portion of the non-luminous radiation of an Argand gas burner, but that when the thickness of the water is increased to 15 cm. the transmitted radiation consists exclusively, or almost exclusively, of those kinds of radiation which affect the eye as light.

(2.) That with the form of apparatus employed (a thermopile and galvanometer) there is no measurable difference between the diathermancy of pure water and of a solution of alum.

(3.) That the radiation from an Argand gas burner consists of about 1·75 per cent. luminous and 98·25 per cent. non-luminous radiation.

[*Note.*—After this paper had been presented to the Royal Society, I was made aware for the first time, by means of a reprint in the December number of 'Wiedemann's Annalen' (vol. 38, 1889, p. 640), of a paper on "the mechanical equivalent of light," which O. Tumlirz had communicated to the Vienna Academy in the summer of this year. He states that the total radiation from the amyl acetate lamp he employed contained 2·4 per cent. of luminous radiation. He obtained this result by allowing either the whole radiation from the lamp, or that portion of it which had traversed a glass cell containing water, to fall upon the face of a thermopile, and noting in the two cases the deflections of the needle of a galvanometer in the thermo-electric circuit.—December 27, 1889.]

"Observations on the Spark Discharge." By J. Joly, M.A., B.E. Communicated by Prof. G. F. Fitzgerald, F.R.S. Received June 15,—Read June 20, 1889.

[Plates 1—5.]

Path of Discharge over the Surface of a Dielectric.

The subject of dust-figures produced by electrical discharge has received much attention at various times. In the following notes I have refrained, to the best of my knowledge, from going over old ground. The subject has been reviewed in Lehmann's recently published 'Molekularphysik.' It is a sufficient substitute for the customary *résumé* of past observations to refer to that work.

(1.) When a spark discharge occurs in a homogeneous dielectric medium, the path of discharge, as is known, in general lies in a fairly straight line between the points of discharge. If the dielectric medium be heterogeneous in character, the path chosen by the spark will vary with the circumstances. Thus, if the straight line between the conductors be interrupted by a layer of a substance offering a higher resistance to discharge than the surrounding dielectric, the

discharge may be chiefly confined to this surrounding dielectric, spreading over the surface of the layer in ramifying lines.

This ramifying discharge is depicted in some measure in Lichtenberg's figures and in Antolik's. But these lose some of their value in the fact that they represent an electrified condition of the surface of a dielectric obtaining subsequent to the period of discharge. The path of discharge revealed in the figures described in this paper is, on the other hand, laid down by the outspreading current in the act of discharge. There is some resemblance between all three patterns of figures, more especially with Antolik's, whose figures are obtained with a similar disposition of apparatus.

The following are the arrangements used in obtaining the dust-figures:—

A plate of glass is coated evenly with a thin layer of lycopodium powder. This is best done by placing the glass on the bottom of a deep box and shaking the powder from a linen bag, surrounded with a couple of folds of gauze, through a hole in the lid of the box. The plate is next transferred to the surface of a smooth sheet of metal. Wires from the + and − poles of a Ruhmkorff coil are then brought down just to meet the surface of the glass, touching it at points 6 or 8 cm. removed from each other and symmetrical about the centre of the plate. It is immaterial if the underlying conductor be connected to earth or not. By drawing back the hammer of the coil and again bringing it sharply forward, a single make and break is effected. At the moment of "make," hardly any disturbance of the dust, save for a couple of millimetres around the poles, is noticeable, but at the moment of "break" the dust is suddenly agitated and thrown into the pattern shown in Plate 1, a flash of burning lycopodium sometimes accompanying.

This figure depicts the case where the poles have been brought into such proximity as to permit, in addition to the ramifying discharge, the direct passage of a spark. If the poles on the glass be so far removed that no spark passes from pole to pole, the figures appear each separate and complete, but in general branching towards one another. If one pole of the coil be put in connexion with the metal plate beneath the glass and the other be applied centrally to the glass, a figure corresponding to the nature of the pole so applied to the glass is produced. These figures tend to become more symmetrical in development and rounded in outline according as care is taken to centre the pole on the plate and the conductor beneath the plate, and also when the plate used is large. Omitting the underlying conductor diminishes the extent of the figures.

(2.) Of these figures, the + pattern is moss-like and irregular on the edge, the − pattern smooth and cloudy in outline. It is seen that within each of the figures the pattern corresponding to the

opposite sign is located. Thus, near the centre of the positive pattern the cloudy-edged negative pattern is found, and *vice versâ.* More than one internal figure may sometimes, but rarely, be observed. Thus a third figure, corresponding to the external pattern, may occur. Whether these secondary figures are due to a certain amount of oscillation in the current flowing through the circuit or not is not well determined. An experiment in which both the capacity and self induction of this circuit was increased by inserting in it the secondary circuit of a second coil of nearly equal dimensions afforded figures no way differing from those previously produced. It is observable, too, that very large and very small coils give a similar arrangement of the figures. There are other reasons for believing that the major part of the current in a coil discharge is unidirectional, but a small amount of return current might cause the central disturbance on the plate. Again, the central figure may be due to a back discharge from the electrified surface of the plate, as Professor Fitzgerald suggests.

If the inner coats of two Leyden jars be connected with the poles of the coil and so arranged that they can spark to each other across a gap of 4 or 5 cm., the outer coats being separately connected with the wires touching the powdered surface of the plate, the phenomena of discharge differ somewhat. This circuit will afford an oscillatory discharge, and accordingly it is found that triple figures are most frequently formed and that the secondary figure is more conspicuously developed. When the poles on the plate are very near each other, so that a very vigorous spark passes, the secondary figures are seen to encroach on the primary, even branching through them and mixing with them, so that it becomes difficult to distinguish the + from the — pattern. With a wider sparking distance the secondary are indeed contained within the primary, but closely border upon them. And as the sparking distance widens, the secondary figures retreat inwards towards the centres. Finally, when the distance is increased to such an extent that no spark passes, the central figure becomes very inconspicuous; the + becomes very much to resemble the straggling lines of the Lichtenberg figure, and the — becomes an irregular cloud. In these observations it is seen that where the conditions for a vigorous oscillation of the current are favoured the multiple character of the figures grows more marked.

(3.) Various powders were tried in the production of these figures —charcoal, French chalk, very fine emery, mixed sulphur and red lead, the protoxide and peroxide of tin. The last two powders, the oxides of tin, differed in some respects in their behaviour from the others. They exhibited, indeed, faintly, the types of pattern observed with the use of lycopodium, but took in addition a ring-like formation round the poles, the rings being irregular and wavy and sometimes

very numerous. All the other powders behaved like lycopodium, but showed less perfectly developed figures.

