,' pl. vi. fig. 2.

33. Transverse section of the leaf of *N. graminea*, Del., from Celebes; enlarged $\frac{130}{1}$. Magnus, 'Beiträge,' pl. vi. fig. 1.

In figs. 31–33 the leading bundles are drawn schematically: *i*=intercellular spaces, *b*=bast-cells.

34. Isolated bast-cell from the leaf of *N. graminea*, from Celebes; enlarged $\frac{152}{1}$. Magnus, 'Beiträge,' pl. vi. fig. 4*b*.

35. Male flower of *N. graminea*; enlarged $\frac{36}{1}$. Magnus, 'Beiträge,' pl. iii. fig. 6.

36. Transverse section of the stem of *Caulinia alaganensis*. From 'Tavole per una Anatomia delle piante aquatiche,' Parlatore, pl. vi. fig. 3.

37. Surface-view of the outer cell-layer of the unripe seed of *N. flexilis*; $\frac{102}{1}$. Magnus, 'Beiträge,' pl. v. fig. 9.

38. Diagonal section of the nearly ripe seed-shell of *N. flexilis*; enlarged $\frac{108}{1}$. Magnus, 'Beiträge,' pl. v. fig. 8.

39 & 40. Diagonal sections of the still (? if not always) unripe seed-shell of *N. graminea*, from Cairo; enlarged $\frac{108}{1}$. Magnus, 'Beiträge,' pl. v. fig. 11.

41. Diagonal section of the quite ripe seed-shell of *N. graminea*, from Cairo; enlarged $\frac{108}{1}$. Magnus, 'Beiträge,' pl. v. fig. 12.

FIGURES IN THE LETTERPRESS.

All the figures are drawn from Reddish specimens of *Naias graminea*, Del., var. *Delilei*, Magnus, except when stated otherwise.

42. *N. graminea.*—Transverse section of stem, drawn diagrammatically; enlarged $\frac{52}{1}$.

43 & 44. *N. graminea.*—Ends of leaves, showing dentition; enlarged $\frac{14}{1}$.

45 & 46. *N. flexilis.*—Spines on margins of leaves, from specimens collected by Dr. Boswell in Loch Cluny, near Blairgowrie, Perthshire; enlarged $\frac{156}{1}$. See 'Journal of Botany,' No. 154, 1875, p. 297.

47–49. *N. graminea.*—Spines on margin of middle portion of leaf; enlarged $\frac{156}{1}$.

50. *N. minor.*—Tooth of leaf from one of Archbishop Haynald's specimens, from ponds in his park at Kalocsa, Hungary; enlarged $\frac{156}{1}$.

51. *N. major.*—Tooth of leaf from plant collected near Coblentz by Dr. Ph. Wirtgen; enlarged $\frac{156}{1}$.

52. *N. graminea.*—Large leaf-sheath from leaf of first pair; enlarged $\frac{14}{1}$.

53. *N. graminea.*—Usual form of leaf-sheath from leaf of first pair; enlarged $\frac{14}{1}$.

54. *N. graminea.*—Usual form of leaf-sheath from leaf of first pair, with irregular-sized auricles; enlarged $\frac{14}{1}$.

Fig. 55. *N. graminea.*—Leaf-sheath from leaf of second pair; enlarged $\frac{14}{1}$.

56 & 57. *N. flexilis.*—Leaf-sheath from Scotch specimens; enlarged $\frac{14}{1}$.

58. *N. graminea.*—Spines on margin of auricles; enlarged $\frac{156}{1}$.

59. *N. flexilis.*—Spines on margin of auricles from Loch Oluny; they are the first four which occur on the left shoulder of fig. 57, above the minute spine, nearest the base of the sheath; enlarged $\frac{156}{1}$.

60–65. *N. graminea.*—Transverse sections of leaves, beginning near the summit; enlarged $\frac{32}{1}$.

66. *N. alaganensis.*—Libriform cells in margin of leaf, from Malinverni's Italian specimens; enlarged $\frac{156}{1}$. The libriform cells are the long cells without cell-contents.

67. *N. graminea.*—Young antheriferous and pistilliferous flowers growing side by side; enlarged $\frac{18}{1}$.

68. *N. graminea.*—Older antheriferous and pistilliferous flowers growing side by side; enlarged $\frac{18}{1}$.

69. *N. graminea.*—Portion of central inflorescence; enlarged $\frac{36}{1}$.

70. *N. graminea.*—Pistilliferous flower with contiguous bracts; enlarged $\frac{18}{1}$.

71. *N. graminea.*—Young pistilliferous flower; enlarged $\frac{18}{1}$.

72 & 73. *N. graminea.*—Young pistilliferous flowers, showing the stigmatoid appendages; enlarged $\frac{18}{1}$.

74 & 75. *N. graminea.*—Young antheriferous flowers; enlarged $\frac{23}{1}$.

76. *N. graminea.*—Young antheriferous flower, showing immature pollen; enlarged $\frac{23}{1}$.

77. *N. graminea.*—Antheriferous flower not fully ripe; enlarged $\frac{23}{1}$.

78. *N. graminea.*—Mature antheriferous flower; enlarged $\frac{22}{1}$.

79. *N. graminea.*—Globose pollen; enlarged $\frac{156}{1}$.

80. *N. graminea.*—Elliptico-cylindrical pollen; enlarged $\frac{156}{1}$.

81. *N. graminea.*—Fruit, with immature pistilliferous flower in the same bract; enlarged $\frac{18}{1}$.

82 & 83. *N. graminea.*—Fruits nearly mature; enlarged $\frac{18}{1}$.

84. *N. graminea.*—Supposed ridges and pits, of hexagonal outline, on surface of fruit, as seen with a $\frac{4}{10}$ objective, Lieberkuhn, and Kelner B eyepiece.

85. *N. flexilis.*—Ridges and pits, of quadrangular outline, on surface of fruit, as seen with a $\frac{4}{10}$ objective, Lieberkuhn, and a Kelner B eyepiece.

86. *N. graminea.*—Three mature fruits and an immature pistilliferous flower in the same verticil; enlarged $\frac{14}{1}$.

87. *N. flexilis.*—Mature fruit from Loch-Cluny specimen; enlarged $\frac{14}{1}$.

88. *N. graminea.*—Perianth removed from fruit; enlarged $\frac{14}{1}$.

89. *N. graminea.*—Transverse section of the root; enlarged $\frac{85}{1}$.

V. *Notes on the Subgenus* Cylinder (*Montfort*) *of* Conus.

By J. Cosmo Melvill, M.A., F.L.S.

Read before the Microscopical and Natural-History Section, February 16, 1885.

Few genera stand out more naturally and prominently in the animal kingdom than the large assemblage of Mollusca associated under the name of *Conus* (L.). Few fall so naturally into subdivisions and, as a rule, present such well-marked specific differences. Recognized as they all are at a glance by the inversely conical shell, with lengthened narrow aperture and simple inner lip, they are, with but one exception, natives of tropical or subtropical seas, the exception being a not uncommon S. Mediterranean shell (*C. mediterraneus*, L.). They approach in form, through *C. Orbignyi* and others of the section *Leptoconus*, to the Pleurotomæ, especially shells of the section *Genota*, e. g. *mitriformis* and *papalis*; and, on the other hand, through *C. mitratus*, of the subgenus *Hermes*, to the anomalous genus *Dibaphus*, and, through that, again, to the *Mitres*.

This is as regards the form only: for the mollusc itself differs in some important particulars, and hence the Cones are classed by themselves in the suborder Toxifera, of Gasteropoda Pectinibranchiata, differing from the other allied suborder Proboscidifera—to which the Pleurotomæ and *Mitres*, just alluded to, belong—by the proboscis being furnished with a tube containing bundles of sharp, needle-like, barbed teeth at the end, instead of the usual lingual band, covered with short teeth. This tube, according to Adams, is extended below, at right angles to the cavity, into a conical prolongation, provided with two series of hooked and subulate teeth. Indeed, the bite of *C. textile*, *C. aulicus*, and *C. marmoreus* is most severe, especially as it is supposed that venom is introduced into the wound, causing great difficulty in healing, while the pain continues intense for a long period.

Many monographs and illustrated descriptions of this diversified genus have been published, the best known being Reeves's 'Conchologia Iconica,' vol. i. (1843–44), with a Supplement of 8 plates, dated some years later, 337 species being described in all, and Sowerby's 'Thesaurus Conchyliorum' (1869), forming vol. iii. of the work, 450 species.

Kiener, 'Coquilles Vivantes,' 324 species.

Weinkauff, in Küster's continuation of Martin and Chemnitz's 'Conchylien Cabinet' (1875), describes 411 species.

The latest monograph is that of Mr. G. W. Tryon, jun., of Philadelphia (published 1884), in which about 450 species, not including varieties, are recognized. He bases his classification on Weinkauff's Catalogue, dividing the genus into seventeen sections, of which the Texti, forming the last or 17th group, are equivalent to the subgenus *Cylinder*, of Montfort, now under discussion.

Most conchologists, however, including the brothers Paetel, in their 'Conchylien Sammlung,' 2nd ed. 1884, still follow the lines of Messrs. H. & A. Adams, as given in their recent 'Mollusca' (1858), and which appears to me to be simple and less artificial. As all agree, however, in the limitation of the group now under discussion, it is out of place to enter into the merits or demerits of the various plans proposed for the arrangement of the whole genus.

Out of 450 species known of *Conus*, but 26 are catalogued by H. & A. Adams, as appertaining to *Cylinder*;

but in Sowerby's 'Thesaurus' (1870) 36 are mentioned. Tryon, of Philadelphia, in his elaborate monograph just alluded to—the 'Manual of Conchology,' vol. vi.—calls but 17 of these true species, with 10 subspecies, and also cites 12 slight varieties, classed almost as synonyms, the total number of named forms coming up to 39. Of these 37 are exhibited in the present collection.

The subgenus *Cylinder* may be briefly thus characterized:—

Shell subconic, smooth, or very lightly striated; spire elevated; whorls never coronated, numerous; body-whorl ventricose, notched at the suture; aperture effuse at the fore part.

"The species," writes Mr. Arthur Adams, "of this section are all very rich in the style of their colouring, and a somewhat similar reticulated kind of pattern runs through the entire series."

Some very widely differing Cones, *e. g. C. archithalassus, ammiralis, acuminatus*, and *cordigerus* (a var. of *nobilis*) among the Leptoconi, and *C. arachnoideus* and *C. nicobaricus*, among the Marmorei have a similar reticulated pattern. All these differ, however, materially in form, either, as in the last section mentioned, by the coronation of the whorls, or, in the former, by the grooved and sculptured spire, and more truly conical shape.

The only species which presents any difficulty at first sight is a variety of *C. cordigerus* (Sowb.), which, in the specimen exhibited, approaches so nearly to *C. omaria*, as to suggest a mimetic principle among the molluscs similar to that which is known to exist in other branches of the Animal Kingdom.

The *geographical* distribution of *Cylinder*, so far as known, is almost exclusively eastern, many species being found ubiquitously in the eastern tropics, from E. Africa to Ceylon, Mauritius, the Philippines, and New Caledonia. Two species, or forms of one (*C. victoriæ* (Reeve) and *complanatus* (Sowb.)), occur in Australia; *C. pyramidalis* (Lam.) is also a native of the same seas; *C. racemosus* (Sowb.), an unique form in my collection, is from the Sandwich Isles; *C. lucidus* (Mawe) from the west coast of Central America; and a doubtful form, *C. Dalli* (Stearns), recently described from a single specimen, is reported from the Gulf of California. This shell, apparently, from the figure, a variety of *C. textile* (L.), is especially interesting as affording a western habitat for a species very universally distributed in the east, but not known before to impinge on American shores

The *locality* in which these Molluscs are found, in common with others of the family, is in fissures of rocks, especially in coral-reefs, where they lead a predatory existence, feeding on other Mollusca &c.

After a very careful study of the Protean forms of the Textile Cones, the forms would seem to come under five heads, the first head having three divisions. I propose to class them as follows:—

I. TEXTILIA.
    a. *vera.*
    b. *abbates.*
    c. *pyramidalia.*
II. RETIFERI.
III. LUCIDI.
IV. AULICI.
    a. *crocati.*
    b. *episcopi.*
V. AUREI.

Of these the first and fourth, as might be expected, harbour the largest number of species, the second and third containing one species apiece, and the last two or three species.

I. Textilia.

a. *vera.*

Shell yellow-brown, with undulating longitudinal lines of umber, interrupted by triangular white spaces; spire raised, similarly marked.

Under this I group the well-known *C. textile* (L.), the "Field of the Cloth of Gold" of the old conchologists: an exceedingly variable shell, whose forms and limitations it is almost impossible to define. It abounds in all eastern tropical seas, and, as before observed, a form, the *C. Dalli* (Stearns), has been detected once on the Californian coast.

The named forms of *C. textile* are as follows:—

i. *tigrinus* (Sowb.). More or less destitute of the brown bands and brown longitudinal markings.

ii. *vicarius* (Lam.). Pattern coarser and larger in detail, greater preponderance of white triangular patches.

iii. *verriculum* (Reeve). Short and stumpy, and coarsely marked.

iv. *concatenatus* (Sowb.). Like No. iii., but of simple zigzag marking.

v. *scriptus* (Sowb.). A delicately striated form, more finely marked than *canonicus,* but otherwise similar.

vi. *canonicus* (Brug.). No brown markings, more finely marked than *vicarius;* a very distinct and well-known form.

vii. *condensus* (Sowb.). A beautiful small shell, with constant pink tinge, marked as *scriptus.*

viii. *corbula* (Sowb.). Of very effuse growth, ventricose, confusedly marked.

ix. *euetrios* (Melvill & Sowb.). Similar to *corbula,* but of different shape, and the markings more regular. Unique in my collection. Locality unknown.

x. *Dalli* (Stearns). Of lighter build. Spire convex; mouth roseate. California. Unknown in European collections as yet.

All these, except *tigrinus,* are called actual species by most authors; but it seems best to merge them as varieties.

b. *abbates.*

The texture and markings finer, and spire, as a rule, more depressed than in the first group.

C. abbas (Brug.). Very beautifully and intricately marked with smaller reticulations; very distinct from any other species.

C. panniculus (Lam.). Perhaps a form of *abbas.*

Var. *textilinus* (Kiener). Of more pyriform shape, but similar markings. I possess Kiener's original type.

C. archiepiscopus (Hwass). Very richly and minutely ornamented.

C. panniculus seems to connect this and *abbas*: it is, in fact, with some hesitation I keep them separate.

C. Victoriæ (Reeve). Of much lighter growth than any of the preceding; the greyish flames peculiar. From Australia. It is a most distinct species.

Var. *complanatus* (Sowb.). Only a more ventricose, squarely based variety of *C. Victoriæ.*

c. *pyramidalia.*

It is in this group that the Textile group reaches its maximum of beauty and perfection. The lengthened and graceful pyramidal shape and straight lip amply characterize it.

C. pyramidalis (Lam.). "A species," writes Tryon, "often misunderstood. Its lengthened form and simple interlaced network fully distinguish it." A var. *convolutus* has been described of more brilliant colouring. There can be no doubt but that this species, through the var. *tigrinus*, is connected with the true Textilia.

C. telatus (Reeve). Is more conical than most of the Textile Cones. In the British Museum this is placed among the Leptoconi, next to *ammiralis*, which, in its markings, it much resembles.

C. Paulucciæ (Sowb.). Allied on the one hand to *C. aureus* and on the other to *C. gloria maris*. Of very straight pyramidal growth, very richly and handsomely marked with warm chestnut and orange. A native of Mauritius, it was only recently (1877) described by Mr. G. B. Sowerby, from a specimen in the collection of the Marchioness Paulucci, at Florence. Three or four specimens besides the type are known, one of which is here exhibited.

C. gloria maris (Chemn.). Larger, very gradually tapering; mouth very straight and long; spire squarely elevated; reticulations exceedingly fine, regular, and minute; orange blotches not so conspicuous proportionately. To this I will refer later.

C. legatus (Lam.). A distinct form, not, to my mind, the young of *canonicus*, to which Tryon assigns it. Noticeable, by great prominence in the longitudinal chocolate blotches, with a suffusion of pink, which is always present in the species, over the whole shell, and by its somewhat compressed conical shape.

II. Retiferi.

C. retifer (Menke) = *solidus* (Sowb.). One species only. Amply characterized by its pyriform outline, great solidity, and coarse reticulations. Native of Eastern seas.

III. Lucidi.

C. lucidus (Mawe) =*reticulatus* (Sowb.). The only species. Very peculiar in its more conical shape, areolate and regular marking, and violet aperture. The locality also is curious: La Plata Island, west coast of Central America.

IV. Aulici.

Shells, as a rule, narrow in proportion to their length; spire rounded, elevated, marking, on most of the species, very bold and distinct dark chestnut or chocolate-brown blotches, alternating with lines of large white spots interlaced with coarse network.

a. *crocati.*

Surface orange-yellow, often nearly suffusing the entire shell. Though the type (*C. crocatus*) is distinct enough, it is connected by intermediate gradations with the Aulici proper.

C. colubrinus (Lam.). Yellow, with oblong white spots. A very uncommon and curious species.

C. crocatus (Lam.). A very handsome orange-yellow conical species, with white spots and markings broader than long, very variable in their disposition. Some specimens are almost unicolorous yellow. This species, at first sight, has less resemblance to the Textile Cones than any other of the group. Native of Ceylon.

C. racemosus (Sowb.). Shell brownish orange, solid, smooth; spire convex, with obscure articulated brown and white revolving lines and clusters of triangular white spots sparingly agglomerated. Unique in my collection; formerly in that of Mr. Bewley, of Liverpool, and subsequently in S. Prevost's, of Alençon.

b. *episcopi.*

Under this head come a very variable assortment of shells, grouped mostly, but, I think, wrongly, by Tryon under the head *C. omaria,* with the exception of *aulicus* and *Elisæ*.

C. Elisæ (Kiener). Shell very closely reticulated with chocolate-brown, so as to appear like a uniform brown surface with innumerable white specks. From Madagascar. A very distinct species, though somewhat like *C. racemosus.*

C. prælatus (Hwass). Always suffused and clouded with grey; very distinct.

C. magnificus (Reeve). A truly magnificent species, very variable, but always recognizable. In form like *episcopus,* with very obtuse spire marked as in the body of the shell in a regular continuation; shell pink, much suffused with dark chocolate and very delicate reticulation. From the Philippines.

C. episcopus (Hwass). Variable, and no doubt allied to *omaria,* but the greater size and greater boldness in marking are always sure to distinguish it. Native of all Eastern seas.

C. omaria (Hwass). Very variable. Among the specimens exhibited are some resembling *C. cordigerus*

(Sowb.), and others like *C. nocturnus* and *Bandanus* in other sections, to which I provisionally give the name *marmoricolor*. Another specimen, again, resembles *C. magus*, a variable Eastern species, here called *magoïdes*. A detailed description of this species seems impossible.

C. pennaceus (Born.) is a variety.

C. rubiginosus (Hwass) is likewise a variety, but both are more constant than some of the forms of the type.

C. Madagascariensis (Sowb.). Though placed by Tryon as a variety of *C. archiepiscopus*, it is far removed from that species, and really approaches *C. omaria*. It is a small, neatly marked, very finely reticulated species, native, as its name implies, of Madagascar.

C. aulicus (L.). The largest and boldest-marked species of the genus, attaining sometimes a length of nearly 6 inches. It is distinguished by its form and revolving striæ, and cannot be mistaken for any species but the next.

C. auratus (Lam.). Merged into *C. aulicus* by Tryon, with which I can hardly agree; the curious zigzag effect of the alternations of warm chestnut-brown coloration and small articulations well represented in the specimen here exhibited, as well as in the plate in Reeve, Conch. Icon., sufficiently serve to distinguish it.

V. AUREI.

Shells subcylindrical, merging into the next subgenus *Hermes*, ribbed transversely; spire elevated, very obtuse, convex.

C. aureus (Hwass). A distinct species, though similar in its markings to *C. Paulucciæ* and some others.

C. clavus (Linn.). A very beautiful species, delicately marbled with orange-brown and white reticulations; its form is oblong; spire convex, spotted. Native of Java and the Philippines and New Caledonia. Tryon and Adams place this species in *Hermes*, between *C. Nussatella* and *circumcisus*, but I think it falls more naturally in here.

Besides the foregoing, one more species of the Textile Cones has been lately described, *C. Prevostianus* (Sowb.). The specimen is unique, and I have not seen it, but it would seem to come under the section Pyramidalia.

But my chief object in calling attention to the arrangement of the Textile Cones was to compare the *Conus gloria maris* (Chemn.) with its congeners.

Although I placed it near *pyramidalis*, it really stands *per se*, prominent among all of its kindred for beauty of shape and excellence of pattern. As Reeve observes, the reticulations are so fine as to defy the skill of the lithographer. Hence no drawing ever does the species justice.

It was originally described by Chemnitz (Conchylien Cabinet) in the year 1788, "ex Museo Moltkiano;" but the shell seems to have received its name, though no description was published, about the year 1756 or 1758, in the Museum Schluyterianum, Berlin.

The nomenclature of Chemnitz, describing in the pre-binomial era, is not always accepted by writers, but this species will always be especially associated with him, although Hwass is sometimes given as the authority for the name.

The following is the bibliography relating to this species, *C. gloria maris* (Chemnitz):—

Chemnitz, Conchylien Cabinet, 10. p. 73, t. 143. f. 1324–25.
Bruguière, Encycl. Méthod. p. 756, n. 146, Tabl. pl. 347. f. 7.
Blainville, Dict. des Sciences Nat. tom. x. p. 260.

Lamarck, Annal. du Mus. vol. xv. p. 438, n. 17*b*.
Dillwyn, Cat. i. p. 424.
Wood, Ind. Test. t. 16. f. 134.
Delessert, Rec. 40. f. 16.
Sowerby, Tankerville Catalogue, 1825, pl. 8. f. 1, 2.
Deshayes, Lamarck, 2 ed. xi. p. 126.
Reeve, Conchologia Iconica, pl. 6. f. 31.
Kiener, Coquilles Vivantes, p. 326, t. 76. f. 1.
Sowerby, Thesaurus Conch. pl. 24. f. 526.
Tryon (G. W.), Manual of Conchology, 1884, vol. 6. pl. 29. f. 90.

There is also a figure of the species in

Chenu, Manuel de Conchyliologie, p. 249, f. 1525.

Dr. S. P. Woodward, in 'Recreative Science' (1860), says :—" The rarest of all Cones, and perhaps of all shells, except the living Pleurotomaria, is the *Conus gloria maris*, which those old Pagan Dutchmen worshipped, as did the Greeks the Paphian Venus. Perhaps it was this Cone of which a Frenchman is related to have had the only specimen except one belonging to Hwass, the great Dutch collector, and when this came to the hammer he outbid every rival, and then crushed it beneath his heel, exclaiming, 'Now my specimen is the only one.' Doubtless many traditions respecting this species yet linger in the marts of Amsterdam; with us it is still worth ten times its weight in gold."

In 1825 the elder Mr. Sowerby, in cataloguing the shells of the late Earl of Tankerville—which catalogue formed the medium for the description, for the first time, of many now well-known species—notes, in his preface at the lot 2463, which contained a *gloria maris* :—" We have never seen more than two specimens of this shell, namely, that which is in M. Saulier's collection in Paris, and that which adorns the Tankerville collection."

It will not be out of place now to enumerate the whereabouts of the 11 or 12 specimens known to exist. It is a curious fact that while nearly every other shell, hitherto highly esteemed, has been brought home in abundance by explorers and collectors, this and one or two others like the *Cypræa leucodon, C. princeps, C. Broderipii, C. guttata,* and *Conus cervus* remain as they were in the days of the Duchess of Portland, the first English collector, in the middle of the last century.

The land of its nativity is known: Jacna, I. of Bohol, Philippines, where the late Mr. Hugh Cuming found two examples, one very juvenile, scarcely more than an inch in length. But its rarity there was so great that, although he employed all the available natives in dredging-expeditions, and the place has been searched frequently since, nothing of the kind has again occurred. Rumour has it that the original very circumscribed locality has been annihilated by an earthquake, but I cannot hear confirmation of this, though it is exceedingly likely, the whole of that region being extremely volcanic.

The total number of specimens known to exist is 12; of these half are either immature or in very poor condition.

There are five in this country, disposed as follows:—

Three in the British-Museum Collection at South Kensington. Of these two are the small specimens, one only an inch and a half long, the other a little larger, collected at Jacna by Mr. Hugh Cuming in 1838.

The third is the specimen formerly in the Portland Collection, then in the Tankerville, from whence it passed into the hands of the late Mr. W. J. Broderip, F.R.S., and thence into the National Collection. This is a fine, full-grown, though pale-marked specimen, and is illustrated in Sowerby's 'Catalogue of the Tankerville Collection,' but very highly coloured.

The fourth specimen in this country is in the private collection of the late Mrs. De Burgh, of 61 Eccleston

Square, London, S.W., and is, perhaps, the finest specimen known. Formerly in Mr. Norris's possession, of Preston.

The fifth is the specimen now exhibited, as being in my collection at Prestwich. It is not quite so large as Mrs. De Burgh's or the Tankerville specimen, but as finely marked, and of mature growth. Formerly in Mr. Lombe Taylor's hands, it passed into that of the late Dr. Prevost, of Alençon, and subsequently into mine.

The sixth specimen is in France, but a very poor one, collected by M. Carl Bock in his eastern travels, and which I saw sold with a great deal of competition at Stevens's Auction Rooms in July 1880. It was very water-worn, and with a disfiguring sea-break. It was purchased by Mr. Bryce Wright, of Regent Street, for M. Dupuis, of St. Omer.

The seventh specimen is in Italy. One formerly in the collection of the Hon. Mrs. MacAdam Cathcart, sold to the Marchese Paulucci, of Florence. This specimen is described by Mr. G. B. Sowerby to me as being fairly marked, but filed in the mouth and not in good condition.

The eighth, a very poor, small example, is in the collection of Madame Macaré, of Utrecht, Holland.

In the same country it is also reported that there is a specimen in the Amsterdam Museum; but, on writing for more particulars to Mr. Sowerby, to whom I am much indebted for details, he assures me there is some mistake as to this. There is, however, I believe, one in the Museum at Rotterdam.

The tenth example known, originally in M. de Verreaux's possession, is now in that of the King of Portugal, at Lisbon, to whom it was sold by Mr. Damon, of Weymouth.

In the United States, Mr. Tryon writes me, there is a good specimen in the American Museum of Natural History, New York; but I know nothing of its history, or whence it was obtained.

In Australia the fine, full-grown, but pale-coloured shell, formerly in the collection of Mr. J. Dennison, of Liverpool, was, in April 1865, bought by Mr. Lovell Reeve for the Melbourne Museum.

There are, therefore, eleven or twelve specimens at most recorded of the shell not inaptly termed

"THE GLORY OF THE SEA."

VI. *Memoir of* ROBERT ANGUS SMITH, *Ph.D., LL.D., F.R.S., F.C.S., &c.* By EDWARD SCHUNCK, Ph.D., F.R.S., &c.

Read April 21st, 1885.

BY the death of Robert Angus Smith the Literary and Philosophical Society has sustained a great loss. His was a life of which it is difficult to form a just estimate, on account of the many-sidedness of his character and attainments. His contributions to science and literature will, indeed, always remain accessible to the judgment of posterity, but there is much in his character and his relations to the world which should be recorded ere those who knew him have also passed away. In his case, fortunately, the record may be perfectly unreserved, for here there are no defacing blots to be concealed, no dark shadows to be passed over.

Robert Angus Smith was born in Glasgow, February 15th, 1817, being the twelfth child and seventh son of John Smith, a manufacturer of that city, and of Janet his wife, daughter of James Thomson, who was an owner of flax and other mills at Strathavon, where he held the office of baron-baillie. Of the brothers, those who attained to maturity were all men of remarkable intellect. The eldest, John Smith, was for many years a master in the Perth Academy, and paid great attention to optics. A paper by him "On the Origin of Colour and the Theory of Light" will be found in vol. i. ser. 3 of the Society's Memoirs. James Smith, a man of highly original character, was the author of several works on religious and philosophical subjects. Another brother, Michaiah, was a distinguished oriental scholar, while Joseph, the youngest, devoted himself to science, but unfortunately died early. The father was, by all accounts, a very earnest man, with profound religious convictions, and though not highly successful in worldly pursuits, was able to give his sons a good education, such as the schools and universities of Scotland were and are presumably still able to offer even to men of moderate means. Two of the sons, James and Michaiah, were ordained ministers in the Scotch Church. At that time, however, the Irvingite schism was exciting the minds and engaging the sympathies of many, especially the young, and it is probable that the father as well as several of the sons felt attracted by the doctrines promulgated by Irving, doctrines which could not possibly find sufficient scope within the somewhat contracted sphere of a Calvinistic communion. So far as the subject of this memoir is concerned, it is certain that his sympathies led him more in the direction of Anglicanism, and from the hints he let drop at various times, it seems that it was only through circumstances that he was prevented, when a choice was possible, from taking orders in the English Church. After passing through the usual course at the Glasgow High School, and spending some time at the

University of Glasgow, a period of his life of which he seldom spoke, simply perhaps because there was little to say, Smith accepted a post as tutor to a family in the Highlands, but was soon compelled to leave from ill-health. He then proceeded to England, where he was employed in a similar capacity in families whose peculiar religious opinions afford some indication of the direction in which his sympathies at that time tended. With the Rev. and Hon. H. E. Bridgeman he spent two years, and with him proceeded to Germany. So far Smith's tastes and pursuits had been purely literary and theological. His education had been entirely classical, being confined to acquiring a knowledge of ancient languages, such as was in his day thought sufficient for all the purposes of life, an acquaintance with science, mathematics, or modern languages being then considered comparatively of little consequence. During his stay in Germany one of the tendencies of his many-sided mind revealed itself. Hearing of Professor Liebig, whose fame was then spreading through Germany, his attention was directed towards science, this tendency being perhaps encouraged by the example of his brother Joseph, who had engaged in the study of chemistry under Professor Penny, of Glasgow, and with whom he corresponded. He accordingly proceeded to Giessen, where he worked in Liebig's laboratory during the years 1840–41, and where, before leaving, he took the degree of Ph.D. During his stay at Giessen he extended his knowledge of the German language and literature, and also paid much attention to German systems of philosophy, a subject that at all times interested him greatly.

It may perhaps be considered a matter for regret that Dr. Smith's early training in science was not more extensive, and that it continued for so short a time. On the other hand it is possible that a more rigorous training in natural science and mathematics might have detracted from the catholicity of mind and wide culture which were prominent characteristics of his. He afforded, indeed, a conspicuous example in favour of the principle held by the conservatives in education, viz. that a thorough classical training affords a basis on which a superstructure, whatever it may consist of, may be confidently erected, though, on the other hand, it would be hazardous to found general rules on such exceptional cases as his. Soon after leaving Giessen, Dr. Smith published a translation of Liebig's work 'On the Azotised Nutritive Principles of Plants.' After his return to England, at the end of 1841, he was engaged in various capacities with families of distinction, and at this time the early inclination towards a theological career seems to have revived, and was probably only given up when it was found that circumstances, such as the necessity for a preliminary education at an English University, placed an insuperable barrier in the way. In the year 1843 we find him working as assistant to Dr. Lyon Playfair, with whom he had become acquainted at Giessen, and who was then engaged as Professor of Chemistry to the Manchester Royal Institution. At Manchester Dr. Smith finally settled down; here, with the exception of intervals of travel, he spent the rest of his life, and here all his most important work was done. With characters combining many-sidedness with great intensity of purpose it is often a mere accident that determines the direction the energies shall take. Such an accident occurred in the career of Dr. Smith. The Health of Towns Commission, of which Mr. Edwin Chadwick was the moving spirit, instituted inquiries in Manchester as in other towns. Dr. Playfair was much interested in these inquiries, and Dr. Smith was engaged in conducting some portion of them, their object being more practical than scientific.

This circumstance directed Dr. Smith's attention to sanitary matters, and led him to commence the series of investigations which occupied a great part of his time and attention from the year 1844 up to the time of his death.

At the time when Dr. Smith commenced his researches sanitary science could not be said to exist, unless a mere collection of unconnected facts can be dignified with the name of science. Since that time much more system has been introduced into the subject, and a great portion of the merit of having developed the purely scientific side of it is due to Dr. Smith. The pathological department of the subject did not, as may be supposed, receive so much attention from him as the physical; nor did he, I think, at any time pronounce decidedly on the question whether the phenomena with which sanitary science deals are purely organic in their nature, or whether they are not also partly due to merely physical causes. What he did was to investigate patiently the physical and chemical conditions as regards outward agents, more especially the air we inhale and the water we drink, on which health and disease seem to depend. No doubt, since the time when he entered the field, our views on this subject have altered considerably. It is now held that most diseases, especially those of the zymotic class, are due to the development of organic germs, but the most ardent advocate of the germ-theory must allow that there are physical and chemical phenomena attending disease which should not be neglected, and to these Dr. Smith chiefly confined his attention, now and then only reverting to the general question of the causes of disease, as to which he was always prepared to modify his opinions when the progress of discovery required him to do so. The results of his labours are contained in a series of papers, of which the Royal Society's catalogue contains a list, though an incomplete one, beginning with one entitled "Some Remarks on the Air and Water of Towns," published in the Chemical Society's Journal, 1845–48. His results are summed up in an independent work entitled 'Air and Rain,' and published in 1872. Much of Dr. Smith's work was necessarily of a purely qualitative character, for the phenomena which he investigated are concerned with almost infinitesimal quantities of matter. Nevertheless, whenever it was possible, he introduced quantitative methods, as when examining the amount of acid contained in the atmosphere, of which an account will be found in his paper "On Minimetric Analysis," read before this Society in the Session 1865–66. This paper contains a description of a very simple and ingenious little apparatus, called by him a "finger-pump," by which the amount of impurity in the atmosphere, in the shape of carbonic acid or hydrochloric acid, can be rapidly and easily determined. On disinfectants, to which Dr. Smith's attention was naturally directed, he worked much, his general views on the subject being contained in a separate work published in 1869, and entitled 'Disinfectants and Disinfection.' The practical result of his studies in this direction was the invention of a very useful disinfectant, which was introduced by Mr. McDougall, and is still largely employed. This short résumé may perhaps suffice to give some idea of Dr. Smith's labours on air and water in their hygienic relations; but before closing it some allusion should be made to his able report "On the Air of Mines," chiefly those of Cornwall, presented to Government, by whose directions the inquiry into the atmospheric conditions prevailing in mines was undertaken. Dr. Smith's memoirs on purely scientific subjects are not numerous. Among them may be mentioned those on rosolic acid, on the absorption of gases by charcoal, which he supposed to take place in certain definite proportions, and on the "Measurement of the Actinism of the Sun's Rays and of Daylight" (Proceedings, Royal Society, xxx. p. 355), in which a novel method of measurement is described. His study of peat, which treated of a favourite subject of his, was perhaps more practical than scientific in character. Those who take an interest in the subject of the formation and utilization of peat should refer to his papers relating to it, published in the Society's Memoirs.

This is perhaps not the place to mention in detail his work in connection with technical subjects, but one of his inventions must not be passed over in silence, viz. that for coating iron tubes with an impermeable varnish, so as to preserve them from corrosion. Of this invention experts entertain the very highest opinion, and it may safely be said that had be been endowed with more worldly prudence, he might by this invention alone have amassed a considerable fortune. Like many other inventors he never enjoyed the rewards to which his ingenuity entitled him. It is for the world to acknowledge, by words at least, the benefits he conferred on it; for those who are unable or unwilling to fight and struggle for wealth and position it has no other recompense to offer.

In the year 1864 Dr. Smith was appointed chief inspector under the Alkali Act, which had just previously been passed by the legislature, a post for which he was, from his intimate knowledge of atmospheric contamination, eminently fitted. Great complaints having arisen regarding the injury done to crops and other things by the emanations from alkali-works, an Act was passed, the object of which was to limit the amount of injurious gases, especially hydrochloric acid, which should be allowed to escape from the flues of alkali-works.

It was this Act, the provisions of which Dr. Smith, with the aid of his sub-inspectors, was to see carried out, by constant supervision on the part of the sub-inspectors and frequent periodical visits to various districts by himself. That he was eminently successful in his attempts to secure for the public the benefits which the legislature had in view when the act was passed, and, on the other hand, in conciliating by his prudence and tact those who were to some extent restricted and interfered with by the provisions of the Act, is universally conceded. It is quite possible that in other hands the task which Dr. Smith was called on to perform might not have been accomplished, and the result might have been complete failure. To continue what he began according to methods initiated by him is a comparatively easy task. As chief inspector under the Alkali Act Dr. Smith had each year to present a report of the proceedings under the Act for the preceding year. These reports, of which the last (presented in 1884) was the twentieth of the series, contain much information over and above what mere official summaries might be expected to give, and they should be carefully studied by all who are interested in hygiene in its relation to manufactures.

In the year 1876 an act similar to the Alkali Act, though of a less stringent character, was passed, styled the "Rivers Pollution Prevention Act." Under this Act Dr. Smith was appointed to examine polluted waters, more especially the state of effluent fluids from sewage-works, and he presented two reports to the Local Government Board as an inspector under the Act. To the results set forth in the second of these reports, presented shortly before his death, Dr. Smith attached the greatest importance. It will be for others to judge of the value of these results, but he himself considered that the discoveries described in the report would open up a wide field of research, throwing quite a new light on the relations between disease and water and soil. To those who take an interest in sanitary science it must be a matter for vivid regret that his labours in this novel field of research were cut short just when they seemed to promise important results.

It remains to say a few words on such of Dr. Smith's publications as are not of a strictly scientific or professional character. These are partly philosophical in their tendency, partly literary, or simply popular in character, and in part treat of antiquarian and historical subjects, for which Dr. Smith had a great liking, and seem often to have been hastily penned to fill up a leisure hour or at the request of friends. Many of them were anonymous, but Dr. Smith's style and the current of his thought were so original that to those who knew him the disguise was only a thin one. One of the works belonging to this class must not, however, be passed over without special notice. During several years of the latter portion of his life he was in the habit of spending his autumn vacation on the shore of Loch Etive in Scotland, where he employed himself—his active mind never being satisfied without some special object to occupy it—in exploring this part of his native country with a view of throwing some light on its state in prehistoric times. The result was a work which is not only instructive, but highly entertaining in the best sense, called "Loch Etive and the Sons of Uisnach," a work which all should read who are interested in prehistoric research and ethnology. Dr. Smith paid great attention to Celtic languages, and made a large collection of works in Gaelic. These, with the rest of his books, have, since his death, been presented to the library of Owens College.

Dr. Smith was elected a member of this Society in the year 1844. For several years he acted as one of the Secretaries of the Society, subsequently he was elected a Vice-President, and during the sessions 1864 and 1865 he filled the post of President. He at all times took a lively interest in the welfare of the Society, and was always ready with advice and active assistance when such were required in the transaction of business.

In connection with this Society he will, however, be chiefly remembered by two works, the 'Life of Dalton and the Atomic Theory' and 'A Centenary of Science in Manchester,' which were written at our request, and form two volumes of our series of Memoirs. The 'Life of Dalton' was a work written *con amore*, as it gave the author an opportunity of setting forth his ideas on two favourite subjects—the rise and development of scientific thought among civilized nations, and the consideration of the metaphysical notions out of which the theory of atoms has sprung. The other of the two works named shows the original turn of thought and terseness of style found in all his writings, though undertaken at a time when his health was declining and he was overburdened with other work. To the same class of writings belongs the preface to the beautiful edition of Graham's 'Chemical and Physical Researches,' undertaken at the cost of the late James Young. In this preface he gives a short history of the atomic theory, beginning with its rise in the schools of Greece and tracing its development in modern times.

Dr. Smith was a Fellow of the Royal Society and of the Chemical Society of London, and a member of several learned societies on the continent. Had he been more of a specialist it is probable that the list of societies that sought to honour him by membership and in other ways would have been longer. In the year 1881 the degree of

LL.D. was conferred on him by the University of Glasgow, a distinction which, coming from his alma mater, the seat of learning in his native town, he valued highly. The same degree was awarded to him by the University of Edinburgh in 1882.

Dr. Smith's health had evidently been declining for some years. Not endowed with a very robust constitution, and unable, as it appeared to some, to take the amount of sustenance required for so active an existence as his, the great labours which were partly imposed on him, and partly undertaken voluntarily, began in time to tell on his health. To the entreaties of his friends to allow himself some rest, he did not reply by a direct refusal, but continued to work on with unabated zeal, as if the stock of vigour he had to draw on were inexhaustible.

Various changes of scene were tried, but without effect, and he gradually sank, the bodily strength declining, but the mind remaining clear to the last. He died at Colwyn Bay, in N. Wales, on the 12th May, 1884. His remains were interred in the churchyard of St. Paul's, Kersal.

This notice would not be complete without some reference to Smith's moral characteristics. To those who knew him these were familiar, but those who come after us should know that in his case an intellect of high order was united to a character of the purest and noblest type. The most marked trait in his character, it always seemed to me, was a wide, to some it might seem an almost inconceivably wide benevolence, a benevolence which seemed capable of embracing all except the unworthy within its folds. It was this that led him to associate with men of the most diverse character and aims, extracting from each specimen of humanity a something with which he could sympathize, putting on one side or excusing what was uncongenial to his nature in each, and establishing bonds, some stronger some weaker, which, in their totality, gave him a sense of relationship to humanity at large. This wide toleration may serve to explain the fact which may sometimes have been observed, that two men mutually repellent and unwilling to associate together might both have been warm friends of his. He appeared, indeed, to be the centre of a system or constellation, the individual members of which knew little of each other, but were all united to him by bonds of sympathy. His extreme conscientiousness and high sense of honour appear even in his works, leading him scrupulously to weigh all that could be said on either side of an argument, and to give every man his proper share of merit, refusing sometimes even to credit himself with what was manifestly his due. This great conscientiousness was occasionally even injurious to himself by preventing his arriving at positive and precise conclusions, such as the world requires even when there is no thorough conviction.

Of the charms of Dr. Smith's conversation, only those are able to form an idea who had the pleasure of his personal acquaintance, for it was not of a kind to be literally reproduced. Without being at all eloquent or indulging in harangue, and always giving due weight to everything his hearers had to say, he was able, from the fulness of his knowledge and the originality of his views, to throw a new light on almost every subject he touched on, and thus he would sometimes continue to instruct without dogmatizing, and entertain without wearying, until it was found that not minutes but hours had slipped away in listening.

One trait in Smith's character must not be passed over, though to mention it in this age of materialism may seem to require some apology—he was a firm believer in a spiritual world, that is of a world above and beyond the senses, of the reality of which, whether we can communicate with it directly or not (and of this he never seemed quite sure) he was firmly convinced. Those who remain to lament his loss, and who share the same belief, may unite in the fervent trust that in the world of which he thought much, but spoke little, his spirit may have found not merely rest and satisfaction, but also a continuance of that mental activity and development which to him were life.

Dr. Smith was never married, but for many years his niece, Miss Jessie Knox Smith, was his constant companion and confidante, ministering to him with a zeal and devotion which could not have been exceeded had the relationship been that of father and daughter.

VII. *On a Property of the Magneto-electric Current to control and render Synchronous the Rotations of the Armatures of a number of Electro-magnetic Induction-machines.* By Henry Wilde, Esq.*

Read December 15th, 1868.

The discovery of the property which I am about to describe arose out of the efforts which have been made, during the last two years, to reduce the internal heat generated in an electro-magnetic machine by the induction-currents set up in the electro-magnet and armature by the rapid magnetization and demagnetization of the latter. This heating of the armature, as is well known, was first observed by

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* The subjects treated of in this and the two following papers having acquired great interest in recent years, it is believed that the papers would be increasingly useful if they were embodied in the more permanent records of the Society.

Dr. Joule in 1843, as the result of a delicate investigation on the quantitative relation existing between ordinary mechanical power and heat*. In the electro-magnetic machines of my invention this phenomenon unfortunately manifests itself on an alarming scale, so much so that the armature of the 10-inch machine rises in the course of a few hours to 300° F. and upwards; and were the action of the machine to be continued for any lengthened period, the insulation of the armature-coils would be endangered.

One method of mitigating this evil was to construct the machine of smaller dimensions, so as to afford greater facilities for the dissipation of the heat by radiation and conduction. But even in the smaller machines an inconvenient residuum of heat still remained when they were worked continuously for a considerable time, so as to render it desirable to adopt some means for abstracting the heat more rapidly. By means of a current of water circulating in the hollow brass segments which form part of the magnet-cylinder, Mr. Charles E. Ryder, the skilful manager at the works of Messrs. Elkington and Co., has happily succeeded in so far reducing this heating as to permit of the machines being worked for days and nights together without intermission, and without any sensible diminution of the power of the current.

The machines which have been found to be the most efficient and economical in their working are those which have armatures from 3½ to 4 inches in diameter. The armatures are driven at about 2000 revolutions per minute; and the water, after having passed through the magnet-cylinder, is used for supplying the boilers which furnish the power for driving the machines.

I have already shown elsewhere that the current from a

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* Phil. Mag. S. 3. vol. xxiii. p. 264.

small magneto-electric or electro-magnetic machine is sufficient to excite the great electromagnet of the 10-inch machine; and it has been further found, by my friend Mr. G. C. Lowe, that the current from one small machine is sufficient to excite simultaneously the electromagnets of several small machines. In a number of 3½-inch machines which have been constructed under my direction for Messrs. Elkington and Co., for the electrodeposition of copper on a large scale, the currents from two 3½-inch electro-magnetic machines are made to excite the electromagnets of twenty similar-sized machines to a degree sufficient to bring out the maximum dynamic effect of each machine. The electromagnets of the two 3½-inch exciting machines are charged by the current from a small 2½-inch magneto-electric machine; but I have found that nearly as good a result may be obtained from the twenty machines by dispensing with the small magneto-electric machine, and employing the residual magnetism of the two 3½-inch exciting machines in a manner similar to that described, almost simultaneously, by Mr. Farmer*, Messrs Varley†, Mr. Siemens‡, and Sir Charles Wheatstone §.

So far I have adverted principally to the means by which a very serious defect in the practical working of the new induction machine was remedied, a defect which many of my friends, who were unacquainted with the efforts which have been made to overcome it, have considered to be fatal to the success of what seemed likely to be a useful invention. But while the difficulty arising from the

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* Letter to the Author, November 2, 1866, Salem, Mass. U.S., Proceedings of the Literary and Philosophical Society of Manchester, February 19, 1867.

† Specification filed at the Office of the Commissioner of Patents, December 24, 1866.

‡ Specification filed at the Office of the Commissioner of Patents, January 31, 1867.

§ Proceedings of the Royal Society, February 14, 1867.

heating was now obviated, the subdivision of the materials of one large machine into a number of small ones gave rise to another defect which it was also found necessary to overcome; for although the armatures of several machines might be driven nominally at the same speed from the same drifting-shaft, by means of straps, yet when the combined direct current from several commutators was required, the want of perfect synchronism in the revolution of the armatures operated to produce a diversion of the currents of some of them through the coils of others at the neutral point of their revolution; and consequently, the maximum useful effect of the combined currents could not be obtained.

As the high speed at which the machines were driven precluded the employment of toothed gearing, the only method which seemed at all feasible for producing the requsite synchronism of the armatures was to place a number of the machines in a straight line, and connect them together by means of a clutch fixed on the end of each armature-spindle. The chief objection to the carrying out of this arrangement was the difficulty of providing the requisite means for preserving the synchronism of the system, when any of the intermediate machines were disabled by accident, or stopped for repairs; so that, practically, it would not have been found convenient to work more than two machines geared together in the manner described.

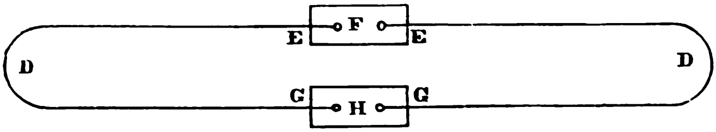
It was while experimenting with a pair of machines so geared together, that I first observed the phenomenon which forms the subject of this communication. These machines were arranged for producing the electric light, with a view to their application to lighthouse illumination. The armatures were 4 inches in diameter, and each of them was coiled with a copper-wire conductor 280 feet long and $\frac{1}{8}$ of an inch in diameter. The currents were taken from the armatures by means of copper brushes rubbing against metal rings connected respectively with the ends of the armature-coils, and were therefore in alternate directions. It has been found that alternating currents are much better adapted for the production of a constant electric light at a fixed point in space than the current which has been rectified by means of a commutator.

The clutch, by which the armatures were connected, consisted of two iron disks about 4 inches in diameter, having, in the face of one, two iron pins which could be guided into two corresponding holes in the face of the other. These disks could be engaged or disengaged either when the machines were at rest or in motion. The relative positions of the pins and holes in the disks were such that the armatures might be engaged in reversed positions of half a revolution when required.

Each of these 4-inch machines, when making about 2000 revolutions per minute, was of itself capable of producing a very efficient electric light; and when the two armatures were clutched together in such a position that the united positive currents from both machines proceeded from one polar terminal simultaneously with the united negative currents from the other polar terminal, the sum of the currents of the two machines was obtained. On the other hand, when the armatures were clutched together in the reverse position without any change being made in the armature connexions, no current was produced outside the two machines.

These experiments, besides exhibiting the necessity of synchronous rotation, further showed that the armatures must also occupy the same relative position in the magnet-cylinders in order that the combined current from the two machines might be obtained. It now occurred to me to see to what extent the want of synchronism in the armatures would affect the magnitude of the current. The armatures were therefore unclutched and allowed to revolve independently of each other, in the same manner as when the attempt was made to take the combined *direct* current from the commutators. After the *alternating* current had been transmitted through the electric lamp for some time, I was surprised to find that there was no perceptible diminution in the amount of light produced from the carbon points, and that the current would fuse very nearly the same quantity of iron wire as when the armatures were clutched together. On examining into the circumstances attending this unexpected phenomenon, I first observed that, whenever the machines were stopped, the pins and holes in the respective disks were exactly opposite each other, and that, while the armatures were revolving, the two disks could at all times be engaged and disengaged with the greatest facility. Moreover, even when, before starting the machine, the disks were set a quarter or half a revolution out of the position in which the maximum amount of current was obtained, it was found that, after the armatures had been revolving for a few moments, the disks resumed their normal position with respect to each other (as indicated by the action of the clutch)—thereby exhibiting not only the synchronous rotation of the armatures, but also that the machines contained a principle of self-adjustment to the position in which the maximum effect of the combined current was obtained. It will therefore be evident that this property of the current, to maintain the synchronism of the armatures, renders it unnecessary to employ mechanical gearing of any kind for that purpose.

Proceeding further in this investigation, I found that, in order to produce synchronous rotation, it was not at all essential that the circuit which conveyed the combined currents for producing the light should be completed, provided that the ends of the coils of each armature were connected respectively with the same metal plates which formed the polar terminals of the machines. In this case the armatures adjusted themselves to their normal positions even more readily than when the current was producing the light. The accompanying diagram will assist in explaining these observations more fully.



Let D and D represent the two armature-coils, which, though each 280 feet long, may virtually be represented by a single turn; EE the two outer extremities of the coils, both connected by means of the metal rings and brushes with the metal terminal plate F; GG the inner extremities of the same coils, similarly connected with the terminal plate H. The synchronous rotation of the armatures and coils D and D, as I have said, occurs either when the light is produced by the combined currents transmitted from the polar terminals F and H, or when the circuit which conveyed these combined currents is broken.

The synchronism, however, is no longer preserved when a short circuit is made between the terminals F and H by substituting a good conductor for the carbon points, or for the long piece of iron wire which was fused. Nor, again, was the synchronism preserved when contact between the metal plate H and one of the ends (G) of the coil was broken. In the latter case it was observed that, whenever contact between G and H was made and broken, a bright spark appeared at the point of disjunction so long as the rotation was not synchronous; but when the synchronism was reestablished, only a trifling residual spark was visible.

Although the synchronous rotation was preserved when the terminals FH, from which the combined current was transmitted, were disconnected from the electric lamp, yet it will be seen, from an inspection of the diagram, that a complete metallic circuit was in fact always formed between these terminals through the coils themselves. Now, when the coils DD happen to be at the same moment in that position during their revolution in which they are producing the maximum and minimum amount of current respectively, as must often be the case where there is no synchronism, that current which is at the maximum rushes through the coil which is producing the minimum current, as is shown by the spark at the point where contact is broken between G and H. The effect of this passage of the current from one coil to the other is to accelerate or retard the rotation of the armature (according to the direction of the current) until synchronism is established.

That this influence of one coil upon the other operates in the manner described was easily shown by the following experiment:—The driving-strap of one of the armatures was removed, so that only one of the armatures should be producing a current, while the magnetism of the electro-magnets of both machines was, as usual, maintained to the same degree. On placing the stationary armature with its coil in a suitable position in relation to the magnet-cylinder for producing electromagnetic rotation, and setting the other armature in motion, the stationary armature with its coil oscillated rapidly in arcs of very small amplitude, the oscillations corresponding in number with the alternations of the current. As the amplitude of the oscillations in this experiment was limited by the *vis inertiæ* of the armature, and in order that the effect of one pulsation only on the armature might be observed, contact was made and broken suddenly between the plate H and the end G of the coil, when the stationary armature was suddenly jerked round nearly a quarter of a revolution, sometimes in the direction in which it would have been driven by the strap, and at other times in the opposite direction, according as the alternating electrical wave which happened to be passing at the instant of making contact was positive or negative.

We have now seen, in the results obtained with the rotating and stationary armatures, a cause sufficient to account for their synchronism when revolving together,—the absence of synchronism observed when the terminals F and H were bridged over by a conductor having comparatively little or no resistance being occasioned by the controlling current traversing the short circuit established between the terminals F and H, instead of the 280 feet of resistance presented by either of the coils when approaching the neutral point of their revolution. The absence of synchronism observed when the direct current was taken from the machines by means of commutators, is caused by the direction of the current being coincident with that which they would receive by induction from the electro-magnets, and consequently opposite to that which tends to impart an accelerating or retarding impulse to the armatures.

Having obtained the full effect of the combined alternating currents from the two machines without any mechanical gearing, it yet remained to obtain the combined direct currents from the machines in the same manner. A pair of rings and a commutator were therefore fitted upon one of the armature-spindles, which was made sufficiently long for the purpose, and metallic connexion was established between the rings of each machine and the commutator on the prolongation of the armature-axis. As the commutator necessarily revolved synchronously with the two armatures, it was found that the combined alternating currents were rectified just as if they had proceeded from only one machine, and were consequently available for electro-deposition, or for any other purpose for which a direct current might be required.

Although this property of synchronous rotation has as yet been observed only in the case of several pairs and a triple combination of machines, yet there is no reason for supposing that it may not be extended to any number of machines that may be conveniently worked together from the same prime mover. It is necessary, however, to observe that as the controlling power of the current is only calculated to correct such minute deviations from synchronism as it is beyond the power of mechanical skill to prevent, the driving and driven pulleys should be respectively as nearly as possible of the same diameters, as the correction of any considerable difference in the number of the revolutions of the armatures, caused by differences in the diameters of the pulleys, must necessarily be attended by a corresponding diminution of the useful effect of the current outside the machines.

VIII. *On the Influence of Gas- and Water-pipes in Determining the Direction of a Discharge of Lightning.*

By Henry Wilde, Esq.

Read January 9th, 1872.

Although the invention of the lightning-conductor is one of the noblest applications of science to the wants of man, and its utility has been established in all parts of the world by the experience of more than a century, yet a sufficient number of instances are recorded of damage done by lightning to buildings armed with conductors to produce in the minds of some an impression that the protective influence of lightning-conductors is of but questionable value.

The destruction, by fire, of the beautiful church at Crumpsall, near Manchester, during a thunderstorm on the morning of the 4th instant, has induced me to bring before the Society, with a view to their being known as widely as possible, some facts connected with the electric discharge which have guided me for some years in the recommendation of means by which disasters of this kind may be averted.

For the proper consideration of this subject, it is necessary to make a distinction between the mechanical damage which is the direct effect of the lightning-stroke, and the damage caused indirectly by the firing of inflammable materials which happen to be in the line of discharge.

Instances of mechanical injury to buildings not provided with conductors are still sufficiently numerous to illustrate the terrific force of the lightning stroke, and at the same time the ignorance and indifference which prevail in some quarters with respect to the means of averting such disasters; for wherever lofty buildings are furnished with conductors from the summit to the base and thence into the earth, damage of the mechanical kind is now happily unknown.

Even in those cases where lightning conductors have not extended continuously through the whole height of a building, or where the lower extremity of the conductor has, from any cause, terminated abruptly at the base of the building, the severity of the stroke has been greatly mitigated, the damage being limited in many cases to the loosening of a few stones or bricks.

The ever extending introduction of gas- and water-pipes into the interior of buildings armed with lightning conductors has, however, greatly altered the character of the protection which they formerly afforded; and the conviction has been long forced upon me that, while buildings so armed are effectually protected from injury of the mechanical kind, they are more subject to damage by fire.

The proximity of lightning-conductors to gas- and water-mains, as an element of danger, has not yet, so far as I know, engaged the attention of electricians; and it was first brought under my notice at Oldham in 1861, by witnessing the effects of a lightning discharge from the end of a length of iron wire rope, which had been fixed near to the top of a tall factory chimney, for the purpose of supporting a long length of telegraph-wire. The chimney was provided with a copper lightning-conductor terminating in the ground in the usual manner. In close proximity to the conductor and parallel with it the wire rope descended, from near the top of the chimney, for a distance of 100 feet, and was finally secured to an iron bolt inserted in the chimney about 10 feet from the ground. During a thunderstorm which occurred soon after the telegraph-wire was fixed, the lightning descended the wire rope, and, instead of discharging itself upon the neighbouring lightning-conductor, darted through the air for a distance of 16 feet to a gas-meter in the cellar of an adjoining cotton warehouse, where it fused the lead-pipe connexions and ignited the gas. That the discharge had really passed between the end of the wire rope and the lead-pipe connexions was abundantly evident from the marks made on the chimney by the fusion and volatilization at the end of the wire rope and by the fusion of the lead pipe. As the accident occurred in the daytime, the fire was soon detected and promptly extinguished.

Another and equally instructive instance of the inductive influence of gas-pipes in determining the direction of the lightning discharge occurred in the summer of 1863, at St. Paul's Church, Kersal Moor, during divine service. To the outside of the spire and tower of this church a copper lightning-conductor was fixed, the lower extremity of which was extended under the soil for a distance of about 20 feet. The lightning descended this conductor, but, instead of passing into the earth by the path provided for it, struck through the side of the tower to a small gas-pipe fixed to the inner wall. The point at which the lightning left the conductor was about 5 feet above the level of the ground, and the thickness of the wall pierced was about 4 feet; but beyond the fracture of one of the outer stones of the wall and the shattering of the plaster near the gas-pipe, the building sustained no injury.

That the direction of the electric discharge had in this case been determined by the gas-pipes which passed under the floor of the church, was evident from the fact that the watches of several members of the congregation who were seated in the vicinity of the gas-mains were so strongly magnetized as to be rendered unserviceable.

The church at Crumpsall is about a mile distant from that at Kersal Moor; and the ignition of the gas by lightning, which undoubtedly caused its destruction, is not so distinctly traceable as it is in other cases which have come under my observation, because the evidences of the passage of the electric discharge have been obliterated by the fire. From information, however, communicated to me by the clerk in charge of the building as to the arrangement of the gas-pipes, the most probable course of the electric discharge was ultimately found.

The church is provided with a copper lightning-conductor, which descends outside the spire and tower as far as the level of the roof. The conductor then enters a large iron down-spout, and is carried into the same drain as that in which the spout discharges itself. Immediately under the roof of the nave and against the wall, a line of iron gas-pipe extended parallel with the horizontal lead gutter which conveyed the water from the roof to the iron spout in which the conductor was enclosed. This line of gas-piping, though not in use for some time previous to the fire, was in contact with the pipes connected with the meter in the vestry, where the fire originated, and was not more than three feet distant from the lead gutter on the roof. As no indications of the electric discharge having taken place through the masonry were found, as in the case of the church at Kersal Moor, it seems highly probable that the lightning left the conductor at the point where the latter entered the iron spout, and by traversing the space between the leaden gutter and the line of gas-piping in the roof found a more easy path to the earth by the gas-mains than was provided for it in the drain.

In my experiments on the electrical condition of the terrestrial globe, I have already directed attention to the powerful influence which lines of metal, extended in contact with moist ground, exercise in promoting the discharge of electric currents of comparatively low tension into the earth's substance, and also that the amount of the discharge from an electromotor into the earth increases conjointly with the tension of the current and the length of the conductor extended in contact with the earth. It is not, therefore, surprising that atmospheric electricity, of a tension sufficient to strike through a stratum of air several hundred yards thick, should find an easier path to the earth by leaping from a lightning-conductor through a few feet of air or stone to a great system of gas- and water-mains, extending in large towns for miles, than by the short line of metal extended in the ground which forms the usual termination of a lightning-conductor.

It deserves to be noticed that in the cases of lightning discharge which I have cited, the lightning-conductors acted efficiently in protecting the buildings from damage of a mechanical nature, the trifling injury to the church tower at Kersal Moor being directly attributable to the presence of the gas-pipe in proximity to the conductor. Nor would there have been any danger from fire by the ignition of the gas if all the pipes used in the interior of the buildings had been made of iron or brass instead of lead; for all the cases of the ignition of gas by lightning which have come under my observation have been brought about by the fusion of lead pipes in the line of discharge. The substitution of brass and iron, wherever lead is used in the construction of gas-apparatus, would, however, be attended with great inconvenience and expense, and moreover would not avert other dangers incident to the disruptive discharge from the conductor to the gas- and water-pipes within a building. I have therefore recommended that in all cases where lightning-conductors are attached to buildings fitted up with gas- and water-pipes, the lower extremity of the lightning-conductor should be bound in good metallic contact with one or other of such pipes outside the building. By attending to this precaution the disruptive discharge between the lightning-conductor and the gas- and water-pipes is prevented, and the fusible metal pipes in the interior of the building are placed out of the influence of the lightning discharge.

Objections have been raised by some corporations to the establishment of metallic connexion between lightning-conductors and gas-mains, on the ground that damage might arise from ignition and explosion. These objections are most irrational, as gas will not ignite and explode unless mixed with atmospheric air, and the passage of lightning along continuous metallic conductors will not ignite gas even when mixed with air. Moreover, in every case of the ignition of gas by lightning, the discharge is actually transmitted along the mains, such objections notwithstanding. A grave responsibility therefore rests upon those who, after introducing a source of danger into a building, raise obstacles to the adoption of measures for averting this danger.

IX. *On the Origin of Elementary Substances, and on some new Relations of their Atomic Weights.* By HENRY WILDE, Esq.

Read April 30th, 1878.

THE hypothesis that the solar system, as at present constituted, was formed by the successive condensations of a gaseous substance rotating under the influence of a central force, has so much evidence in its favour that it may be affirmed to equal the best of that obtained from the geological record of the changes which in past times have taken place on the surface of the terrestrial globe. That this gaseous or primordial substance consisted of a chaotic mixture of the 65 elements known to chemists is a notion too absurd to be entertained by any one possessing the faculty of philosophic thinking, as the regular gradation of properties observable in certain groups of elements clearly shows that elementary species are not eternal, but have a history, which it is the proper object of physical science to unfold.

One of the principal facts which, to my mind, establishes the nebular theory of the formation of planetary systems on a firm basis, is Bode's empirical law of the distances of the members of the solar system from each other and from the central body, as in this law is comprehended the idea of nebular condensation in definite proportions. Now, if elementary species were created from a homogeneous substance possessing a capacity for change in definite proportions, it is probable that the greater number of elements would be formed during, or after, the transition of the nebular matter from the annular to the spheroidal form. Moreover, as great cosmic transitions are not made *per saltum*, it might be expected that some modification of the law of nebular condensation into planetary systems, as exhibited in Bode's law, would be found on the further condensation of the primitive matter into elementary species.

That relations such as I have indicated exist between the nebular and elementary condensations, represented by the planetary distances on the one hand, with the atomic weights of well-defined groups of elementary substances on the other, will be evident on comparing the numbers in the following Tables :—

I.

0 . 0 . 4 = 4 Mercury.
1 × 3 + 4 = 7 Venus.
2 × 3 + 4 = 10 Earth.
4 × 3 + 4 = 16 Mars.
8 × 3 + 4 = 28 Ceres, Pallas, &c.
16 × 3 + 4 = 52 Jupiter.
32 × 3 + 4 = 100 Saturn.
64 × 3 + 4 = 196 Uranus.

In the above Table the numbers expressing the relative distances of the planetary bodies from the sun and from each other are obtained by multiplying successively the difference (3) between the distance of the first and second members of the system by a geometric series, and adding to the products the constant distance (4) of the first member from the sun. Now, if the atomic weight of the second member of the alkaline and silver group of metals (Na=23) be multiplied successively by an arithmetical series, then will the products, minus the atomic weight of the first member (Li=7), be the atomic weights of all the elements belonging to that group.

II.

0 . 0 . 7 Li 7
1 × 23 . 0 = Na = 23
2 × 23 − 7 = Ka = 39
3 × 23 − 7 = Cu = 62
4 × 23 − 7 = Rb = 85
5 × 23 − 7 = Ag = 108
6 × 23 − 7 = Cs = 131
7 × 23 − 7 = — = 154
8 × 23 − 7 = — = 177
9 × 23 − 7 = Hg = 200

Again, by multiplying in like manner the atomic weight of the second member of the alkaline-earth and cadmium group of metals, the products, minus the atomic weight of the first member (Gl=8), are the atomic weights of all the elements of this group.

III.

0 . 0 . 8 = Gl = 8
1 × 24 − 0 = Mg = 24
2 × 24 − 8 = Ca = 40
3 × 24 − 8 = Zn = 64
4 × 24 − 8 = Sr = 88
5 × 24 − 8 = Cd = 112
6 × 24 − 8 = Ba = 136
7 × 24 − 8 = — = 160
8 × 24 − 8 = — = 184
9 × 24 − 8 = Pb = 208

The further relations observable between interplanetary voids and atomic condensations of the natural groups of elements in Tables II., III., are as follows:—

1. The regular geometric series of the planetary distances commences at the second member of the system, and the regular arithmetical series of atomic weights commences at the second and corresponding member of each group.

2. As the atomic weight of the second element in each group is half the sum of the atomic weights of the first and third elements, so is the distance of the second

member of the solar system an arithmetical mean, or half the sum of the distances of the first and third members.

3. The atomic weight of the fourth member in each group of elements is equal to the sum of the atomic weights of the second and third; and the distance of the fourth member of the solar system is also equal, within a unit, to the sum of the distances of the second and third members.

4. As the smallest planetary distance is a constant function of the distances of the outer planetary bodies, so is the smallest atomic weight in each group a similar function of all the higher members of the series to which it belongs. It will also be observed that the plus and minus signs of these constants are correlated respectively with the interplanetary spaces, and the elementary condensations.

5. Each of the atomic weights, after the third in the groups, is an arithmetical mean of any pair of atomic weights at the same distance above and below it; and the distance of each member of the solar system (minus the constant 4) is a mean proportional of the distances of any two members, externally and internally to it, from the central body.

6. The geometric ratio of the planetary distances from each other terminates at the two members nearest the central body, and approaches to an arithmetical one; and a similar departure is also noticeable from the regular arithmetical series of the atomic weights of the first two members of the groups, which renders the third less than an arithmetical mean of the atomic weights of the second and fourth members.

While most of the atomic weights in Tables II., III., excluding fractions, agree with those generally received by chemists, the remainder, except Cæsium = 133, do not vary more than a unit from the classical numbers. When it is considered that some of these numbers have been obtained by doubling the fractions of the old atomic weights, and that slight differences in the determinations may arise from the latent affinity which some elements have for minute quantities of another, the numbers in the tables are remarkably near to those determined by experiment—more so in fact, than is Bode's law to the actual distances of the planets from the sun.

It will be observed that there are gaps to be occupied by two elements in the first group, with atomic weights 154 and 177, and by their homologues of position in the second group, with atomic weights 160 and 184, which remain to be discovered.

The numerical relations subsisting among the atomic weights in Tables II., III., and their resemblance to homologous series in organic chemistry, afford further evidence in support of the theory that elementary species are formed by the successive condensations of a primordial substance of small specific gravity and low atomic weight. The physical and chemical properties of hydrogen, especially its low atomicity and its exact multiple relations with many elementary substances, long since suggested to Prout that this element might be the ponderable base of all the others [*]. Prout's hypothesis has not, however, made much progress, as chemical knowledge was not sufficiently advanced in his time to enable the intermediate steps to be perceived by which elements of high atomicity could be built up from hydrogen; and, besides this, the hypothesis afforded no explanation of the widely diverging properties of elements having nearly the same atomic

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[*] 'Annals of Philosophy,' vol. vi. p. 330 (1815); vol. vii. p. 113 (1816).

weights. If, however, it be assumed that a particle of hydrogen combines successively with one, two, three or more of its own particles, to form the molecules H_2, H_3, H_4, H_5, H_6, H_7, and that each of these molecules forms the type of a group of elements under it, the intermediate steps between the low atomic weight of hydrogen and the high atomic weights of other elements are perceived, and the different properties of elements of approximately equal atomic weights admit of a rational explanation.

Although it is herein assumed that hydrogen is the ponderable base of all elementary species, it is probable that this element itself, as further maintained by Prout, may have been evolved from an ethereal substance of much greater tenuity *. Further knowledge of the outer regions of the solar atmosphere and of the zodiacal light may possibly indicate the steps by which hydrogen was formed.

I would also observe that the term "molecule" is here used only in the sense of a larger or denser particle of matter, and does not imply the idea of a composite aggregation of the separate particles, each preserving its distinctive character after the molecule is formed, any more than rain-drops preserve their distinctive character after falling into the ocean. It appears to me much more in accordance with the truth of nature to suppose that the smallest conceivable particle of a chemical substance or compound has the same physical properties absolutely as the mass. If it be objected that such a union of particles would have relations of infinity, and is therefore inconceivable, it may be answered that the central particles of a rotating body have mathematical and physical relations of a similar kind, and as the instrument of thought is incapable of forming a distinct conception of the magnitude

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* Prout's 'Chemistry and Meteorology,' 8th Bridgewater Treatise, p. 130.

of the infinitesimals involved in a centre of rotation, still less is it capable of comprehending the mode of union of the unknowable essences on which the physical qualities of chemical substances, after combination, depend. Philosophical chemists, I apprehend, will hereafter be able to refer the origin of the theory of the composite structure of matter, after chemical union, to the influence of ideas derived principally from the mechanical mixtures employed in pharmacy and in the culinary art.

In the present hypothesis it is assumed that a mass of hydrogen, of a curvilinear form, acquired a motion of rotation about a central point, which caused it to take a spiral or convolute form. As each successive spiral or convolution was formed, the particles of hydrogen combined with themselves as far as the septenary combination, to constitute the type of each group of elements—the number of types or groups being equal to the number of convolutions of the rotating gas. According to this view, the elementary groups may be represented as forms of Hn, $H2n$, $H3n$, $H4n$, $H5n$, $H6n$, $H7n$; the internal convolutions forming the highest type $H7n$, and the outer convolution the type Hn. That on a further condensation of the elementary matter a transition from the spiral to the annular form occurred, during or after which the group or species under each type was generated in concentric zones and in the order of their atomic weights, until the highest member of each species was formed. That as the elementary vapours began to condense, or assume the liquid form, their regular stratification would be disturbed by eruptions of the imprisoned vapours from the interior of the rotating mass. This disturbance would be further augmented by the subsequent combination of the negative with the positive elements, and also by the variable solubility of their newly formed compounds; so that the evidence of such stratification of the elementary vapours as I have indicated must necessarily be more fragmentary than that of the geological record. The constant association in nature, however, of several elements belonging to the same group, a remarkable example of which is the presence of lithium, potassium, rubidium, and cæsium in a single mineral, *lepidolite*, appears to confirm this view of the primitive arrangement of elementary vapours.

In the annexed table are arranged all the known elements in natural groups, wherein gaps appear, as in Tables II. and III., which indicate the existence of missing elements. The atomic weights of other elements which have not been sufficiently investigated are also determined.

If the theory which I have enunciated of the evolution of elementary substances from hydrogen in definite proportions be correct, the numbers representing the atomic weights also represent the number of particles of hydrogen from which the elements were formed. Where these numbers do not coincide exactly, as in the case of Cu=62, and its homologue of position, Zn=64, which are each a unit less than the classical numbers, it is not to be supposed that these discrepancies are due to errors of experiment, but to some unknown cause which prevents their true atomicity from being ascertained.

Although the ideas of chemists on the classification and quantivalence of elements have greatly changed during recent years, there is no question that the alkaline metals, lithium, sodium, potassium, rubidium, and cæsium belong to the group which I have classified under H*n*. Chemists are also agreed that silver, notwithstanding the great divergence of some of its characteristics from those of the alkaline metals, also belongs to the same group. Now some of the physical and chemical properties of copper and mercury are more nearly allied to those of silver than to metals of other groups, and recent investigations have shown that silver may, like copper, be regarded as bivalent, since many of its compounds can be represented by formulæ exactly analogous to those of cuprous compounds with which they are isomorphous *. The position of Hg, Ag, and Cu, as alternate members of the series H*n*, indicate their relationship with sodium, and are thereby brought into still closer connexion with Li, K, Rb, and Cs. That a relationship exists between sodium and silver by the isomorphism of their anhydrous sulphates and in other ways, has already been pointed out by Odling. The greater specific gravity of sodium, while possessing a lower atomic weight than potassium, its passivity in the liquid state to the action of chlorine †, and its inferior volatility and oxidability to K, confirm the relationship of Na to the heavy metals of the series.

From what cause elements possessing physical properties so widely different should be associated alternately in regular order in the same series, can only, in the present state of knowledge, be a subject of speculation; but, if the views which I have enunciated on the formation of the types H*n*—H7*n* be correct, it may be conceived that after the transition of the cosmical vapours from the spiral to the annular form, the gaseous material of each pair of members might rotate in concentric zones, separate from each other by an interval of space. It may be further conceived that the rotating zones of elementary matter were of sufficient thickness to cause a difference of density between their upper and lower regions. That the zones were in a highly electrical condition, and that their mu-

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* "Quantivalence of Silver,—Wislicenus," Watts, Dic. Chem., 2nd Suppl. 1088.

† Watts, Dic. Chem., Suppl. 1030.

tual influence on each other, through the annular space between them, would induce opposite electrical conditions in their external and internal regions, all the inner and denser regions of the zones being in a negative, and the outer and rarer regions in a positive electrical condition. Each zone would then be in a condition to form an electro-positive and an electro-negative element, which, on a subsequent condensation, would separate and form two zones of elements having dissimilar properties alternating with the other members of the same series.

Just as silver and sodium are the connecting links between Hg and Cu and the alkaline metals Li, K, Rb, and Cs, so do cadmium and magnesium connect lead and zinc with the alkaline-earth metals glucinum, calcium, strontium, and barium, which I have classified as forms of $H2n$.

The classification of glucinum with the alkaline-earth metals has only recently been made; but chemists are not yet agreed upon the atomic weight of this element, as it has been fixed at Gl=7 (Awdejew) and Gl=9·4 (Reynolds). It may, however, be suspected from the anomalously high specific gravity assigned to glucinum (2·10) as compared with that of magnesium (sp. g. 1·74), and with their homologues of position Li (sp. g. 0·59), and Na (sp. g. 0·97), that this element has not yet been isolated in a state of purity*. By assigning to glucinum the atomic weight Gl=8, it enters as a multiple into all the members of the series $H2n$, and may be regarded as the product of the first, second, or third powers of $H2$.

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* Since this paper was written, MM. Nilson and Petterson have communicated to the French Academy the results of their researches on the physical properties of glucinum, and have found for the metal a density equal to 1·64, which, although still too high, the theoretical density being about 1·3, is less than that of magnesium, and, consequently, stands in the same order of density as lithium and sodium.—*Comptes Rendus*, April 1st, 1877, p. 825.

While the property of quantivalence would appear to be correlated with the number of hydrogen particles in the typical molecules from which the elements were evolved, and is a valuable aid in the classification of elementary species, this property, in the present state of knowledge, is not in many cases sufficient, of itself, to indicate the group to which an element belongs. This will be seen from the recognized bivalency of copper and mercury, and by the doubtful quantivalence of silver, and by analogy of sodium, all of which belong to the series Hn. That tetratomic lead$=$208, is a member of the group $H2n$, is shown by the isomorphism of its oxide, carbonate, and sulphate, with the oxides, carbonates, and sulphates of barium, strontium, and calcium; besides which there is no other place vacant in the system of elements where one with the atomic weight and physical properties of lead would fit.

Were it not for the analogous physical properties and the numerical relations subsisting among the elements grouped as forms of $H3n$, their classification from the property of quantivalence alone would hardly have been possible. There can, however, be little doubt that aluminum, yttrium, erbium, and thorium are rightly classified together, and that indium and thallium are true analogues of each other. As considerable interest attaches to this group at the present time, on account of the recent additions which have been made to it by the aid of spectral analysis, I here show the atomicities of its members in a separate Table, calculated on the same principle as those in Tables II., III.

IV.

0 . 0 . 12 = C = 12
1 × 27 . 0 = Al = 27
2 × 27 − 12 = — = 42
3 × 27 − 12 = — = 69
4 × 27 − 12 = — = 96
5 × 27 − 12 = Yt = 123
6 × 27 − 12 = In = 150
7 × 27 − 12 = E = 177
8 × 27 − 12 = Tl = 204
9 × 27 − 12 = Th = 231

It will be observed that there are three elements missing in this group, the atomic weights of which can be predicted in like manner with those of the missing elements in the preceding groups. The Table also affords the means of correcting and determining the atomicities of elements of the series which, from their rarity, have not been sufficiently investigated. It will be further observed that, besides the similar numerical relations of the members of this group with those shown in Tables II., III., the atomic weights are all multiples of 3, and are classified accordingly as forms of $\mathrm{H}3n$.

The spectral reactions of this series of elements are remarkable from the oxides of carbon and of erbium giving a spectrum of lines at low temperatures, and by the simplicity of the spectral lines of indium and thallium in the more refrangible parts of the spectrum. The atomic weights of C, Al, Tl, and Th, are identical with those generally received, and afford presumptive evidence that the atomic weights of the intermediate members are equally correct. It will, however, be observed that the atomic weights of yttrium and indium are double the accepted numbers (Yt=61·7, In=75·6); but in regard to the latter element, it has not yet been definitely agreed which multiple of 37·6, the original determination, shall be the classical one, as the atomicity has been fixed by different chemists at 75·6, 113, and 150, the number assigned to it in the Table. The relations which the double atomic weights of In and Yt have to each other, and with their homologues of position Cs, Ba, and Ag, Cd, in Tables II., III., render it highly probable that the atomic weights of Yt and In in the table are correct. For similar reasons it is probable that the atomic weight of erbium will be found to be 177. It is only very recently that any investigations of the atomic weight of this rare element have been made, from the difficulty attending its isolation from yttrium, with which it is found associated in nature. According to some chemists, the atomic weight of erbium is 112·6, which, in relation to 177, is nearly in the ratio of 5 to 8. The more recent researches of M. Cleve on the quantivalence of this element have, however, raised its atomic weight to 170·55 *, which, considering the wide difference between it and the previous determination, is a near approximation to the number in the Table. The researches of the same chemist have also raised the atomic weight of yttrium from 61·7, the accepted determination, to 89·5, or three fourths the calculated value. Now the history of chemical science abundantly shows that it is only after long and repeated investigation that the highest quantivalence of an element can be ascertained, and the result of M. Cleve's researches is a further confirmation of the correctness of the atomic weights of yttrium and erbium given in the Table.

By comparing the electro-positive members of the series H*n* with those of H2*n*, it will be seen that a complete parallelism exists between them; the light alkaline, and alkaline-earth metals alternating with the heavy members in homologous positions in both series. Odling has already indicated that this is the natural order of the dissimilar members of the zinco-calcic group of elements †,

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* Bull. Société Chemique, Paris, tome xxi. p. 344 (1874).

† Watts, Dic. Chem. 1865, vol. iii. p. 963.—"Classification of Metals."

and similar alternations in other natural groups have been recognized in the arrangement of elements proposed by Mr. Newlands * and Mendeleeff †.

Just as $\mathrm{Cu}=62$, $\mathrm{Ag}=108$, and $x=154$, alternate with $\mathrm{Rb}=85$, $\mathrm{Cs}=131$, and $x=177$, in the series $\mathrm{H}n$; and $\mathrm{Zn}=64$, $\mathrm{Cd}=112$, and $x=160$, alternate with $\mathrm{Sr}=88$, $\mathrm{Ba}=136$, and $x=184$; so in the series $\mathrm{H}3n$, do $x=69$, $\mathrm{Yt}=123$, and $\mathrm{Eb}=177$, alternate with $x=96$, $\mathrm{In}=150$, and $\mathrm{Tl}=204$. Again, just as K, Rb, Cs, and $x=154$, are analogues of each other in the series Hn, so are $x=42$, $x=96$, In, and Tl, analogues of each other in the series $\mathrm{H}3n$, and are in homologous positions with the alkaline, and alkaline-earth metals in the series $\mathrm{H}n$, and $\mathrm{H}2n$. The specific gravities of analogous members of these two series, except glucinum, which is anomalous, increase in the order of their atomic weights, and so far as the specific gravities of the members of the series $\mathrm{H}3n$ have been ascertained, they follow the same order. Now, M. Lecoq de Boisbaudran has shown that the new metal which he has discovered, and named gallium ‡, is, from its spectral reactions and other properties, the analogue of indium and thallium. The position of the new metal in the series $\mathrm{H}3n$, should therefore be either — $=42$, homologous with Ca, and K, or — $=96$, homologous with Sr and Rb. In comparing the alkaline metals of the series Hn, the specific gravity of sodium (0·97), as will be seen, is greater than that of potassium (0·86), although Na has a less atomic weight; and the same inversion of specific gravities in relation to atomic weights is observable in their homologues of position Mg (sp. g. 1·74), and Ca (sp. g. 1·58), in the series

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* Chem. News, vol. xii. p. 83; vol. xiii. p. 113.

† Die periodische Gesetzmäfsigkeit der chemischen Elemente.—Ann. Chem. Pharm. Suppl. Band. viii. pp. 133–229 (1872); Phil. Mag. 5th ser. vol. i. p. 543.

‡ Comptes Rendus, tome lxxxi. pp. 403, 1000 (1865).

$H2n$. It may therefore be assumed that the missing member $x=42$, $H3n$, would have a less specific gravity than Al (sp. g. 2·56), probably 2·5. Now, the specific gravity of gallium, as determined by M. Lecoq de Boisbaudran, is 5·9 [*], and its analogues indium and thallium have specific gravities of 7·42 and 11·9 respectively, consequently $x=42$ is not gallium. If gallium were $x=69$ it would be the analogue of Yt, E, and Th, and homologous in position with Zn and Cu, whereas it has been shown to be the analogue of In and Tl, and homologous in position with Sr and Rb. There is then no other place for a metal having the physical properties of gallium but the one assigned to it in the series $H3n$, with the atomic weight $=96$, and forming a triad with indium and thallium. If, however, the experimental determination of the atomicity of gallium pass through the same stages as the atomicities of indium, yttrium, and other members of the series, its atomic weight will be represented by the submultiple and proportional numbers 48 and 72 [†].

Just as silver and copper are analogues of each other, and are frequently associated in nature; and just as their homologues, cadmium and zinc, are analogues, and are also found together, so is yttrium the analogue of $x=69$, and will be found associated with it in nature. Now, if $x=69$ be not the terbium of Mosander and Delafontaine, and the researches of Bahr and Bunsen render the existence of this element doubtful, it is probable that $x=69$ is

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[*] Phil. Mag. 5th ser. vol. ii. p. 398.