(4.) When a plate has been exposed to the action of the spark in producing these dust-figures, the powder which before was loose on the surface of the plate will be found to have become fixed, or to a considerable extent adherent, to the plate where the figure has been formed, and continues to remain so for many weeks; so far as I have observed, indeed, indefinitely.

If a plate bearing a dust-figure be laid by and subsequently (a couple of weeks later) be dusted clean and then breathed upon, breath-figures, differing in the finer detail from those formed on the powder, appear. They more nearly resemble the curious photographic figures obtained recently by Mr. Brown, by passing coil sparks over photographic dry plates ('Philosophical Magazine,' December, 1888). Brisk rubbing, or washing with soap and water, destroys the "magic" qualities of these breath-figure plates. I have not obtained these breath-figures at all so distinctly developed on plates which had very recently been sparked over. It would appear that a certain lapse of time is necessary to confer this quality on the plate. Breath-figures of somewhat similar character have been noticed before.

(5.) Formed in an atmosphere of *coal gas*, the patterns show a marked variation.

In the negative a very regular, halo-like ring surrounds the pole, through which the characteristic cloudy fronds of the negative pattern break out, as it were, in places, extending further on the plate. The + pattern appears in the centre of the halo. The development of spark veins is less conspicuous.

In the positive there is less variation from the normal pattern in air. There are fewer spark veins, and hence less branching. The characters are more those of an irregular outline, with deep mossy edging.

Formed in *hydrogen*, the negative is reduced to a faint, circular halo, with a very faint positive pattern within. No spark veins observable. The positive pattern shows only a few thin, sharp-branching spark veins, fragmentary and radiate to the pole, with an indefinite aggregation of the powder around them.

Formed in *carbon dioxide*, there is no notable change from the figures formed in air. The distinction between the two patterns, the + and —, is perhaps better developed, there being some increased likeness with the Lichtenberg figures.

When the figures are developed under the receiver of an air-pump at *diminished air pressure* it is found that at a pressure of 15″ of mercury the negative form appeared very much as in coal gas, *i.e.*, with a regular halo, having straight radiate marking, few and faint spark veins and a mossy positive pattern near its centre. The positive

form had a mossy outline, with but little branching and few and faint spark veins. Then a negative cloud-edged pattern, with finally a second mossy development of the + form at the centre. At 10″ pressure the — pattern was a very regular halo, with uniform texture. No spark veins, and central mossy + form. The + pattern was a mossy edging, with a second mossy pattern at the centre and an intermediate undisturbed region, in which no definite marking could be detected. At 6″ pressure the halo of the — form is more extended, very faint, and shows the moss pattern at its centre. No spark veins. The + form consists of a few coarse, straggling lines, extending towards the centre, a region within of unmarked powder, and a few more thick straggling lines wandering from the centre. All these thick lines show a central core of unmoved powder, each, in fact, consisting of two parallel lines in which the powder has been removed, leaving an undisturbed central axis. No spark veins.

In air at 3″ pressure both forms have become very indistinct. The suggestion of a halo in the negative: a little pitting here and there, not deep enough to expose the glass, in the positive.

It appears from these experiments that the nature of the gaseous dielectric exerts a considerable influence on the nature of the path taken by the outspreading current. It would seem to be also a question as to the degree of conductivity possessed by the gas. The ring-like symmetry of the negative pattern, as well as the generally more symmetrical outspread of the positive, and the absence of spark veins in both, seem to indicate a uniformity of spread of the current in the better conducting media, as hydrogen, or air, at reduced pressure. This suggests, in fact, that these dust-figures owe their forms chiefly to the manner in which the current spreads in the surrounding gas. It has already been seen that the nature of the powder in general exerts little qualitative influence. The nature of the plate carrying the powder has yet to be dealt with.

(6.) Formed on the surface of a sheet of vulcanite, the figures exhibited no distinguishing feature from those on glass. Thus it appears that a difference of specific inductive capacity (vulcanite is two-thirds that of glass, according to Gordon) does not appear to affect what influence the non-conducting plate may exert on the form of the figure. It will now appear, however, that the isotropic quality or otherwise of the plate is an important factor in determining the path taken by the current.

A plate of selenite cleaved on the clinodiagonal, measuring about 6 × 7 cm., was polished smooth on opposite faces, having been reduced to a thickness of about 4 mm. Owing to perforations, due to loose crystallisation, the crystal had to be laid down on glass with melted paraffin. Dust-figures taken on this crystalline surface showed a very marked variation from those effected on glass. This is espe-

cially observable in the positive figure. The straggling lines of the tufts on this pattern are distorted considerably into the direction of cleavage of the crystal. The outlying "crow's feet," common on these figures, are symmetrically oriented with reference to the cleavage. The entire figure, indeed, evinces unequal development in directions coinciding with the cleavage of the crystal. Wiedemann describes experiments on the conductivity of crystals by discharge from a Leyden jar over dusted surfaces. The dust was thrown into a ring more or less elliptical, according to the degree in which the conductivity of the crystal differed in different directions. ('Poggendorff's Annalen,' vol. 76 (1849), p. 406).

It would be interesting to try the effects on stressed dielectrics. An attempt of my own to deal with stressed glass failed ultimately from want of adequate means of putting a uniform and sufficient stress on the material.

The distortion of the figure produced by an unequally conducting plate shows that the plate, as might be expected, shares in the conduction of the current, which it will do more or less, of course, according to the degree of conductivity it possesses compared with that of the gaseous dielectric. The characters of the figures are, however, probably conferred by the gas, the parts of which being isolated and mobile will tend to favour want of uniformity in the discharge, losing equilibrium under small electrostatic stresses.

(7.) Figures may be formed by inductive action exerted through the dielectric plate.

A glass plate, dusted on *both* sides, is supported about 5 mm. above a smooth metallic surface which is placed in contact with one pole of the coil. The other pole touches the upper surface of the plate centrally. On the current passing a figure is formed on the upper surface corresponding to the pole in contact with it, and on the lower surface a pattern of the opposite kind, but less distinct. Looking through the plate, it is seen that these figures are fairly superimposed, *i.e.*, the outline of the + form corresponds with the outline o the − form. If two glass plates be laid one above another separated by 3 or 4 mm., the lower resting on metal, the figure on the upper surface of the lower plate corresponds in a feeble way to the figure on the upper surface of the upper plate. Similar inductive effects were observed by Mr. Brown in the case of his photographic figures (*loc. cit.*).

(8.) If a plate be dusted on both sides and touched at each side centrally by one of the poles, figures may be formed by direct action on both sides of the plate. The plate may be held in a vertical position. When the dielectric plate is thin the coincidence of the figures so formed is very remarkable. Thus, taken in a plate a couple of millimetres in thickness, every tuft of the pattern on the + side

covers a cloud on the negative. The branching spark veins, too, correspond or overlie closely. Sometimes, however, the coincidence of these latter is not perfect, for, if a plate be dusted and breathed on upon both sides, the spark veins, then showing out more clearly, are seen to diverge a little in some cases.

That this coincidence of development at each side of the plate is inductive and not ascribable to luminous action, possibly initially developed on one side and then determining by its influence discharge along certain paths on the other, is shown by repeating the experiment on red photographic glass, when the coincidence is as striking as before.

It is hard to make out the exact nature of the coincidence. It does not appear to be that of photographic positive and negative throughout. However, the clear margin around the clouds on the − pattern is invariably backed by the marginal frill of the + pattern. It is interesting and curious to observe in the dark this inductive transmission of the current across a sheet of clean glass, arranged as in the above experiment. The close but not perfect coincidence of the spark veins is then easily noticeable.

(9.) If a bundle of plates making up about a centimetre in thickness be arranged as in the last experiment (*i.e.*, the extreme surfaces powdered and touched centrally by the poles), the figures no longer show the coincidence observed in the experiment with the thin dielectric, but are smaller and more of the Lichtenberg type. That is, the + tends to be more straggling and tufted, the − more rounded and lobed. The inductive action is here feebler, and matters are more as in Lichtenberg's experiment.

(10.) On the other hand, diminishing the thickness of the dielectric gives rise to figures of great minuteness and detail. With very thin dielectrics it is difficult any longer to distinguish the + pattern from the −. If such thin dielectrics be laid down on a metallic surface as in the first-described experiment (1), the extreme delicacy of form is still obtained. In this way the figures of Plate 2 were formed upon a sheet of the thin glass used for microscopic cover glasses. Still greater delicacy may be obtained by using thin sheets of mica, but ultimately the piercing of the plate by the spark sets a limit to the experiments. In these experiments the conditions are those for a very strong inductive action. The double nature of each figure is apparent in these as well as in the former figures, and the similarity, or perhaps identity, of the forms of opposite sign is very well seen by comparing the inner with the outer of these patterns.

(11.) Figures taken on opposite sides of a thin insulator at diminished air pressure present some peculiarities. A thin plate of micro-cover glass was arranged to stand vertically beneath the receiver of an air-pump, the poles touching it centrally at each side.

Figures obtained on both sides of this plate at pressures in the receiver of over 15″ of mercury showed much the same minutely divided patterns, in which the + is hardly distinguishable from the —, as occur at ordinary pressures. At about 15″ pressure, however, a sudden transition in the nature of the figures occurs. The negative becomes very indistinct, a hazy ring with little veining. The positive becomes a few long straggling lines, radiate to the centre. So abrupt is the transition that a plate was obtained on which about one-third, or 120°, of the first sort of pattern was definitely replaced by a sector of the second sort, a faint halo on the negative and a ring of straggling radiate lines backing it on the positive side.

As the pressure diminishes the second order of pattern persists and develops. The positive ring spreads outwards, the straggling lines of which it consists becoming shorter. The negative grows so indistinct as to be no longer easily located on the plate; it is found, however, backing the positive ring on close observation. Ultimately both forms disappear from the plate, the positive persisting at pressures at which the negative is quite indiscoverable.

It would appear from all these observations that where the discharge is chiefly in the gaseous dielectric it is to some property of this medium that the peculiar characters of the patterns are to be ascribed. Faraday's view that much of the individualities of positive and negative brushes, sparks, &c., was to be ascribed to the behaviour of the matter conveying the current may possibly be an approximation to the truth in the present case, although affording no insight into the manner in which such a remarkable distinction in the nature of the figures can be brought about by a difference in the behaviour of the gaseous matter towards positive and negative discharges. This view is, however, I think, rather confirmed by the lessening of the distinction between the patterns as the dielectric plate gets thinner, for it is probable that in the case of a thin screen separating the discharges these occur to a greater extent in the matter of the screen, the parts of which, yielding only slightly to stresses, refuse to show any distinguishing behaviour towards positive or negative.

That the distinguishing features of the positive and negative patterns vary with the nature of the matter which shares with the gas in carrying the discharge is apparent, from Mr. Brown's results, in air discharges over photographic plates. The photographic film in this case probably possessed a considerable degree of conductivity, and so modified the air discharge. In the case of the peroxide and protoxide of tin there was also, as already observed, a modifying, or at least a superadded, effect. It is probable that with the use of lycopodium there is with thick plates little modification of the air discharge. The next experiment is a case in point, although much of

the detail observed may result from the fact that the powder was fine and adherent to the glass.

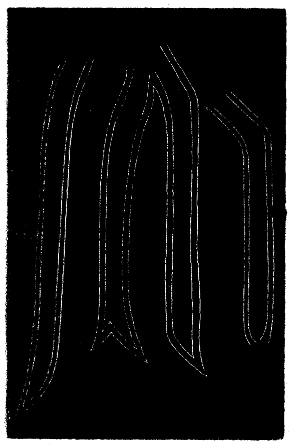
(12.) A glass plate was held over burning magnesium ribbon till a fairly even sublimate of magnesia covered its surface. On this a

FIG. 1.

Discharge over sublimate of magnesia.

discharge was taken, resting the glass on a conductor. It is to be observed, in the first place, that the figures obtained on this surface do not generally penetrate to the glass, but are impressed on the surface of the sublimate. At the same time, the grain is exceedingly fine, bearing examination with a high power under the microscope. Taken on ordinary glass (such as is used in photography), the negative exhibits a centre of fine bent veins and a faint but very beautiful, irregular halo, with wavy border, extending in the direction of the positive pole. The positive most resembles the outspread tentacles of some of the larger sea anemones (fig. 1), but the tentacles, magnified, are seen to have the curious structure sketched in fig. 2. Their extreme

FIG. 2.



Enlargement of tentacles.

points are deeply sunken in the powder, and they sometimes bifurcate at the extremity and curl round, meeting each other in a very peculiar way. Each contains a central core of undisturbed material; they are, in fact, outlined only. On thin glass very delicate figures are obtained. The positive somewhat resembles Mr. Brown's photographs for that pole—veins bordered with innumerable streaming lines. The negative shows a strong resemblance to the positive, being, in fact, a similar pattern with finer streamers. In this last case again we might suppose that the discharge was shared to a greater extent by the sublimate, and differences between the positive and negative gas discharges accordingly reduced.