[†] From a calcination of the gallo-ammoniacal alum, M. Lecoq de Boisbaudran has recently found for gallium the equivalent 70·03, and from a calcination of the nitrate, 69·6.—*Comptes Rendus*, April 15th, 1878. The researches of M. Berthelot on the specific heat of gallium indicate, however, a higher equivalent for the metal than 70·03, as the atomic heat calculated from this determination (5·55 solid) is lower than that of any other metal except silicium.—*Ibid.* April 15th, 1878.

cerium, as this element and yttrium are nearly always found associated in the mineral species ceritc and yttrocerite. Moreover, it will be observed that $x=69$ is just 1·5, or 0.75 the atomic weight of cerium, according as it is regarded as 46 or 92. Mendeleeff and other chemists have already proposed 138 as the atomic weight of cerium[*], which is double that of $x=69$. MM. Hildebrand and Norton have recently obtained cerium, lanthanum, and didymium in a massive state, and have thereby been able to investigate some of the physical properties of these rare metals[†]. According to these experimenters the specific gravities of Ce, La, and Di, range between 6 and 6·7. Bearing in mind that elements of approximately the same atomic weights and specific gravities generally belong to different series, and that the specific gravities of analogous members in each series increase in the order of their atomic weights, it would appear that cerium does not belong to the same series as lanthanum and didymium. Moreover, considering the important position which $x=69$ occupies in relation to its analogues Al, Yt, and the position which these three elements occupy in relation to their homologues Mg, Zn, Cd, and Na, Cu, and Ag, it may be doubted if $x=69$ should, up to the present time, have remained undiscovered, especially as all its analogues of the series Th, E, Yt, and Al, are well known. If, therefore, $x=69$ be cerium, the only element missing in the series $H3n$ is $x=42$, the analogue of Ga, In, and Tl. As these elements have been discovered by spectrum analysis, it is probable that $x=42$ will also be found by the same means. It may, however, be observed, that the characteristic lines of the alkaline metals in the series Hn, and of their homologues $H3n$, advance in the blue or violet end of

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[*] Ann. Chem. Pharm. Suppl. viii. pp. 185–190.

[†] Chem. Soc. Journal, 1876, vol. ii. p. 276.

the spectrum, towards the more refrangible parts in the inverse order of their atomic weights. The spectral lines of $x=42$ must therefore be sought for in the violet or ultra violet part of the spectrum. The high refrangibility of the lines which the missing element will have, may be the reason why it has hitherto escaped detection, as from the wide distribution in nature of its homologues of position Ca, and K, in relation to their respective analogues Sr and Rb, $x=42$ ought to be more abundant in nature than gallium *.

From the physical and chemical relations which subsist among the halogens F, Cl, Br, I, and the alkaline metals Li, Na, K, Rb, Cs, chemists have already justly considered these elements as positive and negative analogues of each other and of hydrogen. In accordance with this view, I have classified the halogens as negative forms of the series H*n*. By assigning to these elements the positions shown in the table, it will be seen that besides the triad of atomic weights formed by Cl, Br, and I, there is a common diffence of 4 between the atomic weights of the halogens and their positive homologues of position Na, K, Rb, and Cs. Now if the groups of oxygen elements O, S, Se, Te, be considered as negative forms of H2*n*, homologous in character and position with the negative forms of H*n*, it will be seen that besides the triad of atomic weights formed by S, Se, and Te, there is a common difference of 8 between them and their positive homologues Mg, Ca, Sr, and Ba; or double the common difference between the positive and negative members of the series H*n*. The oxygen elements are multiples of 2, 4, 8, and 16, and may accordingly be

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* Nilson discovered in 1879 (Comptes Rendus, lxxxviii. p. 645) a metal with an atomic weight of 44, which he regards as trivalent, and has named scandium. This metal, from several of its properties, would appear to be $x=42$, H3*n*, and as all its homologues of position are well-known elements, I have placed scandium (symbol Sc=42) in the Table.—H. W. 1886.

considered as products of the first, second, third or fourth power of $H2n$. Whichever view be taken of the formation of the first negative member of the series $H2n$, it is probable that both fluorine and oxygen were not formed direct from Hn, and $H2n$, but from members homologous in position with Li, and Gl, but which have become extinct by absorption into F and O.

Another numerical relation subsisting among the halogens which it may be of interest to point out is, that the difference of a unit in their atomic weights will make them multiples of 3 and 9, and these numbers, commencing with $Cl = 36$, are all respectively three times the atomic weights of the first three members of the series $H3n$. These relations would indicate that the halogens, usually regarded as monatomic, are also built up in multiple proportions, and may also throw some light on the variable quantivalence which Wanklyn and other chemists have shown the alkaline metals and halogens to possess.

The recent researches of chemists leave no doubt that all the elements which I have classified as forms of $H5n$, except boron, belong to the same group. Now, boron bears a greater resemblance to phosphorus in its combinations and occurrence in nature than it does to other elements, and whether the first three members of the series be considered as forms of $H5n$, or $H5n+1$, they form a triad as well defined as their homologues of position in $H3n$, $H2n$ and Hn. Triads are also formed by antimony, arsenic, and phosphorus,—bismuth, antimony, and phosphorus,—tantalum, niobium, and boron,—$x=140$, $As=75$, and $B=10$,—$x=140$, $Nb=95$, and $V=50$. The atomic weights of boron, phosphorus, and vanadium have been so carefully determined by chemists, as to preclude any doubt of their being represented by $H5n+1$, rather than $H5n$; but the fact that arsenic, antimony, and bismuth are better represented by the formula $H5n$, and that Cu, and Zn, in the series Hn, and $H2n$, exhibit the same constant minus difference from the classical atomic numbers as B, P, and V, are further indications of some unknown property of the elements which conceals their exact multiple relations from view. If the discovery of two new elements of this group by Hermann*, to which this chemist has given the names of neptunium and illmenium, be confirmed, the former element will have an atomic weight of 140, and the latter element an atomic weight of 165, as shown in the table.

Although the numerical relations of the members of the series $H5n$ are very interesting, yet, it will be seen that the ratios are not so simple as those of the series Hn, $H2n$, $H3n$, as multiples of the second member, minus the first, do not give the atomic weights of the other members of the series.

The series $H4n$ is incomplete, not only by reason of the absence of several of its members, but also because the atomicity of lanthanum and didymium is not yet agreed upon by chemists. There can, however, be no question as to the position of titanium as the third member of this series, as there is no other place vacant where an element with an atomic weight of 48 would fit, while the isomorphism of rutile with cassiterite and zirconia indicates the relation of tin and zirconium with the same series.

The classification of uranium presents some difficulty on account of the fewness of its analogies with other elements, but there can be little doubt that the atomic weight assigned to U=120, until recently, is much too small, as there are no elements with atomic weights so low, correlated with specific gravities so high as that of

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* 'Nature,' April 12th, 1877. H. Kolbe's 'Journal für praktische Chemie,' Feb. 1877, pp. 105–150.

U, sp. gr. = 18·3. From a study of the chemical combinations of this element, Mendeleef has assigned to it the atomic weight of 240*, or double the number formerly received, and which number I have adopted. The admission of this high atomic weight, however, separates uranium from chromium, molybdenum, and tungsten, with which it has been classified, as there are no elements of approximately the same high specific gravities as tungsten = 18·26, and uranium = 18·3, correlated with so great a difference of atomic weights as U = 240, and W = 184. From the fact that the highest places in all the series, except that in H4*n*, are filled up with their highest members, and that uranium is generally found in combination with the mineral species *yttrotantalite, fergusonite, polykrase, pyrochlore, pyrrhite,* containing elements of the series H3*n* on the one side, and in combination with minerals containing elements of the series H5*n* on the other, I have classified uranium as the highest form of H4*n*. The two lower forms of H4*n*, as will be seen from the table, are missing†; but, assuming that titanium is the highest member in a triad with the missing elements, the atomic weights of the latter are 16 and 32, isomeric with oxygen and sulphur. It may, however, be surmised that no elements now exist to fill the gaps in the series, as they may have become extinct by absorption into titanium and its analogues, or by transformation into the negative forms of H2*n*.

The elements which I have classified as forms of H6*n*

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* Ann. Chem. Pharm. Suppl. viii. pp. 178–184.

† Prof. Winkler of Freiberg has recently discovered a new element which he has named "Germanium" (symbol Ge). ('Nature,' March 4, 1886; 'Berichte' of the Berlin Chemical Society, No. 3). Germanium was first considered by Winkler to belong to the antimony and bismuth group; but the subsequent determinations of its specific gravity 5·469, and atomic weight 72·75, place the new element in the vacant position $x = 72$ in the series H4*n*, and in the group of titanium and tin.—H. W., 1886.

are only three in number, and the atomic weight of chromium = 52·2 establishes its position as the third member of the series, and there is no other place for an element with the chemical and physical properties of chromium vacant in the table. For like reasons the positions in the series of molybdenum and tungsten (the analogues of chromium) are also determined. By assigning to chromium the constitution 9 H6, it forms a triad with the missing elements $x=36$, and $x=18$, which are, within a unit, the atomic weights of fluorine and chlorine.

In the arrangement of the elements which I have classified as H7*n*, little assistance is derived from known analogies, when nitrogen and silicium are admitted in the same series with the iron and platinum groups of metals; yet, it might be expected that elements so abundant, and so widely diffused in nature as nitrogen, silicium, and iron, would occupy important positions in any rational classification of elementary species. We have seen that the first three places in the preceding series H*n*, H2*n*, H3*n*, H5*n*, are all occupied by elements with atomic weights which exclude nitrogen, silicium, and iron, while the latter element is excluded from the series H4*n*, and H6*n*, by chromium and titanium. The atomic weights of N, Si, and Fe, besides being whole numbers, are exact multiples of 7. N and Si are, consequently, excluded from the vacant homologous positions in the series H4*n*, H6*n*.

Since the investigation of the properties of silicium by Berzelius, who regarded silicic acid as a trioxide, much discussion has arisen as to whether the atomic weight of silicium be 21 or 28; or the formula for its oxide SiO_3 or SiO_2. Chemists are now generally agreed upon the latter formula for silicic acid, and have accordingly classified silicium with titanium, as the oxide SiO_2, agrees with titanic acid TiO_2. Now, if silicium were the true analogue of titanium, the oxides of these elements should be isomorphous, whereas the crystalline form of quartz is hexagonal, while rutile, anatase, brookite, zirconia and tinstone (similar oxides of members of the series $H4n$), are tetragonal; consequently, silicium does not belong to the series $H4n$.

By assigning to silicium the atomic weight 35, it forms with nitrogen and iron a triad similar to the first three members of Hn, $H2n$, $H3n$, $H5n$. The position of $Si=35$, as the second member of the series $H7n$, not only throws new light on the disputed atomicity of this element, but also explains the anomalous atomic heat which has been assigned to it.

Through the classical researches of Regnault the specific heat of silicium was found to be 0·176*. The determination was made with specimens of the metal of considerable size, and in a state of compactness and purity to receive a polish which formed a perfect mirror. The above number multiplied by 28, the highest atomic weight assigned to Si, gives the product 4·93, while the law of Dulong and Petit requires the value 6·25.

In discussing the cause of the anomalous atomic heat of silicium, Regnault pointed out that in order that it might enter into the law of the specific heat of other elements, it would be necessary to write the formula of silicic acid Si_2O_5; it would then resemble that of nitric, phosphoric, and arsenic acid. The atomic weight of silicium would then be 35, and the product of this number and the specific heat would be nearly 6·25, which agrees with the analogous products which other simple bodies give. By assigning to silicium a higher atomic weight

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* 'Annales de Chimie et de Physique,' tome lxiii. pp. 24–31 (1861).

and a polybasic character like that of phosphorus or nitrogen, Regnault remarked that it is easy to explain the existence of the great number of silicates which nature presents in well-defined and beautiful crystals, and to understand the existence of the natural hydro-silicates.

Whichever view chemists may ultimately adopt in regard to the constitution of silicic acid, or whether its atomic weight be fixed at $3H7$, $4H7$, or $5H7$, silicium will still retain its position as the second member of the series $H7n$.

The chief properties which distinguish the elements of the series $H7n$ are their high fusing-point, their occlusive affinity for hydrogen, and their passivity in the presence of ordinary reagents, to which iron, under peculiar conditions, forms no exception. In regard to their occlusive affinity for hydrogen, the relation of nitrogen to iron and palladium may explain the existence of the ammonium amalgam, in which nitrogen and hydrogen are held together in the nascent state by means of mercury. The formation of silicium hydride by electrolysis, in a manner analogous to that of the ammonium amalgam, would also indicate for silicium a similar occlusive affinity for hydrogen to that possessed by nitrogen.

Although gold in some recent classifications of elements has been separated from the platinum metals, yet, in its primary qualities, it exhibits closer analogies with them than with the members of any other series, and there is no other place vacant in the groups which an element with the atomic weight and physical properties of gold would fit. The constant association in nature of quartz, hematite, and specular iron ores with gold and platinum is a fact fully recognized by chemical geologists*, and

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* Bischoff's 'Chemical and Physical Geology,' vol. iii. p. 534. Cavendish Soc. Works. Murchison's 'Siluria,' chap. xvii. pp. 433–439.

confirms the positions assigned for Si, Fe, and Au, in the table as forms of $H7n$.

The remarkable resemblance which the members of the iron group have to one another, while their atomic weights are nearly, if not exactly the same, has long been a subject of much interest to philosophical chemists, and if the views which I have enounced respecting the formation of elementary species by condensation be correct, the cause of these resemblances admits of a possible explanation. From the great abundance and wide distribution of iron in nature, it is probable that the vapour of this element would form a zone of considerable depth; the upper and lower regions of which, by differences of pressure and temperature, might produce allotropic varieties before a definite change to the next higher members in the series occurred. When once varieties of an element were formed, these varieties would be propagated through successive condensations into the next higher members of the series, just as they are found in the palladium and platinum groups of metals. Chemists have already observed that each of the metals of the palladium group appears to be more especially correlated with some particular member of the platinum group, and all are found associated together naturally in the metallic state. If the four members of the platinum group be considered the analogues of the corresponding members of the iron and palladium groups, it will be seen that one of the members of the latter group is missing. M. Sergius Kern, a Russian chemist, has recently discovered a new metal which he classifies with the platinum group, and has given to it the name of davyum*. The specific gravity of the new metal was found to be 9·39, and pre-

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* Comptes Rendus, tome lxxxv. pp. 72, 623, 667 (1877).

liminary experiments on its equivalent show that it is greater than 100 and supposed to be 150–154. Now the specific gravity and atomic weight of the new metal exclude it from the platinum group, and also from the iron group of metals; davyum is therefore the missing element in the palladium group, and will have a specific gravity of about 11, and an atomic weight of 105; or the same density and equivalent as the other members of the group. The state of aggregation of the small quantity of the new metal obtained by M. Kern, may have prevented the same specific gravity being found for it as for the other members.

Although I have designated the highest members of the series $H7n$, as the platinum group, yet if the slight differences in their atomic weights and physical properties admit of explanation by the assumption of their being allotropic varieties of each other, then gold, palladium, and iron, may stand at the head of their respective groups, and determine the species to which the varieties belong. It is no objection to the theory of the members of the respective groups being varieties of each other, that they cannot by any known power of analysis be resolved into their primaries, as the same objection would apply to the natural varieties of organic species determined by naturalists.

We have seen that the quantivalence of most of the members of the preceding groups Hn, $H6n$, is in some way correlated or dependent on the construction of the typical molecules at the head of each series; but in the series $H7n$ the only element which is known to be septivalent is manganese, but the relation which this metal has to the iron group, and bearing in mind that the determination of the highest quantivalence of elements is limited by the knowledge of chemists at particular times, and is only arrived at after much research, the septivalency of manganese indicates a much higher quantivalence for the other members of the series $H7n$ than has up to this time been accorded to them.

I have hesitated to introduce hypothetical elements alternating with the iron, palladium, and platinum groups, as the regular sequence of elementary forms is broken by varieties, and from the density of the typical molecule H7, it may be that the members of this series are limited to those shown in the table. The density of the typical molecule $H6n$ may also explain the absence of members alternating with Cr, Mo, and W, and I have therefore only introduced one hypothetical element in this series, the analogue of Cr, with the atomic weight=144.

Considering how nearly the numbers representing the molecular constitution and atomic weights of the members in homologous positions in the higher groups approximate, the idea occurs that the subsequent condensations of these higher groups are in some way influenced or determined by the antecedent condensations of homologous members of the lower groups, and may be the cause of the departure in the higher groups from the simple ratios and multiple relations observed amongst the elements of the series Hn and $H2n$. Such perturbations would appear to be similar to those which the planetary bodies exercise on each other to produce modifications in the forms of their orbits, but I leave this question to the further consideration of physicists and astronomers.

The complete parallelism of the halogens and oxygens to each other, and their intensely electro-negative character, point irresistibly to the conclusion that at one period of their history these elements existed in a state of isolation from all the others. How, and under what conditions, they acquired their electro-negative properties can in the present state of knowledge be only a matter of conjecture; but it may be conceived that these elements may have existed originally in the form of a ring or rings revolving within the moon's orbit, but high above the incandescent terrestrial surface, probably before the lunar substance changed from the annular to the globular form. These intra-lunar rings may have gradually acquired their electro-negative properties by lunar and terrestrial induction, and by the loss of their primitive heat by radiation into space. Their orbits being too near the earth to permit the rings to assume the spheroidal form, they would upon rupture become incorporated with the positive terrestrial elements, and remain dissociated till the temperature of the mass was sufficiently reduced to enable chemical combination to take place. If Draper's discovery of oxygen in the sun be confirmed, the hypothesis of the existence of an intra-mercurial ring of negative elements which subsequently united with the solar positive elements is at least as probable as the assumption of an intra-mercurial planet which has recently been discussed by astronomers. May not the sudden increase in the brightness of variable stars like T Coronæ, Nova Ophiuchi, 1848, and Nova Cygni, 1876, be due to the intense heat generated by the union of rings of negative elements with the central bodies round which they revolve, or by the condensation of lower into higher forms of elementary species.

All the positive forms of $H2n$, except glucinum and lead, are well-ascertained solar elements, and the remarkable relations which the members of this group have to those of Hn render it highly probable that, besides sodium and copper, other members of Hn are present in the solar atmosphere. From the fact that aluminum, titanium, chromium, and the irons are solar species, higher forms of these elements may also be expected to be found in the sun.

To face p. 144.]

H4*n*	**H5*n***	**H6*n***	**H7*n***	
— = 16	B = 10	— = 18	N = 14	
— = 32	P = 30	— = 36	Si = 35	
Ti = 48	V = 50	Cr = 54	Fe = 56 Mn = 56 Ni = 56 Co = 56	56 55 58 58
Ge = 72	As = 75			
Zr = 92	Nb = 95	Mo = 96		
Sn = 116	Sb = 120		Pd = 105 Rh = 105 Ru = 105 Da = 105	106 105 105 —
La = 140	— = 140	— = 144		
— = 165	— = 165			
D = 188	Ta = 185	W = 186	Au = 196 Pt = 196 Ir = 196 Os = 196	196 197 197 198
U = 240	Bi = 210			

The numerical relations of the atomic weights to which I have directed attention, and the brief outline of a theory of the origin of elementary species which I have founded upon them, give new force to the doctrine of the transmutable nature of elementary substances. But when the synthetical formation of organic compounds is regarded as the greatest triumph of modern chemical science, the problem of building up the higher elements from the lower may well be deemed insoluble, as they have been formed under cosmical conditions of which we have little or no acquaintance. Very different, however, is the aspect of the problem of resolving the higher elements of each series into their respective types or into hydrogen. For just as by the application of heat the higher members of homologous series are resolved, through their lower members, into their ultimates, so may it be expected that the elements themselves will, in their turn, give way to more powerful instruments of analysis.

When it is considered that through the investigations of Dumas, Cooke, Odling, Mendeleeff and others, nearly all the mathematical relations of the atomic weights to each other have been unfolded during the brief interval of thirty years, so that but few steps are now required to render the natural classification of the elements complete, the resolution of elementary species into their primordial ultimates would not appear to be far off.

X. *On the Velocity with which Air rushes into a Vacuum, and on some Phenomena attending the Discharge of Atmospheres of Higher into Atmospheres of Lower Density.* By HENRY WILDE, Esq.

Read October 20th, 1885.

CONSIDERING the present condition of our knowledge respecting the mechanical properties of air and other gases, some apology might appear to be needed in bringing before this Society the results of an investigation touching some fundamental principles in pneumatics which for more than a century have been considered to rest on foundations as secure as the laws of gravitation of the heavenly bodies. A survey of the history of the dynamics of elastic fluids will, however, show that, great as are the advances which have been made in this branch of science, the laws of the discharge of elastic fluids under the varied conditions of elasticity and volume are still left in much obscurity. The several circumstances which have combined to produce this anomalous state of our knowledge of this subject are:—(1) The application of the laws of discharge of inelastic fluids, without any modification, to those which are elastic; (2) the confusion of the quantity of the discharge of elastic fluids after leaving the vessel, with the velocity of discharge through the aperture in the vessel; and (3) the want of a sufficient number of experiments, under varied conditions and through sufficient range of pressure, to compare with the deductions derived from theory.

It has hitherto been assumed, as a leading proposition in pneumatics, that air rushes into a vacuum with the velocity which a heavy body would acquire by falling from the top of a homogeneous atmosphere of the same density as that on the earth's surface; and since air is about 840 times lighter than water, if the whole pressure of the atmosphere be taken as equal to support 33 feet of water, we have the height of the homogeneous atmosphere equal to 27,720 feet, through which, by the free action of gravity, is generated a velocity of 1332 feet per second. This, therefore, is the velocity with which air is considered to rush into a vacuum, and is taken as a standard number in pneumatics, as 16 and 32 are standard numbers in the general science of mechanics, expressing the action of gravity on the surface of the earth.

Now, so far as I am aware, no experiments have hitherto been made directly proving this important proposition. It is true that attempts have been made to determine the initial velocity by discharging air at extremely low pressures into the atmosphere; but, apart from the conditions of the discharge into the air and into a vacuum being different, the history of physical science shows that it is unphilosophic to predicate absolute uniformity of any law through the order of a whole range of phenomena of the same kind; as nature is full of surprises when pushed to extremes, or when interrogated under new experimental conditions.

It was long ago shown by Faraday* that, in the passage of different gases through capillary tubes, an inversion of the velocities of different gases takes place under different pressures, those which traverse quickest when the pressure is high moving more slowly as it is diminished. Thus, with equal high pressures, equal volumes of hydrogen gas and olefiant gas passed through the same tube in 57″ and 135″·5 respectively; but equal volumes of each passed

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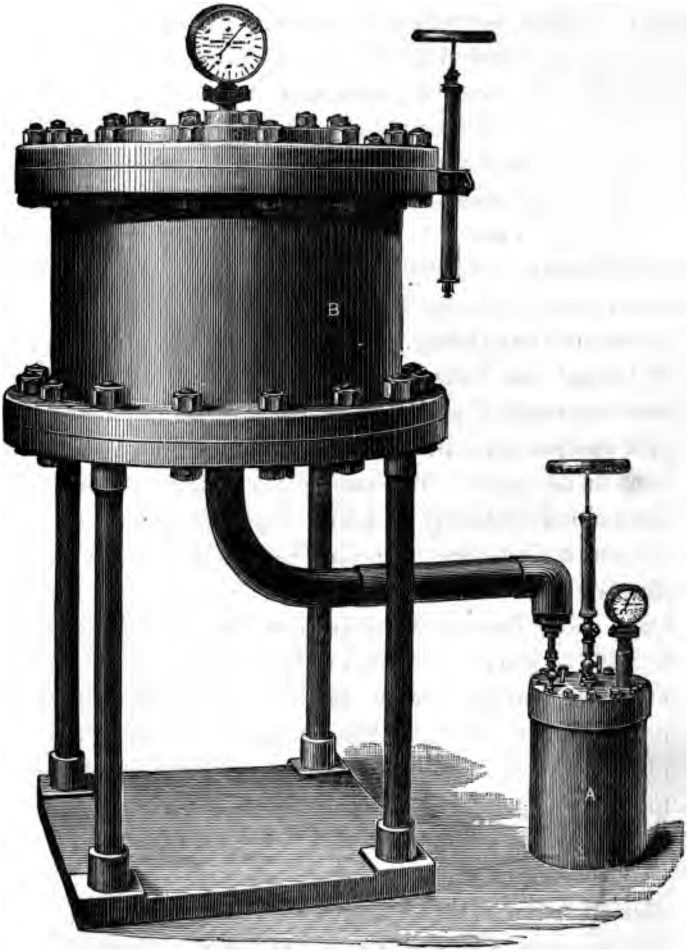
* Quarterly Journal of Science, 1818, vol. vii. p. 106.

through the same tube at equally low pressures in 8′ 15″ and 8′ 11″ respectively. Again, while the velocities of discharge of inelastic fluids are as the square roots of the heads, some mathematicians have justly considered that this law does not apply to those which are elastic, and have assumed with good reason (though what appears unlikely at first sight) that the velocity of air discharged into a vacuum is the same for all pressures. But whatever differences of opinion there may be amongst natural philosophers on this point, all are agreed in estimating the quantity of air discharged from a higher into air of a lower density, from the difference between the two densities, as in the similar case of the discharge of inelastic fluids, by the difference or effective head producing the pressure. This mode of determining the amount of the discharge from a higher to a lower density, like that of the velocity of the atmosphere into a vacuum, has not, so far as I know, been made the subject of experiment through any considerable range of pressure. It therefore appeared to me that, as each gas has its specific velocity of discharge, such a series of experiments might be useful in confirming and extending our knowledge of the dynamics of elastic fluids. In the course of these experiments I have met with some results which I thought of sufficient importance to bring before the Society.

The apparatus employed in this investigation consisted of two strong cylinders of cast iron, shown in the engraving. The small cylinder, A, had an internal capacity of 573 cubic inches, while the large cylinder, B, had a capacity of 8459 cubic inches, or about fifteen times the capacity of the cylinder A. To the top of this cylinder was fitted a syringe for condensing the air up to nine atmospheres, and also a Bourdon's pressure-gauge of an improved construction, graduated through every pound of the above pressure. The accuracy of this gauge was tested in my presence by the constructors, Messrs. Budenberg and Co., through the whole range of pressure, by comparing its readings with a column of mercury of equivalent height. For pressures of 15 pounds above, and for pressures below the atmosphere, a mercurial gauge and



a Bourdon's vacuum-gauge were employed, the readings of which were compared with each other: 30 inches of mercury were considered equal to one atmosphere, and 2 inches of mercury to one pound of pressure. The upper part of the glass tube of the mercurial gauge was fitted with a brass cap and screw-stopper, so that it could readily be used as a pressure-gauge, or as a vacuum-gauge when required. The discharging arrangement on the cylinder A consisted of a stopcock and union for securing a thin plate, through which the discharge was made. The orifice in the plate opened as required, either directly into the atmosphere or into the end of a short iron tube two and a half inches internal diameter, communicating with the bottom of the cylinder. The thin plate was a small disk of tinned iron, three quarters of an inch in diameter and one hundredth of an inch in thickness. The centre of the disk was pierced with a circular hole two hundredths of an inch in diameter. The size of the hole was accurately determined by means of a wire expressly drawn down to the above diameter; the wire being calibred by one of Elliott's micrometer-gauges, divided into thousandths of an inch. The hole in the plate was enlarged so as to fit tightly the gauged wire, and the burrs on each side of the hole were carefully removed, as this small amount of projection, as Dr. Joule has shown*, exercises a notable influence on the rate of discharge through apertures in thin plates.

The general reasonings, and the inferences drawn from the experiments to be described, are based on Boyle and Mariotte's law of the density of a gas being as the pressure directly, and the volume as the pressure inversely for constant temperatures.

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* Memoirs of the Manchester Literary and Philosophical Society, vol. xxi. p. 104.

I have said that the capacity of the cylinder A was 573 cubic inches, which represents the same number of cubic inches of air in the vessel at atmospheric pressure of 15 lb. on the square inch; and, generally, *n* times 573 cubic inches of air forced into the cylinder would be the equivalent of *n* atmospheres of absolute pressure.

In converse manner, 5 lb. of pressure, or one third of an atmosphere, is the equivalent of one third of 573 cubic inches, or the equivalent of 191 cubic inches of air at atmospheric pressure; and, generally, 5 lb. of pressure is the equivalent of 191 cubic inches of air at atmospheric pressure and for all the higher pressures. The mode of experiment was as follows:—Air was forced into the cylinder to the required density, and after the heat of compression had subsided, the time of each 5 lb. reduction of pressure was taken by means of a half-seconds pendulum, commencing its oscillations at the moment of discharge; and the stopcock was suddenly closed, and the number of oscillations noted for every definite discharge and reduction of 5 lb. of pressure. In my earlier experiments, it was found that when the air was compressed to nine atmospheres, and successive reductions of 5 lb. were made to the lowest pressure, the cooling of the air produced a notable effect in diminishing the rate of discharge. By commencing the experiments with the lower pressures and increasing them by 10 lb. successively after each discharge of 5 lb., the changes of temperature attending the changes of density of the air were kept within the limits of 5 lb. of pressure till the highest density was attained. The small changes of pressure attending each discharge by the addition and abstraction of heat to and from the cylinder were after a little practice easily corrected, so that each discharge may well be considered as having been made under conditions of constant temperature. The large cylinder B was first used as a vacuum-chamber to receive the discharge from the small cylinder. The chamber was fitted with an exhausting pump and suitable vacuum-gauges, and the pressure within the chamber was reduced to six tenths of an inch of mercury; and that degree of vacuum was maintained during the experiments.

The following Table shows the velocity of air flowing into a vacuum, as deduced from the time and difference of pressure for every 5 lb. from 135 lb. to 5 lb. absolute pressure. The velocities of the first column are deduced from actual experiments, and in the next column the velocities are calculated from the difference of the area of

TABLE I.—Discharge into a Vacuum 0·6 inch Mercury.
Barometer 29·42. Thermometer 54° F.

Absolute pressure, in pounds per square inch.	Time of discharge, in seconds.	Velocity, in feet per second.	Velocity coefficient ·62.
135	7·5	750	1210
130	7·75	753	1214
125	8·0	759	1225
120	8·5	743	1198
115	9·0	734	1184
110	9·5	726	1171
105	10·0	724	1168
100	10·5	722	1165
95	11·0	725	1169
90	12·0	703	1134
85	13·0	688	1109
80	14·0	678	1094
75	15·0	675	1089
70	16·5	657	1060
65	18·0	650	1048
60	20·0	632	1020
55	22·0	628	1011
50	24·5	620	1000
45	27·0	624	1007
40	31·0	613	985
35	36·0	602	971
30	43·0	589	950
25	53·0	573	924
20	69·0	550	887
15	97·0	522	842
10	170·0	446	720

the discharging orifice and the *vena contracta* by applying the hydraulic coefficient ·62.

From this Table it will be seen that the time of discharge of 5 lb. from 135 lb. absolute pressure is 7·5 seconds. Now, as 5 lb. pressure is the $\frac{1}{27}$ part of the total pressure, we have $\frac{573}{27}=21{\cdot}22$ cubic inches of air from 135 lb. pressure discharged into the vacuum chamber in 7·5 seconds: or, in another form, since 5 lb. and 191 cubic inches of air at atmospheric pressure are equivalents, so 191 cubic inches condensed at 9 atmospheres $\frac{191}{9}=21{\cdot}22$ cubic inches of discharge, as in the above calculation. Again, we have for a cubic inch extended into a cylinder 0·02 of an inch in diameter (the size of the discharging orifice), 265·25 feet $\times\, 21{\cdot}22=5628$ feet. Hence $V=\frac{5628 \text{ feet}}{7{\cdot}5 \text{ seconds}}=750$ feet per second for the discharge of air from 135 lb. to 130 lb. into a vacuum through a hole in a thin plate. Or $V=\frac{750}{{\cdot}62}=1210$ feet per second when the orifice is formed to the contracted vein. By the like method of calculation the velocities for the discharge of of each 5 lb. of pressure from 135 lb. to 10 lb. have been found.

The velocity with which air rushes into the vacuum, as seen from the table, is considerably less than that which has hitherto been assigned to it by theory, and is not constant for all pressures, as might have been expected from the known ratio of elasticity and density: the difference in the velocities between each discharge for the higher pressures, as will be seen, is so small as to be exceeded by experimental errors. The amount of this difference will, however, appear more clearly when we are considering the velocity of air discharged into the atmosphere. Meanwhile I may remark that the velocities increase with the pressures by small asymptotic quantities, so that the theoretic velocity of 1332 feet per second would be obtained at a pressure of 40 atmospheres if the law of Boyle and Mariotte held good for so high a density.

While the rate of each discharge may be considered approximately uniform for the higher pressures, the initial and terminal velocities of each discharge of 5 lb. for the lower pressures would be much different. This is specially noticeable for the velocity (842 feet per second) assigned to atmospheric pressure of 15 lb.; and as it was a matter of much interest that this important constant of nature should be determined with all the accuracy attainable, experiments were made to ascertain the velocity of discharge for every pound of pressure from 15 lb. to 2 lb. In these experiments the readings were taken from the mercurial gauge, and the vacuum in the chamber was reduced to 0·4 of an inch of mercury.

The results obtained are shown in the Table.

TABLE II.—Discharge into a Vacuum 0·4 inch Mercury.
Barometer 29·96. Thermometer 60° F.

Absolute pressure, in pounds per square inch.	Time of discharge, in seconds.	Velocity, in feet per second.	Velocity-coefficient ·62.
15	16·0	633	1021
14	17·5	621	1001
13	19·0	614	990
12	21·0	606	977
11	23·0	600	968
10	25·5	596	961
9	28·5	593	956
8	32·5	584	942
7	37·5	577	931
6	45·0	563	908
5	55·0	559	901
4	70·0	542	874
3	102·0	497	802
2	180·0	421	679

By a calculation similar to that for the higher pressures, we obtain for the initial velocity with which the atmosphere rushes into a vacuum through a hole in a thin plate

$$V=\frac{573}{15}\times\frac{265{\cdot}25}{16}=633 \text{ feet per second,}$$

or

$$V=\frac{633}{\cdot 62}=1021 \text{ feet per second for the contracted vein.}$$

That the differences between the theoretic and experimental velocities was not caused by the friction of the stream of air against the circumference of a smaller orifice being greater in proportion to that of the circumference of a larger orifice, was proved by discharging air of 15 lb. pressure through a hole one hundredth of an inch in diameter in another similar thin plate, when the times of discharge through the short range of 1 lb. of pressure were found to be in the ratio of 4 to 1, or inversely as the areas of the orifices.

Taking into further account the difference between the initial and terminal velocities due to the reduction of pressure from 15 lb. to 14 lb., the results of these experiments show that with an absolute pressure of 30 inches of mercury, and at a temperature of 60° Fahrenheit, the atmosphere rushes into a vacuum with a velocity not greater than 1050 feet per second, or less than the velocity of sound.

Some anomalous rates of discharge which I obtained when air of different densities was discharged into the atmosphere, induced me to repeat the experiments with the same apparatus and under precisely the same conditions as those which had been made into a vacuum as

Table III.—Discharge into the Atmosphere.
Barometer 30·17. Thermometer 59° F.

Effective pressure, in pounds per square inch.	Time of discharge, in seconds.	Apparent velocity, per second.	Velocity-coefficient ·62.
15	8·0	1266	2043
14	8·25	1318	2126
13	8·5	1373	2214
12	9·0	1413	2280
11	9·5	1454	2345
10	10·0	1519	2450
9	10·5	1609	2595
8	11·5	1652	2664
7	12·5	1734	2797
6	13·5	1876	3026
5	15·5	1985	3202
4	17·5	2110	3403
3	22·0	2300	3710
2	29·0	2616	4219

above described. The results are shown in Tables III. and IV.

On comparing the times of discharge in Table III. and the velocities calculated therefrom with the times and velocities in Table II., a remarkable difference will be observed in them for the same effective pressures. Thus, the velocity of discharge from 15 lb. to 14 lb. appears to be double that assigned to the same pressure when the discharge is made into a vacuum; while in the discharge from 2 lb. to 1 lb. (the lowest pressure in the Table) the velocity appears to be more than six times greater, or 4219 feet per second. No less remarkable than this apparent increase in the rate of discharge is the complete inversion of the order of the velocities as compared with those when the discharge was made into a vacuum for the same effective pressure. Now, we have knowledge of several causes competent to diminish the velocity of air of constant temperature flowing into the atmosphere, but none to increase the velocity except the form of the aperture, which in this case remained unchanged. Recognizing the fact that when air of 15 lb. effective pressure was discharged into the atmosphere the cylinder actually contained two atmospheres of absolute pressure, we are led to the conclusion that the phenomenal increase in the rate of discharge observed is caused by the external atmosphere acting as a vacuum, and offering no resistance to the discharge into it of air of 15 lb. pressure, which thereby becomes 30 lb. effective pressure. The velocity of air of 15 lb. effective pressure discharged into the atmosphere based on this conclusion is 1021 feet per second, the same as the velocity found for the discharge into a vacuum. For effective pressures below 15 lb. the velocities are compounded of the rate of discharge into a vacuum, and the

TABLE IV.—Discharge into the Atmosphere.
Barometer 29·64. Thermometer 58° F.

Effective pressure, in pounds per square inch.	Time of discharge, in seconds.	Apparent velocity, per second.	Velocity-coefficient ·62.
120	7·5	843	1360
115	7·75	852	1374
110	8·0	862	1390
105	8·5	852	1374
100	9·0	843	1360
95	9·5	842	1360
90	10·0	843	1360
85	10·5	851	1372
80	11·0	863	1392
75	12·0	844	1362
70	13·0	836	1348
65	14·0	833	1344
60	15·0	843	1360
55	16·5	837	1350
50	18·0	843	1360
45	20·0	843	1360
40	22·0	863	1392
35	24·5	886	1429
30	27·0	935	1509
25	31·0	980	1581
20	36·0	1053	1699
15	43·0	1178	1900
10	58·0	1311	2114

resistance of the atmosphere without any regular ratio, but approximating to the square roots of the pressures.

That the atmosphere acts as a vacuum to the discharge of air into it of 15 lb. effective pressure, is further evident from the results obtained, and shown in Table IV.

In this Table it will be observed that the times of each discharge from 120 lb. to 15 lb. effective pressure into the atmosphere are identical with the times of discharge from 135 lb. to 30 lb. absolute pressure into a vacuum. Hence we are able to formulate and prove the general proposition *that the atmosphere acts as a vacuum, and offers no resistance to the discharge of air of all pressures above two absolute atmospheres.*

Although the times of discharge for each reduction of 5 lb. of pressure, as we have seen, are the same as those for pressures one atmosphere higher, when the discharge was made into a vacuum, yet it seemed to me that a table showing the *apparent* velocities due to the effective pressure would be useful as exhibiting some further points of interest, and revealing the fallacy involved in estimating the velocities from the effective pressures. On comparing the velocities of each discharge from 120 lb. to 40 lb., it will be seen that the theoretic velocity of 1332 feet per second is as nearly attained as the units of pressure and time adopted in these experiments would permit. We have therefore in the Table a measure of the difference of the theoretic and experimental velocities with which air rushes into a vacuum by the same method of calculation. This difference, as will be seen, amounts to exactly one atmosphere of pressure.

For each reduction of 5 lb. from 120 lb. to 40 lb. the times of discharge are inversely as the pressures; and as the density of the issuing stream of air diminishes in the same proportion, the velocity of discharge is the same for all the pressures from 120 lb. to 40 lb., as shown in the Table. Hence it appeared to me at the commencement of this investigation, that the theoretic and experimental velocities with which air rushes into a vacuum were rigorously exact. The anomalous and apparent increase in the velocities from 40 lb. to 10 lb., however, led me to suspect that the atmosphere in some manner affected the results, and induced me to make the discharge into a vacuum with the results shown in Table I.

That the phenomenal rate of discharge which I have described should not hitherto have manifested itself in some form, or be associated with some facts explanatory of it, would indeed be surprising considering the varied circumstances in which the discharge of elastic fluids comes into play. Hence, it has long been known that a jet of air issuing from an aperture in a vessel produces a rarefaction of the atmosphere near to the discharging orifice. This phenomenon was first observed on a large scale by Mr. Richard Roberts in the year 1824, and is described in a paper read before this Society in 1828[*]. Roberts noticed that when a valve was placed over an aperture in a pipe used for regulating a strong blast of air for blowing a furnace, the valve, instead of being blown off by the force of the blast, remained a short distance from the aperture, and required considerable force of the hand to remove it to a further distance. Subsequent experiments showed that the adhesion of the valve was caused by the partial vacuum formed between the valve and its seating by the expansion of the issuing air. These experiments were repeated and extended by Mr. Peter Ewart to similar effects produced by the discharge of steam

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[*] Memoirs of the Literary and Philosophical Society, 2nd series, vol. v. p. 208.

through various apertures. Some of these experiments were described before this Society, and afterwards published in the Philosophical Magazine in 1829*. The degree of rarefaction produced by the discharge of air and high-pressure steam was carefully measured by Ewart by means of gauges inserted in different parts of the jet. He also noticed the sudden fall of temperature from 292° to 189° F. in the rarefied part of the jet when steam of 58 lb. pressure was discharged into the atmosphere.

Sir William Armstrong also, in his experiments on Hydro-electricity in the year 1842†, described a singular effect of a jet of steam by which a hollow globe made of thin brass, from two to three inches in diameter, remained suspended in a jet of high-pressure steam issuing from an orifice; and when the ball was pulled on one side by means of a string, a very palpable force was found requisite to draw it out of the jet.

It is abundantly evident from these experiments, that whenever elastic fluids escape into the atmosphere a partial vacuum is formed near to the discharging orifice, the degree of vacuum depending on the density of the issuing stream. Ewart's ingenious explanation, that the vacuous space formed near the discharging orifice is caused by the joint action of elasticity and momentum of the suddenly released particles repelling each other beyond the distance necessary to produce equilibrium with the external pressure, has a high degree of probability; but that this vacuous space should have the effect of increasing the rate of discharge could only be ascertained, as we

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* "Experiments and Observations on some of the Phenomena attending the Sudden Expansion of Compressed Elastic Fluids."

† "On the Efficacy of Steam as a Means of producing Electricity, and on a Curious Action of a Jet of Steam upon a Ball," Phil. Mag. ser. 3. vol. xxii. p. 1.

have seen, by a direct comparison, under like conditions, with the amount of the discharge into a vacuum.

Having established the fact that the atmosphere acts as a vacuum to the discharge of air of all pressures above two atmospheres within the range of my experiments, it appeared to me that this phenomenon might only be a particular case of a general law of the discharge of elastic fluids, and that it would be interesting to know through what range of relative pressures in two vessels the one would act as a vacuum to the other. With this object air was compressed into the large receiving cylinder from two up to eight atmospheres absolute pressure, while air was condensed into a small discharging cylinder up to nine atmospheres of absolute pressure. The air was discharged from the same orifice as in the former experiments, and the time of discharge recorded for each atmosphere was for a reduction of 5 lb. of pressure. The results obtained are shown in the Table.

TABLE V.