The undisturbed core in the spark lines has been observed in the case of spark tracks over smoked glass (Töpler). It is developed in breath-figures, or is seen when sparks from a Holtz machine, or from

a jar, are passed over emery dusted on glass. The phenomenon recalls the shallow penetration of transient currents in conductors, and suggests that possibly the inflow of energy from the surrounding medium is not, in these cases of heavy sparks, concentrated to form linear disruption, but disruption on a cylindrical surface.

(13.) To investigate in some measure the effects of the discharge in the substance of the dielectric plate, a plate of ordinary glass was employed, having its upper surface flooded with melted paraffin, kept fluid by resting the glass on a warm sheet of metal. During discharge a ridge or mound of the liquid paraffin was repelled into the region between the poles extending nearly across the plate, and always nearer to the negative pole. Around the poles the paraffin was repelled as if by a strong wind, leaving a circle of glass clean and bare. The circle was largest round the positive pole. Beyond this a radial puckering of the surface of the fluid could be observed. By allowing the glass to cool while continuing the action of the coil, these phenomena could be examined in the solid paraffin. It was curious to observe that as cooling progressed isolated heaps of paraffin gathered from the surrounding fluid, principally near the negative pole, when cold standing 5 or 6 mm. above the general level—possibly a surface tension effect. Short lengths of finely cut up copper wire scattered over the plate while the paraffin was still fluid gathered towards the poles, and, with much gyration and oscillation, set themselves radially to the poles and along lines of flow between the poles. In many cases they struggled into the vacant ring close to the pole, and moved about till they gradually built up lines reaching from the edge of the paraffin nearly to the pole. In some places they set themselves into a kind of network, attaching themselves together, end to end, as if magnetised. These appearances were observed on cooling. Very remarkable are innumerable whirls and eddies to be found on the frozen surface, in some cases so minute as only to be defined with a strong lens.

Similar phenomena were observed using fluid paraffin oil. They reveal the presence of stresses in the dielectric accompanying discharges, which the rigid nature of the glass refuses to show, and suggest the degree to which discharge takes place in the plate.

Some Phenomena Occurring in the Path of Discharge.

The degradation of energy taking place in an electric discharge through a gaseous medium is complex in character. There is development of heat, probably according to the laws of Ohm and Joule; kinetic energy imparted to the molecules by electrostatic repulsion and attraction, and chemical potential energy in the liberated ions. The liberation of ions cannot be supposed to occur in the same manner as in liquid electrolytes. In the latter case the actual expendi-

ture of energy is confined to the immediate surface of the poles. In the spark the expenditure of energy is continuous from pole to pole. The abundance with which ions are liberated precludes the idea that they are liberated only at the poles. This distinction is doubtless ascribed partly to the free motion and isolation of the molecules disintegrated by the spark, partly owing to the explosive disturbance and dispersion of the atoms. For heating, repulsion, and chemical dissociation will unite in setting up a violent rush of atoms and molecules from the axis of the spark outwards, in fact, conferring its explosive character upon it.

The following observations for the most part find their explanation in the mechanical conditions obtaining in the spark path and relate to the behaviour of the spark in passing through confined spaces.

(14.) Two leads of very thin platinum foil are laid down on a slip of glass. The leads are about 30 mm. in length by 1 mm. in width. The glass slip may be an ordinary microscope slip. The leads are laid along the slip in the same straight line, with their ends (preferably cut to points) separated by about 20 mm. at the centre. A piece of thin cover glass is now cut into a rectangular shape, 40×20 mm. *q.p.*, warmed and touched on one side at each corner with shellac. This is laid down centrally on the slip, covering the gap between the leads, and the whole is held over a flame till the shellac between the cover glass and the slip begins to melt. It is then placed on a smooth table and the cover pressed and rubbed down till Newton's rings appear in the space separating the leads. This is easily accomplished if the surfaces have been wiped clean before putting them together. The rubbing is continued till the black spot is produced at the centre of the rings.

If wires from a Ruhmkorff coil are now brought to touch the leads where they extend beyond the cover glass, it will be seen that the spark in its passage across the confined space between the cover glass and the slip refuses to cross the centre of the rings. It makes a detour, curving round at a distance of four or more rings from the black spot, that is, it will sometimes pass in the fourth ring, sometimes in the sixth or eighth. It will often divide into several sparks, some going one side, some going the other. These sparks show no difference in appearance from free sparks. The rings will be seen to be disturbed by the sparks, generally widening as if the glasses came closer. In some cases, however, they soon become destroyed. It is observable, however, that sparks passed through such a narrow space will often produce the rings where none at first existed. Such rings persist for many hours, so that the effect is hardly due to heating, but probably due to an electrostatic straining of the glass.

It appears from this experiment that the spark experiences a higher resistance near the centre of the rings, either because the molecules

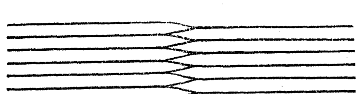
are there constrained in their motion or are fewer in number. If an external by-path be arranged, the spark will often prefer to clear as much as 5 cm. of free air to passing a distance of 1·5 cm. between the glasses. Accurate measurements were not attempted, for with the apparatus used it would evidently have been difficult to have arranged that definite conditions should obtain as to the space between the glasses.

On arranging the slip beneath the receiver of an air pump so that the path of the spark can be observed at low pressures it is sometimes, not always, seen that at low pressures the curvature of the spark increases. It may move outwards by three or more rings, the rings themselves remaining unaltered. When the pressure is much reduced it becomes difficult any longer to keep the spark between the glasses. It chooses then some external path.

(15.) In the last experiments after the first half-dozen sparks were passed through the straitened space between the glasses a faint etched line becomes apparent at the place where the constraint was greatest, *i.e.*, close to the rings. The formation of this line may be observed. It is accompanied by a local brightening of the spark and an emission of sodium tinted rays as if the glass was being volatilized. The line will preserve the curve described by the spark. It may be as long as 4 or 5 mm. or merely a speck.

On placing this under the microscope the line is resolved into a very beautiful and regular structure, diatom-like in its delicacy of marking. Fig. 1, Pl. 3 is a photograph of such a spark track magnified 64 diameters. The width of the track is about one-tenth of a millimetre, but this is slightly variable. Measurements of the side rays show that they are from 330 to 420 to the millimetre. Such a track may be deepened and lengthened by repeatedly passing the spark, the side rays remaining apparently undisturbed in position, but widening a little and lengthening a little, so that a track which is a very faint impression when first examined may be submitted again to the current and gradually brought up. It will be found too in this process that the pitted central core of the track widens and sinks deeper into the glass. The contrast between a fresh and a worn track is interesting. In the former none of the central pitting is developed, but the side rays meet at the centre somewhat as shown in the cut (fig. 3). If the glasses be taken asunder it will be

FIG. 3.