Absolute atmospheres.	0	1	2	3	4	5	6	7	8	
9	7·5	7·5	7·5	7·5	7·5	7·5	7·5	9·0	11·0	seconds.
8	8·5	8·5	8·5	8·5	8·5	8·5	10·0	13·5		"
7	10·0	10·0	10·0	10·0	10·0	11·0	14·5			"
6	12·0	12·0	12·0	12·0	12·5	16·0				"
5	15·0	15·0	15·0	15·5	20·5					"
4	20·0	20·0	20·0	25·5						"
3	27·0	27·0	31·0							"
2	43·0	43·0								"
1	97·0									"

In this Table the first vertical column to the left shows the number of atmospheres in the small cylinder from which each discharge of 5 lb. was made into the receiver.

The ordinal numbers at the head of the table indicate the atmospheres in the receiver when the discharge was made, commencing with vacuo; and the time of each discharge, in seconds, is shown against the pressure in the discharging and receiving cylinders respectively. The times in the second and third vertical columns are obtained from those in Tables I. and IV., when the discharge was made into a vacuum and into the atmosphere. On examining these results, commencing with the lower pressures, it will be seen that for two atmospheres of absolute pressure, the time of discharge (43 seconds) was the same for a vacuum as it was when made into the atmosphere, as has already been demonstrated. It will also be seen that a pressure of two atmospheres in the receiver acts as a vacuum to four atmospheres in the discharging cylinder. This is evident from the equality of the time (20 seconds) when the discharge was made into one atmosphere or into a vacuum. The like ratio will also be observed up to three atmospheres in the receiver, which act as a vacuum to the discharge of six atmospheres of pressure from the small cylinder. As the pressure in the receiver was increased, the diminution of resistance of the recipient atmospheres becomes still more marked, till for the highest pressures we have the remarkable phenomenon of six atmospheres acting as a vacuum to the discharge of nine atmospheres of pressure. That this peculiar relation of the discharging and receiving atmospheres has not reached its full limit will be obvious from a comparison of the numbers in the Table, from which it would appear that, for pressures exceeding those used in these experiments, the resistance of the recipient atmospheres would be still further diminished correlatively with an increase in the amount of discharge.

With the object of giving more completeness to this research, experiments were made to ascertain through what range of relative densities the air in two vessels would act as a vacuum to the other for pressures below that of the atmosphere. The results are shown in Table VI., which are arranged in the same manner as those in Table V. The times in the second vertical column are taken from those shown in Table II. when the discharge was made into a vacuum for each pound of pressure, and the other times in the Table are those obtained for successive discharges into air of different densities below the atmosphere, the larger cylinder being again used as a receiver.

TABLE VI.

Pounds per square inch.	0	1	2	4	6	8	10	12	14	
15	16·0	16·0	16·0	16·0	16·0	16·5	18·0	21·5	35·5	seconds.
14	17·5	17·5	17·5	17·5	17·5	18·5	20·5	26·5		,,
12	21·0	21·0	21·0	21·0	21·0	22·5	30·0			,,
10	25·5	25·5	25·5	25·5	26·5	33·5				,,
8	32·5	32·5	32·5	32·5	38·0					,,
6	45·0	45·0	45·0	47.5						,,
4	70·0	70·0	72·0							,,
2	180·0	190·0								,,

As equality in the times indicates equality in the quantities and velocities of the discharge for constant pressures, a simple inspection of the Table shows that, for discharging pressures as low as 6 lb., the recipient air still acts as a vacuum up to half the density of the discharging stream, and the regularity of this law is maintained within the limits of 6 lb. and 90 lb. absolute pressure, as shown in Table V. For discharging pressures below 6 lb. the relative times of discharge and the resistance of the recipient air *increase*; and as we have already seen that the similar times and resistances for discharging pressures above six atmospheres *diminish,* the continuity of regular law is broken at both ends of the series of pressures, just as it is in the series of planetary distances and some other quantitative phenomena of nature.

XI. *On the Flow of Gases.*

By Professor OSBORNE REYNOLDS, LL.D., F.R.S.

Read November 17th, 1885.

1. AMONGST the results of Mr. Wilde's* experiments on the flow of gas, one, to which attention is particularly called, is that when gas is flowing from a discharging vessel through an orifice into a receiving vessel, the rate at which the pressure falls in the discharging vessel is independent of the pressure in the receiving vessel until this becomes greater than about five tenths the pressure in the discharging vessel. This fact is shown in tables iv. and v. in Mr. Wilde's paper: thus, the fall of pressure from 135 lbs. (9 atmospheres) in the discharging vessel is 5 lbs. in 7·5 seconds for pressures in the receiving vessel, ranging from one half-pound to nearly 5 or 6 atmospheres.

With smaller pressures in the discharging vessel the times occupied by the pressure in falling a proportional distance are nearly the same until the pressure in the receiving vessel reaches about the same relative height.

What the exact relation between the two pressures is when the change in rate of flow occurs is not determined

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* Proc. Manchester Lit. and Phil. Soc. Oct. 20, 1885, or present vol. of Mem. p. 146.

in these experiments. For as the change comes on slowly, it is at first too small to be appreciable in such short intervals as 7·5 and 8 seconds. But an examination of Mr. Wilde's table vi. shows that it lies between ·5 and ·53.

This very remarkable fact, to which Mr. Wilde has recalled attention, excited considerable interest fifteen or twenty years ago. Graham does not appear to have noticed it, although on reference to Graham's experiments it appears that these also show it in the most conclusive manner (see table iv., Phil. Trans. 1846, vol. iv. pp. 573–632; also Reprint, p. 106). These experiments also show that the change comes on when the ratio of the pressures is between ·483 and ·531.

R. D. Napier appears to have been the first to make the discovery *. He found, by his own experiments on steam, that the change came on when the ratio of pressures fell to ·5 (see Encyc. Brit. vol. xii. p. 481). Zeuner, Fliegner, and Hirn have also investigated the subject.

At the time when Graham wrote, a theory of gaseous motion did not exist. But after the discovery of the mechanical equivalent of heat and thermodynamics, a theory became possible, and was given with apparent mathematical completeness in 1856. This theory appeared to agree well with experiments until the particular fact under discussion was discovered. This fact, however, directly controverts the theory. For on applying the equations giving the rate of flow through an orifice to such experiments as Mr. Wilde's, it appears that there is a marked disagreement between the calculated and experimental results. The calculated results are even more

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* The account of R. D. Napier's experiments is contained in letters in the 'Engineer,' 1867, vol. xxiii. January 4 and 25. They were made with steam generated in the boiler of a small screw-steamer and discharged into an iron bucket, the results being calculated from the heat imparted to a constant volume of water in the bucket in which the steam was condensed.

remarkable than the experimental; for while the experiments only show that diminishing the pressure in the receiving vessel below a certain limit does not increase the flow, the equations show that by such diminution of pressure the flow is actually reduced and eventually stopped altogether.

In one important respect, however, the equations agree with the experiments. This is in the limit at which diminution of pressure in the receiving vessel ceases to increase the flow, which limit by the equations is reached when the pressure in the receiving vessel is ·527 of the pressure in the discharging vessel.

The equations referred to are based on the laws of thermodynamics, or the laws of Boyle, Charles, and that of the mechanical equivalence of heat. They were investigated by Thomson and Joule (see Proc. Roy. Soc., May 1856), and by Prof. Julius Weisbach (see 'Civilingenieur,' 1856); they were given by Rankine (articles 637, 637 A, Applied Mechanics), and have since been adopted in all works on the theory of motion of fluids.

Although discussed by the various writers, the theory appears to have stood the discussion without having revealed the cause of its failure; indeed, Hirn, in a late work, has described the theory as mathematically satisfactory.

Having passed such an ordeal, it was certain that if there were a fault, it would not be on the surface. But that by diminishing the pressure on the receiving side of the orifice the flow should be reduced and eventually stopped, is a conclusion too contrary to common sense to be allowed to pass when once it is realized; even without the direct experimental evidence in contradiction, and in consequence of Mr. Wilde's experiments, the author was lead to reexamine the theory.

2. On examining the equations, it appears that they contain one assumption which is not part of the laws of thermodynamics or of the general theory of fluid motion. And although commonly made and found to agree with experiments in applying the laws of hydrodynamics, it has no foundation as generally true. To avoid this assumption, it is necessary to perform for gases integrations of the fundamental equations of fluid motion which have already been accomplished for liquids. These integrations being effected, it appears that the assumption above referred to has been the cause of the discrepancy between the theoretical and experimental results, which are brought into complete agreement, both as regards the law of discharge and the actual quantity discharged. The integrations also show certain facts of general interest as regards the motion of gases.

When gas flows from a reservoir sufficiently large, and initially (before flow commences) at the same pressure and temperature, then, gas being a nonconductor of heat when the flow is steady, a first integration of the equation of motion shows that the energy of equal elementary weights of the gas is constant. This energy is made up of two parts, the energy of motion and the intrinsic energy. As the gas acquires energy of motion, it loses intrinsic energy to exactly the same extent. Hence we have an equation between the energy of motion, *i. e.* the velocity of the gas, and its intrinsic energy. The laws of thermodynamics afford relations between the pressure, temperature, density, and intrinsic energy of the gas at any point. Substituting in the equation of energy, we obtain equations between the velocity and either pressure, temperature, or density of the gas.

The equation thus obtained between the velocity and pressure is that given by Thomson and Joule; this equation holds at all points in the vessel or the effluent stream. If, then, the pressure at the orifice is known, as well as the pressure well within the vessel where the gas has no energy of motion, we have the velocity of gas at the orifice; and obtaining the density at the orifice from the thermodynamic relation between density and pressure, we have the weight discharged per second by multiplying the product of velocity with density by the effective area of the orifice. This is Thomson and Joule's equation for the flow through an orifice. And so far the logic is perfect, and there are no assumptions but those involved in the general theories of thermodynamics and of fluid motion.

But in order to apply this equation, it is necessary to know the pressure at the orifice; and here comes the assumption that has been tacitly made: *that the pressure at the orifice is the pressure in the receiving vessel at a distance from the orifice.*

3. The origin of this assumption is that it holds, when a denser liquid like water flows into a light fluid like air, and approximately when water flows into water.

Taking no account of friction, the equations of hydrodynamics show that this is the only condition under which the ideal liquid can flow steadily from a drowned orifice. But they have not been hitherto integrated so far as to show whether or not this would be the case with an elastic fluid.

In the case of an elastic fluid, the difficulty of integration is enhanced. But on examination it appears that there is an important circumstance connected with the steady motion of gases which does not exist in the case of liquid. This circumstance, which may be inferred from integrations already effected, determines the pressure at the orifice irrespective of the pressure in the receiving vessel when this is below a certain point.

4. To understand this circumstance, it is necessary to consider a steady narrow stream of fluid in which the pressure falls and the velocity increases continuously in one direction.

Since the stream is steady, equal weights of the fluid must pass each section in the same time; or, if u be the velocity, ρ the density, and A the area of the stream, the joint product $u\rho\mathrm{A}$ is constant all along the stream, so that

$$\mathrm{A} = \frac{\mathrm{W}}{g\rho u},$$

where $\frac{\mathrm{W}}{g}$ is the mass of fluid which passes any section per second.

In the case of a liquid ρ is constant, so that the area of the section of the stream is inversely proportional to the velocity, and therefore the stream will continuously contract in section in the direction in which the velocity increases and the pressure falls, as in fig. 1, also fig. 2 A.


FIG. I.

In the case of a gas, however, ρ diminishes as the velocity increases and the pressure falls; so that the area of the section will not be inversely proportional to u, but to $u \times \rho$, and will contract or increase according to whether u increases faster or slower than ρ diminishes.

As already described, the value of ρu may be expressed in terms of the pressure. Making this substitution, it appears that ρu increases from zero as p diminishes from a definite value p_1 until $p = \cdot 527 p_1$; after this ρu diminishes to zero as p diminishes to zero. A varies inversely as ρu, and therefore diminishes from infinity as p diminishes from p_1 till $p = \cdot527p_1$; then A has a minimum value and increases to infinity as p diminishes to zero, as in fig. 2.

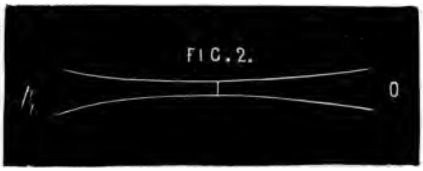
FIG. 2.

The equations contain the definite law of this variation, which, for a particular fall of pressure, is shown in fig. 2 A.

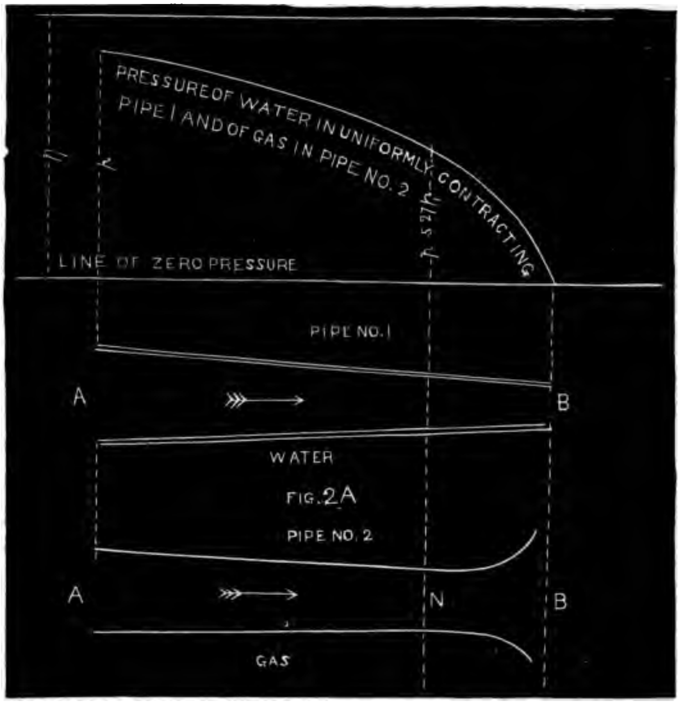

FIG. 2A

For the present argument it is sufficient to notice that A has a mimimum value when $p = \cdot527p_1$; since this fact determines the pressure at the orifice when the pressure in the receiving vessel is less than $\cdot527p_1$, that being the pressure in the discharging vessel.

5. If, instead of an orifice in a thin plate, the fluid escaped through a pipe which gradually contracted to a nozzle, then it would follow at once, from what has been already said, that when p_2 was less than $\cdot527p_1$, the narrowest portion of the stream would be at N, for since the stream converges to N the pressure above N can be nowhere less than $\cdot527p_1$; and since emerging into the smaller surrounding pressure p_2 the stream would expand laterally, N would be the minimum breadth of the stream, and hence the pressure at N would be $\cdot527p_1$. In a broad view we may in the same way look on an orifice in the wall of a vessel as the neck of a stream. But if we begin to look into the argument, it is not so clear, on account of the curvature of the paths in which some of the particles approach the orifice.

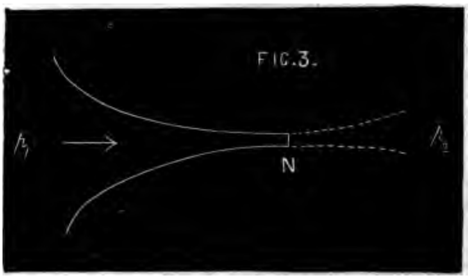
FIG. 3.

Since the motion with which the fluid approaches the orifice is steady, the whole stream, which is bounded all round by the wall, may be considered to consist of a number of elementary streams, each conveying the same quantity of fluid. Each of these elementary streams is bounded by the neighbouring streams, but as the boundaries do not change their position they may be considered as fixed.

The figure (4) shows approximately the arrangement of such stream. But for the mathematical difficulty of integrating the equations of motion, the exact form of these

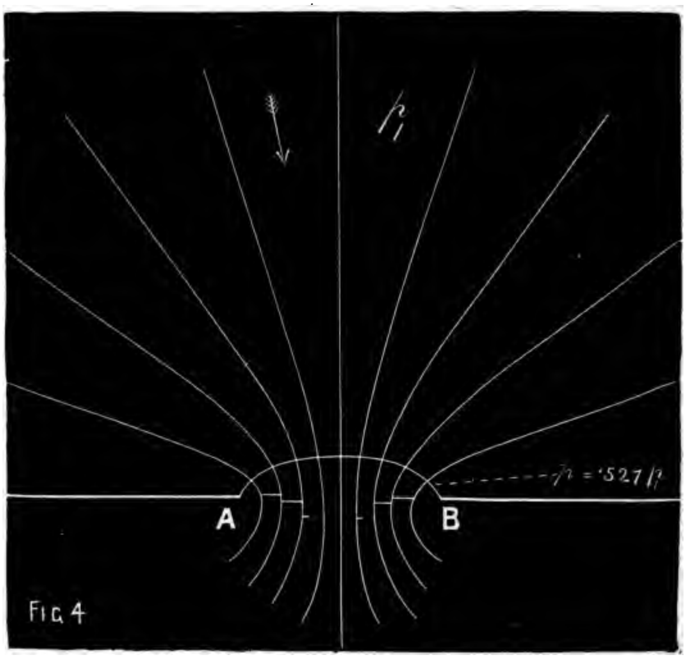

FIG. 4

streams might be drawn. We should then be able to determine exactly the necks of each of these streams. Without complete integration, however, the process may be carried far enough to show that the lines bounding the streams are continuous curves which have for asymptotes on the discharging-vessel side lines radiating from the middle of the orifice at equal angles, and, further, that these lines all curve round the nearest edge of the orifice, and that the curvature of the stream diminishes as the distance of the stream from the edge increases.

These conclusions would be definitely deducible from the theory of fluid motion could the integrations be effected, but they are also obvious from the figure and easily verified experimentally by drawing smoky air through a small orifice.

From the foregoing conclusions it follows, that if a curve be drawn from A to B, cutting all the streams at right angles, the streams will all be converging at the points where this line cuts them, hence the necks of the streams will be on the outflow side of this curve. The exact position of these necks is difficult to determine, but they must be nearly as shown in the figure by cross lines. The sum of the areas of these necks must be less than the area of the orifice, since, where they are not in the straight line A B, the breadth occupied on this line is greater than that of the neck. The sum of the areas of the necks may be taken as the effective area of the orifice; and, since all the streams have the same velocity at the neck, the ratio which this aggregate area bears to the area of the orifice may be put equal to K, a coefficient of contraction.

If the pressure in the vessel on the outflow side of the orifice is less than $\cdot 527p_1$, this is the lowest pressure possible at the necks, as has already been pointed out, and on emerging the streams will expand again, as shown in the figure, the pressure falling and the velocity increasing, until the pressure in the streams is equal to p_2, when in all probability the motion will become unsteady.

If p_2 is greater than $\cdot 527p_1$, the only possible form of motion requires the pressure in the necks to be p_2, at which point the streams become parallel until they are broken up by eddying into the surrounding fluid (fig. 5).

6. There is another way of looking at the problem, which is the first that presented itself to the author.

Suppose a parallel stream flowing along a straight tube with a velocity *u*, and take *a* for the velocity with which sound would travel in the same gas at rest, the velocity with which a wave of sound or any disturbance would

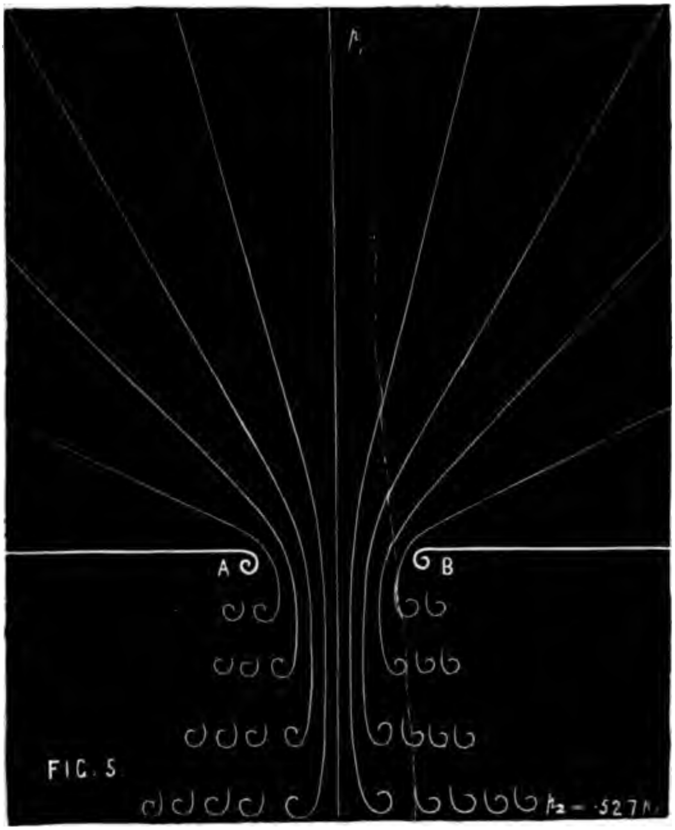

FIG. 5

move along the tube in an opposite direction to the gas would be $a-u$. If then $a=u$, no disturbance could flow back along the tube against the motion of the gas; so that, however much the pressure might be suddenly diminished at any point in the tube, it would not affect the pressure at points on the side from which the fluid is flowing. Thus, suppose the gas to be steam, and this to be suddenly condensed at one point of the tube, the fall of pressure would move back against the motion, increasing the motion till $u=a$, but not further; just as in the Bunsen's burner the flame cannot flow back into the tube so long as the velocity of the explosive mixture is greater than the velocity at which the flame travels in the mixture.

According to this view, the limit of flow through an orifice should be the velocity of sound in gas in the condition as regards pressure, density, and temperature of that in the orifice; and this is precisely what it is found to be on examining the equations.

7. The following is the definite expression of the foregoing argument.

The adiabetic laws for gas are: p being pressure, ρ density, τ absolute temperature, and γ the ratio of specific heats at constant pressure and constant density,

$$\frac{\tau}{\tau_0}=\left(\frac{p}{p_0}\right)^{\frac{\gamma-1}{\gamma}}=\left(\frac{\rho}{\rho_0}\right)^{\gamma-1} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The equation of motion, u being the velocity and x the direction of motion, is

$$\rho u\frac{du}{dx}=-\frac{dp}{dx},$$

or

$$\frac{u^2}{2}=-\int_0^p\frac{dp}{\rho}+C. \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Substituting from equations (1),

$$\int_0^p\frac{dp}{\rho}=\frac{\gamma}{\gamma-1}\frac{p_0}{\rho_0}\frac{\tau}{\tau_0};$$

$$\therefore\ u=\sqrt{\frac{2g\gamma}{\gamma-1}\frac{p_0}{\rho_0}\frac{\tau_1}{\tau_0}\left\{1-\left(\frac{p}{p_1}\right)^{\frac{\gamma-1}{\gamma}}\right\}}, \quad . \ . \ . \ . \ . \ . \quad (3)$$

$$\rho=\frac{\rho_0\tau_0 p_1}{p_0\tau_1}\left(\frac{p}{p_1}\right)^{\frac{1}{\gamma}}; \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (4)$$

$$\therefore\ \frac{W}{g}=Ap_1\sqrt{\frac{2\gamma g\rho_0\tau_0}{(\gamma-1)p_0\tau_1}}\sqrt{\left\{1-\left(\frac{p}{p_1}\right)^{\frac{\gamma-1}{\gamma}}\right\}}\left(\frac{p}{p_1}\right)^{\frac{1}{\gamma}}. \quad (5)$$

Hence along a steady stream, since W is constant, equation (5) gives a relation that must hold between A and p.

Differentiating A with respect to p and making $\frac{dA}{dp}$ zero, it appears

$$2p_1^{\frac{\gamma-1}{\gamma}}=(\gamma+1)p^{\frac{\gamma-1}{\gamma}}, \quad . \ . \ . \ . \quad (6)$$

or

$$\frac{p}{p_1}=\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}. \quad . \ . \ . \ . \ . \ . \ . \quad (7)$$

For air $\gamma=1{\cdot}408$.

$$\therefore\ \frac{p}{p_1}={\cdot}527. \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (8)$$

It thus appears that as long as p falls, the section continuously diminishes to a minimum value when $p={\cdot}527p_1$, and then increases again. Substituting this value of p in equation (3),

$$u=\sqrt{\frac{2\gamma g p_0\tau_1}{(\gamma+1)\rho_0\tau_0}}, \quad . \ . \ . \ . \ . \ . \ . \ . \quad (9)$$

$$=\sqrt{\frac{2\gamma g p_0}{(\gamma+1)\rho_0}\left(\frac{p_1}{p_0}\right)^{\frac{\gamma-1}{2\gamma}}}, \quad . \ . \ . \ . \quad (10)$$

$$=\sqrt{\frac{2\gamma g p_0}{(\gamma+1)\rho}\left(\frac{p}{p_0}\right)^{\frac{\gamma-1}{2\gamma}}\left(\frac{p_1}{p}\right)^{\frac{\gamma-1}{2\gamma}}}. \quad . \ . \ . \quad (11)$$

Hence by equation (6),

$$u=\sqrt{\frac{\gamma g p_0\tau}{\gamma_0\tau_0}}, \quad . \ . \ . \ . \ . \ . \ . \ . \quad (12)$$

which is the velocity of sound in the gas at the absolute temperature τ.

It thus appears that the velocity of gas at the point of minimum area of a stream along which the pressure falls continuously is equal to the velocity of sound in the gas at that point.

8. From the equation of flow (5) it appears that for every value of A other than its minimum value, there are two possible values of the pressure which satisfy the equation, one being greater and the other less than

$$\cdot 527 p_1 .$$

It therefore appears that in a channel having two equal minima values of section A and C, as in fig. 6, the flow

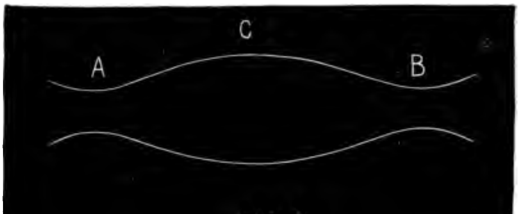

FIG. 6.

from A to B may take place in either of two ways when the velocity is such that the pressure at A and B is $\cdot 527 p_1$, *i. e.* the pressure may either be a maximum or a minimum at C. In this respect gas differs entirely from a liquid, with which the pressure can only be a maximum at C.

9. For air through an orifice, since $\gamma = 1\cdot 408$, when the pressure in the receiving vessel is less than $\cdot 527 p_1$, the numerical value of U_n, the velocity in the neck of the orifice, is

$$U_n = 997 \text{ (feet per sec.)} \sqrt{\frac{\tau_1}{\tau_0}} ; \quad . \quad . \quad . \quad (13)$$

and if the temperature is 57° F., as in Mr. Wilde's experiments,

$$U_n = 1022. \quad \ldots\ldots\ldots \quad (14)$$

Reducing this in the ratio of the density at the neck to the density in the discharging vessel,

$$\left.\begin{aligned}\rho_n &= (\cdot 527)^{\frac{1}{\gamma}}\\ \rho_1 &= \cdot 6345\end{aligned}\right\}. \quad \ldots\ldots\ldots \quad (15)$$

We have the reduced velocity

$$U_n\frac{\rho_n}{\rho_1} = 650 \text{ (feet per sec.)}. \quad \ldots\ldots \quad (16)$$

Therefore the discharge will be given in cubic inches per second, KO being the effective area of the orifice, by

$$\left.\begin{aligned}\rho_1 Q &= 12 U_n \rho_n KO\\ &= 12 \times 650 KO\end{aligned}\right\}. \quad \ldots\ldots\ldots \quad (17)$$

Or, since the actual area in square inches

$$O = \cdot 000314 \text{ sq. inches},$$
$$Q = 2\cdot 44K \text{ (cubic inches per sec.)}. \quad . \quad (18)$$

10. In order to compare the experimental discharges with those calculated, it is necessary to know, besides the size of an orifice and the pressure and temperature of the discharging vessel, the coefficient of contraction or the effective area of the orifice. To obtain this from the equations requires that the terms depending on viscosity should be introduced, which renders the integration so far impossible. The only plan is to obtain this coefficient by comparing the theoretical results with the experimental. Such comparisons have been made by Prof. Weisbach for air; and in the case of short cylindrical orifices such as that used by Mr. Wilde (a cylindrical hole through a plate having a radius equal to the thickness of the plate),

the value of K, the coefficient of contraction, given by Weisbach ('The Steam Engine,' p. 324, Rankine) is from ·73 to ·833. Whether these are the real coefficients of contraction may, however, well be doubted, as it is extremely difficult to determine the experimental quantities of gas discharged owing to the great effect of slight variations of temperature on the relations between changes of pressure and changes of temperature, such changes of temperature being almost necessarily incidental on changes of pressure.

11. In Mr. Wilde's experiments the pressure was allowed to fall in the discharging vessel during the discharges; this would cause a corresponding fall of temperature, which would again cause heat to flow from the metal vessel into the gas within.

It is difficult therefore to say what the change of temperature was except in the extreme cases. With the experiments on the highest pressure, however, the times 7·5 seconds, and the greatest possible falls of temperature 5°·5, were so small that the communication of heat from the walls of the receiver would have been very slight; and hence we might expect that the discharges, calculated on the assumption of no communication of heat, would agree with the theoretical discharges multiplied by the real coefficient of contraction. This would be shown by an agreement in the successive coefficients obtained from the experiments with the higher pressures. On the other hand, with the lowest pressures the times were so considerable, 170 seconds, and the greatest possible falls of temperature (assuming no conduction, 94°) so great, that the communication of heat would have been very great and, considering the comparatively small mass to be heated (only one thirteenth of what it is in the highest experiments), might maintain the temperature approximately constant after falling some considerable amount below the initial temperature. In these last experiments, therefore, it would be expected that the discharge might be estimated as taking place at nearly constant temperature.

The intermediate experiments would give intermediate results.

According to this view, for the high pressures, since

$$\frac{\rho}{\rho_{1}} = \left(\frac{p}{p_1}\right) = \left(\frac{p}{p_1}\right)^{\cdot 71}, \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

and

$$\frac{d\rho}{\rho_1} = \cdot 71 \frac{dp}{p_1}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

or putting V for the volume 573 cub. in. of the discharging vessel,

$$\frac{\mathrm{Q}}{\mathrm{V}} t = \cdot 71 \frac{dp}{p_1} t, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

where t is the time. Or, since $tdp = 5$ lbs.,

$$\mathrm{K} = \frac{\cdot 835}{p_1 t}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

Substituting the value of $p_1 t$ in the first six experiments, we have:—

p.	K.	V_n Velocity at orifice.	$\mathrm{V}_n \frac{\rho_n}{\rho}$.
135	·825	1022	650
130	·826	,,	,,
125	·835	,,	,,
120	·820	,,	,,
115	·810	,,	,,
110	·790	,,	,,

For the first three of these experiments K is nearly constant, showing that the conduction of heat could have but slight if any effect, but the effect is decidedly apparent in the next three.

Proceeding now to the other extreme, and assuming that the temperature, after undergoing some diminution, remains constant, we have

$$\frac{dp}{p_1} = \frac{Q}{V};$$

or, integrating,

$$\log_e \frac{p_1}{p_2} = Vt,$$

$$\log p_1 - \log p_2 = \frac{Q}{V} \log e;$$

from which, taking the last three experiments in Table II.,

p.	K.	V_n.	$V_n \frac{\rho_n}{\rho_1}$.
4	·95	1022	650
3	·98	,,	,,
2	·89	,,	,,

In these it appears that the values of K are approximating to the value ·825; but the great differences show that the temperature effect is far from having become steady, and are quite sufficient to explain the discrepancies in the actual values of K. There is thus no reason to doubt but that ·825 is about the real value of the coefficient of contraction for the orifice, and that the experimental results are quantitatively in accordance with the theory.

Pipe No. 1.—WATER (see fig. 2A, page 170).

$$V_B = \sqrt{2g\frac{P_1}{D}}.$$

Pipe No. 2.—GAS.

$$V_B = \sqrt{\frac{\gamma}{\gamma - 1}} \times \sqrt{2g\frac{P_0}{D_0}} \times \sqrt{\frac{T_1 + 461}{32 + 461}},$$

$$V_W = \sqrt{\frac{\gamma - 1}{\gamma - 1}}\, V_B.$$

AIR.

$$V_B = 2{\cdot}413 \text{ (feet per second)} \sqrt{\frac{T_1+461}{31+461}},$$

$$V_W = 997 \text{ (feet per second)} \sqrt{\frac{T_1+461}{32+461}}.$$

XII. *On the Efflux of Air as modified by the Form of the Discharging Orifice.* By HENRY WILDE, Esq.

Read March 23rd, 1886.

IN my former paper on the efflux of air, the hydraulic coefficient ·62, as commonly applied to the discharge of elastic fluids through an orifice in a thin plate, was taken as the value of the contraction of such orifice, and from this coefficient the highest velocities shown in the several Tables were deduced. A review of the results of my experiments by Prof. Osborne Reynolds* led me to doubt the value of this coefficient, and to make further experiments with the object of determining the maximum rate of discharge from an orifice of the best form.

Five disks of brass had each a hole drilled through its centre two-hundredths of an inch in diameter. Equality in the size of the holes was accurately determined by means of a standard cylindrical gauge. These disks I shall designate A, B, C, D, E.

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* Proceedings Manchester Lit. and Phil. Society, vol. xxv. p. 55, or present vol. of Mem. p. 164.

The disk A was three diameters of the orifice in thickness, and was equal to a plain cylindrical tube three diameters in length.

Disk B was the same thickness as A, but the hole was coned out on one side to a depth of one diameter and a half.

C was six diameters in thickness, and was coned out on one side to a depth of three diameters.

D had a thickness of twelve diameters of the orifice, and was coned out on one side to a depth of six diameters.

E was eighteen diameters of the hole in thickness, and was coned out on both sides to a depth of six diameters, which left a plain tube in the centre of the disk six diameters in length.

The wide sides of the coned orifices were equal to two diameters, and their outer edges were rounded off to a conoidal form.

The thin iron disk O was ·007 of an inch in thickness, or nearly one third the diameter of the orifice, which was two-hundredths of an inch. One side of the orifice was chamfered to reduce the cylindrical part of the hole as much as possible to a sharp edge. The effect of the chamfering had, however, so small an effect in diminishing the rate of discharge that the determinations might have been taken from the cylindrical orifice without interfering with the general accuracy of the results.

The mode of experimenting was similar to that already described. Air of an initial absolute pressure of 135 lbs. was discharged into the atmosphere through the orifice in the thin plate O, and through the orifices in A, B, C, D, E successively, and the times were recorded for the reduction of 10 lbs. from each of the atmospheres of pressure, as shown in the following Table :—

TABLE I.—Discharge into the Atmosphere.

Lbs. per square inch absolute pressure.	Orifice in thin plate. O	Plain tube orifice. A	Conoidal orifice inside. B	Conoidal orifice inside. C	Conoidal orifice inside. D	Double conoidal orifice. E	Coefficient for orifice. O
	sec.	sec.	sec.	sec.	sec.	sec.	
135	15·5	14·5	14·5	14·5	15·0	15·5	·935
120	17·5	16·5	16·5	16·5	17·0	17·5	·943
105	20·5	19·0	19·0	19·0	20·0	20·5	·927
90	25·0	23·5	23·5	23·5	24·5	25·0	·940
75	31·5	29·5	29·5	29·5	30·5	31·5	·936
60	42·0	39·5	39·5	39·5	41·0	42·0	·940
45	58·0	54·5	54·5	54·5	56·5	58·0	·940

Mean coefficient for orifice in thin plate ·937.

An examination of this Table will show that the form of the orifice has very little influence on the rate of discharge of elastic fluids compared with what it has on those which are inelastic.

No difference was observable in these experiments in the rates of discharge through the orifices A, B, and C, notwithstanding that A was a plain cylinder, and B and C were coned to a depth of half their thickness and formed tubes from three to six diameters in length. Moreover, although the results shown in the Tables were obtained with the coned sides of the orifices inside the vessel; yet, when the sides were reversed, the rate of discharge through A, B, and C was only diminished by one-thirtieth part, and there was no difference in the rate of discharge through D whether the coned side of the orifice was inside or outside the vessel.

Taking A, B, and C as the orifices producing the maximum rate of discharge, we have ·935 as the value of the coefficient of discharge from an orifice in a thin plate for the highest pressure of 135 lbs. This value, as will be seen, is the same for all the pressures in the Table within errors of observation and experiment, and the mean value of the coefficient for all the pressures is ·937.

Applying this coefficient to the velocity deduced in Table I. of my former paper for an orifice in a thin plate, we have for the maximum velocity with which air of 135 lbs. pressure rushes into a vacuum, before expansion,

$V = \frac{750}{\cdot 937} = 800$ feet per second.

Some anomalous rates of efflux from the same orifice which were obtained when air of less than 15 lbs. effective pressure was discharged into the atmosphere, induced me to make a series of experiments on the discharge of air of an initial pressure of 15 lbs. through the same orifices as in the last experiments, and the times were recorded for each reduction of 2 lbs. of pressure.

All the discharges were made with the conoidal orifices inside the vessel, but they were also made through C and D with these orifices outside the vessel. The results are shown in the following Table :—

TABLE II.—Discharge into the Atmosphere.

Lbs. per square inch effective pressure.	Orifice in thin plate. O	Plain tube orifice. A	Conoidal orifice inside. B	Conoidal orifice inside. C	Conoidal orifice outside. C	Conoidal orifice inside. D	Conoidal orifice outside. D	Double conoidal orifice. E	Coefficients for orifice. O
	sec.	sec.	sec.	sec.	sec.	sec.	sec.	sec.	
15	16·0	13·5	14·0	14·0	14·0	14·5	14·5	15·0	·829
13	17·5	14·5	15·0	15·0	15·0	16·5	16·0	16·0	·829
11	19·5	16·0	16·5	16·5	16·5	18·5	18·0	17·5	·820
9	22·5	18·0	18·5	18·5	18·5	20·5	19·5	19·0	·818
7	26·0	21·0	21·5	22·0	21·5	24·0	21·5	22·0	·808
5	33·0	26·0	26·5	27·5	26·5	30·0	25·5	27·0	·788
3	51·0	39·0	40·5	42·5	40·5	47·0	38·5	42·5	·765

On comparing the times of discharge through the several orifices among themselves, and with those in Table I., a marked difference is observable in them. Thus the ratio of discharge through the tube orifice A and the orifice in a thin plate is greater than that for the same orifices in Table I., the coefficients for the highest and lowest pressures in this Table being ·935 and ·940 respectively; whereas the coefficients for the same orifices in Table II. are ·829 and ·765 respectively. Again, while there is little difference in the times of discharge from the tubular orifices among themselves, a remarkable change occurs during the fall of pressure from 15 lbs. to 1 lb., when the discharge is made through C and D with the conoidal orifices outside the vessel.

The discharge through D from 15 lbs. to 13 lbs. is the same whether the conoidal orifice is inside or outside; but in the latter position, as the pressure diminishes, the rate of discharge increases, till at the lowest pressure this increase amounts to 8·5 seconds, and exceeds the maximum discharge from the tube orifice A. A similar change is also noticeable in the rate of discharge through reversing the orifice C; but as the change does not come on before the pressure is below 7 lbs., it is less marked than when the discharge is made through D.

Suspecting that the phenomenal change in the rate of discharge for the same orifice was due to the varying resistances of the discharging and receiving atmospheres of pressure described in my former paper, the discharges from the orifices O, A, and D were made into a vacuum of 1·5 inch of mercury instead of into the atmosphere, and the times of discharge were recorded for each reduction of 1 lb. of pressure.

The results are shown in the Table :—

TABLE III.—Discharge into a Vacuum 1·5 inch Mercury.

Lb. per square inch absolute pressure.	Hole in thin plate. O	Plain tube orifice. A	Conoidal orifice inside. D	Conoidal orifice outside. D	Coefficient for orifice. O
	sec.	sec.	sec.	sec.	
15	16·0	15·0	16·0	16·0	·937
14	17·5	16·5	18·0	18·0	·943
13	19·0	17·5	20·0	20·0	·921
12	21·0	19·5	22·5	22·0	·928
11	23·0	21·5	24·5	24·0	·935
10	25·5	24·0	27·5	27·0	·941
9	28·5	27·0	31·0	30·5	·947
8	32·5	31·0	35·5	35·0	·954
7	37·5	35·5	41·0	40·0	·947
6	45·0	42·5	49·5	48·5	·944
5	55·0	52·5	63·0	61·0	·955
4	70·0	67·0	81·0	79·0	mean
3	102·0	101·0	125·0	120·0	coefficient
2	180·0	192·0	241·0	224·0	·941

A comparison of the times of discharge through D with the conoidal orifice in both positions will show that they approach nearly to a ratio of equality. The phenomenal change in the rate of discharge from the same orifice was consequently due to the diminished resistance of the external atmosphere, the conoidal form of the orifice increasing the amount of rarefaction above that obtained with a plain tube orifice. This conclusion is further evident on comparing the times of discharge from D in reversed positions from a pressure of 3 lbs. to 1 lb.; for as the rarefaction in the vacuum-chamber was only reduced to 1·5 inch of mercury, the phenomenal change in the rate of discharge again presents itself, making a difference of 17 seconds in the times of discharge between the reversed position of the orifice for the lowest pressure.

Comparing the times of discharge through the tube orifice A and the orifice O in the thin plate, it will be seen that there is much less difference between them than for the same orifices in Table II., the ratio agreeing very closely with those shown in Table I. for similar times of discharge. The approaching equality in the times of discharge through the tube orifice A and the orifice in the thin plate for the lower pressures is, no doubt, due to the friction of the issuing stream of air against the sides of the tube orifice. The effect of this friction for the lowest pressure, as will be seen, reduces the rate of discharge from the orifice A below that from the orifice in the thin plate.

From the results of my previous experiments on the discharge of atmospheres of higher into atmospheres of lower density, the times and coefficients in Table I. and Table III. for the higher pressures may well be considered as having been obtained for discharges into a perfect vacuum, the difference in the coefficients for pressures below 10 lbs. in Table III. being entirely due to friction of the issuing stream of air against the sides of the orifices.

From the results shown in Tables I. and II. the maximum rate of efflux is obtained from the orifices A, B, and C, and taking the efflux from these orifices as unity, the value of the coefficient for the efflux of air into a vacuum through an orifice in a thin plate is ·937.

These experiments also prove conclusively that the coefficients which have hitherto been applied to the efflux of air below 15 lbs. effective pressure derive nearly the whole of their value from the phenomenal changes of resistance between the discharging and receiving atmospheres, and not from the forms of the orifices and lengths of the adjutages, as in the discharge of inelastic fluids.

Applying the coefficient ·937 to the velocity with which the atmosphere of 15 lbs. absolute pressure rushes into a vacuum, before expansion, as deduced in Table II. in my former paper, we have $V=\frac{633}{\cdot 937}=677$ feet per second, or approximately one half the velocity due to the height of the homogeneous atmosphere.

The following approximate velocities with which atmospheres of several gases of 15 lbs. absolute pressure rush into a vacuum through an orifice of the best form, before expansion, have been calculated on the basis of Graham's law of the velocities of efflux for equal pressures being inversely as the square roots of the specific gravities:—

Air	1·000 × 677 =	677	feet per second.
Oxygen	0·950 × 677 =	643	,, ,,
Nitrogen	1·015 × 677 =	687	,, ,,
Hydrogen	3·800 × 677 =	2572	,, ,,
Saturated steam...	1·445 × 677 =	978	,, ,,

XIII. *On the Morphology of* Pinites oblongus (Abies oblonga *of Lindley and Hutton*). By Wm. Crawford Williamson, LL.D., F.R.S., Professor of Botany in Owens College.

Read April 6th, 1886.

(Plate IX.)

The question of the range of the Coniferæ in time, and its important bearing upon the problem of evolution, sufficiently accounts for the interest attached to the discovery of cones belonging to that order in the various stratified rocks. Several such have already been met with, but amongst these a few objects have been obtained from the Palæozoic and other Mesozoic rocks that are either not cones of any kind, or are those of Cycadean plants. At present the only remains which present a claim to Coniferous rank found in the Palæozoic rocks are the Dadoxylons; and even of these, assuming that, as is most probable, they are Coniferous stems and not Cycadean, their affinities appear to be with the Taxineæ, rather than with the more highly developed Abietineæ. Of the latter we discover no indisputable examples until we approach the base of the Cretaceous rocks *. Mr. Carruthers has expressed his conviction that no truly Coniferous cone has been found below the Kimmeridge clay.

For evidence of the occurrence of true Coniferous cones in rocks of Mesozoic age, we are mainly indebted to Lindley and Hutton, Dr. Fitton, Dr. Mantell, and Mr. Carruthers.

In a memoir published by the last-named author in vol. iii. p. 534 of the 'Geological Magazine,' he reviewed those previously described by other observers, and added some new ones. Mr. Carruthers also described additional ones in vols. vi. and viii. of the same Magazine.

One of the most interesting of the cones thus recorded it that figured by Lindley and Hutton in vol. ii. plate 137 of the 'Fossil Flora of Great Britain,' under the name of *Abies oblonga*. The interest of this specimen resides in the fact that, in it, the large seeds are all preserved in their normal positions in the cone.

A few weeks ago Professor Boyd-Dawkins showed me the half of a waterworn silicified cone, cut through longitudinally, which had been submitted to him by the Rev. H. H. Winwood, F.G.S., of Bath, but was the property of a Miss Flood. Mr. Winwood has since entrusted this spe-

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* The *Pinus primæva* of Lindley & Hutton, from the Inferior Oolite, is in all probability a Cycadean cone.

cimen to me, accompanied by a second half of the same specimen, for the purpose of description and publication.

The specimen was originally obtained from the beach at Sidmouth, where it has most probably been washed out of the Lower Greensand, as was supposed to have been the case with Lindley and Hutton's specimen, found on the shore near Lyme Regis *.

I at once saw that the sections placed in my hands were identical with the *Abies oblonga* of Lindley and Hutton; but since they show some details of structure and morphology not mentioned by the above authors, they deserve an independent examination.

Fig. 1 represents a vertical section through the centre of Miss Flood's specimen, twice its natural size. It exhibits a small portion of the central axis at *a*, the superficial zone of which is obviously woody, being traversed horizontally by numerous parallel lines, which are evidently medullary xylem rays; its more central portion consists of narrow, vertically elongated fibres, in which no special structure can be discerned. From this axis numerous lignified carpellary scales, *b*, *c*, are given off, as in modern cones. Sections of these scales show a difference between their superior and inferior component tissues. The former, *b′*, is composed of large, thick-walled, sclerous parenchyma, the cells of which are generally a little elongated parallel to the long axis of the cone. In Lindley and Hutton's description this tissue is vaguely described by the term "corky." Cork it certainly is not. The inferior layer is much more dense, being composed of vertically elongated and very narrow fibres. The peri-

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* Lindley and Hutton speak of this specimen as from "the *Dresent* shore." Mr. Starkie Gardner informs me that after an exhaustive search he can find no such place, and is inclined to assume that "Dresent" is a misprint for some other word.

pheral extremities of these carpellary scales do not become so thin as Lindley and Hutton affirmed to be the case with their example. Though rolled and waterworn, the exterior of our specimen rather suggests a slight thickening of those extremities, resembling what is seen in *Pinus Stròbus* and *P. Cémbra.*

In fig. 2, Plate IX., which represents portions of two carpellary scales, *b* and *c,* from the second section entrusted to me by Mr. Winwood, the distinctions between the two woody layers are obvious at *b′* and *b″*, *c′* and *c″*. The several seeds, *d,* are borne on the upper surfaces of the basal portions of the carpellary scales, each having its micropilar extremity pointed downwards and inwards. Each seed is invested by a firm testa, fig. 1, *e,* Plate IX., within which we have, in several of them, a thin nucellar membrane; small fragments of this membrane are seen in the two seeds, fig. 1, *f, f*; the almost unbroken membrane is seen in the seed, fig. 1, *f′*, and its concave half is lodged within the concavity of the testa of fig. 1, *e.* In each of two other seeds, *g, g,* of fig. 1, a narrow tubular structure extends from the outer end of the seed to its inner or micropilar extremity. This is obviously the embryo-sac. The large wing of the seed is more or less conspicuous in nearly every instance. Thus it is nearly, if not wholly, coextensive with the length of the subjacent carpellary scale, as at *h, h,* whilst its opposite or lower portion covers the upper surface of each seed, as far as its micropile.

In most cases the wing is slightly bifid where it touches the outer apex of the seed, as in *h′, h′,* a very narrow margin of it overlapping the sharply angular edge of the latter organ. These wings therefore were very large in proportion to the size of the seed.

In fig. 2, which represents a portion of Miss Flood's second half of the cone, enlarged six diameters, we have evidence that each carpellary scale bore two seeds, as is the case with the true Abietineæ. Most of the features seen in fig. 1 are repeated in these two seeds, which are intersected in an obliquely transverse manner, the section being tangential to the surface of the entire cone. We have the testa of each seed at *e*. Each intersected embryo-sac appears at *g*, *g*. The wings are at *h*, *h*, extending over the entire upper surface of each seed so completely as to invest their two contiguous surfaces; whilst the thickened portions, already referred to, are very obvious at *h'*, *h'*. The testa of each seed in this section is fringed at its inferior surface with some detached flocculent tissue.

In the interior of the nucellar cavity of some of these seeds a number of small and very delicate spheres, of various sizes, are visible; these may be products of mineralization, but how produced is not easy to determine. As already observed, Lindley and Hutton placed their cone in the modern genus *Abies* in consequence of the apparent absence of the terminal thickening usually seen in the carpellary scales of the cones of *Pinus*. But the relatively large size of the seed is more suggestive of affinities with *Pinus* than with *Abies*; the more so since in such cones as those of *Pinus Stròbus* and *Cémbra* the terminal portions of these scales are only thickened in a small degree beyond what occurs in those of *Abies*. But apart from these facts, Mr. Carruthers, in one of the memoirs referred to*, has given excellent reasons for avoiding the use of such ill-defined general terms as *Pinus* and *Abies*, hence he has placed Lindley and Hutton's cone in the provisional genus *Pinites*, and I have followed his example.

This name sufficiently indicates the general affinities of such specimens as the one under consideration, without

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* Geological Magazine, vol. iii. p. 536.

suggesting closer relationships than can be affirmed with certainty to exist.

DESCRIPTION OF THE FIGURES.

Fig. 1. Internal surface of one half of the cone: enlarged two diameters.
- *a.* Part of the axis of the cone.
- *b*, *c.* Carpellary scales.
- b', c', the upper; b'', c'', the lower tissues of these scales.
- *d.* The seeds *in situ.*
- *e.* The testa of the seed.
- *f.* The nucellar membrane of the seed.
- *g.* The embryo-sac.
- *h.* The wing of the seed.

Fig. 2. Transverse section of portions of two carpellary scales, enlarged six diameters, the lower bearing two ovules, as seen in a tangential section of the exterior of the cone. The reference letters as above.
- *i.* Portion of a seed belonging to a collateral carpellary scale.

XIV. *On the Hymenoptera of the Hawaiian Islands.*

By the Rev. T. Blackburn, B.A., and P. Cameron.

Read before the Microscopical and Natural-History Section, January 18th, 1886.

The investigation of the natural history of oceanic islands is now rightly regarded as a subject of great interest and importance. Not only do their fauna and flora throw much light on the manner in which species have been distributed over the globe, but many of the species themselves are, from the peculiarities of their structure, of extreme value in throwing light on the origin of species. The natural history of oceanic islands ought, furthermore, to be seriously investigated without delay; for there is not the slightest doubt that the introduction of cultivated plants, and the changes caused in the ground by their cultivation, as well as the introduction of Old-World weeds and insects, must, before long, lead to the extermination of many of the native species. This is the more likely to be the case from many of them being of extreme rarity. In fact, according to Mr. Blackburn, one of the most remarkable features in connection with the insects of the Hawaiian Islands is "the extreme rarity of *specimens* in comparison of the number of *species*, the common insects being very few indeed, and the rather common ones almost none at all"*. We know that many of the animals of oceanic islands have become extinct within comparatively recent times; and in my mind there is not the slightest doubt that many more will be driven out of existence within the next generation or two. Every endeavour, therefore, ought to be made to induce residents in these remote islands to collect and preserve their insect inhabitants. That good results would be obtained from their doing so can be proved by the remarkable discoveries made by the late Mr. Wollaston in St. Helena, and by Mr. Blackburn in the Hawaiian Archipelago, discoveries of the greatest morphological and biological importance.

In all countries where the Coleoptera and Hymenoptera have been equally studied, it is found that the latter in numbers equal, if they do not surpass the former. Mr. Blackburn collected in the islands 428 species of beetles, whereof 352 species are at present only known from the Archipelago. As there is not one fourth of this number known of Hawaiian Hymenoptera, I think we may conclude that very many more species have yet to be discovered, even although it may ultimately be proved that they are scarcer relatively than the beetles.

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* Scient. Trans. of the Roy. Dubl. Soc. iii. p. 202.

Dr. Sharp* divides the coleopterous fauna of the islands into three divisions: first species (chiefly cosmopolitan) introduced in stores, ballast, &c., by commerce; secondly species introduced by natural currents in drift-wood, &c.; and thirdly endemic or autochthonous species, the latter being distinguished from the second by structural peculiarities, being to all appearance forms of great antiquity, the distinction between the two groups being owing, no doubt, to the fact that the autochthonous species were introduced into the islands at a much more remote period —so remote, indeed, that their nearest allies have become extinct, or nearly so, on continents, where the struggle for existence has been much keener.

My knowledge of the Hymenoptera is not sufficient to enable me to separate the species which belong to Dr. Sharp's two last categories; yet I have no doubt at all that most of the species of *Crabro, Odynerus,* and *Prosopis* have originated in the islands by evolution from one or two species introduced at some remote period into the islands by currents on drift-wood. The aculeate species found in the Archipelago belong to genera which we might *à priori* expect to find there, being species which form their nests in or on wood, the genera which nidificate in the ground being absent.

The following species have, I believe, been introduced by man's agency :—*Camponotus sexguttatus, Ponera contracta, Monomorium specularis, Tetramorium guineense, Prenolepis longicornis, Pheidole megacephala, Solenopsis geminata,* all ants of wide range. *Pelopæus cæmentarius, Polistes aurifer, P. hebræus, Xylocopa æneipennis, Evania lævigata, Metacœlus femoralis,* and *Spalangia hirta.*

It is possible that *P. hebræus* may belong to Sharp's second group, but I have no doubt that *P. aurifer* and the

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* Scient. Trans. of the Roy. Dubl. Soc. iii. p. 269.

Xylocopa have been introduced in timber from America. *Metacœlus* and *Spalangia* are parasites on the house-fly. Neither of them is, I believe, common in Europe; nor am I aware if they inhabit America. A species of *Spalangia* has been found in the Galapagos Archipelago.

The genera *Prosopis, Megachile, Odynerus, Leptogenys, Pimpla, Ophion, Limneria, Chelonus, Epitranus, Chalcis, Eupelmus,* and *Evania* have a wide range over the earth. The genus *Echthromorpha* is, so far as we know, confined to oceanic islands, the five known species being from the Hawaiian Islands, St. Helena, Ascension, and Tahiti, Society Isles, in which latter island a new species has recently been discovered by Mr. J. J. Walker, R.N. The genera *Sierola, Moranila,* and *Solindenia* are only known from the Archipelago, but our knowledge of the Chalcididæ is not sufficient to enable me to say anything very definite about the affinities of the island species. *Sierola* and *Scleroderma* belong to a group of much interest, being one which is intermediate between the Terebrant and Aculeate sections of Hymenoptera. A species of *Scleroderma,* it may be noted, is found in St. Helena.

Smith offers the opinion that the Hymenoptera are most nearly related to the American fauna. On this point I am not prepared to offer an opinion at present; and I rather think that Smith formed his conclusion on the occurrence of *Xylocopa æneipennis, Polistes aurifer,* &c., which have been introduced, as I believe, by man's agency, and consequently must not be taken into account in judging of the affinities of the endemic species.

The following is the literature relating to the Hymenoptera of the Archipelago:—

Fabricius, Ent. Syst. ii. p. 269 (*Odynerus radula*).

F. Smith, Cat. of Hymen. Ins. i. p. 23 (*Prosopis flavipes* and *P. anthracina*).

F. Smith, *l. c.* iv. p. 421 (*Crabro unicolor* and *C. distinctus* and *Mimesa antennata*).

Holmgren, Eugenies Resa, Zool. vi. pp. 406 & 441 (*Echthromorpha maculipennis* and *Rhynchium nigripenne* = *Odynerus maurus*, Smith).

F. Smith, "Descriptions of New Species of Aculeate Hymenoptera collected by the Rev. Thomas Blackburn in the Sandwich Islands," Proc. Linn. Soc. xiv. pp. 674–685; also described in his 'Description of New Species of Hymenoptera,' 1879.

Thomas Blackburn and W. F. Kirby, "Notes on Species of Aculeate Hymenoptera occurring in the Hawaiian Islands," Ent. Month. Mag. xvii. pp. 85–89.

P. Cameron, "Notes on Hymenoptera, with Descriptions of New Species," Trans. Ent. Soc. 1881, pp. 555–562 (*Sierola* (g. nov.) *testaceipes*, *Chelonus carinatus*, *Monolexis*? *palliatus*, *Chalcis polynesialis*, *Crabro polynesialis*).

P. Cameron, "Descriptions of New Genera and Species of Hymenoptera," Trans. Ent. Soc. 1883, pp. 187–193 (*Epitranus lacteipennis*, *Moranila testaceipes*, *Solindenia picticornis*, *Eupelmus flavipes*, *Evania sericea*, *Limneria polynesialis*, *L. Blackburni*, *Ophion lineatus*, *O. nigricans*).

The descriptions of new species of *Prosopis*, *Odynerus*, and *Crabro*, and the remarks thereon are by Mr. Blackburn. All that I have done in these genera is to catalogue and bring together the references to the species; also I have made certain alterations in synonymy. I have likewise to thank Mr. G. F. Matthews, R.N., for some specimens from the islands.—*P. C.*

As I have in my collection of Hawaiian Hymenoptera a considerable number of undescribed species, and made various observations of habits &c., at periods subsequent to the description by Messrs. F. Smith, W. F. Kirby, and P. Cameron, of certain new species, I think that it will be desirable for me to put forth a paper on these insects in which I shall endeavour to include the hitherto undescribed species, and add such remarks as may seem profitable concerning those that have already been described.

The Hymenopterous fauna of the Hawaiian Archipelago is, I believe, a rich one. It held a claim on my entomological energies so decidedly second to that of the

Coleoptera, that I think the fact of its being represented in my collection by considerably more than a hundred species, to be very conclusive on the point, that a specialist studying the group would reap a great harvest were he to visit the locality.

I have published (in the Scientific Trans. of the Royal Dublin Soc. 1884, pp. 87 *et seq.*) some general remarks on the climate &c. of the Hawaiian Islands in their relation to the insect-fauna, to which I will venture to refer for the generalities that might perhaps be looked for as an introduction to such a paper as the present, merely adding that (so far as I can judge) Maui is not, in respect of this group of insects, so clearly the metropolis of the islands as it is in respect of other groups. It has produced (as will appear from what follows) one or two of the most striking and specialized types, it is true; but, nevertheless, I am inclined to think that it must yield to Hawaii the claim to be the Hymenopterous centre, as that island has yielded the most numerous and most strongly-marked forms in every family but two, viz. Apidæ and Sphegidæ. The species (*Prosopis rugiventris,* mihi) of the former, on which this remark is founded, very probably is confined to Maui (and the closely adjacent island Lanai), while the occurrence there, either solely or in much greater numbers than elsewhere, of *P. Blackburni,* Sm., and *P. hilaris,* Sm. (two of the most striking species of the genus), confirms the probability that Maui really is peculiarly rich in these insects. The occurrence in very small numbers of *Mimesa antennata,* Smith, of which no close ally has occurred in other localities, may possibly be due merely to insufficient observation on my part, and, therefore, will not count for much; while, on the other hand, the fact that the Vespidæ and Crabronidæ of Hawaii are so much more striking in appearance and specialized in structure than those of any other island is, I feel no doubt whatever, due genuinely to the Hymenopterous wealth of the island.

ANTHOPHILA.

ANDRENIDÆ.

In this family the indigenous species are not improbably confined to the genera *Megachile* and *Prosopis*. *Apis mellifica,* Linn., is of course introduced, and it can hardly be thought likely that *Xylocopa æneipennis,* De Geer, is a true native of the islands. It may fairly be questioned whether the destructiveness of the latter does not more than counterbalance the profitableness of the former. The habits of the single Hawaiian species of *Megachile* noticed by me have been fully reported by Mr. F. Smith. The descriptions &c. of the species of *Prosopis* found on the Archipelago are so scattered, and contain so many slight inaccuracies, that I think it might be well for me to review them *seriatim,* adding descriptions of certain additional species, and furnishing a Table of their distinctive characters, as follows:—

1. *Prosopis fuscipennis.*

Prosopis fuscipennis, Smith, Proc. Linn. Soc. xiv. p. 682; Kirby, Ent. Month. Mag. xvii. p. 85.

I have nothing to add to the excellent description of this species in Mr. F. Smith's two papers. I have never taken it elsewhere than on Oahu, and there only rarely.

2. *Prosopis satellus,* sp. n.

Niger; confertim punctatus; clypeo (antice rotundato), antennarum articuli basalis fronte, tarsis tibiarumque anticarum fronte, testaceis, antennarum articulo basali valde compresso; alis fuscis.

Long. 11 millim.

This species is allied to *P. fuscipennis*, Sm., from which it differs as follows:—The clypeus is yellow, the anterior margin of the thorax is not testaceous, the tegulæ are paler, the punctuation throughout is finer and closer (especially so on the metathorax, which is a little rugose only in front and on the hind body). The basal joint of the antennæ is much more strongly compressed, being on its flat face as wide as long, and has its front side more strongly rounded than the hinder side.

I have seen only a single male of this insect, which occurred in September on Haleakala, Maui, at an elevation of about 5000 feet.

3. *Prosopis Blackburni.*

Prosopis Blackburni, Smith, Proc. Linn. Soc. xiv. p. 682; Kirby, Ent. Month. Mag. xvii. p. 85.

The original description of this insect was founded, I believe, on a single individual of each sex, the male being an unusually brightly coloured one. At a subsequent period I met with the species plentifully, and the examination of something like a hundred specimens has satisfied me that it is subject to much variation. I think therefore that it will be well to supplement the description with a further one, somewhat more in detail. The distinctive characters seem to be as follows:—Head unusually elongate in both sexes, the width across and including the eyes being scarcely equal to the total length. The clypeus is abruptly truncate or even gently concave at the apex. In the male the whole space below the antennæ is yellow, and this colour is produced in a triangular form between the base of the antennæ, and also runs back as a gradually narrowing vitta adjacent to the eyes on either side of the head. The extent of this colouring is subject to occasional variety; I have a specimen in which the small plate between the clypeus and the antennæ is black, and several specimens in which the lateral yellow vittæ are abbreviated, but none in which the yellow colouring is confined to the space in front of the antennæ. The least brightly coloured specimens, moreover, differ from *P. facilis,* Sm., in having the entire space between the eyes and the clypeus yellow. The scape of the antennæ is not much dilated in the male, being more than twice as long as wide, and moderately arched; it is generally black, and rarely displays the yellow line mentioned in the original description. In both sexes the flagellum is yellow (or at least ferruginous) beneath; in some instances the whole flagellum, and even the scape, is red, the underside of the former being then of a vivid yellow. The colouring of the legs varies, even in the male, from that described by Mr. Smith, to an almost uniform pitchy colour, save that the front of the front tibiæ is always pale, and the tarsi are seldom obscured. The wings have scarcely any trace of fuscous colouring in the male and not much in the female. The size of the male varies from 7–10 millim. long, that of the female from 8–11 millim. long. I have this species from Maui, Lanaii, and Hawaii. Specimens from Hawaii seem to be, as a rule, more obscurely coloured than those from other localities. The brightly coloured type occurs on Maui, near the sea-coast.

4. *Prosopis facilis.*

Prosopis facilis, Smith, Proc. Linn. Soc. xiv. p. 683; Kirby, Ent. Month. Mag. xvii. p. 85.

Of this insect I have examined about 50 examples. It is not very close to any other of the genus, nor does it vary much. The original description is a good one, but may advantageously be amplified a little. *P. Blackburni,* Sm., is, I think, its nearest ally. The head is moderately elongate, but decidedly less so than in *P. Blackburni,* the width from eye to eye in front of the base of the antennæ being about the same as the length from the base of the antennæ to the apex of the clypeus. The apex of the clypeus is rounded. There is a very distinct elongate depression on either side of the head close to the eyes. The clypeus and the plate between it and the antennæ are yellow in the male, as also is a narrow space on either side of the clypeus, but the yellow colouring extends laterally to the eyes only in the extreme front, and does not extend at all behind the antennæ, so that the head even in front of the antennæ is only partially yellow. The antennæ are uniformly of a blackish colour, the basal joint being not much dilated but very strongly arched in the male. The punctuation does not differ much from that of *P. Blackburni,* the upper surface of the hind body showing no distinct punctures. The legs are of a blackish colour, except the front tibiæ and tarsi of the male, which are more or less testaceous in front. The size of the male varies from 6½–10 millim. long, that of the female from 7–10½ millim. long.

The original types of *P. facilis,* Sm., were from the Pauoa Valley, Oahu (not from Maui as stated by Mr. Smith). The insect, however, occurs on Maui and also on Hawaii.

The only colour vars. I possess of the male have the plate between the clypeus and the antennæ black.

5. *Prosopis flavifrons.*

Prosopis flavifrons, Kirby, Ent. Month. Mag. xvii. p. 85 (♂).

Allied (but not very closely I think) to *P. Blackburni,* Sm., and *P. facilis,* Sm. This insect may be readily identified by the following characters:—The yellow mark on the face occupies the whole space in front of the antennæ, but does not extend behind them. The clypeus is rounded in front. The basal joint of the antennæ is extremely compressed, being, on the flat face, scarcely longer than wide, and of subcordiform shape; the anterior margin of this joint is narrowly testaceous. Near its apex the flagellum is testaceous beneath, while the legs are of an obscure colour except the front tibiæ, which are testaceous in front. The head does not differ much in shape from that of *P. facilis*, Sm., nor is the punctuation of the insect much different. The length is about 7½ millim. I have found this species only on Kauai, and have not seen the female.

6. *Prosopis Kona*, sp. nov.

Niger, flavo-variegatus, haud crebre punctatus; capite minus elongato, clypeo antice rotundato; alis hyalinis.

♂. Antennarum articulo basali fortiter compresso.

Long. ♂ 5 millim., ♀ 7 millim.

This is a very distinct species. In the male the face is coloured as in typical *P. Blackburni.* The anterior margin of the thorax and a spot under the tegulæ are yellow; the tibiæ are yellow with a black spot on the posterior face of the front pair, and a similar spot on each side of the others; the first joint of each tarsus is yellow, the remainder are fuscous; of the antennæ the lower surface of the flagellum is testaceous, and the basal joint is much compressed (considerably more so than in *P. Blackburni*), but the dilated face is quite evidently not so wide as long, and its sides are strongly rounded. The hinder portion of the head is closely and very finely punctured; the surface of the thorax is opaque with excessively minute punctuation, and has also some larger punctures (but even these are fine), the cavities of which, under a strong lens, are shining; on the postscutellum the system of larger punctures seems to fail; the metathorax is more shining, and its sculpture seems to consist of a mixture of very fine granulation and some oblique wrinkles; the upper surface of the hind body is not very shining, and its sculpture consists of excessively minute punctuation invisible, except under a very strong lens; while the undersurface is similarly punctured with the addition of a system of much larger but very feeble shallow punctures.

The female (save in the usual respects) does not differ much from the male; it is larger, however, and the colouring of its head consists in a slender yellow line along the internal margin of the eyes.

I obtained three specimens of this little insect on the western slopes of Mauna Loa, Hawaii, at an elevation of about 6000 feet, in May.

7. *Prosopis coniceps*, sp. nov.

Niger, flavo-variegatus, punctatus; capite brevi pone antennas tumidulo; clypeo antice rotundato; alis hyalinis.

♂. Antennarum articulo basali compresso, minus elongato. Long. ♂ 6½ millim.

In this species the markings on the head are peculiar,—the anterior third of the clypeus is entirely yellow, the posterior quarter entirely black, the apical yellow being produced backwards in the middle of the intervening space as a broad band, while the basal black is narrowly produced forwards on either side of it; there is also a large yellow triangle on either side between the clypeus and the eye. The yellow colouring does not extend as far backwards on the head as to the base of the antennæ. The front side of the front tibiæ is yellow; the tarsi are testaceous at the base, becoming fuscous towards the apex; the rest of the insect is black. I find no very noticeable difference between this species and *P. facilis*, Sm., in respect of punctuation, except that the head is rather more roughly punctured behind the antennæ. The head is very short, the distance from eye to eye across the front of the base of the antennæ being very considerably greater than from the base of the antennæ to the base of the clypeus. The portion of the head behind the antennæ is tumid, so that the ocelli seem to be placed on a rounded swelling. The apex of the clypeus is rounded. The underside of the hind body is sparingly and not strongly punctured. The basal joint of the antennæ is rather strongly dilated in the male, its length being hardly twice its width.

A single specimen occurred on Mauna Kea, Hawaii, at an elevation of about 7000 feet, in February. A female taken in the same neighbourhood probably belongs to this species, as its head is similarly formed, though it is less roughly punctured. It is quite black, except the legs, which are dark pitchy, and the wings are much clouded with fuscous.

8. *Prosopis rugiventris*, sp. nov.

Niger; obscure punctatus; antennarum flagello apicem versus ferrugineo; abdomine plus minusve rufescente; clypeo antice subtruncato.

♂. Fronte testacea; tibiis anticis dilutioribus; antennarum articulo basali fortiter compresso, vix quam latus longiore; abdominis segmentis ventralibus nitidis, inæqualibus.

Long. ♂ 5½–8 millim., ♀ 7 millim.

The punctuation does not appear to differ much from that of *P. Blackburni*, Sm., which this insect resembles also by its scarcely less elongate head and the only slightly rounded apex of the clypeus. In the male the face is entirely (or almost entirely) yellow in front of the antennæ, but the yellow colouring does not pass the antennæ backwards. The flagellum is testaceous on the underside, in some specimens entirely ferruginous. The front tibiæ of the male are testaceous in front. In both sexes the hind body is reddish (in some specimens quite red). The basal joint of the antennæ in the male is strongly compressed, its flat face being scarcely longer than broad. The hind body beneath is almost impunctate and very shining in the same sex, while across each segment runs a transverse, rounded, and sinuated ridge, more strongly developed in some specimens than in others.

I possess two specimens of this insect from Maui and five from Lanai. One of them (taken in company with the males) is a female, and closely resembles the female of *P. Blackburni*, Sm.

9. *Prosopis hilaris.*

Prosopis hilaris, Smith, Proc. Linn. Soc. xiv. p. 683; Kirby, Ent. Month. Mag. xvii. p. 85.

The male has been well described by Mr. Smith. The female closely resembles it, being, however, somewhat larger (9–9½ millim. long). The colouring is precisely similar, save that bright yellow is replaced by obscure testaceous. The basal joint of the antennæ is, of course, not dilated, and the apical segments of the hind body present the usual sexual differences.

10. *Prosopis volatilis.*

Prosopis volatilis, Smith, Proc. Linn. Soc. xiv. p. 683; Kirby, Ent. Month. Mag. xvii. p. 85.

This species (the male of which has been well described by Mr. Smith) was taken on Oahu (not Kauai, as stated in the original description). I have not seen the female.

Table of Species of Prosopis.

1.	Anterior margin of thorax yellow	2
	Anterior margin of thorax not coloured yellow	3
2.	Upper surface of hind body distinctly punctured	*fuscipennis*, Sm.
	Upper surface of hind body not distinctly punctured.	*Kona*, mihi.
3.	Ventral segments even in both sexes	4
	Ventral segments transversely ridged in the male	*rugiventris*, mihi.
4.	Upper surface of hind body not distinctly punctured	5
	Upper surface of hind body with well-defined punctuation	*satelles*, mihi.
5.	Hind body black	6
	Hind body red	9
6.	Head short (*i. e.* distance from eye to eye in front of antennæ considerably greater than from antennæ to apex of clypeus)	*coniceps*, mihi.
	Head elongate (*i. e.* the former of these distances not, or scarcely, exceeding the latter)	7
7.	Apical margin of clypeus distinctly rounded	8
	Apical margin of clypeus truncate	*Blackburni*, Sm.
8.	Basal joint of antennæ not, or scarcely, longer than wide in male	*flavifrons*, Sm.
	Basal joint of antennæ much longer than wide	*facilis*, Sm.
9.	Yellow markings on face of male extending behind the antennæ	*hilaris*, Sm.
	Yellow markings on face of male not passing behind the antennæ	*volatilis*, Sm.

The following two species have been described by Mr. F. Smith in his Cat. of Hymen. Ins. pt. i. p. 23, from the Sandwich Islands. It is more than probable that they are identical with some of the species described above, but, as the descriptions are not very clear, and as I have not specimens of all the species for comparison, I have not been able to satisfy myself as to this. To make the descriptions of *Prosopis* complete, I give a copy from Smith's work of those of *P. anthracina* and *P. flavipes*.—*P. C.*

11. *Prosopis anthracina.*

"*Female.* Length 2½ lines. Entirely black, head and thorax very finely punctured, the apical joints of the antennæ testaceous beneath. Thorax, the tegulæ testaceous, the wings hyaline, the nervures dark testaceous; the enclosed portion of the metathorax longitudinally irregularly sulcate at its base. Abdomen very smooth and shining, beneath it is dark fusco-ferruginous, as well as the legs; the claws ferruginous.

"*Male.* The clypeus and a space on each side not touching the eyes, forming together an oval, bright yellow; the scape dilated, triangular; the flagellum testaceous beneath. Thorax, the anterior tibiæ in front, and the claws testaceous; otherwise as in the other sex.

"*Hab.* Sandwich Islands."

12. *Prosopis flavipes.*

"*Male.* Length 2¼ lines. Black; the face yellow, the colouring is continued upwards on each side nearly to the vertex of the eye; the scape cylindrical, black, the rest of the antennæ orange, yellow beneath. Thorax, the metathorax has no distinctly enclosed space, and is subrugose; the wings hyaline, the nervures dark fuscous, all the tibiæ and tarsi bright yellow, the former have a ferruginous stain behind. Abdomen smooth and shining, the margins of the segments narrowly rufo-testaceous.

"*Hab.* Sandwich Islands."

APIDÆ.

13. *Megachile diligens.*

Megachile diligens, Smith, Proc. Linn. Soc. xiv. p. 684; Kirby, Ent. Month. Mag. xvii. p. 86.

Not uncommon. "Forming nests of leaves of a species of *Acacia* rolled up into cylindrical cells, which are joined one at the end of another to the length of several inches, and are placed in crevices of masonry."—*T. B.*

14. *Xylocopa æneipennis.*

Xylocopa æneipennis, De Geer, Mémoires, iii. p. 573, tab. 28. f. 8; St. Fargeau, Hym. ii. p. 186; Smith, Proc. Linn. Soc. xiv. p. 684.

Very common and extremely destructive to wood by forming its nests in it, the nests being long galleries and made in dead or living trees.

FOSSORES.

VESPIDÆ.

15. *Polistes aurifer.*

Polistes aurifer, Saussure, Mon. Guêpes Soc. p. 78.

Common, forming its nests in wood.

16. *Polistes hebræus.*

Vespa hebræa, Fab. Mant. Ins. i. p. 292.
Polistes macaensis, Fab. Syst. Piez. p. 272.

Common in Oahu. The specimen I have is nearly identical with the figure given by de Saussure of the var. *macaensis* in his Mon. Guêpes Soc. pl. vii. f. 1. The species has a wide range over Asia &c.

17. *Odynerus radula.*

Vespa radula, Fab. Ent. Syst. ii. p. 269.
Odynerus localis, Smith, Proc. Linn. Soc. xiv. p. 678; Kirby, Ent. Month. Mag. xvi. p. 86.

Common on Kauai.

18. *Odynerus extraneus.*

Odynerus extraneus, Kirby, Ent. Month. Mag. xvii. p. 86.

Hab. Kauai.

19. *Odynerus nigripennis.*

Rhygchium nigripenne, Holmgren, Eugenies Resa, Zool. vi. p. 441.
Odynerus maurus, Smith, Proc. Linn. Soc. xiv. p. 679.

Common at Honolulu.

20. *Odynerus dromedarius*, sp. nov.

♀. Robustus, subnitidus, subtiliter pubescens, punctatus, niger; fronte rubro-maculato; alis læte cæruleis; clypeo leviter emarginato; abdominis segmento primo fortiter transverso, antice verticali, segmento secundo fortiter tuberculato-elevato; metathorace haud rugoso.

Long. 15 millim.

The head is rather closely and coarsely, but not deeply, punctured; the prothorax, mesothorax, and scutellum have two systems of punctuation,—one very fine and close, the other larger and sparing,—the larger punctures being almost non-existent on the scutellum and postscutellum. The metathorax is finely alutaceous, and bears a few rather large, but not deep, punctures. The hind body is finely and sparingly punctured to near the apex of the second segment, where the punctuation becomes (and it continues over the next three segments) coarse and rather close. The wings are of a very beautiful bright blue colour. The elevation of the second segment of the hind body gives the insect a most remarkable appearance, the summit of the "hump" into which the segment is gathered up appearing (when viewed from the side) to be abruptly raised above the first segment by about a third the total height of the segment. The pubescence (of a whitish colour) is very fine and is dense enough to prevent the surface from being very shining.

A single specimen of this most distinctive insect occurred in February on Mauna Loa, Hawaii, at an elevation of about 4000 feet, near the crater Kilauea, flying in the forest. Another (much dilapidated) specimen taken at the same time and place, is probably conspecific, but if so has lost the beautiful colour from the wings. It is devoid of pubescence, and therefore, I think, more shining and more conspicuously punctured. This difference, however, is so strongly defined on the metathorax that I hesitate to associate the two.

21. *Odynerus vulcanus.*

O. vulcanus, sp. nov. ♀. Robustus, vix nitidus, subtiliter pubescens, fortiter punctatus, niger; alis violaceis; clypeo vix emarginato; abdominis segmento primo fortiter transverso, antice verticali, secundo fortiter tuberculato-elevato; metathorace rugoso.

Long. 15–16 millim.

This species is allied to the preceding, from which it differs as follows:—The apex of the clypeus is scarcely emarginate; there is no red spot on the forehead; the punctures on the head are much deeper, and therefore more distinct; the system of larger punctures on the prothorax, mesothorax, and scutellum is much closer and deeper; the metathorax is opaque and strongly rugose; the first segment of the hind body is very strongly and rather closely punctate; the second segment of the same is a little less conspicuously elevated, and the wings are violet rather than blue.

Two specimens occurred at the same time and place as the preceding.

N.B. In my collection are two males and one female of an *Odynerus,* taken on Mauna Kea, Hawaii, which I am unable to separate from *O. vulcanus,* although they appear somewhat more shining than a little rubbing would account for. The length of these males is 13 millim. Their differences from the female do not seem to call for remark, being only the usual structural differences. The small apical joint of their antennæ is of a testaceous colour.

22. *Odynerus hawaiiensis.*

O. hawaiiensis, sp. nov. Minus robustus, subopacus, subtiliter pubescens, niger; mandibulis rufis; alis violaceis; clypeo vix emarginato; capite abdomineque obscure, thorace vix evidenter punctatis; abdominis segmento primo vix transverso, antice subverticali, secundo tuberculato-elevato.

Long. ♂ 12 millim., ♀ 13–13½ millim.

Rather an obscure-looking species. The head is somewhat closely punctured, but the punctures are faintly impressed; the rest of the trunk appears impunctate, but opaque; when examined with a lens, however, it is seen to have a double system of punctuation, but it is all so faintly impressed as to be hardly noticeable. The metathorax is delicately alutaceous rather than punctured. The basal segment of the hind body is about as long as its greatest width, somewhat (but not abruptly) vertical in front, and thickly covered with large shallow punctures; the next two segments have fine punctures in front and large ones behind; the remainder (except the last) are coarsely but not deeply punctured. The apical joint in the antennæ of the male is testaceous. Allied to *O. vulcanus.* This species is easily distinguishable by its mandibles, more or less red, and by the shape of the first segment of the hind body, which is especially noticeable if looked at from the side, when it is seen to be longer (from the apex of the petiole) than high, whereas the proportion is reversed in *O. vulcanus.*

I have taken this insect several times on the mountains of Hawaii. It is somewhat variable; I have several specimens that I attribute to it, in which the punctuation is even more faintly impressed than in the type, and one in which the metathorax is slightly rugose. I have also a male (possibly a distinct species) which seems a little more strongly punctured, and has the basal segment of the hind body margined with testaceous behind. I have also a female differing from the type in having the apex of the clypeus (as well as the mandibles) red. One specimen departs from the type in having the clypeus somewhat more deeply emarginate, in one or two the tuberculate form of the second segment of the hind body is only feebly developed, in another the wings are almost devoid of colouring, and in another one mandible is black.

23. *Odynerus haleakalæ.*

O. haleakalæ, sp. nov. Subnitidus, subtiliter pubescens, niger; mandibulis plus minusve rufis; alis violaceis; clypeo minus emarginato; capite thoraceque crebre fortiterque punctatis; abdominis segmento primo transverso, antice parum verticali, crassius nec fortiter punctato; segmento secundo tuberculato-elevato.
Long. ♂ 12 millim., ♀ 15 millim.

Both head and thorax have a double system of punctuation. On the head the larger punctures are so close and deep that the finer ones need looking for; on the thorax (including the scutellum) the larger ones are more sparing, while the smaller ones are more noticeable on the prothorax, but become less so backwards, being scarcely discoverable on the metathorax. The first segment of the hind body is rather strongly transverse, much rounded off (*i. e.* not vertical) in front, and is only sparingly, though rather strongly, punctate. The second segment is rather strongly elevated into a tubercular shape; it is very finely and sparingly punctate to near the hind margin, where the punctuation becomes coarse. The next three segments are coarsely punctate. The apical joint of the antennæ in the male is testaceous. The wings are of a bright violet colour.

The general resemblance of this insect is to the preceding species, from which it differs in being much more shining and much more strongly punctate, as well as in the shape of the first segment of the hind body &c. &c. From *O. congruus*, Sm., it differs in the shape of the second segment of the hind body, the punctuation of the head, &c.; from *O. dubiosus*, Sm. (which has a faint development of the tubercular form of the second segment of the hind body), by its considerably stronger and closer punctuation, and by the much less vertical front of the basal segment of the hind body; from *O. maurus*, Sm., by the much less crowded punctuation of the head and thorax.

I have taken this insect occasionally on Haleakala, Maui, always at a considerable elevation (4000–6000 feet above the sea).

24. *Odynerus congruus.*

Odynerus congruus, Smith, Proc. Linn. Soc. xiv. p. 680.

Hab. Honolulu: not rare.

25. *Odynerus dubiosus.*

Odynerus dubiosus, Smith, *l. c.* p. 681.

Hab. Honolulu.

26. *Odynerus rubritinctus.*

Odynerus rubritinctus, Smith, Proc. Linn. Soc. xiv. p. 679.

Not uncommon on Kauai.

27. *Odynerus Blackburni.*

Odynerus Blackburni, Kirby, Ent. Month. Mag. xvii. . 87

A succession of accidents have resulted in the publication of this name without any insect having been described under it. Some time in 1878 I presented to the British Museum a small collection of Hymenoptera containing, among other things, two red-spotted *Odyneri* (male and female), one specimen of each. Mr. F. Smith described them as the sexes of a new species, which he called *O. rubritinctus*. As I possessed the other sex of each, I knew that the differences were not sexual. Mr. Smith's lamented death prevented any further communication with him on the subject, but soon afterwards I wrote to his successor at the museum (Mr. W. F. Kirby) regarding this, and others of Mr. Smith's determinations, and the result was that Mr. Kirby published in the 'Entomologist's Monthly Magazine,' a paper to which he attached my name as well as his own, initialing each constituent part thereof. In this paper he published what I had written to him regarding *O. rubritinctus*, Sm., and added a note of his own, in which he proposed a new name for the male mentioned above (paying me the compliment of calling it *O. Blackburni*), and proposed to leave the female (on the ground, I suppose, that Mr. Smith described it before the male) in sole possession of the name *O. rubritinctus*, Sm. Hence of *O. Blackburni*, Kirby, the only description existing is one of less than five lines under the heading "*O. rubritinctus*" (Linn. Soc. Journ. vol. xiv. p. 674, and "Descriptions of New Species of Hymenoptera in the Collection of the British Museum, 1879"), pointing out its supposed sexual differences from its (supposed) female. I think, therefore, that it will be necessary for me now to describe *O. Blackburni*, Kirby, as follows:—

Subnitidus, parce subtiliter pubescens, punctatus, niger, rufo-maculatus; alis fuscis (nec violaceis); clypeo vix emarginato; abdominis segmento primo fortiter transverso, antice verticali; segmento secundo vix tuberculato-elevato, postice haud rufo-marginato.