Formation of spark tracks.

found that both glasses have shared in the marking, seemingly to an equal extent. The marks, too, are apparently *vis à vis*.

What has caused this structure? The answer is, I think, not hard to find. In the first place these marks are melted in the glass. Their rounded contours and ridges leave no doubt of this. They are quite distinct in appearance from the hair-like cracks to be observed extending from the track at more or less regular intervals. If the spark be regarded as a line of explosion from which atoms raised to a high temperature are being repelled, the effects observed are quite explicable. These atoms, in the free spark escaping all round, are here compelled to make their escape by the narrow side ways only. The side rays depict the lanes of escape cut by the heated, outrushing molecules. Shift the slide under the microscope till the extremity of track is approached. Here the "head-room" is increasing. Fig. 2, Pl. 3, is a photograph of such a part of the track. Here there is a relief of pressure in the longitudinal direction. The outrush becomes more axial along the spark. Not quite axial, because there is also a possible sideway escape and the lines brush out in the intermediate direction of easiest escape. Hence the tracks generally end up in these beautiful feathery forms.

Occasionally the spark reaches a point in its path where side escape is difficult or impossible. It then assumes the appearance of fig. 1, Pl. 4. The central part is much pitted and lines of escape appear diverging at each end. This is perhaps in some respects remarkable. It might be thought that the unidirectional current would polarize the motion of the atoms, but it would appear as if the atoms, having received their energy from the ether, were left uninfluenced sensibly by any stress or motion in the medium to polarize their movements, other than their tendency to move from the spark axis in a radial direction. In fact the directions of longitudinal flow are apparently obedient to conditions of pressure only, or seem at least sufficiently explained by such.

The lines on the concave side of a sharply curved track are shorter by a little than those on the convex side. The reason of this is that escape is not so free on the inner side. Passing round sharp obstacles accidentally occurring in the path, the axis of the spark track is close in near the obstacles, the lines chiefly radiating outwards.

I made up a slide in which a couple of very fine lines had been engraved with an etching diamond on the surface of the slip, extending across the field at right angles to the path of the spark. On passing sparks it was found that for a little distance at either side of the point where the track crossed these lines the side rays were discontinued, evincing the relief of pressure afforded by the channels.

When a spark bifurcates the course of the outrushing atoms is

shown in (fig. 2, Pl. 4). It is probable that in this figure we are looking at a point on the spark track where a considerable outflow of atoms initiated a divergence of the spark or a bifurcation of it.

(16.) To investigate the nature of these tracks a slide was experimented with when exposed to the reduced air pressure of 10″ of mercury. The spark tracks produced at this pressure were found devoid of the side rays. Instead, beads of melted glass had arranged themselves along the centre of the track, some drawn out into long streaks, others globular. Another slide at 12″ pressure showed very rudimentary development of the rays. At 20″ some rays were obtained, but all these slides treated at ordinary pressures rapidly developed side rays, sometimes bordering the old tracks. The low-pressure tracks, it is to be observed, often develop a budded appearance at irregular intervals, as if the accumulated pressure was content with an occasional relief. The buds open outwards from the sides and ends of the track, fanwise. These are often quite smooth, but develop grooved lines or rays when treated at ordinary pressures. They, in fact, experience a more intense outrush of matter at high pressures than at low pressures.

Why a track can be intensified by repetition of the spark is easily understood. The channels of escape once indicated by the faintest grooving will naturally continue their functions at the passage of each spark, and in this way become deepened.

(17.) It has frequently been shown that on glass there is a surface condensation of moisture. To find if this had a part in the production of the rays, slides were made up of glasses which had just cooled after being heated to redness over a Bunsen burner. The results of several experiments showed that the rays were obtained without difficulty, but perhaps not quite so readily as on slides which had only been rubbed clean in the usual way. The effect of the surface layer of moisture is slight, almost inappreciable.

(18.) The regular spacing of the rays might suggest that the free path of the atoms or molecules might determine in some degree their spacing. To test this question the slides were arranged for experiment in an atmosphere of hydrogen. Great care was taken by a preliminary heating of the glasses composing the slides and subsequent frequent exhaustions, after each exhaustion admitting hydrogen around the slide, to withdraw all air from the space between the glasses. The tracks obtained in this atmosphere of hydrogen turned out to be very similar, generally, to those obtained in air; in places quite indistinguishable from them. In some places, however, a striking distancing or widening of the side lines is observed. The lines here are thicker, shorter, and gapped, *i.e.*, one ray is not continued unbroken from the axis, but is divided by minute gaps. Measurements showed such lines to be spaced about 250 to the milli-

metre. But again measurements in other places, where the spacing was finer, gave similar numbers to those obtained in the case of air, rising to 420 to the millimetre.

It seems probable, in the first place, that some air will linger in these narrow spaces. This might explain the occurrence of the finer spacing. However, granting this, it is not certain that a wider spacing of the lines in the case of hydrogen may not be explained on its superior conductivity or inferior density. These qualities might very conceivably influence the intensity and effects of the outrush from the spark axis. The spacing of the lines might, in fact, be considered as dependent on the accumulation of pressure at points along the axis of the spark. When this accumulation at any point becomes sufficiently intense it breaks out, cutting a channel. It might easily be supposed that such points, where the conditions were uniform along the path of the spark, would be very evenly spaced. The distance separating such points might depend on many properties of the gas, as its conductivity, specific heat, density, and pressure. There is not then, I think, sufficient reason to suppose that there is anything in common between these marks and the striæ observed in vacuum-tubes. The explanation just given seems quite adequate to explain the formation of the marks, but no mere modification of such an explanation will fit in with many of the observations on striæ. The conditions obtaining are really quite different in the two cases.

(19.) Whether the period of electric oscillation of the spark path and leads had an influence in determining the spacing of these lines, was investigated by an experiment on a slide in which the dimensions had been altered till nearly double the ordinary size. The tracks obtained in this, however, presented no peculiarities.

(20.) Observations on the appearance of the spark, confined between the glasses, in the field of the microscope, using a magnification of about 60 diameters, revealed no visible peculiarity. Nor did the use of a wedge of neutral tinted glass, introduced to lessen the dazzling light, enable any detail to be grasped. When, however, passing in a narrow space, the sparks could be seen rapidly melting the glass. Photography of the sparks thus magnified was also tried. The photographs show a bright central part, hazy border, and—very faintly—flame-like streamers extending rectangularly from the border and to some two or three diameters of the sparks at either side.