Long. ♂ ♀ 11 millim.

Head closely set with large but shallow punctures; thorax punctured as much as the head, but with the punctures becoming more sparing backwards, the metathorax strongly rugose. The first segment of the hind body is rather closely and strongly punctured, very transverse and somewhat abruptly vertical in front, the second segment has fine and deep punctures at the base, which become gradually larger and shallower towards the apex; the segment itself only slightly approaches the tubercular form, but, viewed from the side, is seen to have a decidedly greater longitudinal convexity than the rest; the following three segments are punctured much as the apical part of the second. The insect is black, with the following parts red: the mandibles, a spot between the eyes, the tegulæ, two spots below the tegulæ, the scutellum, the postscutellum, the first segment of the hind body, a large spot on either side of the second segment. These markings are probably variable, as some of them, in one or other of my two specimens, are more or less obscured with black spots or clouds. The wings are shining fuscous, without any coloured iridescence. The legs are blackish, with shining fuscous pubescence. The apical joint of the antennæ, in the male, is obscurely testaceous.

Very closely allied to *O. rubritinctus*, Sm., but differs in the colour of the wings and in the absence of a red hind margin to the second segment of the hind body. Of fifteen specimens of *O. rubritinctus* in my collection not one varies in either of these respects.

Occurred on Kauai in August.

28. *Odynerus montanus.*

Odynerus montanus, Smith, *l. c.* p. 680.

Common on mountains of Oahu.

29. *Odynerus cardinalis.*

O. cardinalis, sp. nov. Robustus, nitidus, parum pubescens, perniger; alis splendide purpureis, capite fortius confertim, thorace sparsim subtilius, punctatis; clypeo vix emarginato; abdomine sparsim subæqualiter punctato, segmento primo fortiter transverso, antice haud verticali, segmento secundo vix tuberculato-elevato.

Long. ♂ 9 millim., ♀ 12–14 millim.

Though not a large insect, nor structurally isolated, this is by far the handsomest of the Hawaiian *Odyneri*. The body is of a deep shining black, the wings of a really gorgeous purple colour. The head is closely and deeply punctured, but the punctures are small. The whole thorax is brightly shining, the punctuation on the prothorax and metathorax being far from crowded, that on the scutellum extremely sparing; the metathorax is almost impunctate, and is quite smooth. The hind body is brilliantly shining, sparingly set with fine punctures, which are rather evenly distributed, but become a little coarser near the apex. The first segment is very strongly transverse, and, viewed from the side, its upper outline forms a continuous gently rounded ascent from the petiole to the apical margin, no part being at all vertical. The second segment has but little indication of tendency to a tubercular form. The apical joint of the antennæ in the male is obscurely testaceous.

The nearest ally of this insect is *O. montanus*, Sm., from which it may be at once distinguished by the richer colouring of the wings, the smooth metathorax, and the form of the first segment of the hind body (which in *O. montanus* is subvertical in front).

I have taken this fine species in several localities on Oahu. It does not seem to be confined to the mountains.

30. *Odynerus pacificus.*

O. pacificus, sp. nov. Parum nitidus, punctatus, subtiliter pubescens, niger; abdomine antice rufo; alis fuscis, obscure violaceis; clypeo antice fortius emarginato; abdominis segmento primo transverso, antice verticali.

Long. ♂ ♀ 11 millim.

Scarcely shining, the clypeus quite strongly emarginate. The head and thorax rather roughly and closely punctured, the punctures large, confused, and faintly impressed. The punctuation of the hind body resembles that of the preceding species; the basal segment is entirely red above, but obscured with black beneath; the second segment is entirely red beneath, but on the upper surface it is black at the base, and (in some specimens) more or less obscure or blackish at the apex; the remaining segments are blackish. In two of my specimens the apex of the clypeus is reddish. The apical joint of the antennæ in the male is testaceous. The wings have scarcely any violet iridescence. This is not closely allied to any other species I have seen. I have taken it singly on Maui and Hawaii.

31. *Odynerus rubro-pustulatus.*

O. rubro-pustulatus, sp. nov. Nitidus, punctatus, parum pubescens, niger; abdomine rubro-maculato; alis fuscis, cæruleo-iridescentibus; clypeo antice truncato; abdominis segmento primo transverso, antice verticali.

Long. ♂ 7–9 millim.

Rather brightly shining, the pubescence scarcely discernible. The head and thorax are rather strongly and closely punctured (but gradually less closely backwards), the metathorax is not very rugose. There is a red spot (absent in some specimens) behind the base of the antennæ. The sides (broadly) and the apical margin (narrowly) of the basal segment of the hind body are red, its undersurface is red, more or less clouded with fuscous or black; the second segment is red, except an abbreviated central line on the underside, and so much of the upper surface that the red appears as a rounded patch on either side, not extending to the base or apex; the remaining segments are black. The apical joint of the antennæ, in the male, is testaceous. The basal segment of the hind body is extremely strongly punctured, the punctures being rather elongate; the punctuation of the remaining segments does not differ much from that in the preceding two species. The legs are of an obscure colour, with fuscous pubescence.

This insect occurs on the higher mountains of Hawaii, at elevations 5000–7000 feet above the sea.

N.B. I regard as probably the female of this species some individuals of that sex taken in the same locality, which differ in being larger (long. 10–11 millim.), in having the wings of a rich blue (rather than violet) colour, and the upper surface of the basal segment of the hind body more broadly red at the sides.

32. *Odynerus obscure-punctatus.*

O. obscure-punctatus, sp. nov. Subopacus, subtiliter pubescens, niger; mandibulis rufis; abdomine rufo-maculato; alis cæruleo-iridiscentibus; clypeo vix emarginato, capite thoraceque vix punctatis; abdomine punctato minus opaco, segmento primo transverso, antice verticali.

Long. ♂ 8–12 millim., ♀ 12 millim.

Less shining than the preceding, which it resembles. The head and thorax are very faintly punctured, the punctures being not at all close to each other, and hardly observable without the help of a lens. The metathorax is only slightly rugose. The pubescence is easily seen with a lens. The first two segments of the hind body are red at the sides on both the upper and undersurfaces. The hind body is evidently more shining than the thorax; its structure and punctuation are much as in the preceding species. The wings of a rich bluish purple colour. The apical joint of the antennæ, in the male, is obscurely testaceous.

This species is, in most respects, perplexingly close to the preceding. It is difficult to specify any colour difference beyond that the mandibles are, in this, red, occasionally varying to reddish pitchy, while in the former they are black varying to pitchy; and that the red markings on the hind body, though similar in form and distribution, are generally smaller in this than in the other; the proportions of the red and black on the underside of the hind body vary in both species. The punctuation of the head and thorax, however, is so entirely different in the two, without appearing to vary, that I must consider them distinct.

Not rare on the higher mountains of Hawaii.

33. *Odynerus diversus.*

O. diversus, sp. nov. ♂. Subnitidus, crasse punctatus, niger, rufo-maculatus; alis hyalinis, harum nervulis et parte anteriori nigro-fuscis; clypeo antice fortiter emarginato; abdomine dense fusco pubescente, segmente primo fortiter transverso, antice haud verticali, secundo vix tuberculato-elevato.

♀. Clypeo vix emarginato.

Long. 12–14 millim.

Black, with the following parts red, viz.:—A spot behind the base of the antennæ, the greater portion of the prothorax, some spots on the tegulæ and a spot below them, some spots on the scutellum and postscutellum, the hind margin of the basal segment of the hind body, the hind margin of the second segment and an oblique spot on each side of the same, and the hind margin of the third segment. The head is closely and coarsely punctured; the thorax has a double system of punctuation, the smaller punctures not very close, the larger very coarse; the metathorax is coarsely punctured, but scarcely rugose; the hind body is sparingly punctured, the punctures obscure and lightly impressed, but becoming stronger in the apical half, the basal segment very strongly transverse, and not at all vertical in front. The fuscous pubescence on the hind body is fine and quite dense, giving the insect a silky appearance.

I have one male and three females of this distinct species; all were captured on the mountains of Oahu. The difference between the clypeus of the male and of the female is so exceptionally strong, that I suspect the male of being a variety, though I notice a slight (indeed scarcely discernible) difference of the same kind in most species of the genus in my collection.

34. *Odynerus agilis.*

Odynerus agilis, Smith, *l. c.* p. 681.

To this species I attribute numerous individuals captured by me in various localities on Maui, Lanai, and Hawaii. If I am right in doing so, this is one of the most variable species of the genus, and the original description needs the addition of the following note:—

The degree of intensity with which the punctuation on the thorax is impressed differs in almost every two specimens, until in the extreme form no punctuation is visible without the use of a lens, by means of which, however, it is seen that the punctures of the type are present, only with the appearance of having been very nearly obliterated. The mandibles vary in colour to pitchy, and even red. The yellow spot behind the base of the antennæ is generally absent. The postscutellum is occasionally spotted with yellow. One or other, or both, of the yellow rings on the hind body may be extremely indistinct or wanting. The length varies from 12–16 millim. The female does not noticeably differ from the male, except by the usual sexual characters.

The distinctive features of the species are its whitish pubescence and the extremely strong emargination of the apex of the clypeus, the edges of the emargination being more or less strongly produced forwards in an almost cylindric shape.

35. *Odynerus insulicola.*

O. insulicola, sp. nov. Subnitidus, pubescens, minus crebre punctatus, niger, flavo-notatus; alis subhyalinis obscure cæruleo-iridescentibus; clypeo antice emarginato; abdominis segmento basali transverso, antice verticali.

Long. ♂ ♀ 9–11 millim.

The punctuation of the head and thorax is rather deep, but not coarse, and is somewhat sparsely distributed, becoming even more sparing on the scutellum and post-scutellum. The metathorax is feebly rugose. The basal segment of the hind body is strongly and moderately closely punctate, while the punctures of the second segment are fine, becoming coarser towards the apex, and the punctuation so continues on the other segments. The tibiæ and tarsi are much clothed with ashy pubescence, and there is a good deal of whitish pubescence on the body.

The male has the following parts yellow, viz.:—The clypeus (wholly or in part), the front of the scape and the apical joint of the antennæ, some spots on the prothorax, on the tegulæ, and on the tibiæ, and the dorsal hind margin of the basal two segments of the hind body. Some or other of these markings are wanting in most specimens, but I have seen none in which the clypeus is not entirely (or very nearly so) of a bright yellow colour. The female is quite devoid of colour, save that in some specimens the apical dorsal margin of one or both of the basal two segments of the hind body is obscurely testaceous.

This insect occurs on the sandy isthmus forming the middle of the island Maui, and on the adjacent lower slopes of Haleakala.

N.B. I possess a single male specimen of an *Odynerus* captured on Oahu, which is probably distinct from the species last described, but is too closely allied to be treated as new without the examination of a series of examples, especially in consideration of my knowledge of the extent to which the coloured markings of the Hawaiian *Odyneri* vary. It has all the yellow markings of a male *O. insulicola* (except those on the flagellum), with the addition of the following:—a spot on the head behind the base of the antennæ, the scutellum and postscutellum, and a large spot below the tegulæ. The posterior margin of the basal segments of the hind body is more broadly yellow, the basal segment itself appears a little more strongly transverse, and the punctuation of the whole insect a little more sparing.

CRABRONIDÆ.

Crabro.

As it seems desirable to furnish some further remarks on the species of this genus already described, I think it will be well for me to make a brief review of them, interpolating descriptions of the new species in my collection.—*T. B.*

36. *Crabro affinis.*

Crabro affinis, Smith, Proc. Linn. Soc. xiv. p. 677.

In this species the eyes are only moderately separated in front, and the space between them is not (as compared with same space in *C. mandibularis*) *strongly* concave near the base of the antennæ. The punctuation of the head is quite evidently (though not at all strongly) rugose, especially in the male, and there are very distinct traces of longitudinal strigosity. The eyes are facetted excessively finely in both sexes. The hind body is rather wide in the middle, thus being strongly rounded laterally.

I possess a single male taken in company with the female I sent to Mr. Smith, and clearly conspecific. The sexual differences here are very similar to those in *C. mandibularis*, Smith. The mandibles of the male are pitchy black, the face and clypeus silvery, the basal joint of the antennæ reddish pitchy (paler at the base), and a little dilated in the middle. The sexual character in the sixth joint of the antennæ consists in little more than an emargination, the apex of the joint being scarcely dentate. The second ventral segment is not at all flattened, the third scarcely, the fourth quite evidently so; the remaining segments are concave. The yellow bands on the hind body are all entire, the basal one very broad, the second narrow, the last broad.

I have no doubt the yellow markings in this species are subject to great variety.

37. *Crabro mauiensis.*

C. mauiensis, sp. nov. ♀. Subnitidus, pubescens, crebre subtiliter punctatus, niger, flavo-ornatus; clypeo aureo-piloso; alis hyalinis, infuscatis; abdomine nitido, in medio lato, vix evidenter punctato.
Long. 9 millim.

The yellow markings are as follows:—The basal two thirds of the upper surface of the mandibles, the anterior face of the basal joint of the antennæ, the sides of the prothorax and a spot near the tegulæ, the postscutellum, an interrupted band on the second dorsal segment of the hind body, a band on the fourth segment, and a spot on the fifth. The eyes are moderately facetted and not strongly separated (as compared with other species), and the forehead is strongly concave. The head is closely, finely, and smoothly punctate. The punctuation of the mesothorax is obscure, that of the scutellum and metathorax extremely fine, these parts being, however, rather strongly strigose longitudinally. The pubescence is whitish, but there is not much of it in my specimen, which is possibly abraded.

Though this insect is closely allied to *C. affinis,* Smith, the much smoother punctuation of the head, on which there is no distinct strigosity, the evidently coarser facets of the eyes and the more strongly concave forehead indicate, I think, that it is a distinct species.

A single female occurred on Maui, near Wailuku, flying over flowers.

38. *Crabro distinctus.*

Crabro distinctus, Smith, Cat. of Hymen. Ins. iv. p. 422.

This seems to be different from any of the species described by Mr. Blackburn. The following is Smith's description (*P. C.*) :—

"*Female.* Length 3 lines. Black; the head and thorax opaque; the stemmata in a curve on the vertex; the face canaliculated; the inner orbit of the eye, halfway towards the vertex and the clypeus, covered with golden pubescence; the scape and mandibles yellowish white, the tips of the mandibles, and a narrow stripe on the scape within, black. Thorax: an interrupted line on the collar, the tubercles (and a spot behind), the scutellum, and post-scutellum yellowish white; wings faintly coloured and iridescent. Abdomen: the basal segment with a large transverse irregularly-shaped spot, which is somewhat arched in front, and with two deep rounded emarginations behind, which have a wide outside extending to the apex of the spot; the second, fourth, and fifth segments have an uninterrupted fascia at their base of a yellowish white; the apical segment shining and punctured.

"*Hab.* Sandwich Islands."

39. *Crabro mandibularis.*

Crabro mandibularis, Smith, Proc. Linn. Soc. xiv. p. 677 (♀).
Crabro denticornis, Smith, Proc. Linn. Soc. xiv. p. 678 (♂); Kirby, Ent. Month. Mag. xvii. p. 87.

I feel no doubt whatever as to the specific identity of these two forms, separated with considerable hesitation by

Mr. Smith. As the female was described before the male, and the latter (as compared with most of its Hawaiian congeners) does not deserve the name *C. denticornis,* the species had better be called *C. mandibularis.*

The space between the eyes is exceptionally narrow and strongly concave. The head is very finely and smoothly punctured, with scarcely any traces of strigosity. The eyes are facetted finely in the male, by no means finely in the female. The hind body is narrow and not at all strongly rounded laterally. The ventral segments of the male resemble those of the same sex in *C. affinis.*

This species varies in colour. I have a male in which there is no yellow tint on the postscutellum.

40. *Crabro polynesialis.*

Crabro polynesialis, Cameron, Trans. Ent. Soc. 1881, p. 562.

Mr. Cameron's description requires no supplement beyond a word as to the differences between this and other species (not in Mr. C.'s possession), and a remark on the male.

The eyes are rather close to each other in front, though a little more separated than in *C. mandibularis,* Smith, and are quite strongly facetted, much more so than in *C. affinis.* The hind body is similar in shape to that of *C. mandibularis.*

In the male the antennal sexual characters are almost as in *C. mandibularis,* while the ventral depression extends quite evidently from the middle of the third segment to the apex.

Hab. Mauna Loa, Hawaii, at an elevation of 4000 feet.

41. *Crabro abnormis.*

C. abnormis, sp. nov. ♂. Minus nitidus, pubescens, creberrime subrugoso-punctatus, niger; clypeo fronteque

> lucide argenteo-pilosis, femoribus anticis antice testaceis; alis hyalinis, parum infuscatis; abdomine sat nitido, subtiliter minus crebre punctato; antennarum articulo primo subfusiformi, quinto abrupte incrassato, sexto valde acute dentato, dente quam articulus vix breviori.

Long. 11 millim.

The space between the eyes is much as in the preceding species, the granulation of the eyes being a little coarser than the male *C. mandibularis*, Smith. The head is very finely and closely punctured, and is clothed with longish fuscous hairs. The prothorax and mesothorax are finely and closely (but not very smoothly) punctured, and are clothed with fuscous hairs. On the scutellum, postscutellum, and metathorax the punctuation becomes shallow, sparing, and decidedly coarse (while there is also a fine and close punctuation), and the hairs are long and whitish. The basal segment of the hind body is clothed with long whitish hairs, the remaining segments and near the apex are devoid of hairs (in my specimen possibly abraded), and on the penultimate and apical segments there are traces of golden pubescence. The punctuation of the hind body, even to the apex, is almost obsolete. The apical third of the second ventral segment is strongly flattened or even a little concave in the middle, nearly the whole of the third segment is distinctly concave, and the remaining segments are all strongly flattened.

A single specimen of this very distinct insect occurred on Konahuanui, Oahu, at an elevation of about 2500 feet.

My collection contains a specimen of a female *Crabro* with yellow mandibles, taken at Oahu, that may possibly prove to be a female *C. abnormis*, with the punctuation not quite in its typical condition. It resembles the male in the brilliancy of the silvery pilosity on the clypeus, and in other points. Its eyes are considerably more strongly facetted. The punctuation differs slightly; on the mesothorax it appears a trifle more sparing and rugose, while the metathorax is smoother and more evenly punctured.

42. *Crabro unicolor.*

Crabro unicolor, Smith, Cat. of Hymen. Ins. iv. p. 421.

I have not seen the original description of this insect; my own examples were named by Mr. Smith. As compared with other Hawaiian species, the eyes appear to be separated by about the usual space (or even a little more) and to be facetted rather coarsely. The shape of the hind body is similar to that of *C. mandibularis*, being evidently longer and narrower than in *C. affinis* and *C. stygius* and their allies. The bright steely-blue colour of the wings is a conspicuous character. In the male the sixth joint of the antennæ is distinctly but not strongly dentate, and the flattened or concave space on the ventral segments begins near the apex of the third segment.

I have met with this insect on Oahu and Maui. It appears to be the commonest of the Hawaiian Crabronidæ, probably occurring on all the islands.

43. *Crabro stygius.*

Crabro stygius, Kirby, Ent. Month. Mag. xvii. p. 88.

The extremely wide separation of the eyes (between which the forehead is scarcely concave), which is exaggerated to the utmost in the female, is the striking feature of this and the following two species. The eyes are rather finely facetted, the hind body resembles in shape that of *C. affinis*, Smith, and in the male the sixth joint of the antennæ is feebly dentate. In this sex the character of the ventral segments is rather peculiar, consisting of a concavity (feeble as a whole) commencing at the fourth segment, but being deepened near the middle of each individual segment. In the female the penultimate dorsal segment of the hind body is densely punctured and set with close red pubescence. I think, too, that the surface of the segment itself is reddish. The wings are almost absolutely devoid of colour in both sexes.

Hab. Oahu.

44. *Crabro adspectans.*

C. adspectans, sp. nov. Subnitidus, pubescens, distincte minus crebre punctatus, niger, flavo ornatus; tibiis anticis rufo-hirsutis; alis infuscatis; abdomine pubescenti, nitido, in medio lato, vix evidenter punctato.

♂. Antennarum articulo sexto dentato, abdominis segmentis duobus ultimis supra rufo-pubescentibus.

♀. Abdominis segmento penultimo supra dense rufo-hirsuto.

Long. 12 millim.

The yellow markings are placed on the prothorax, scutellum, and postscutellum (in the female there is a large yellow spot on the second ventral segment of the hind body); they are much less conspicuous (judging by my specimens) in the male than in the female, but are probably subject to variation in both sexes. The head is shining and very distinctly punctured, the punctures being rather crowded behind the base of the antennæ and becoming gradually more sparing backwards; the mesothorax is shining and is distinctly and evenly punctured; the punctuation of the metathorax is rather coarse. The hind body is quite shining, but its brightness is hidden by close short whitish pubescence. In the male the apical half of the penultimate, and the whole of the apical segment, are rather densely covered with rather long golden-red pubescence, which is still more conspicuous on the whole of the penultimate segment in the female; in this sex the elongate apical segment also having a dense fringe of long golden-red hairs. In both sexes the clypeus, front of the head, and front tibiæ are set with long golden-red hairs. In the male the tooth on the sixth joint of the antennæ is only moderately developed, and the ventral segments resemble those of *C. stygius*, Kirby.

This beautiful species is allied to *C. stygius*, Kirby, which it resembles in having the eyes widely separated and the space between them but little concave. The eyes are excessively finely facetted, and the hind body is shaped as in *C. stygius* &c.

A single pair occurred on Haleakala, Maui, at an elevation of about 5000 feet.

45. *Crabro rubro-caudatus.*

C. rubro-caudatus, sp. nov. ♂. Vix nitidus, pubescens, obscure punctatus, niger; alis late cæruleis; abdomine in medio lato, segmentis sexto et septimo dense aureo-pilosis.

Long. 10 millim.

The head and thorax are excessively finely punctured, and are obscurely and confusedly sprinkled with a larger system of punctures. The punctuation is rougher and more obscure on the metathorax than on the anterior parts, and there are some conspicuous oblique wrinkles about its sides. The first five segments of the hind body are brightly shining, and are distinctly finely and rather closely punctured, without much pubescence; the apical two segments are very conspicuously and densely clothed with long golden-red hair. The pubescence of the head and thorax is rather dense, but not conspicuous, being of a dark colour. The wings are of a beautiful clear blue (it is remarkable in how many of the Hymenoptera taken near the crater of the active volcano this colour appears). The eyes are separated in the last two species named above, and are excessively finely facetted. The face is little concave. The denticulation of the sixth joint of the antennæ is only moderate. The ventral segments resemble those of *C. stygius* and *C. adspectans.*

In the same locality as the male *C. rubro-caudatus* I procured two examples, which are probably its female. As, however, they differ rather exceptionally, I hesitate to assign them to this species with certainty, for the wings are entirely devoid of the blue tint. In other respects they might well be the female *C. rubro-caudatus.* The penultimate and apical segments in the hind body of these specimens do not seem to differ much from the same parts in the female *C. adspectans.*

Occurred on Mauna Loa, Hawaii, at an elevation of about 4000 feet, in close proximity to the burning crater.

LARRIDÆ.

46. *Pison iridipennis.*

Pison iridipennis, Smith, Proc. Linn. Soc. xiv. p. 676.

Hab. Honolulu.

47. *Pison hospes.*

Pison hospes, Smith, *lib. cit.* p. 676.

Hab. Oahu, Kauai, and Maui. Not uncommon.

SPHEGIDÆ.

48. *Pelopæus cæmentarius.*

Sphex cæmentaria, Drury, Exot. Ins. i. p. 105.
Pelopeus flavipes, Fab. Syst. Piez. p. 202; Smith, Proc. Linn. Soc. xiv. p. 676.

A common species in the islands, and, according to

Mr. Blackburn, provisions its nest with spiders. The var. *flavipes*, Fab., *sec.* Saussure, and var. *limatus*, Fab., *sec.* Sauss. (*cf.* Hymen. der Novara Reise, p. 30), both occur, the latter being distinguished from the former by the greater extension of the yellow on the thorax, the metanotum being nearly all yellow. The species has a wide range in North America, but does not, I think, extend further south than Mexico.

49. *Mimesa antennata.*

Mimesa antennata, Smith, Cat. of Hymen. Ins. iv. p. 431.

Hab. Maui.

HETEROGENA.

FORMICIDÆ.

50. *Camponotus sexguttatus.*

Formica sexguttatus, Fab. Ent. Syst. ii. p. 354.

Hab. Honolulu, in a house. Common in South America.

51. *Tapinoma melanocephala.*

Lasius melanocephalus, Fab. Syst. Piez. p. 417.

A few specimens in a house at Lahaina, Maui.

The only locality from which this species has been recorded is Cayenne.

52. *Prenolepis longicornis.*

Formica longicornis, Latr. Hist. Nat. d. Fourm. p. 113.

Hab. Honolulu.

A widely-distributed species; found in Europe, in hothouses.

53. *Prenolepis obscura*, Mayr.

Prenolepis obscura, Mayr, Verh. zool.-bot. Ges. Wien, 1862, p. 698; Formicidæ der Novara Reise, p. 52, pl. ii. figs. 15 & 15^a.

Smith records this species as *Prenolepis clandestina*, Mayr, but it is, I believe, *P. obscura*, for I cannot find any trace of pubescence on the mesonotum. Mr. Blackburn has taken the male, which has not been described. It is dark brown; the antennæ are testaceous, the scape a little darker than the flagellum; the mouth, base of the legs, and tarsi pale yellowish testaceous, the femora and tarsi fuscous, pale beneath. Head and thorax shining, finely shagreened, and bearing some longish (comparatively) blackish hairs. Abdomen shining, impunctate, the apical half bearing longish black hairs. Wings brownish yellow, but not deeply, the nervures pallid testaceous. The apex of the abdomen is pale yellow. The only specimen I have appears to be somewhat immature.

The species has only been recorded from Australia.

PONERIDÆ.

54. *Ponera contracta.*

Formica contracta, Latr. Hist. Nat. d. Fourm. p. 195, t. 7. f. 40.

Rare in Oahu. A widely-distributed species over the world.

55. *Leptogenys insularis.*

Leptogenys insularis, Smith, Proc. Linn. Soc. xiv. p. 675.

Smith only describes the worker of this species. The male (the female I have not seen) is black, the antennæ on lower side of scape incline more or less to fuscous, the spurs and trophi pale testaceous; tips of mandibles fuscous; apex of abdomen (broadly) and antennæ rufo-testaceous; anterior tarsi inclining to testaceous at apex. Head and thorax opaque, alutaceous, covered with a fine close ashy pile; apex of abdomen with long pale hairs. Head narrower than thorax, clypeus almost transverse at apex; eyes reaching a little below the base of antennæ and not far from the base of the mandibles; ocelli prominent; there is a fine Λ-shaped furrow over the antennæ. Antennæ with a short pedicle at the base, 13-jointed, microscopically pilose; the basal joint three times as long as the second (a little longer than the basal joint of the flagellum, which is shorter than the second; the other joints longer, the last is longer than the twelfth; a fine keel runs down the centre of the mesonotum, the sutures dividing the front lobe shallow; sides of scutellum behind shining, obliquely striated; the apical half of the metanotum with several stout transverse keels. Abdomen opaque, finely alutaceous, longer than the head and thorax united. First segment shorter than the second; its suture at base smooth and shining, the apex striated; the tooth on lower side short, thick, slightly curved (the node as in worker). Wings hyaline, the apex in front of stigma smoky; nervures testaceous, stigma fuscous.

MYRMICIDÆ.

56. *Monomorium specularis.*

Monomorium specularis, Mayr, Sitz. d. Math.-Nat. Wien, 1866, p. 509.

Hab. Honolulu.

This is a South-Sea Island species; also found in Brazil.

57. *Tetramorium guineense.*

Formica guineense, Fab. Ent. Syst. ii. p. 357.

Hab. Oahu. Common in the tropical parts of America, in Manilla, and Australia, and in hothouses in Europe.

58. *Pheidole megacephala.*

Formica megacephala, Fab. Ent. Syst. ii. p. 361.
Œcophthora pusilla, Heer, Ueber die Hausameise Madeiras.

Hab. Honolulu. One of the commonest ants in the

Archipelago. The nests are formed under stones. A very widely-distributed species. Found in hothouses in Europe.

59. *Solenopsis geminata.*

Atta geminata, Fab. Syst. Piez. p. 423.

Hab. Honolulu, in palm-trees.

OXYURA.

60. *Scleroderma polynesialis.*

Scleroderma polynesialis, Saunders, Trans. Ent. Soc. 1881, p. 116.

Hab. Haleakala, Maui, at an elevation of 4000 feet.

61. *Sierola testaceipes.*

Sierola testaceipes, Cameron, Trans. Ent. Soc. 1881, p. 556.

62. *Sierola monticola*, sp. nov.

Black; anterior tibiæ and tarsi testaceous, the tips of the latter black; the base and apex of hind tibiæ fusco-testaceous, the tarsi fuscous, paler in the middle; the extreme base and apex of basal joint of antennæ and the second to fourth joint testaceous. Antennæ scarcely so long as the thorax; the basal joint pear-shaped, narrowest at the base, a little longer than the third and fourth united; second joint a little longer than third, and of the same thickness; second to fourth longer and thicker than the other joints; the apical seven more moniliform than the others, and a little longer than broad; the last longer and thinner than the penultimate. Head smooth and slightly alutaceous; mandibles piceous at tip, faintly striated; thorax smooth, a little alutaceous. The abdominal segments laterally at their junction narrowly milk-white.

Wings hyaline, stigma and prostigma fuscous; nervures testaceous. Female.

Length 4 millim.

Differs from *S. testaceipes* in being longer and stouter; in the antennæ being longer, the basal joint being longer and more pear-shaped, the other joints also not being so thick nor so moniliform; in the abdomen being shorter and broader, it being almost shorter than the head and thorax united, the segments, too, not being broadly testaceous at their edges; the femora are black; the head is more narrowed in front of the eyes; the wings are longer, and the nervures are darker.

Hab. Mountains of Hawaii (no. 134).

63. *Sierola leuconeura*, sp. nov.

Black; the knees, tibiæ, tarsi, and basal half of antennæ testaceous; the hind tibiæ fuscous in the middle; antennæ scarcely so long as the thorax, the basal joint shortly pedunculated, double as long as wide, double the length and thickness of the second, which is thinner and shorter than the third, the third to sixth thicker than the following, broader than long, the apical two joints subequal. Head and thorax smooth, faintly alutaceous. Abdomen shining, longer than the thorax. Wings semifuscous; stigma and prostigma fuscous, nervures lacteous.

Length 2 millim.

The nervures are so colourless that I cannot make out if the small oval cellule uniting the humeral cellules is present or not; if absent the species would form the type of a new genus, as genera are now considered.

Hab. Lanai.

TEREBRANTIA.

ICHNEUMONIDÆ.

Pimplides.

64. *Echthromorpha maculipennis.*

Echthromorpha maculipennis, Holmgren, Eugenies Resa, Zoologi, vi. p. 406, tab. viii. f. 3.

Hab. Honolulu.

65. *Echthromorpha flavo-orbitalis*, sp. nov.

This species differs from *E. maculipennis* as follows:—The face is entirely yellow, the eyes are narrowly bordered with yellow except at the top, the scape beneath, and the anterior coxæ and trochanters, the basal half of the scutellum, and the postscutellum are yellow; the wings are much more darker tinted, the nervures and stigma are quite black; the metanotum is more strongly punctured, and the oblong depression found near the base in *E. maculipennis* is absent; the punctuation on the abdomen is stronger, there being also a distinct punctuation on the second segment, and the transverse impressions are more conspicuous. Possibly an examination of a large series of specimens may prove that *E. flavo-orbitalis* is only a variety of *E. maculipennis*.

The maxillary palpi in this genus are 5-, and the labial 3-jointed.

66. *Pimpla hawaiiensis*, sp. nov.

Black; legs red, the anterior tibiæ inclining to yellowish in front, the hind tibiæ and tarsi black, the extreme base of hind tibiæ and a broad band above the middle and the spurs white; the tips of four anterior tarsi black; extreme base of posterior testaceous. Antennæ scarcely so long as the thorax and abdomen united, stoutish, tapering towards the apex; inclining to brown on the lower side, covered with microscopic pile. Head as wide as the thorax, shining, impunctate, the face somewhat protuberant, covered sparsely with white hairs; front a little depressed above the antennæ; clypeus clearly separated; maxillary palpi testaceous, labial fuscous. Thorax shining, impunctate, the mesonotum sparsely, sternum and metapleuræ densely covered with longish white hair; metanotum without any keels, the thoracic spiracle oblong. Abdomen about double the length of the thorax, covered with a longish white pubescence; base of petiole excavated, the middle portion sparsely punctured; apical part shining, impunctate, separated from the part in front by being a little raised. The other segments (except the apical) are closely and rather strongly punctured; the second is longer than broad; the others to the seventh broader than long; the seventh is longer than broad; the eighth is narrowed gradually to the apex; the cerci are three times longer than broad, stout, pilose. The edges of the second segment are testaceous at the base and apex. Wings hyaline, shorter than the thorax and abdomen; the nervures and stigma black; areolet 4-angled, angled on lower side; the lateral nervures uniting at top; the recurrent nervure angled a little above the middle.

Hab. Oahu.

Tryphonides.

67. *Metacœlus femoratus.*

Exochus femoratus, Grav. Europ. Ich. ii. p. 346.

Hab. Oahu.

Ophionides.

68. *Ophion lineatus.*

Ophion lineatus, Cameron, Trans. Ent. Soc. 1883, p. 192.

Hab. Hawaii, Lanai.

69. *Ophion nigricans.*

Ophion nigricans, Cameron, *l. c.* p. 193.

Hab. Hawaii.

70. *Limneria polynesialis.*

Limneria polynesialis, Cameron, *l. c.* p. 191.

Hab. Haleakala, Maui, at an elevation of about 4000 feet.

71. *Limneria Blackburni.*

Limneria Blackburni, Cameron, *l. c.* p. 192.

Hab. Mauna Kea, Hawaii, at an elevation of at least 13,000 feet, on the snow near the summit.

72. *Limneria hawaiiensis*, sp. nov.

Very similar in coloration and size (except that it is somewhat smaller) to *L. Blackburni*, but differing from it in the head and thorax being *densely* covered with silvery-white pubescence, on *L. Blackburni* (especially on the thorax) it being very sparse and the pleuræ almost glabrous; the posterior median area of the metanotum is narrower and longer; the femora are of a much paler red, the four posterior trochanters are entirely yellow, there is no black at the base of the hind femora, the black on the tibiæ is lighter, the four anterior tarsi are pale testaceous without any black, and the areolet is not only longer, but is also somewhat wider; the postpetiole is more strongly punctured, as are also the second and third segments, and the apical segments are more densely covered with white hair, the hair being also longer. The apex of the second segment and the greater part of the third segment externally are testaceous.

Hab. Oahu.

The three species of *Limneria* known from the islands are so closely allied to each other that I have no doubt that they have been evolved from one stem; in fact, I am not sure but that if we had a long series of each, it would be found that they were varieties of one species. It is noteworthy that they are all from the mountains. The three species may be known as follows :—

1 (2). Stigma and nervures pallid testaceous; areolet nearly pedunculated; first transverse humeral nervure not interstitial .... *polynesialis.*

2 (1). Stigma fuscous, nervures black; first transverse humeral nervure interstitial.

3 (4). Head and thorax densely covered with white pubescence, four anterior tarsi and middle tibiæ without black; the base of hind femora without black .... *hawaiiensis.*

4 (3). Head and thorax not densely pilose, four anterior tarsi and middle tibiæ marked with black; base of hind femora black .... *Blackburni.*

BRACONIDÆ.

73. *Chelonus Blackburni.*

Chelonus carinatus, Cameron, Trans. Ent. Soc. 1881, p. 559 (non Cresson).

Hab. Oahu.

74. *Monolexis ? palliatus.*

Monolexis ? palliatus, Cameron, *l. c.* p. 560.

Hab. Near Honolulu. Not common.

EVANIIDÆ.

75. *Evania sericea.*

Evania sericea, Cameron, Trans. Ent. Soc. 1883, p. 191.

Hab. Hawaii and Oahu.

76. *Evania lævigata.*

Evania lævigata, Latr. Gen. Crust. et Ins. iii. p. 251.

Hab. Common about Honolulu.

CHALCIDIDÆ.

77. *Epitranus lacteipennis.*

Epitranus lacteipennis, Cameron, Trans. Ent. Soc. 1883, p. 187.

Hab. Oahu.

78. *Chalcis polynesialis.*

Chalcis polynesialis, Cameron, Trans. Ent. Soc. 1881, p. 561.

Hab. Near Honolulu.

79. *Spalangia hirta.*

Spalangia hirta, Haliday, Ent. Month. Mag. i. p. 334.

In an outhouse near Honolulu. Probably introduced, being a parasite on the house-fly. It is a European species.

80. *Moranila testaceipes.*

Moranila testaceipes, Cameron, Trans. Ent. Soc. 1883, p. 188.

Hab. Oahu.

81. *Solindenia picticornis.*

Solindenia picticornis, Cameron, Trans. Ent. Soc. 1883, p. 189.

Hab. Oahu.

82. *Eupelmus flavipes.*

Eupelmus flavipes, Cameron, *l. c.* p. 190.

83. *Encyrtus? insularis*, sp. nov.

Dark blue; the antennæ, apex of fore femora, apical third of middle and apical half of hind femora, the tibiæ and tarsi yellowish testaceous, base of four anterior tibiæ fuscous; club of antennæ darker than scape; abdomen more or less green. Wings hyaline, nervures testaceous. Head covered with large, distinctly separated punctures; thorax more closely punctured, the punctures being also smaller than those on the head; scutellum closely and more finely punctured than the mesonotum; abdomen shining, impunctate. Head and mesothorax finely and sparsely pilose; scutellum densely pilose; abdomen glabrous.

Scape of antennæ longer than the flagellum, nearly cylindrical, but slightly thickened towards the apex, the flagellum 7-jointed, the first six broader than long, the edges projecting, forming a serration broader than long, becoming gradually broader until the sixth is double as wide as long; last joint (forming a club) longer than the preceding six; the apex produced laterally, the elongation forming about one fourth of the total length, and half the thickness of the central part; the club becomes gradually thickened towards the apex. The flagellum is covered with longish stiff hairs, directed towards the apex. Head broad, rather large; eyes large, converging above; ocelli in a wide triangle, widely separated, the upper two nearly touching the eyes; occiput concave. Face deeply excavated, the excavation reaching laterally to the mouth; epistomia projecting, broadly keeled. Thorax large, broad, without sutures; scutellum large; metathorax small. Abdomen shorter than the thorax, the apex narrowed, transverse. Wings scarcely so long as the body; cubitus more than double the length of ulna, which is very short; radius absent; edge of wing shortly ciliated. The cubitus does not reach to the middle of the wing. Hind tibiæ almost one-spurred, the inner being a mere stump.

The above-described species is certainly not an *Encyrtus* as now understood. I cannot make it fit into any of the genera as defined by Mayr and Fœrster; but having only a single example (a male), I do not care to found a new genus for its reception. The sculpture of the head and thorax is pretty much as in *Bothriothorax*.

Taken on several of the islands.

Obs. Mr. Blackburn (*anteà*, p. 199) states that he has taken in the Archipelago over one hundred species of Hymenoptera; but I am only acquainted with eighty-three (or eighty-four with *Apis mellifica*). I believe there are two or three undescribed species in the British Museum, which were sent by Mr. Blackburn some years ago.—*P. C.*

XV. *The pollution of the River Irwell and its Tributaries.*

By Charles A. Burghardt, Ph.D.

Read February 23rd, 1886.

[Plates X., XI., XII., & XIII.]

I have thought it would be interesting to the Members of this Society perhaps, if I laid before them the results of many analyses of the water of the River Irwell extending over a period of two years, and also analyses of some of the most important tributaries of the Irwell *above* Manchester, including at the same time the Irk and the Medlock *within* the boundary of Manchester. There have been several investigations already into the condition of the Irwell &c., the first being that of Lyon Playfair, in 1844. Undoubtedly at that time the river was extremely filthy, but I am quite certain from my own investigations that it was inaccurate to state that large quantities of sulphuretted hydrogen, phosphoretted hydrogen, and other dangerous gases were evolved from the waters. Most certainly it could never have evolved phosphoretted hydrogen, because this gas can only be prepared by the reduction of phosphates under difficult chemical circumstances, which could not obtain in a river, but assuming for the sake of argument that this gas did succeed in forming after immense effort, and arrived in the shape of a bubble at the surface, if it consisted of the very inflammable modification, it would immediately take fire in the air, and burn at once to phosphorus pentoxide, and this latter body being one of the most hydroscopic bodies known to the chemist, would immediately vanish into the river again, now in the form of phosphoric acid. After this it might recombine with calcium or magnesium, and await a second metamorphosis. Regarding the sulphuretted hydrogen at the period of Lyon Playfair's investigation, I cannot of course dispute it directly, but I state most emphatically, that if the river bed were of the same composition as it is at the present day, and if the vegetable dyes &c., turned into the river *then,* were at all like those turned into the river *to-day,* it would be almost impossible for sulphuretted hydrogen to be given off in the form of gas from the water, because it is now a well-known fact that the oxide of iron largely present in the mud of the Irwell and its tributaries, coupled with the large amount of iron present in solution in the water (derived from dye-works, chemical works, paper works, &c.), combines with it when in the "status nascendi," forming ferrous sulphide. This black compound enters largely into the constitution of the mud of sewage-polluted streams, and I know from a long series of examinations of the mud of the Irwell at Throstle Nest, that ferrous sulphide is largely present in the mud.