(21.) The following experiment is explained in an outrush of matter *uniformly* from all points along the spark. Into a piece of thermometer tubing about 0·2 mm. in bore and about 4 cm. in length, two leads of very fine, straight platinum wire are laid loosely. They are separated in the tube by about 1 cm. Let this gap be situated at a distance of 1 cm. from one end, and therefore 2 cm. from the other,

and connect with a coil so that sparks pass. If now a stream of coal-gas be passed across the end of the tube nearest the spark, two-thirds of the length of the spark near this end will become coloured with the blue tint assumed by a spark in coal-gas at atmospheric pressures, the remainder of the spark length remaining as before. Altering the direction of the current does not influence the result. If the coal-gas be passed across the other extremity of the tube, the one-third of the spark length near that end becomes blue, the other two-thirds continuing an air spark.

Move the spark gap into the middle of the tube and repeat the experiment. Now it is seen that *half* the spark turns blue when the gas is approached to one end; always that half nearest the end opening into the current of gas.

If finally, a flame of any kind be approached one end of the tube, at each spark the flame is seen to be blown outwards as if acted on by a blow-pipe. The explanation of the coloration of the coal-gas is to be found in a back suction of gas occurring after each explosion, the succeeding spark becoming coloured according to the distribution of gas in the tube. This is a question of facility of egress and ingress. When the spark is centrally placed in the tube these are equal at each end, and half the spark will be coloured. In the unsymmetrical position of the spark, outflow and inflow are facilitated at one end and obstructed at the other according as the spark is located nearer the one end and further from the other.

When a spark is caused to pass in the centre of a tube so long as 10 or 12 cm., the puffing out of a flame applied at the end may still be observed, but there is no coloration of the spark when coal-gas is passed across the end. It fails to penetrate so far along the tube as to reach the spark.

The partial coloration of the spark, taking place in this very symmetrical way, must evidently depend on a uniform repulsion of matter along the length of the spark. Were the molecules, for example, only repelled close to the positive pole the symmetry of effects would hardly obtain.

(22.) In addition to the fine rays bordering the spark tracks in more worn tracks, the arrangement of the melted glass is noteworthy. Very often three strings of glass beads are discernible, a central one of large beads or globules, spherical or elongated, and a string of very small spherical globules extending along either side. All are contained in a smooth trough-shaped track. Occasionally the globules are, however, differently arranged. Thus the tiny somewhat V-shaped marks, all pointing one way, shown in (fig. 1, Pl. 5), consist of very minute beads; the largest at the apex, the smaller streaming backwards and outwards like the wash from the bow of an advancing boat. Observations show that this arrangement

may occur reversed in order in the same slide, *i.e.*, the pattern may point towards either pole.*

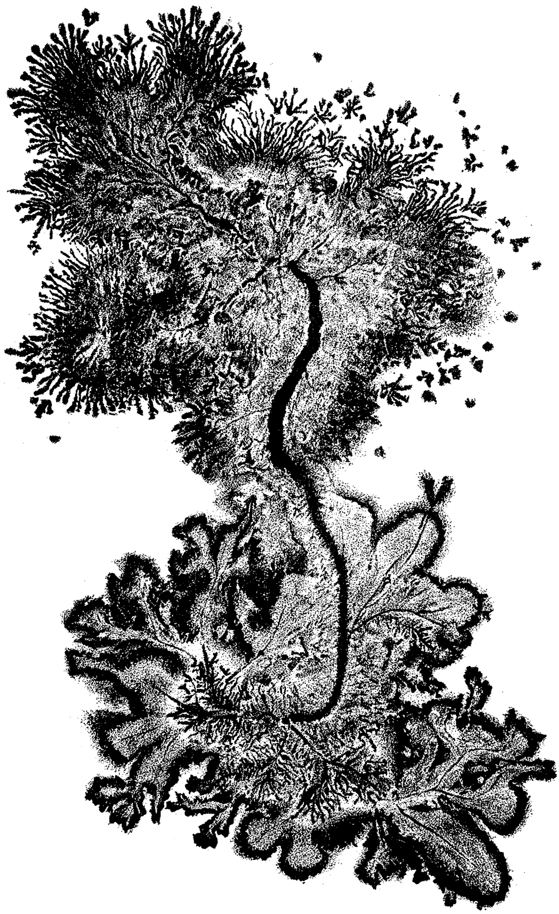
(23.) A few of the cracks which cross the spark tracks are seen on the last figure and on the other figures. When the spark traverses wider places cracks alone appear, and these are sometimes very regular in appearance. It would appear that these are the result of electrostatic stresses in the glass exerted orthogonally to the lines of flow. Thus, near the poles these cracks curve round the pole with a small radius of curvature, the curves flatten as they are further removed from the pole and in the centre of the field cross the line joining the poles perpendicularly. Intersecting these orthogonally are the spark tracks, which, in cases where the glasses are at a uniform but short distance from one another throughout, or parallel, appear to pass in elliptical lines from pole to pole. Fig. 2, Pl. 5, is a photo magnified fifteen diameters of the field near the positive pole. It will be seen that it recalls the usual figures of the distribution of equipotential lines and lines of flow for such a disposition of the poles. It is remarkable that near the negative pole the flow lines often curve outwards at some little distance from the pole. If free sparks, taken from carbon points or dusty terminals, be observed, the luminous particles of burning carbon or dust will be seen to have the same outward curvature at the − pole. Those at the + pole curve elliptically towards the negative (fig. 4).

FIG. 4.

Path of incandescent particles at the poles.

(24.) The homogeneousness of the glass is essential to all the foregoing effects. A plate of Iceland spar was polished parallel to a rhombohedral cleavage face. On this a thin cover glass was laid down over platinum leads as before and sparks passed. Search for tracks of the usual appearance on this was in vain; different phenomena presented themselves. The track was marked by innumerable little pits with raised, rounded edges, running on the whole in cleavage directions, *i.e.*, dividing up the surface into rhombohedral pits. These pits look as if they had been melted into

* The cloudy marking at either side of the track seen in the figure is due to moisture which had penetrated between the glasses before the photograph was taken. In the case of the other photographs the glasses were separated before photographing, the figures being obtained from one of the glasses only.