I have analysed repeatedly, at various times in the year, gas collected from the Irwell at spots immediately above the weir at Throstle Nest, below it at the place where all the water samples were taken during 1883, 1884, 1885, and at Barton above the locks. At the first-mentioned locality an immense evolution of gas is to be often seen during the summer months, but I can say without hesitation that it contains no trace of sulphuretted hydrogen, having tested it many times for that gas, and never detected the slightest trace. The gas thus rising to the surface varies very much in composition at different places. That coming to the surface at the Throstle Nest weir containing a large quantity of carbon dioxide and a small quantity of "marsh gas" (CH_4), whereas the gas rising near Barton often contains nearly 60 per cent. of "marsh gas," the rest being mostly carbon dioxide. The river water is nearly saturated with carbon dioxide gas (at the atmospheric temperature), a very bad state of things, because it prevents to a very great extent that further special self-purification of the water by oxydation. The carbon dioxide is mostly formed by the oxydation of the sewage and other carbonaceous contaminations present in the water. I have made a great number of determinations of the amount of *free* carbon dioxide gas in solution, in the Irwell water, and always found that on allowing the same water sample to stand for a week (or even a day or two in summer), a further amount of carbon dioxide had been formed and *dissolved* in the water. *This further amount was entirely derived from the oxydation of the carbonaceous impurities of the water.* I ascertained on making further experiments that an increase of temperature had a very great influence upon the formation of carbon dioxide in sewage-polluted water. The way I ascertained this was very simple. I first determined very carefully the amount of *free* carbonic acid gas (carbon dioxide) dissolved in the Irwell water, by gently warming it in a flask to about 94° C., and drawing all gas evolved through a standard solution of barium hydrate. When no further amount of gas was thought to be coming off, the barium-hydrate flask was removed and the amount of baryta still remaining not saturated determined by standard oxalic acid solution; then another flask containing a further charge of the barium hydrate solution was attached to the apparatus as before, and the water sample again heated in its flask for half an hour at 94° C.; if no more gas came off I at once proceeded to heat the flask to 100° C., when a copious generation of carbon dioxide always took place. If the carbon dioxide came off during the second heating to 94° C., then this heating was continued for a considerable time until I assumed nothing more did come off (and in actual practice it was not at all difficult to be quite sure), then I titrated the barium hydrate solution as before. *From the experiments thus made I am very strongly of opinion that determina-*

tions of the amount of FREE *carbon dioxide dissolved in river waters, are valuable indicators of the state of that river as regards organic pollution.*

I consider the Irwell the best possible example of the saturation of a water with the gaseous products of the decomposition of its carbonaceous constituents, and I am quite certain that it is absolutely necessary to remove at once the large quantity of sewage pollution from the river so that the other organic matters, which are less easily oxydized, may have a chance of being changed and destroyed by further oxydation. Owing to the rapid falling movement of the river, from its source above Bacup, at an altitude of 1300 feet, to Manchester, which may be, on the bed of the river, about 150 feet above the level of the sea, there is a first-rate chance for an ordinary river to purify itself. It will be at once apparent on consulting the Table "C" that the Irwell at Bury is HALF as much polluted as it is at Throstle Nest, in Manchester. Again, on consulting Table "D," it will be seen that the Irwell at the Salford Boundary is far purer than the Irwell at Throstle Nest. Making a calculation from the analytical data given in the Table, it appears that the water at Throstle Nest contains 76 per cent. more albuminoid ammonia, and 36 per cent. more oxydizable organic matter than the same water as it arrives at the Salford boundary. How can this tremendous increase in pollution be accounted for? *It is almost entirely due to pollution of the Irwell by its tributaries, the Irk and the Medlock, the sewage being mostly that poured into the rivers by the Manchester sewers,* because the sewage of Salford has been diverted from the Irwell altogether, I believe. On referring to Table "D" it will be seen that the river Medlock is nothing more or less than a filthy sewer. It is a burning disgrace to a civilized community to allow such a stream to flow through a town like Manchester in its present condition. The table mentioned above shows that on comparing the Irwell at the Salford boundary with the Medlock (just before it joins the Irwell), that the Medlock contains 89 per cent. more albuminoid ammonia, 49 per cent. more free ammonia, 75 per cent. more oxydizable organic matter, and 86 per cent. more filth in suspension (flocculent matter), in short, it contains about 80 per cent. or so more sewage pollution than the Irwell at the Salford boundary. The Irk is very little better than the Medlock. On going up the river towards Bury it will be seen that the principal tributary of the Irwell is the river Roach. This river rises at a height of about 1500 feet above ordnance datum and on arriving at the place of junction with the Irwell it has only a height of 197 feet above the ordnance datum, consequently the Roach is a river which can easily purify itself, if it has a proper chance given to it, owing to the rapid flow of the water. The Roach is a purer stream than the Irwell, although it is largely polluted with sewage and other contamination still, and could and ought to be far cleaner than it is. The streams flowing through Elton and Bury are highly polluted with dye-water, bleaching refuse, sewage, &c.; they flow through sewers into the Irwell, but the Bury Corporation intends to treat all its sewage outside the town, and divert it from the river in its crude condition; and they will also doubtless insist upon all manufacturers purifying their waste waters to such a state of purity as to comply with the requirements of the Rivers Pollution Act. It will be seen that there is much reason for this action on the part of the Bury Corporation, for on consulting Table "D," and comparing the analysis there of the Tottington Brook before it joins the Irwell, with the analysis of the Irwell (taken on the same occasion, before being joined by the Tottington Brook) in Table "C," it will be at once seen that the Irwell is a pure stream in comparison.

I have analysed other small streams flowing through Bury into the Irwell, and found all were largely polluted with manufacturer's waste water. Between the junction of the Roach and the Irwell there is a pollution of the Irwell by the River Croal. This river is formed by the junction of several brooks, of which the principal is the Bradshaw Brook, flowing near Bolton. This brook—and, in fact, all of them—are largely polluted with manufacturer's waste waters and sewage, but all of them are much purer than the Irwell at the Salford boundary. From my examinations of the river, and the curves plotted from the weekly analyses of 1884, compared with the analyses of 1885, I cannot draw any other conclusion than this: that about ONE-HALF the total pollution of the Irwell, before it arrives at the weir at Throstle Nest, is due to manufacturer's waste water—in other words, to *avoidable pollution*. This conclusion is supported by looking at the oxygen curves produced by calculating on 100 parts of the total matters in solution (Curve No. 6). It will be seen that there was a continuous rise in the amount of oxygen required to oxydize the organic matter in 100 parts of the total soluble matters, owing, no doubt, to the long drought in 1884 (extending from March to July 4th; see rainfall in Table "A"); *but suddenly, on June 6th, the curve drops from about* 47 *grains to* 22. *This diminution is due to the whole week being a universal holiday in Lancashire, viz., Whit-week.* The same fact is observed on examining Curve No. 6 (for the Christmas and New Year holidays in 1884–85) in quite as striking a manner. Again in the Easter holidays and Whit-week in 1885 the same improvement is observed, proving conclusively that the pollution of the river is very much less when manufacturers are doing nothing. In Table "B" I give the percentage of volatile organic matter present in 100 parts of the respective amounts of "total matter in solution." By treating the analytical data in this manner a very fair opinion can be obtained as to the pollution of a stream like the Irwell. I have made similar calculations in regard to streams which were only polluted with what is known as "domestic sewage," and always found that the total matter in solution in the water contained from 27 to 60 per cent. of volatile organic matter; and, further, that this excessive amount of organic matter rapidly precipitates out on being exposed to the air. This precipitation of the organic "sewage matter" in solution is well illustrated in the analysis of the Irwell at Throstle Nest and the Irwell at Barton (in Table "D"). It will be seen, on calculating out the percentages, that the Irwell at Throstle Nest contains 37·5 per cent. of volatile organic matter in 100 parts of its "total matter in solution," whilst at Barton the same water contains only 17·61 per cent. of volatile organic matter in 100 parts of its "total matter in solution." *Exactly one-half of the organic contamination has been precipitated out of the water in the flow from Throstle Nest to Barton.*

Regarding the method of analysis of the waters, I may say that I consider Frankland's process quite useless *by itself* in ascertaining the state of the pollution of a river in a manufacturing district, because it cannot discriminate between the pollution by sewage and the pollution by manufacturer's waste waters. By adopting a parallel testing of the water by the processes of Wanklyn and Tidy, a very good idea is obtained of the state of the water, especially if these two processes are supplemented by the determination of the amounts of chlorine, volatile matter in both "*suspended* matter" and "matter in solution." I always filtered the water, and considered the residue dried at 100° C., obtained on evaporating the filtered water, to be "total matter in solution," but I was of course aware that much loss arose by the decomposition of the sewage matter in the water into carbon dioxide at about 100° C. The oxygen tests were applied directly the water arrived in my laboratory; also the ammonia deter-

Fig. 1.

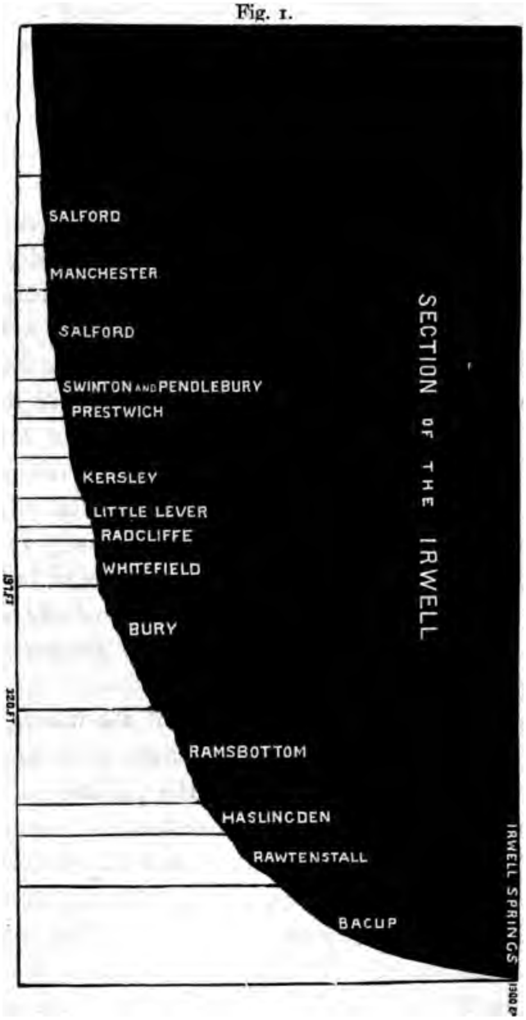
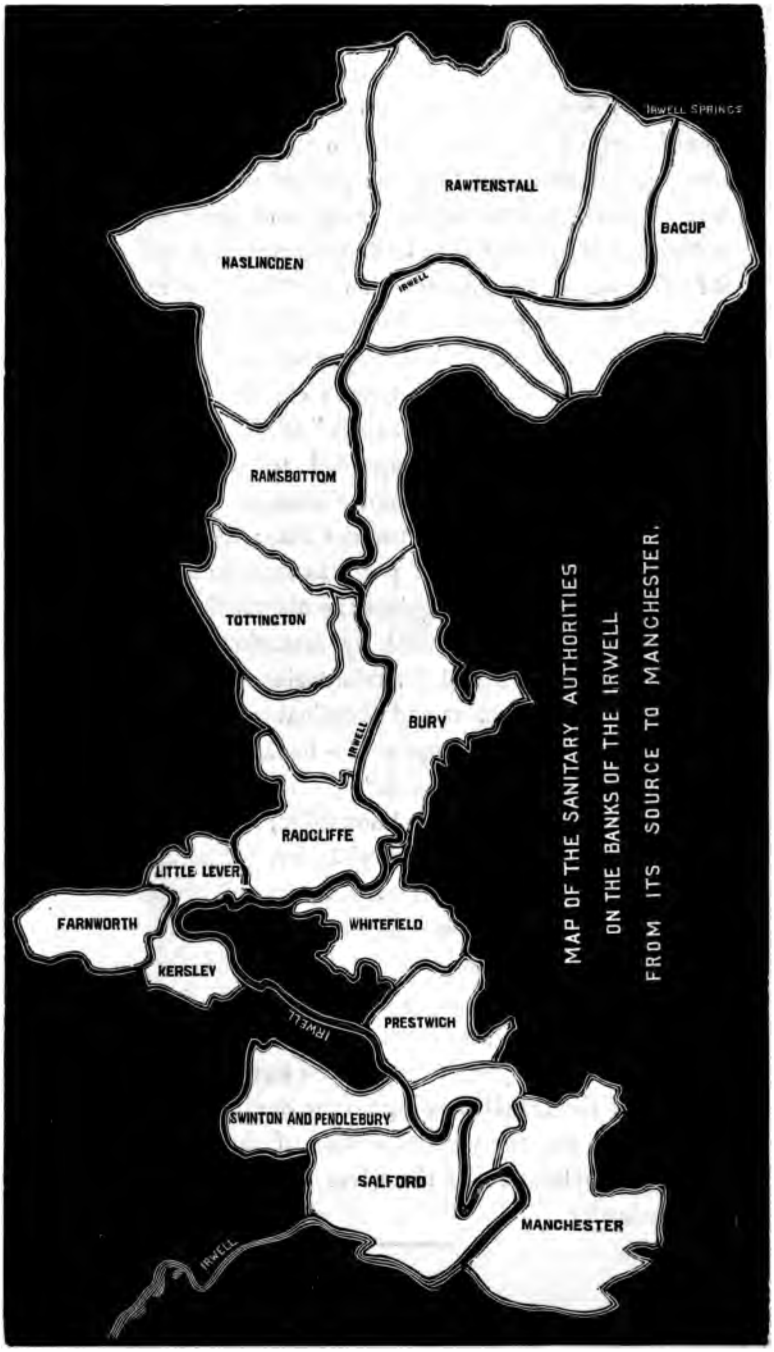


Fig. 2.


IRWELL SPRINGS
RAWTENSTALL
BACUP
HASLINGDEN
IRWELL
RAMSBOTTOM
TOTTINGTON
BURY
IRWELL
RADCLIFFE
LITTLE LEVER
FARNWORTH
WHITEFIELD
KERSLEY
IRWELL
PRESTWICH
SWINTON AND PENDLEBURY
SALFORD
MANCHESTER
IRWELL
MAP OF THE SANITARY AUTHORITIES
ON THE BANKS OF THE IRWELL
FROM ITS SOURCE TO MANCHESTER.

minations. I do not wish to make comparisons between Wanklyn's or Tidy's methods, because both are excellent; but it would appear from the curves that the first-mentioned method is more reliable in its indications of *real* sewage contamination than the method of Tidy. Having now shown the state of the Irwell and some of its tributaries, I ask, What is to be done to cleanse it or improve it? The answer to this question is, "Insist sternly upon the sewage of all towns and local authorities abbutting on the river being treated in a proper manner and removed in the crude state from the rivers; see that the so-called 'sewage processes' or 'schemes' of the various local authorities on the map appended to this paper, *are thoroughly carried out,* and not shams, as some of them are to my knowledge at the present time; have the powers of the Rivers Pollution Act put into force in a reasonable but determined manner against the disgraceful and selfish pollutions at present caused by manufacturers on the banks of the Irwell and its tributaries, and at once do away with the dangerous and abominable practice of casting ashes and cinders upon the banks in order to be washed away at the first flood."

I know, from personal knowledge, that the Rivers Pollution Act is an absolute dead letter, not being applied at all on the Irwell, and might never have been passed.

I must not conclude my paper without acknowledging the very valuable assistance I have received throughout this inquiry from my assistants, Messrs. A. E. Fasnacht and W. J. Rowley; also from my friend Mr. Cartwright, the Borough Surveyor of Bury, who has prepared for me the map of the Irwell showing all the Sanitary Authorities on its banks, and the vertical section of the same districts giving the inclination of the River Irwell from its source to Manchester.

TABLE A.

35	„ 19	„	0·712	5·880	3·220	52·360	9·520	8·081=13·496	0·0784	0·1568	1·1263	2·1312	2·6134
36	„ 26	Higher.	0·700	4·088	1·988	44·460	10·800	6·358=10·618	0·0728	0·1092	0·7822	1·5725	1·8535
37	Oct. 3	Low.	0·537	7·840	3·080	47·432	10·800	7·770=12·974	0·1568	0·1258	0·8990	1·7220	2·2960
38	„ 10	„	0·487	3·696	2·548	49·280	13·440	7·417=12·387	0·1120	0·0728	0·8873	1·8264	2·1861
39	„ 17	„	0·525	2·380	1·078	43·540	9·240	6·358=11·219	0·0840	0·1400	0·8400	1·6786	2·0265
40	„ 24	Very low.	0·075	5·180	3·570	53·760	12·600	8·830=14·746	0·1120	0·2016	1·2880	2·4556	2·4780
41	„ 31	Low.	1·286	2·800	1·300	37·520	10·920	6·711=11·247	0·1232	0·1120	0·6216	1·3454	1·6184
42	Nov. 7	Very low.	0·687	2·520	0·672	40·180	6·650	4·945= 8·258	0·1344	0·1176	0·6886	1·4151	1·6170
43	„ 14	Low.	0·150	2·800	1·190	47·180	16·800	7·064=11·796	0·1456	0·1568	0·8844	1·7038	2·2230
44	„ 21	„	0·025	5·040	3·220	56·000	20·020	8·830=14·746	0·1960	0·1568	1·3060	1·9054	3·0730
45	„ 28	„	0·052	8·120	2·660	48·160	10·640	7·417=12·386	0·1736	0·1120	1·0822	2·1448	2·5998
46	Dec. 5	Very high.	1·687	11·381	2·610	30·187	7·318	2·119= 3·539	0·1288	0·1512	0·6877	1·4154	1·6170
47	„ 12	Low.	0·942	12·501	6·645	33·600	12·600	3·885= 6·488	0·1087	0·1321	1·2851	2·4164	2·4810
48	„ 19	„	1·299	12·218	7·910	40·600	15·400	4·6269=7·682	0·0954	0·1101	0·8406	1·6786	2·0272
‡49	„ 26	„	0·350	9·800	7·700	21·000	5·600	2·119= 3·539	0·0560	0·1680	0·2180	0·4353	0·9408
‡50	1885. Jan. 2	„	0·000	2·940	1·400	42·392	9·912	4·945= 8·258	0·0728	0·1568	0·6135	1·2271	1·4014
51	„ 9	„	0·176	5·880	3·670	48·160	9·800	7·064=11·796	0·1440	0·1120	0·8651	1·8900	2·2056
52	„ 16	„	0·825	4·370	2·650	42·000	13·160	6·004=10·027	0·0840	0·1120	0·8568	1·7406	2·0910

* Good Friday Holidays. † Whitweek Holidays. ‡ Holidays.

TABLE D.

Comparative Analysis of the Irwell and its Tributaries, during the year 1885.

SAMPLES.	Suspended Matter.	Volatile Matter in Suspended Matter.	Total Matter in Solution.	Volatile Matter in Solution.	Chlorine=Sodium Chloride.	Ammonia.		Oxygen absorbed by Organic Matter in		
						Free.	Albuminoid.	3 minutes.	1 hour.	3 hours.
Irwell at Bury before the Roach joins it, Sept. 17th	3·808	1·845	27·440	8·960	2·822= 4·657	0·0210	0·1750	0·4652	1·0528	1·2032
River *Roach* before joining the Irwell, Sept. 17th................	3·640	1·400	26·320	8·960	2·822= 4·657	0·0070	0·1470	0·1351	0·8764	1·0242
Irwell, after the Roach has joined it, Sept. 17th	3·920	1·400	28·880	7·840	2·822= 4·657	0·0350	0·1750	0·3878	1·0392	1·3413
Irwell, at the Salford boundary, Oct. 30th.................................	1·400	0·700	30·800	12·600	3·551= 5·852	0·2240	0·0504	0·2772	0·5740	0·6855
River *Irk*, at the Lancashire and Yorkshire Railway Station, Oct. 30th.................................	8·400	5·600	45·500	15·400	4·939= 7·894	0·3248	1·9040	0·4133	0·7862	1·1995
River *Medlock*, just before joining the Irwell	10·300	7·000	63·700	18·200	6·914=11·393	0·4424	0·4704	1·4616	2·3587	2·7821
Irwell, at Throstle Nest, October 30th	4·200	2·100	39·900	14·000	4·939= 7·894	0·1628	0·2128	0·4636	0·8266	1·0715
Irwell, at Barton, above the Locks, Oct. 30th.................................	4·900	2·100	35·700	6·300	4·939= 7·894	0·2072	0·1064	0·3528	0·7358	0·9778
Bradshaw Brook, at Quarlton Vale, Turton, Jan. 21st, 1885	1·400	1·050	14·700	5·600	1·273= 2·098	0·0140	0·0224	0·0840	0·2940	0·2940
Tottington Brook, at Bury, before entering the Irwell, June 5th ...	3·360	2·940	26·600	10·080	3·461= 5·710	0·0070	0·0560	1·8802	2·7286	3·4122

XVI. *On the Relations of* Calamodendron *to* Calamites.

By Professor W. C. WILLIAMSON, LL.D., F.R.S.

Read October 5th, 1886.

[PLATES XIV., XV., & XVI.]

THE relations in which the genus *Calamodendron* of Brongniart stands to that of *Calamites*, originally established by Suckow, and adopted by Brongniart and later authors, are involved in a considerable amount of confusion; this confusion is partly due to some indefiniteness in the statements of Brongniart himself on the subject, and partly to differences of opinion existing amongst palæobotanists as to what those relations really are.

In 1828 Brongniart published his 'Prodrome d'une Histoire des Végétaux Fossiles,' in which, for the first time, a serious attempt was made to classify the various types of fossil vegetation. In that volume Brongniart divided the family of the *Equisétacées* into the two genera *Equisetum* and *Calamites*, thus recording his opinion that the latter plants were true members of the Equisetaceous family.

But in 1849 Brongniart published, in the 'Dictionnaire universel d'Histoire naturelle,' his "Tableau des Genres de Végétaux Fossiles." In the interval he had become acquainted with some fossils from Autun, belonging to deposits occupying the boundary-line between the uppermost beds of the Carboniferous series and the lowest Permian ones. These fossils had meanwhile been studied by M. Cotta, who gave to them the generic name of *Calamitea.*

It appears that, under this generic term, Cotta comprehended some Conifers; two plants, however, to which he gave the names of *Calamitea striata* and *C. bistriata,* seemed to have true Equisetiform affinities. Specimens of the former of these species in which the internal organization was preserved, were obtained by Unger, and were described by that palæontologist in Petzholdt's work *.

Brongniart concluded, from Unger's observations, that the two plants referred to above were distinct from the true *Calamites*; and he also objected to Cotta's generic term *Calamitea* as approximating too closely to Suckow's *Calamites*; he therefore substituted for it the term *Calamodendron.* Describing the *C. striata* of Cotta, he says:—"Cette tige, comme toutes les autres de ce genre, présente une moëlle très volumineuse, souvent réduite par la compression à une forme elliptique ou même linéaire, entourée par une zone ligneuse de quelques centimètres d'épaisseur, sans zones d'accroissement distinctes, mais formée de bandes rayonnantes alternatives fort différentes de couleur et d'aspect, presque égales en largeur dans le *Cal. striatum,* alternativement larges et étroites dans le *Cal. bistriatum.* On croirait au premier abord que ce sont de très larges rayons médullaires alternant avec des faisceaux ligneux à peu près de même dimension. Mais l'anatomie microscopique a montré dans le *Cal. striatum,* que la moitié des lames rayonnantes sont formées par des vaisseaux rayés, ou plutôt par de larges fibres rayées comme celles des *Psaronius* et des *Stigmaria,* séparées par des rayons médullaires très étroits, d'un seul rang de cellules, et peu étendus en hauteur; les lames qui alternent avec celles-ci sont formées de fibres ligneuses, plus fines, très nombreuses, disposées aussi en séries rayonnantes, et chaque lame est partagée dans son milieu par un rayon médullaire plus large, continué et composé de deux ou trois rangées de cellules dirigées, comme dans les

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* Ueber Kalamiten und Steinkohlen.—Bildung. 8vo. Dresden, 1841.

rayons médullaires, du centre à la circonférence"[*]. The above description agrees with sections in my cabinet, for which I am indebted to Professor Edouard, Graf von Solms, of Göttingen, with the exception of the *continuity* of the central medullary ray last referred to. I find that this ray is not regularly continuous, but decidedly irregular and interrupted in its continuity: indeed tangential sections of these fibrous zones exhibit rather numerous narrow, vertically elongated, lenticular, medullary rays, composed of one, two, or three vertical rows of cells; those rays nearest the centre are undoubtedly the largest and most conspicuous, but they are not continuous, merely *primi inter pares*.

Had the above description stood alone, no confusion would have resulted; but on p. 48 of his Tableau, M. Brongniart makes the following observations :—

"Je serais donc porté à penser, qu'on a confondu sous le nom des Calamites deux groupes des végétaux très différents. L'un, comprenant les Calamites à écorce mince, régulière, recouvrant le noyau central d'une couche charbonneuse qui en suit tous les contours, qui montre à sa surface externe des stries et des articulations très nettes des insertions de rameaux appliqués sur des articulations dépourvues de gaînes ou en offrant quelquefois une étalée. Leur structure est celle que je viens de décrire.

L'autre, comprenant les Calamites à écorce charbonneuse, épaisse, qui, extérieurement, offre à peine des traces de stries longitudinales et d'articulations, dont le noyau interne correspondant à la tige est, au contraire, profondément sillonné et présente des articulations très marqués. Ces tiges, lorsque leur partie centrale a conservé sa structure, paraissent offrir celle décrite par MM. Cotta, Petzholdt et Unger dans les *Calamitea*, c'est-à-dire une moëlle

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[*] *Loc. cit.* p. 50.

centrale, un cylindre ligneux, partagé par de nombreux rayons médullaires très réguliers, en faisceaux rayonnants, composés eux-mêmes de lames rayonnantes, de tissu vasculaire strié, analogue à celui des Fougères, des Lepidodendron, des Sigillaria et des Stigmaria, et de tissu plus fin, sans stries ou ponctuations."

As I shall show directly, this latter description includes within M. Brongniart's genus *Calamodendron* the group of objects which for many years past I have demonstrated to be true Equisetiform Calamites, but which M. Brongniart thus unites with objects which he believed to be dicotyledonous Gymnosperms. I may observe here that M. Brongniart had no conception of the existence of an enormous number of Carboniferous Cryptogams which possess largely developed, exogenous, vascular or xylem zones within their cortical layers; he believed such a combination to be impossible; therefore the fact that a plant possessed such a zone was to him, as it has long been to some of his disciples, a clear proof that it could not possibly be a Cryptogam.

In 1869 I published, in the 'Transactions of the Literary and Philosophical Society of Manchester'*, a memoir "On the Structure of the Woody Zone of an undescribed form of Calamite," in which I demonstrated the existence of an exogenous woody zone, and also I arrived at the conclusion, "that the Calamites constitute essentially *one* large group of plants, with some considerable range of variation in the details of their internal organization" (*loc. cit.* p. 179). This conclusion, as might be expected, was rejected by many who had been trained in the school of Brongniart. A few remain who still reject it.

Like myself, M. Göppert obtained specimens of Calamites with distinct, exogenously developed, vascular zones,

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* Vol. iv., 3rd ser.

such as had been found in Brongniart's *Calamodendron*, but he saw that the radiating masses of cellular tissue (the primary medullary rays of my memoir) which alternated with the vascular wedges, differed from those of Cotta's plant; therefore he left the latter in Brongniart's genus *Calamodendron*, whilst for the reception of the others he instituted the new genus *Arthropitus* *. Brongniart's genus *Calamodendron*, as defined on p. 256, undoubtedly comprehended Göppert's new genus; the French author had been misled by his ignorance of the fact that both these genera possessed an exogenous vascular zone, which zone he obviously regarded as the chief feature distinguishing his *Calamodendron* from *Calamites*. M. Grand'Eury has followed Göppert in accepting his genus *Arthropitus*; but consistently with the Brongniartian views which he adopted when he published his 'Flore Carbonifère du Département de la Loire,' he there placed the genus along with *Calamodendron* in his "Famille des *Calamodendrées*," regarding both as Gymnospermous genera.

From 1869, the time of the publication of my Calamitean memoir already referred to, I have continued to demonstrate that all the Carboniferous Calamites began to develop exogenously a vascular zone even in their youngest state, and that the supposed non-exogenous Equisetiform type existed only in the minds of a few men, unbelievers in exogenous Cryptogams. Unger's *Arthropitus* is, I have long been convinced, merely an ordinary Calamite, in which the development of the exogenous zone has made some conspicuous progress. M. Grand'Eury himself has advanced so far as to recognize this fact. In his 'Détermination Spécifique des Empreints végétales du terrain houiller" †, he says :—" J'ai assez bien

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* 'Die fossile Flora der Permischen Formation,' p. 179.

† 'Comptes Rendus,' Séance du 22 février, 1886.

reconnu que les *Calamites cannæformis* et *varians* vont avec les *Asterophyllites* du type Equisetiformes, Schl., et les *Volkmannia gracilis*, Pr., que le moule des tiges de ces végétaux est l'empreint de la structure du bois d'*Arthropitus*;" and in a private letter to myself, that eminent geologist says, "Comme vous, j'ai reconnu que le bois d'*Arthropitus* appartient aux Calamites du type *C. cannæformis*." Since the contrary idea prevailing in the French school of palæontologists has chiefly rested, of late years, upon the discoveries of M. Grand'Eury himself, I presume we shall now hear no more of that mistaken hypothesis.

The identity of *Calamites* and *Arthropitus* being thus established, the latter genus disappears; but there yet remains for consideration the relationship subsisting between *Calamites* and *Calamodendron*, regarding the latter genus as identical with the *Calamitea* of Cotta.

On this point, I think, some light is thrown by a study of the plant which I described in 1869 *, under the provisional name of *Calamopitus*. The figures in the accompanying Plates will facilitate an apprehension of what I propose saying on this subject.

Fig. 1 represents an ordinary form of a fossil Calamite, with its transverse nodal constrictions, *a*, and its longitudinal internodal ridges and furrows, *b*. When covered with a very thin film of coal moulded upon the contours of figure 1, this form represents the ordinary Equisetiform Calamite of the Brongniartian school. But all parties now see in such a specimen something more. I long ago pointed out that these fossils were merely the inorganic casts of the fistular medulla of a Calamite, in which a nodal medullary septum extended more or less completely across the medullary cavity at each node, and to the presence of which the transverse constrictions

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* Trans. Lit. and Phil. Soc. Manchester, 3rd ser. vol. iv. Session 1868–9.

of the cast, fig. 1, *a*, are due. In like manner, the origin of the longitudinal grooves and ridges, *b*, running vertically along each internode is illustrated by fig. 2, which represents a fragment, including a node and parts of two internodes, of a decorticated Calamite. Here *a* is the fistular medullary cavity; *b* a thin film of medullary parenchyma which surrounds the fistular cavity; *c c* is a ring of vascular wedges; the sharp apex of each wedge projects inwards, encroaching upon the medullary zone, at which latter point a narrow vertical canal [*], *d*, is present. All the wedges of each internode extend vertically in parallel lines, *e'*, as do the homologous vascular bands of living Equisetums, through the entire length of the internode; but those of each internode alternate at each node, *f*, with the corresponding wedges of the next internode above and below. Each of these vascular wedges originated in a few vessels in contact with the longitudinal canal, *d*; but as each wedge grew exogenously, its peripheral, tangential diameter increased.

Viewed in transverse section, as in the upper part of fig. 2, we see that these wedges were separated widely from one another in their youngest state by a broad radiating band, *g*, of the fundamental parenchyma, connecting the medulla with the cortex, exactly as the protoxylems of any young, vascular, exogenous growths are separated from one another. In 1870 I applied to these cellular bands in the young Calamite, the name of *primary* medullary rays [†], to distinguish them from those which instead of commencing in the bark commence in the wedges, and to which latter I applied the term *secondary*

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[*] In my various writings I have designated this the *internodal* canal, regarding it as the homologue of the canals that accompany the vascular bundles in the recent Equisetums.

[†] "On the Organization of the Fossil Plants of the Coal-Measures.—Part I.," Phil. Trans. (1871), p. 479.

medullary rays. As the vascular wedges grew radially, they also enlarged tangentially, and as they did so they encroached laterally upon the peripheral prolongations of the primary medullary rays (*g*, *g*), which, as we have seen, ran parallel to, and on either side of, each wedge, throughout the length of the internode. In this way the primitive medullo-cortical origin of each such ray was lost sight of, its peripheral extension becoming, both in its cambial development and in its aspect, like an ordinary secondary ray. It results that, when we examine the exterior of a *young* decorticated Calamite, such as is represented in the lower part of fig. 2, we find the longitudinally extended vascular wedges, *e*′, separated throughout their entire length by tangential sections, *g*′, of the parallel primary medullary rays. In stems with a more developed vascular growth, these alternations of tissue disappear, as shown in fig. 3 *g*.

The alternations of these vertical lines of cellular and vascular tissue in contiguous internodes are brought about in exactly the same way in living Equisetums and in fossil Calamites. As each end of a vascular wedge approaches the node above and below the internode to which it belongs, it splits into two short diverging branches (fig. 2, *e*). Each one of these meets a similar branch, derived from the contiguous vascular wedge of the same internode, and the two halves thus derived from two distinct wedges form a third one, which continues its upward or downward course through the next internode, but in a line midway between those from which it sprang, as in the living Equisetums; the internodal canals, *d*, branch and recombine at the nodes of some of the fossil Calamites in exactly the same way as the vascular wedges do.

Fig. 3 represents a restoration of a Calamite like fig. 2, only corticated and in a more advanced stage of growth. Here, again, we have the central cavity, *a*, the thin medulla, *b*, and the vascular wedges *c*, represented by the same alternations of black and white as in fig. 2; but by detaching the vascular zone, we have also represented, at *b*, *b′*, the causes of the alternating ridges and grooves of specimens like fig. 1; at *c* the *exteriors* of the vascular wedges project *externally* as their inner angles project inwardly into the medullary cavity *. At *c′* a vascular lamina of one of these wedges is seen in radial vertical section, showing the characteristic arched arrangement of its vessels where they cross the node *f*. At *h″* is one of the infranodal canals passing out from the pith to the bark, through the upper end of each primary medullary ray, as at *h*, *h′*, and at fig. 2, *h*, whilst at *i*, *i′*, as at *i*, *i* of fig. 2, we have lines of cellular tissue passing outwards through both wood and bark, being apparently lines of communication, doubtless containing some vessels, between the interior of the plant and each of its verticillately arranged leaves. At *k* we have the bark with its absolutely smooth, ungrooved, and unconstricted exterior at *k′*, its nodes being prominent, rather than constricted, as they are at fig. 1, *a*.

Independently of the bark which encloses them, we have here a complex series of structures:—*a*, the fistular cavity; *b*, medulla; *c*, vascular wedges; *d*, internodal canals; *f*, node; *g*, primary cellular medullary rays,—besides which each vascular wedge, *c*, is composed of a number of thin, parallel, radiating, vertical laminæ of vessels, between which are numerous secondary medullary

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* On the right hand of this figure the vascular zone has been removed from the interval between the two stars, showing the undulating outline, *b*, of the very thin medulla, which has adapted itself to the corresponding undulating contours of the medullary angles of the vascular wedges, *c*, the intervening primary medullary rays, *a*, and upon which the inorganic cast, fig. 1, of the medullary cavity, *a*, was moulded in its turn.

rays. Now this very complicated arrangement of parts is admitted by all to exist alike in *Calamites* and *Calamodendron,* and the inorganic cast of the interior of the medullary cavity of a Calamite also reappears unchanged in the *Calamodendron.* This remarkably detailed identity in the morphological features of two plants, the former of which is admitted to be a Cryptogam, whilst the latter is assumed to be an Gymnospermous Phanerogam, is, in itself, sufficient to suggest the strongest doubt as to the accuracy of this assumption; but fig. 3 carries us further. Abundance of specimens in my cabinet prove the absence from the bark of all the nodal constrictions, as also of the longitudinal ridges and furrows, formerly supposed to be characteristic of the exterior of the bark of a true Cryptogamic Calamite. We possess little evidence respecting the bark of *Calamodendron,* but M. Brongniart inclined to the belief that it also had a smooth exterior.

There being such a remarkable identity in the general, as well as in the minute morphology of *Calamites* and *Calamodendron,* let us now see what value may be assigned to the differences of detail that are supposed to distinguish the two plants.

To facilitate an apprehension of this part of the subject, I have prepared diagrammatic outlines of three cubical wedges. One of these (fig. 4) is cut out of the stem of a Calamite, fig. 5 is from my so-called *Calamopitus,* and fig. 6 is from a *Calamodendron* from Chemnitz. Each of these blocks comprehends superiorly, a portion of the horizontal transverse section, and inferiorly, of a vertical tangential section. In like manner in each block the two outer portions, *g, g,* represent two primary medullary rays, and the central area, *c,* is part of a single vascular wedge. In each of these figures the further margin, *c,* of each cube is supposed to be the portion nearest to the medulla.

In fig. 4 (*Calamites*) we find that the cells of the broad medullary ends of the two primary medullary rays *g, g,* are larger in size and less regular in their arrangement than those of the narrower, more peripheral portion *g′,* of each ray, where the cells are smaller in size and disposed in regular radial rows, parallel to those of the vessels of the vascular wedge, *c.* Turning to the tangential side of the block, we see that the vertical extensions of the same rays, *g″, g″,* are still composed of parenchyma, the component cells of which tend to assume an arrangement in vertical lines.

Between these two rays we have part of a vascular wedge, *c,* narrower at its medullary end than at its opposite one. It is composed, as is most usual, of barred vessels or tracheids, not always easily distinguishable in transverse sections from the cells of the more peripheral extremities of the primary medullary rays. In the tangential section, we see the secondary medullary rays, *l,* of the wedge, each being composed of variable numbers of cells arranged in vertical rows.

Turning to a similar diagram of a cubic block from my *Calamopitus,* fig. 5, we find the general arrangements to be identical with those of fig. 4. The differences between them are chiefly twofold. In this plant, the transverse section shows the cells *g, g,* of the two primary medullary rays to be more uniform in size and more regular in their linear, radial arrangement than is usual amongst the Calamites. This exceptional condition exists close to the medullary axis as well as more peripherally, as will be seen on contrasting fig. 4, *g, g,* with fig. 5, *g, g.* But the most striking feature in this second type is seen in tangential sections of these rays, as at fig. 5, *g′, g′.* Instead of being composed of an aggregation of parenchymatous cells, these rays consist of a very marked *prosenchymatous* form. At the same time these are merely fusiform cells, not lignified fibres. The difference between them and what are found in fig. 4, *g''*, *g''*, is merely a morphological one, probably of small physiological import; nevertheless we have here a true Calamite possessing one of the distinctive morphological features supposed by Brongniart to be characteristic of *Calamodendron*.

The vessels of the vascular wedge, *c*, *c*, are identical in their arrangement, and in the distribution of their secondary medullary rays, *l*, with what we find in ordinary *Calamites*. Structurally, however, these vessels present a peculiarity. Instead of their walls being transversely barred round their entire circumference, they are reticulated, and apparently only on those sides of each vessel that are parallel to the secondary medullary rays. There is, however, nothing in these reticulations, beyond their positions, to identify them with the true bordered pits of the Gymnosperms. These reticulated tracheids are very common in other Carboniferous Cryptogams.

At fig. 5, *g'' g''*, we see traces of special parenchymatous rays passing outwards through the prosenchymatous tissue.

Turning to fig. 6, where we have a similiar cubic block from the *Calamodendron striatum* of Autun, we have further peculiar features of resemblance and of differentiation.

As before, the central division of the transverse section, *c*, is the vascular wedge, made up of numerous radial lamellæ consisting of very large vessels separated by very conspicuous secondary medullary rays, *l*, the latter usually consisting of two rows of cells which frequently separate isolated single vascular lamellæ from one another. A little less frequently we have two and occasionally even three such rows of vessels between each two medullary rays. Turning to the longitudinal section, *c'*, we find the vessels to be barred, as we have seen to be the case with those of ordinary Calamites; the medullary rays, *l′*, consisting of parenchymatous cells, are as conspicuous here as they are in the transverse section. This greater development of these secondary medullary rays distinguishes *Calamodendron striatum* from ordinary Calamites, but this cannot be regarded as a generic feature, much less as an ordinal one.

On each side of this vascular wedge we have the two radial zones *g*, *g*, corresponding to the primary medullary rays of figures 4 and 5. The transverse section shows these rays to be composed of cells whose diameter is very much smaller than that of the vessels composing the vascular wedge on each side of which they are grouped. Their appearance in this section closely corresponds with that of a Coniferous wood. Turning to their longitudinal and tangential sections, *g′*, *g′*, we find that these cells are prosenchymatous and partially sclerenchymatous. They are long fibrous structures such as we find abundantly in many Equisetiform and other Cryptogamic plants. In the transverse section, *g*, we see some parenchymatous medullary rays, as at *g′*, *g′*, and at *g″*, *g″*, in the tangential surface, we see vertical prolongations of these rays as described by Brongniart (see page 257). These have a lenticular vertical section, and those near the centre of the fibrous zone are unquestionably longer and broader than those in its more lateral portions; but these central ones are far from being continuous though the internode, as they are described by Brongniart.

In my transverse sections of *Calamodendron striatum* the radial length of what I call the primary medullary rays (fig. 6, *g*) is much greater than is common amongst Calamites. In the latter plants these rays generally diminish rapidly in diameter as they proceed outwards, and their ultimate external prolongations become, in the most matured stems, almost undistinguishable from those of the secondary medullary rays (fig. 3, *g*). At the same time ordinary Calamites vary extremely in the length of these primary rays, and I have transverse sections in my cabinet which, in this respect, approximate very closely to what I find in my sections of *Calamodendron.*

Comparing the three forms of organization illustrated by figs. 4, 5 and 6 we find them unmistakeably constructed upon a common plan, even as regards the most important of the details. The differences between the vascular or xylem elements of the three examples have no more than specific value. The chief distinctions between figures 4 and 6 are to be found in what I term the primary medullary rays. What in the ordinary Calamites we have seen to be entirely composed of parenchyma, in the Calamodendron consists of prosenchymatous fibres largely intermingled with radial parenchymatous laminæ. My numerous examples of very young and minute Calamites show me that, in them, these primary medullary rays originate in exactly the same way as they do in the first year's growth of any ordinary exogenous stem*; whilst, as is also the case in these Exogens, the peripheral ends of these primary rays become undistinguishable from the secondary medullary rays in the more external layers of older stems. These identities justify my designating both medullary rays. The only question of importance therefore to be asked is, Does the alteration of their composition seen in *Calamodendron,* compared with what we find in *Calamites,* materially alter the character of these organs? I conclude that it does not. In the first place, it is indisputable that fig. 5, my so-called *Calamopitus,* is but a very slightly

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* De Bary applies to these organs in Phanerogams precisely the same terms that I have for years applied to those of the Calamites. See 'Comparative Anatomy of the Phanerogams and Ferns,' English Translation, p. 235.

modified form of a Calamite; yet, in it, the parenchymatous constituent cells of these primary rays are replaced by prosenchymatous ones, without disturbance of any of the other Calamitean features of the plant; the further modifications of these prosenchymatous cells merely involve questions of size, and of a slight degree of lignification in *Calamodendron*, which are surely not features of any ordinal value! De Bary, speaking of the difference between parenchymatous and prosenchymatous structures, says, "We find cells whose protoplasm and contents are reduced relatively to the strongly thickened and often lignified membrane, and which accordingly, without giving up the properties of typical cells, or their part in the process of assimilation, obviously participate in the mechanical functions, *i. e.* the strengthening of the parts to which they belong" (*op. cit.* p. 28). In accordance with the clear common sense of the above quotation, I conclude that the substitution of a mixture of parenchymatous and prosenchymatous elements in the primary medullary rays of *Calamodendron* for the solely parenchymatous ones constituting the same organs in the commoner Calamites, is utterly insufficient to justify the separation of these two plants into Cryptogamic and Gymnospermous groups. My plant, represented in fig. 5, which is obviously an intermediate form connecting these two extremes, reduces yet further the value of the small differences that distinguish them, and at fig. 5, $g'' g''$, we already find traces of the same combination of parenchymatous and prosenchymatous elements that appears to be characteristic of the primary medullary rays of *Calamodendron*.

But one more point yet remains to be dealt with: M. Renault considers that he has obtained clear proof that *Calamodendron* was a Gymnospermous Phanerogam, inasmuch as he believes that he has obtained its male, or antheridial organs, and that its supposed anthers are filled with true pollen-grains. To this I make but two answers:—first, even supposing it true that these objects were polleniferous structures, we have no evidence whatever that they belong to *Calamodendron*. Their doing so is a pure assumption. But even could it be proven that they were so related, I deny altogether that these objects are either antheridial or polleniferous.

My friend Mr. Cash, of Halifax, has received from M. Renault two sections of these objects, which he has kindly allowed me to examine. These sections being inscribed, in the handwriting of the French savant, "Epi de Calamodendron, Pollen divisé," there is no doubt as to their being really the objects to which I have just referred. I have no hesitation in saying that these are nothing more than sections of a very distinct form of *Calamostachys*, of which the supposed pollen-grains are merely the spores, enclosed within their mother-cells, exactly as I have figured similar ones from the sporangia of *Calamostachys Binneyana*, in my memoirs "On the Organization of the Fossil Plants of the Coal-measures," Phil. Trans. pt. ii. plate 15, fig. 17. From all these combined facts I once more conclude that *Calamodendron striatum* is an Equisetiform plant, closely allied to the true Calamites*.

INDEX TO THE PLATES.

PLATE XIV.

Fig. 1. Inorganic cast of the medullary canal (fig. 2, *a*) of a Calamite, with the transverse nodal constrictions, *a*, produced by the projection inwards of the nodal tissues at that point. The longitudinal furrows produced by the similar inward projection of the inner angles of the longitudinal vascular wedges (fig. 2, *c*).

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* I need scarcely remind Palæo-botanists that in 1881, Vom c. M. D. Stur, of Vienna, arrived at the same conclusion, in his valuable memoir "Zur Morphologie der Calamarien." Aus dem lxxxiii. Bande der Sitzb. der k. Akad. der Wissensch. I. Abth. Mai-Heft, Jahrg. 1881.

Fig. 2. Diagram of a *young* decorticated Calamite. *a*, medullary canal; *b*, thin layer of medullary parenchyma; *c*, circle of vascular wedges, each commencing internally at the internodal canal, *d*; *e'*, longitudinal extensions of these wedges through each internode; *f*, a node; *g*, *g'*, primary medullary rays; *h*, external orifices of the vertically elongated variety of infranodal canals; *i* cellular, and probably also vascular, extensions, apparently connected with a verticil of leaves.

PLATE XV.

Fig. 3. Diagram of an older stem of a Calamite. *a*, medullary canal; *b*, *b'*, exterior of the medullary cellular layer; *c'*, radial section through a vascular wedge; *c*, exterior surface of the vascular zone; *f*, the node; *g*, primary medullary rays; *h''*, an infranodal canal extending from the exterior of the medulla (*b*) to the inner surface of the bark, *k*; *i*, *i'*, verticil of radial organs identical with *i* of fig. 2.

Fig. 4. A diagram of a cube cut out of a stem like fig. 2. *c*, portion of a vascular wedge; *g*, *g*, portions of two primary medullary rays; *l*, secondary medullary rays.

PLATE XVI.

Fig. 5. Similar cube to fig. 4, from a rare form of Calamite, in which the primary medullary rays, *g g*, consist of prosenchyma instead of parenchyma. *c*, vascular wedge. *l*, secondary medullary rays.

Fig. 6. Similar cube, from a stem of a *Calamodendron*. *c*, vascular wedge; *g*, *g'*, tissues occupying the positions of the primary medullary rays. *g''*, *g''*, vertical layers of parenchyma separating some of the prosenchymatous layers which represent the primary medullary rays of *Calamites*.

Botanical Laboratory,
Owens College,
Oct. 1st, 1886.

Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9.

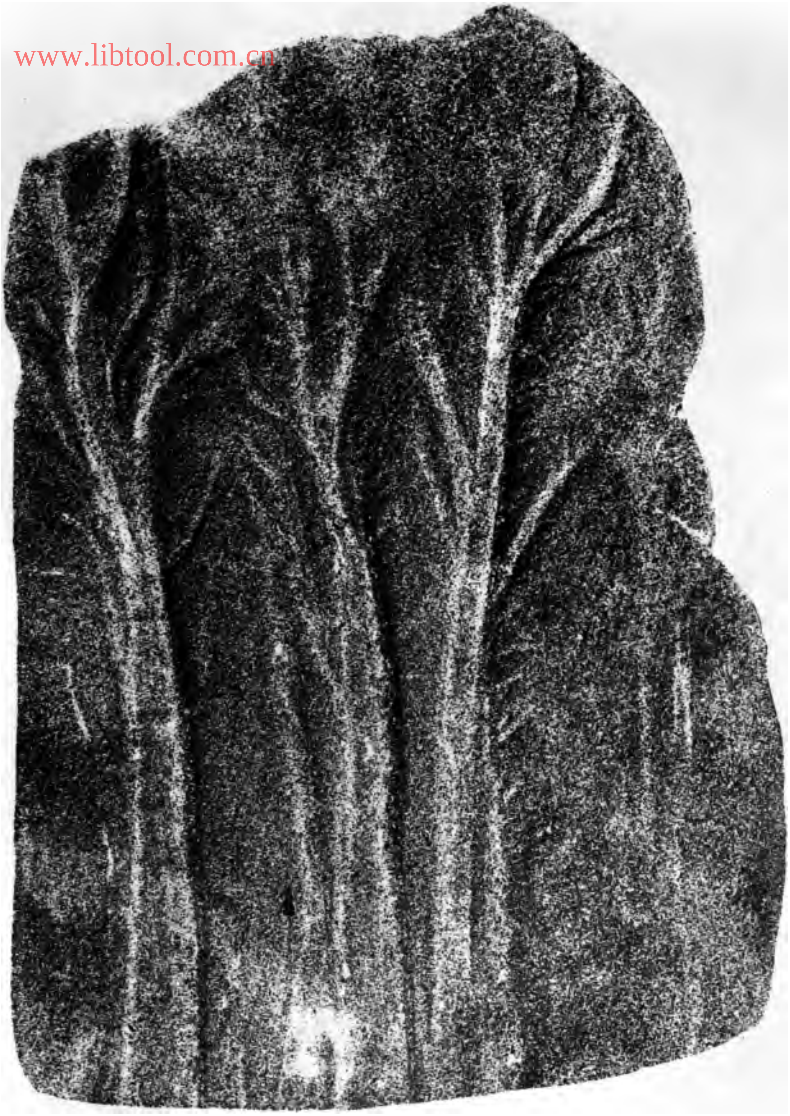

Fig. 11.

Fig. 10.

A BROTHERS, Photo.

Fig. 14.

Fig. 12.

Fig. 13.

Fig. 15.

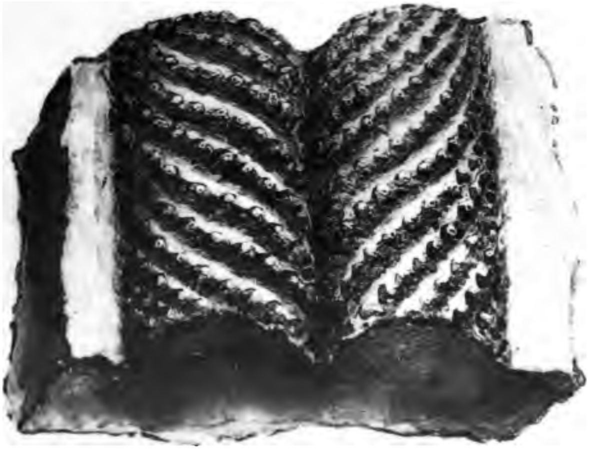

Fig. 2

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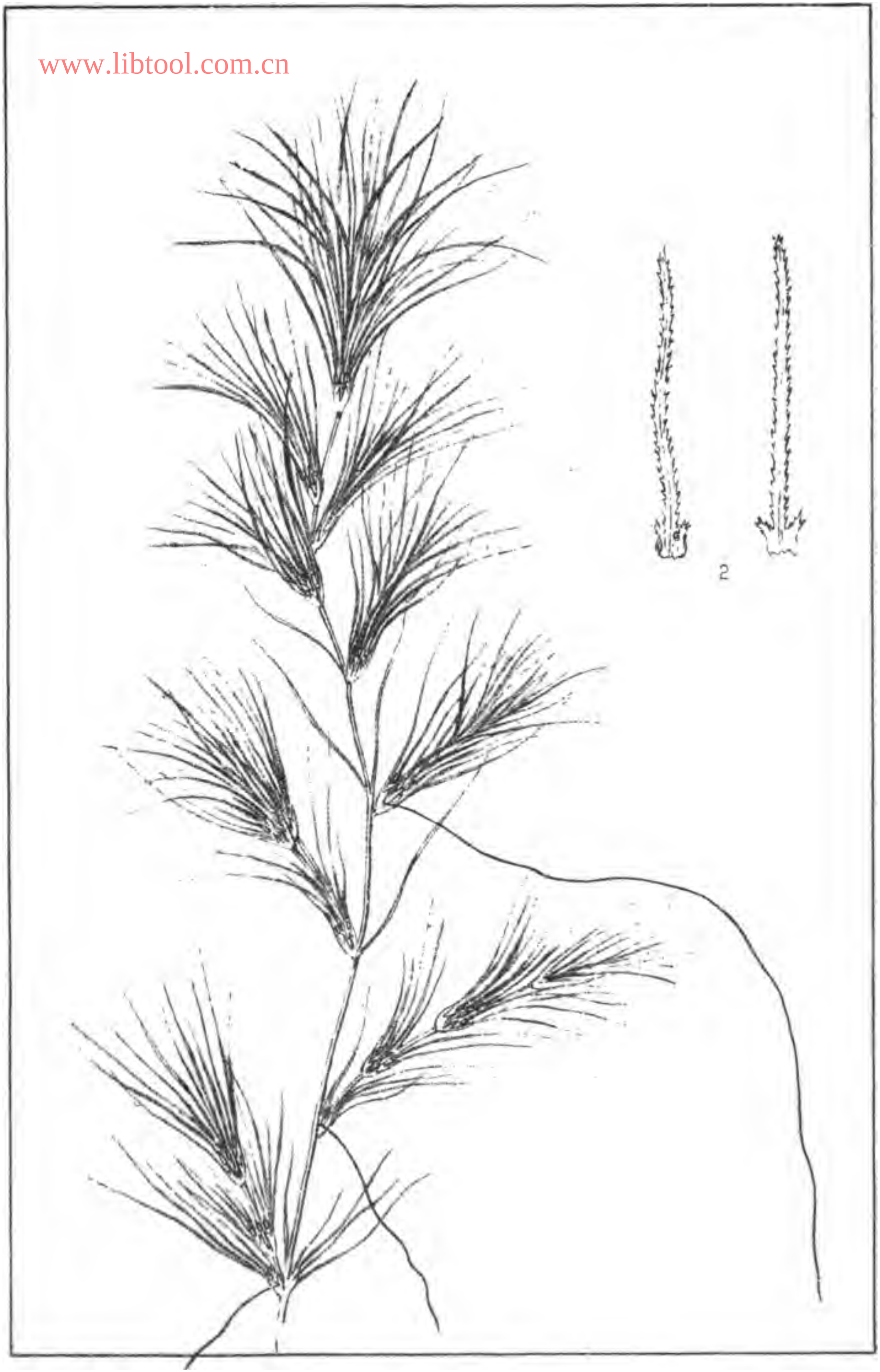

Naias graminea, Del., var. Delilei, Magnus,
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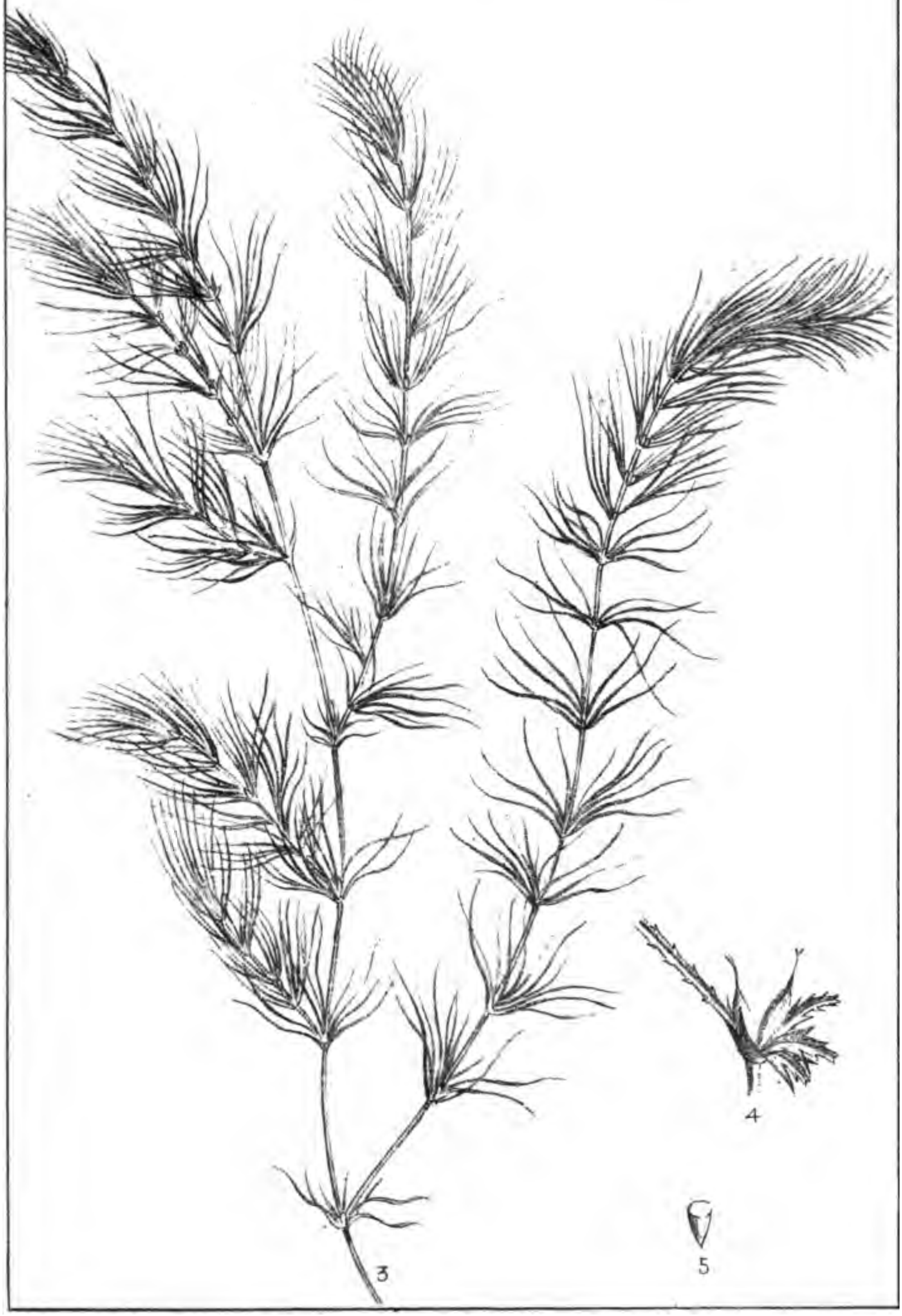
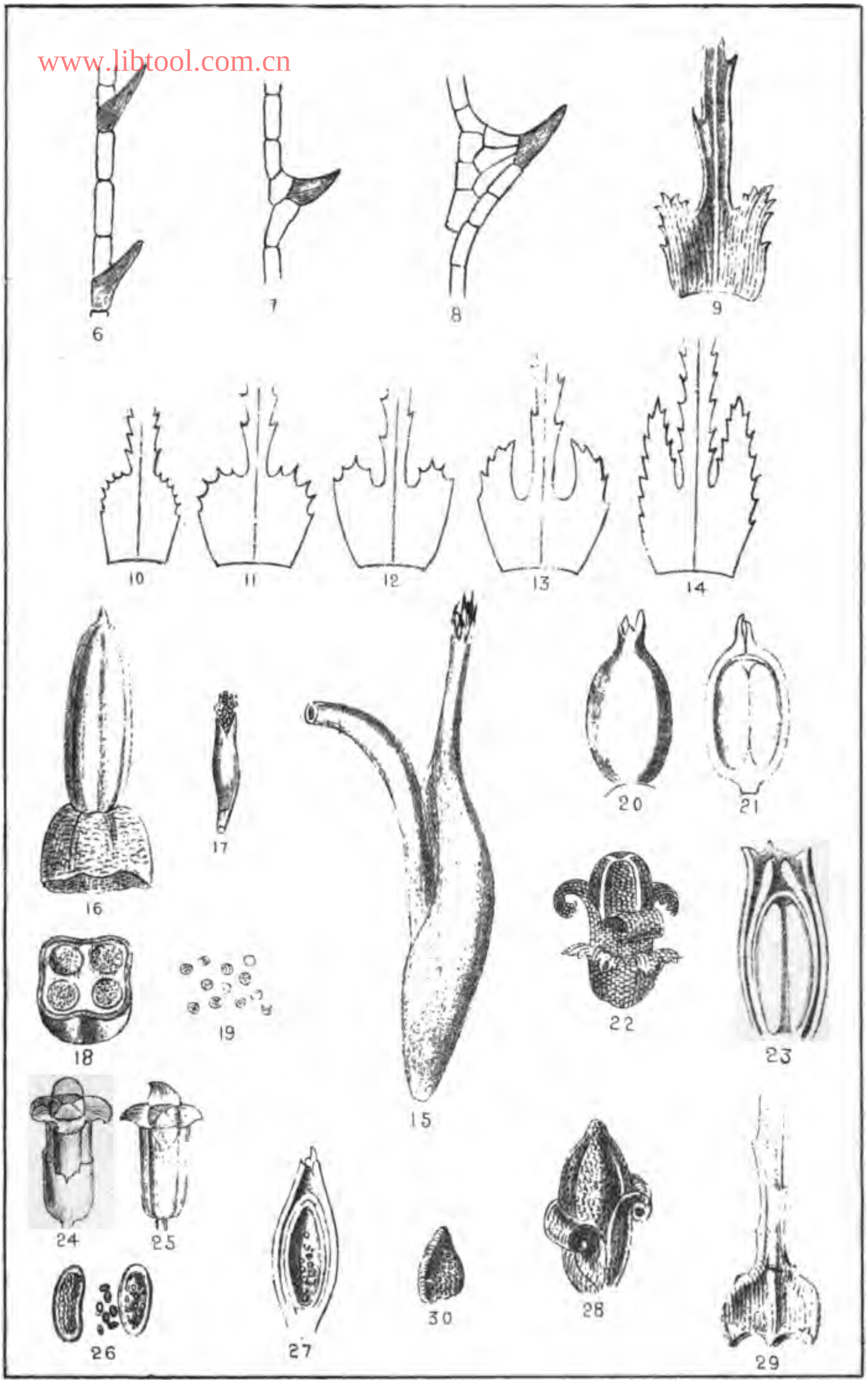
TO ILLUSTRATE PAPER BY MR. CHARLES BAILEY.

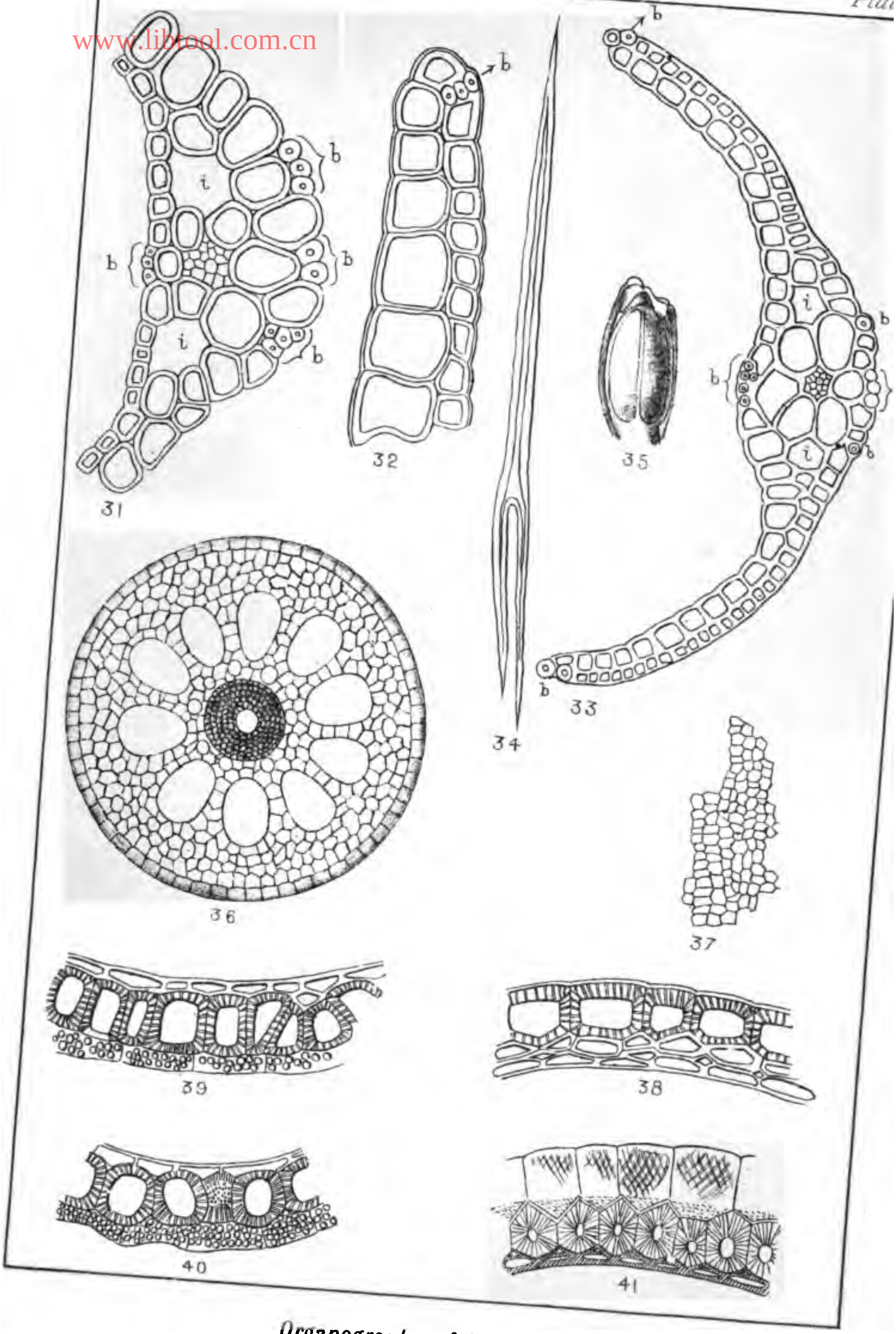


Naias graminea, Delile,
from Lower Egypt.
TO ILLUSTRATE PAPER BY MR. CHARLES BAILEY.



Organography of Naias.

To illustrate Paper by Mr. Charles Bailey.



Organography of Naias.
To illustrate Paper by Mr. Charles Bailey.

Mem. Lit. & Phil. Soc., Manchester, 3rd Ser. Vol. x. Pl. viii.

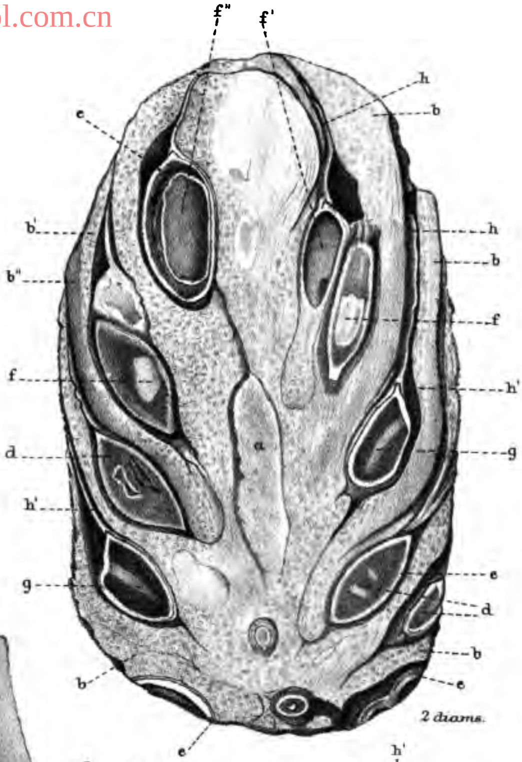
1 C. racemosus. (Sowb.)

2 C. gloria maris. (Chem.)

3 C. euetrios. (Sowb. & Melvill.)

4 C. Paulucciæ. (Sowb.)

Fig. 1.



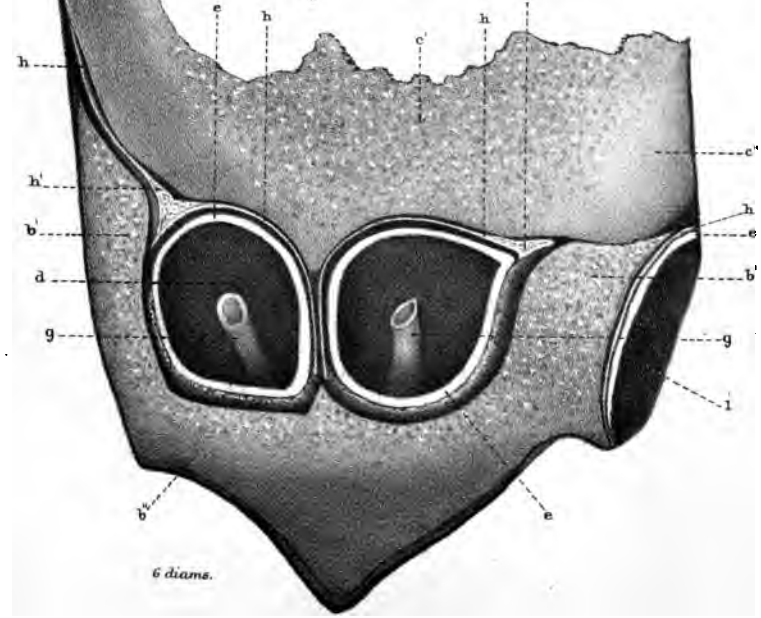


Fig. 2

W. C. Williamson del. A. T. Hollick lith.

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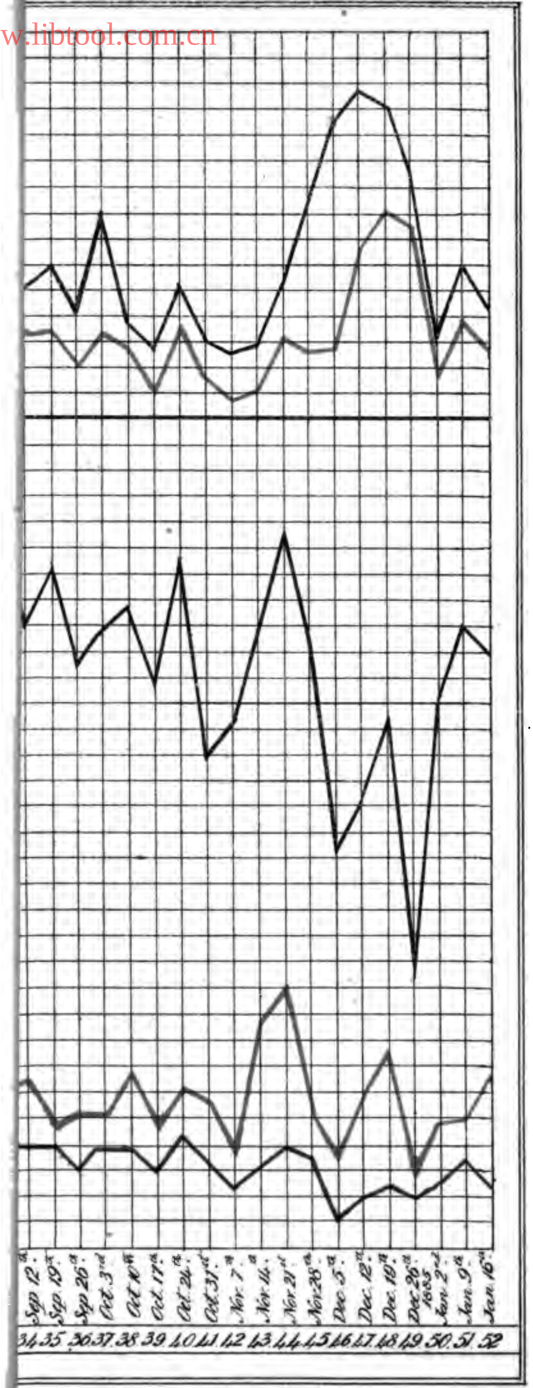

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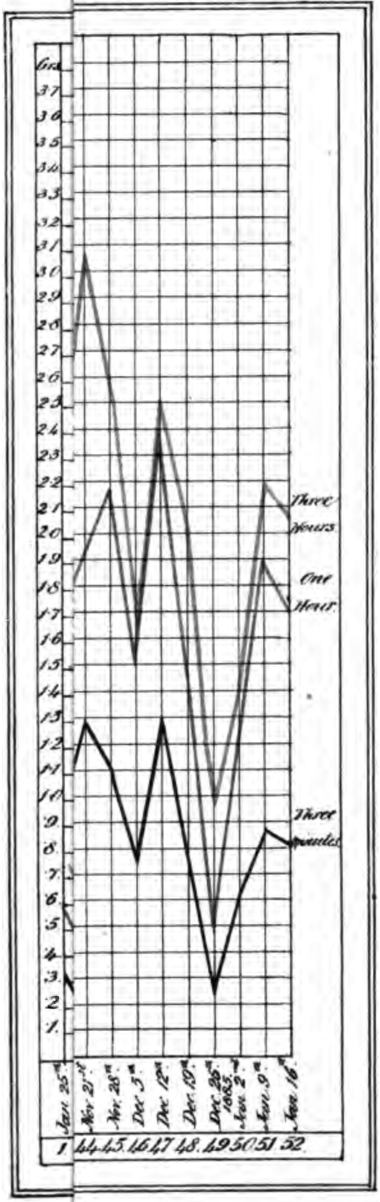

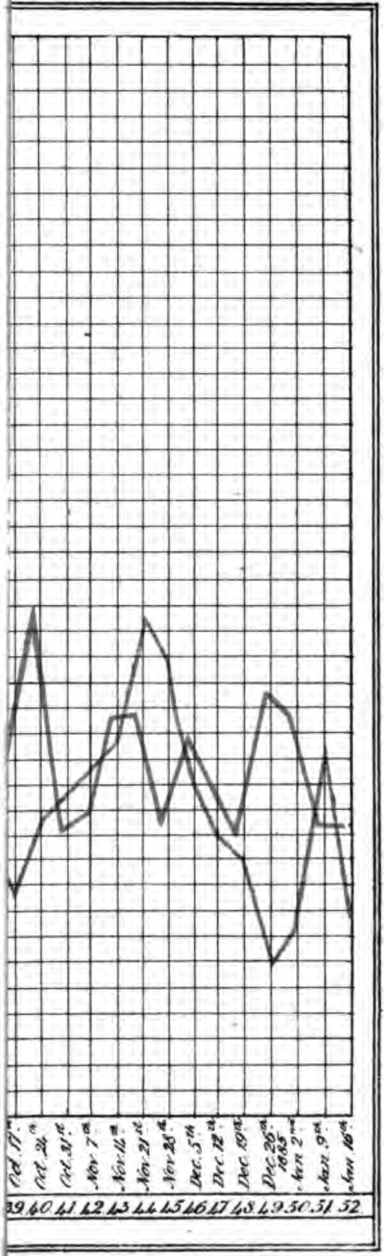
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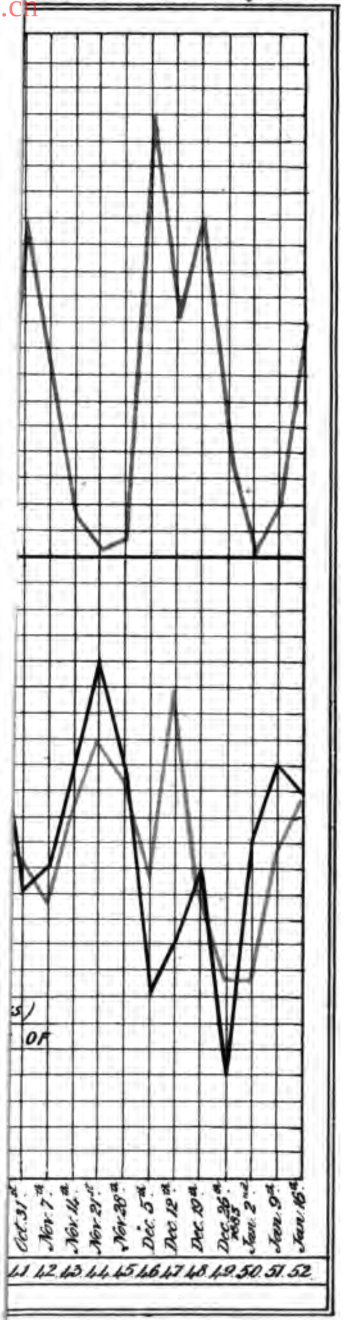
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Fig. 1

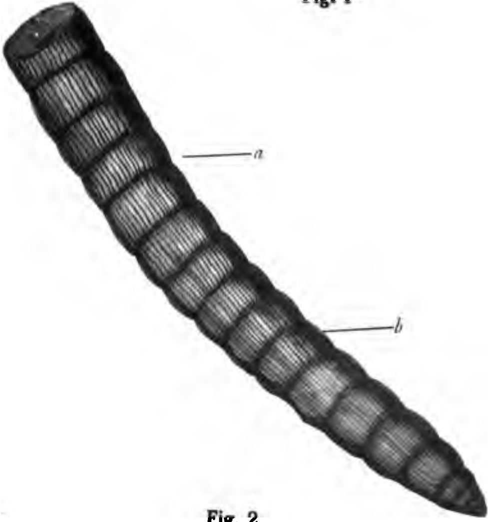
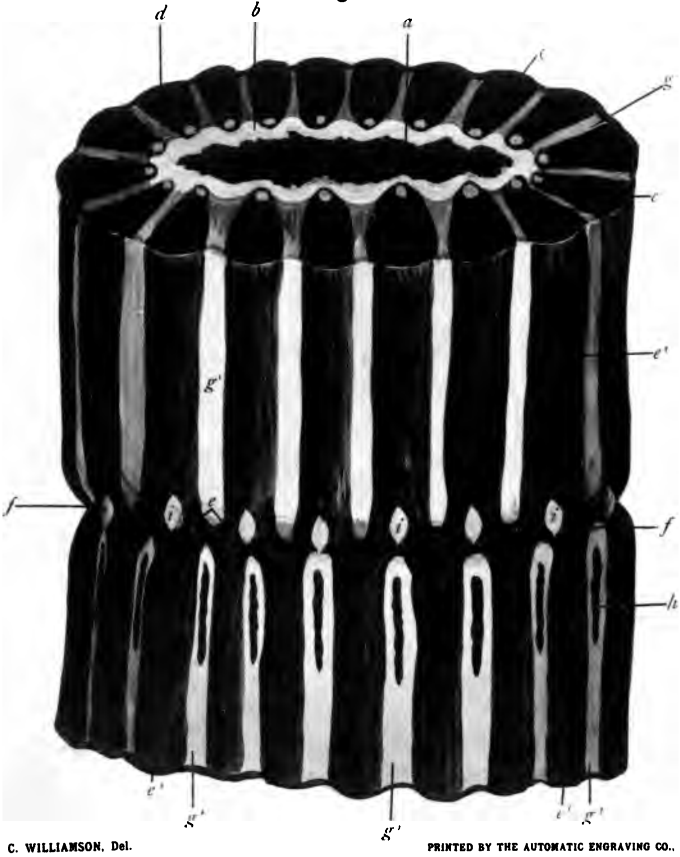


Fig. 2



W C. WILLIAMSON, Del.

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Fig. 3

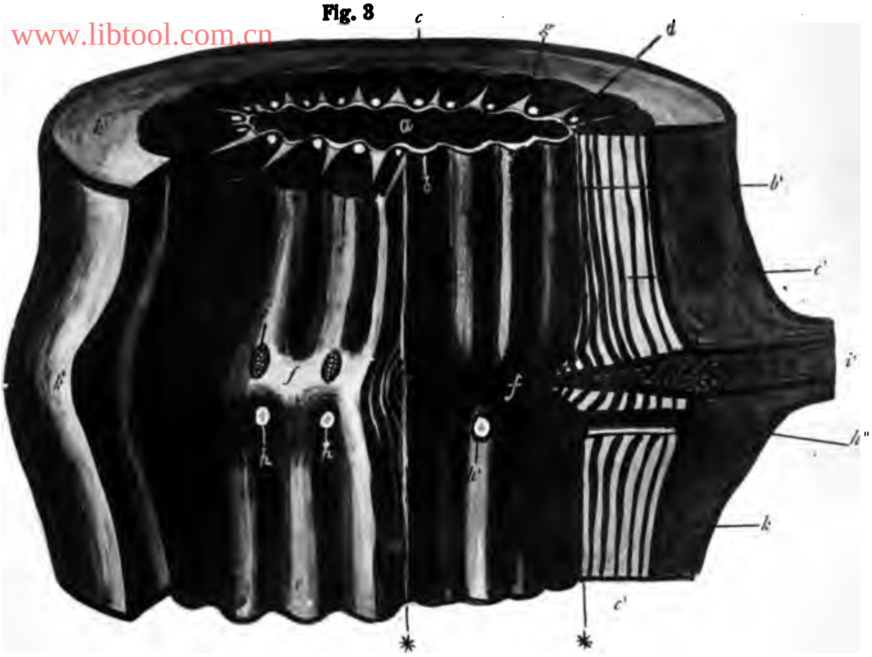

Fig. 4

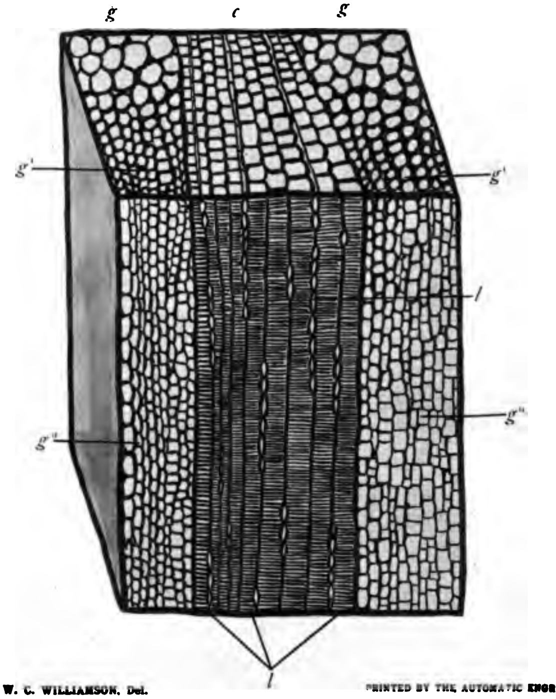

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Fig. 5

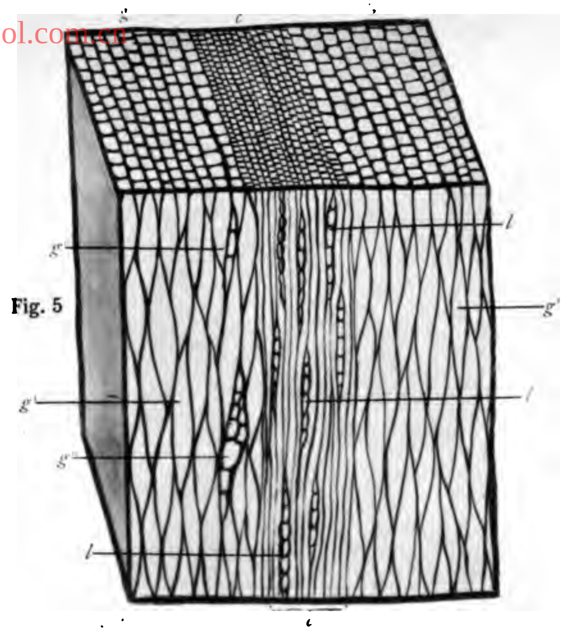
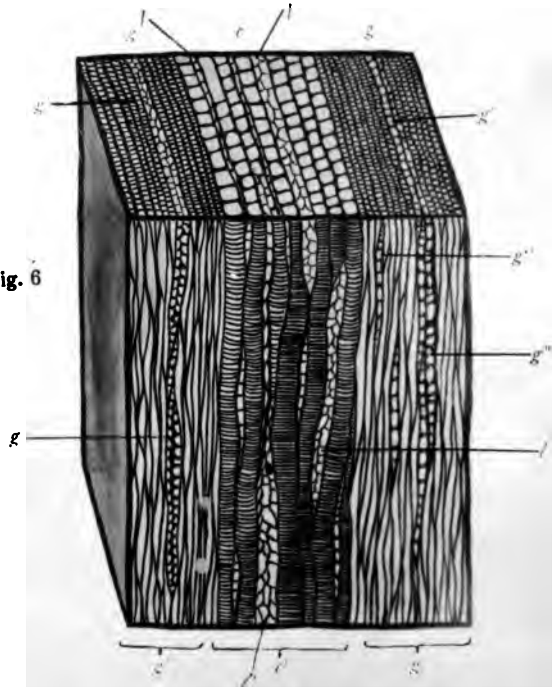


Fig. 6



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