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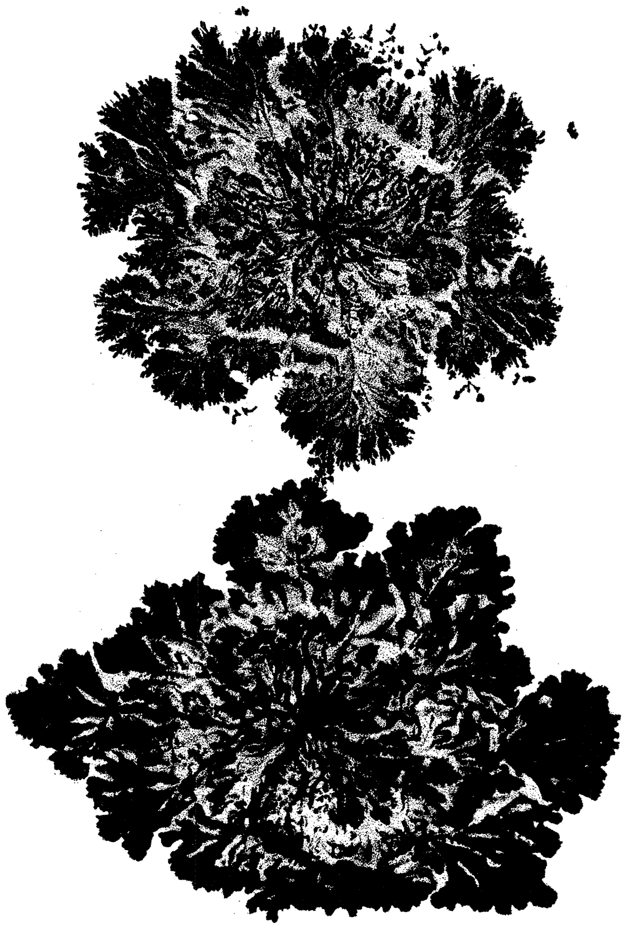

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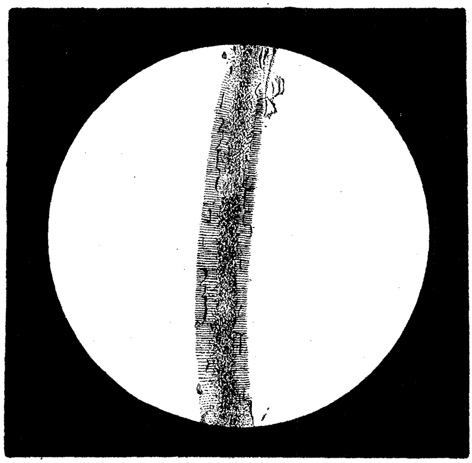

Fig. 1

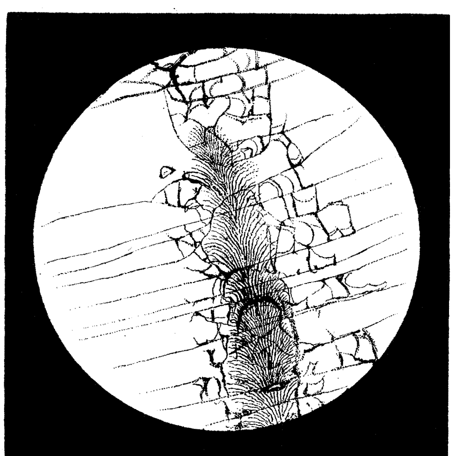

Fig. 2.

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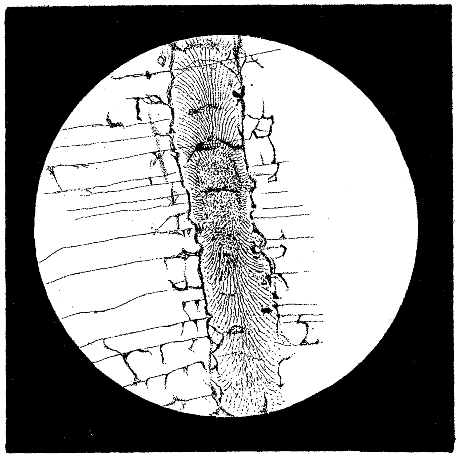

Fig. 1.

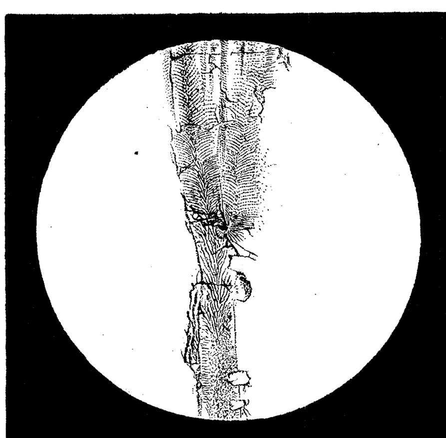

Fig. 2.

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Fig. 1.

Fig. 2.

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the surface of the crystal. Fine cracks, set along the spark tracks, quite distinct from the pitting, and bent in cleavage directions, add to the curious appearance in the field of the microscope. Sometimes a track approximating to those obtained on glass is met with, but the side rays are bent and distorted. I found, also, that the appearance of the tracks varied with the direction which the spark took in reference to the cleavage lines.

A similar experiment on a plate of selenite gave like results, the pits being more elongated in accordance with the more acute cleavage intersection. Mica plates showed a fine net of hexagonally arranged lines covering the surface where the spark had passed. Further experiments in this direction might be of interest, but other work has hindered me from pursuing the subject.

(25.) Sparks from the Leyden jar will produce tracks on glass similar to those described in the foregoing; but experimenting with such sparks is difficult, as their very explosive nature leads to a rapid break up of the cover glass.

January 9, 1890.

Sir G. GABRIEL STOKES, Bart., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read :—

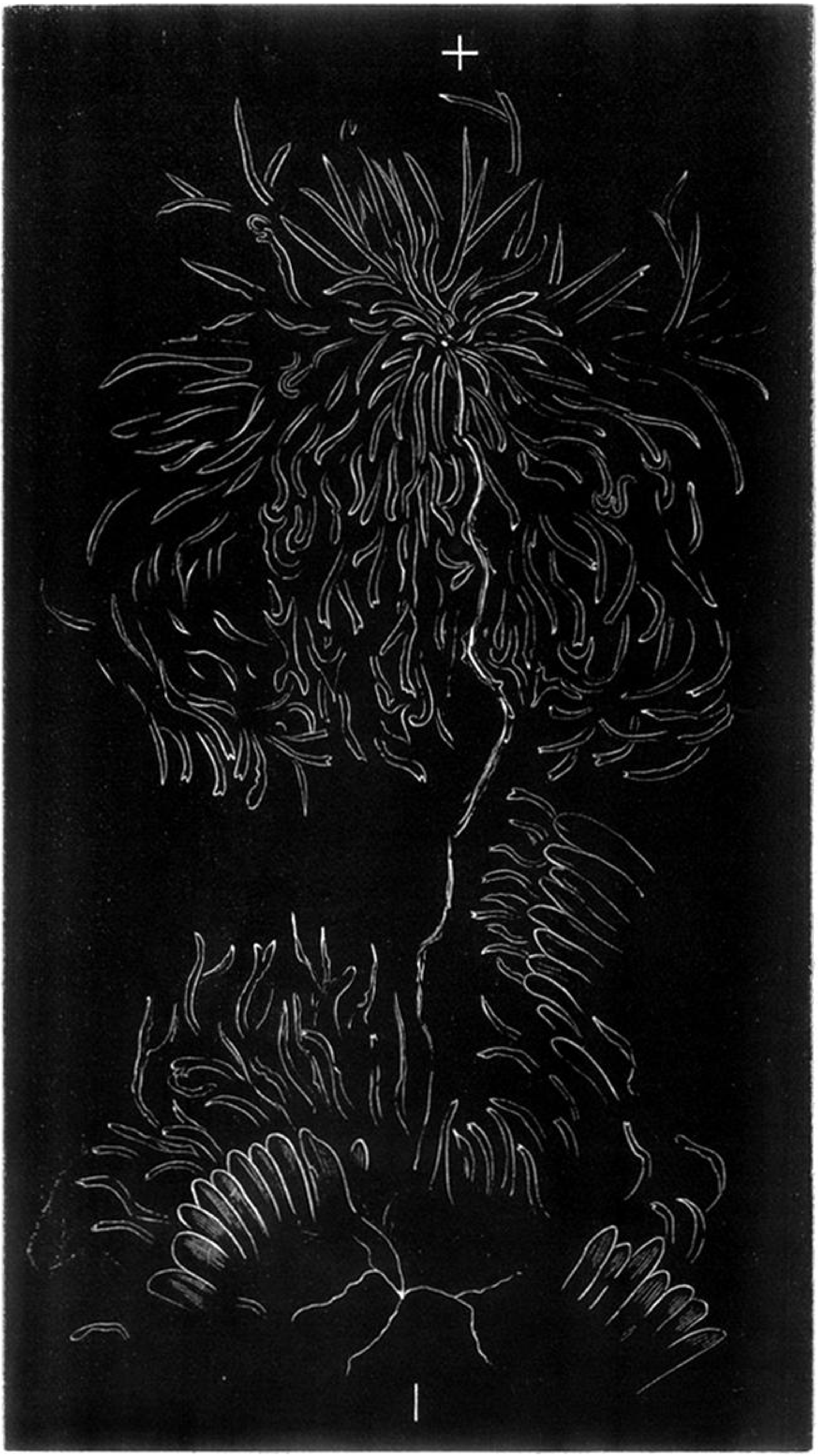
I. "New Experiments on the Question of the Fixation of Free Nitrogen. (Preliminary Notice.)" By Sir J. B. LAWES, Bart., LL.D., F.R.S., and Professor J. H. GILBERT, LL.D., F.R.S. Received (in part) and read January 9, 1890.

Received January 9.

In a paper presented to the Royal Society in 1887—1888, and printed in vol. 180 of the 'Philosophical Transactions,' we discussed the history and the present position of the question of the sources of the nitrogen of vegetation. We referred to the conclusions arrived at about thirty years ago from the results of Boussingault and from those obtained at Rothamsted, up to that time. We gave the results of some experiments which had been recently made at Rothamsted in connexion with the subject, and reviewed the evidence and conclusions of others published within the last few years.

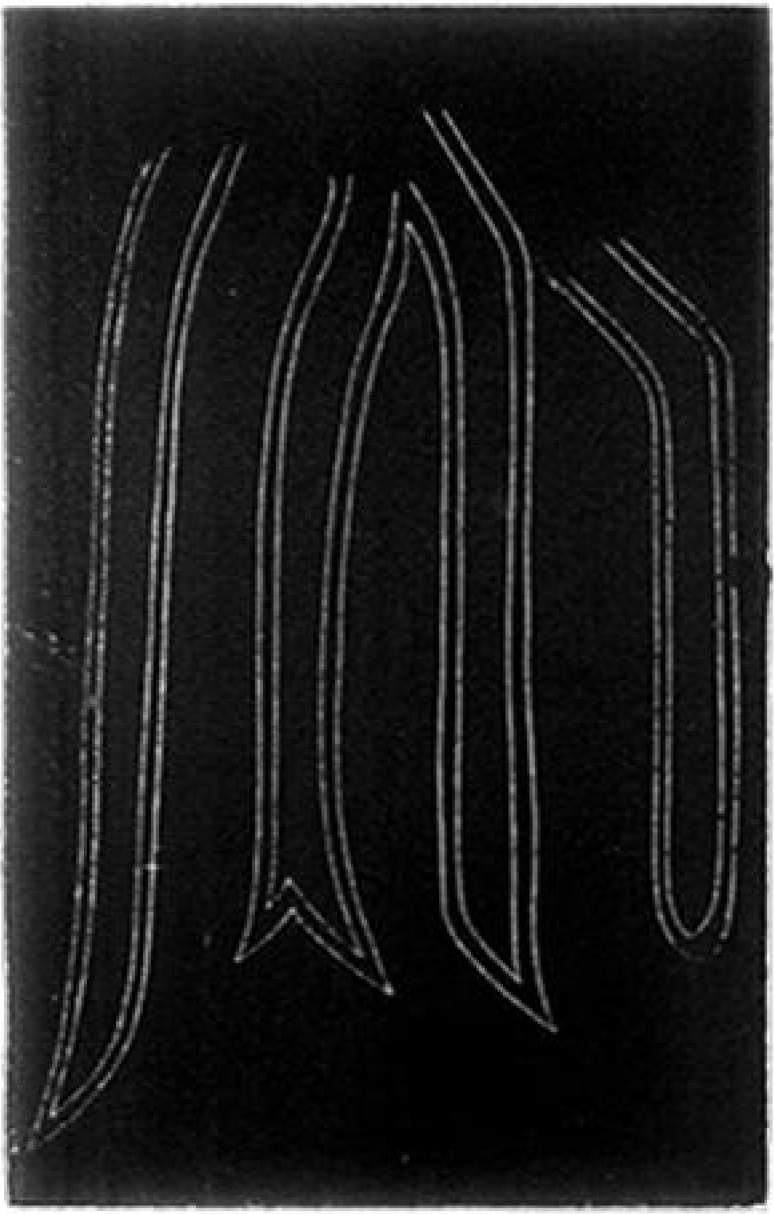
It was considered that the earlier results obtained by Boussingault,

Fig. 1.



Discharge over sublimate of magnesia.

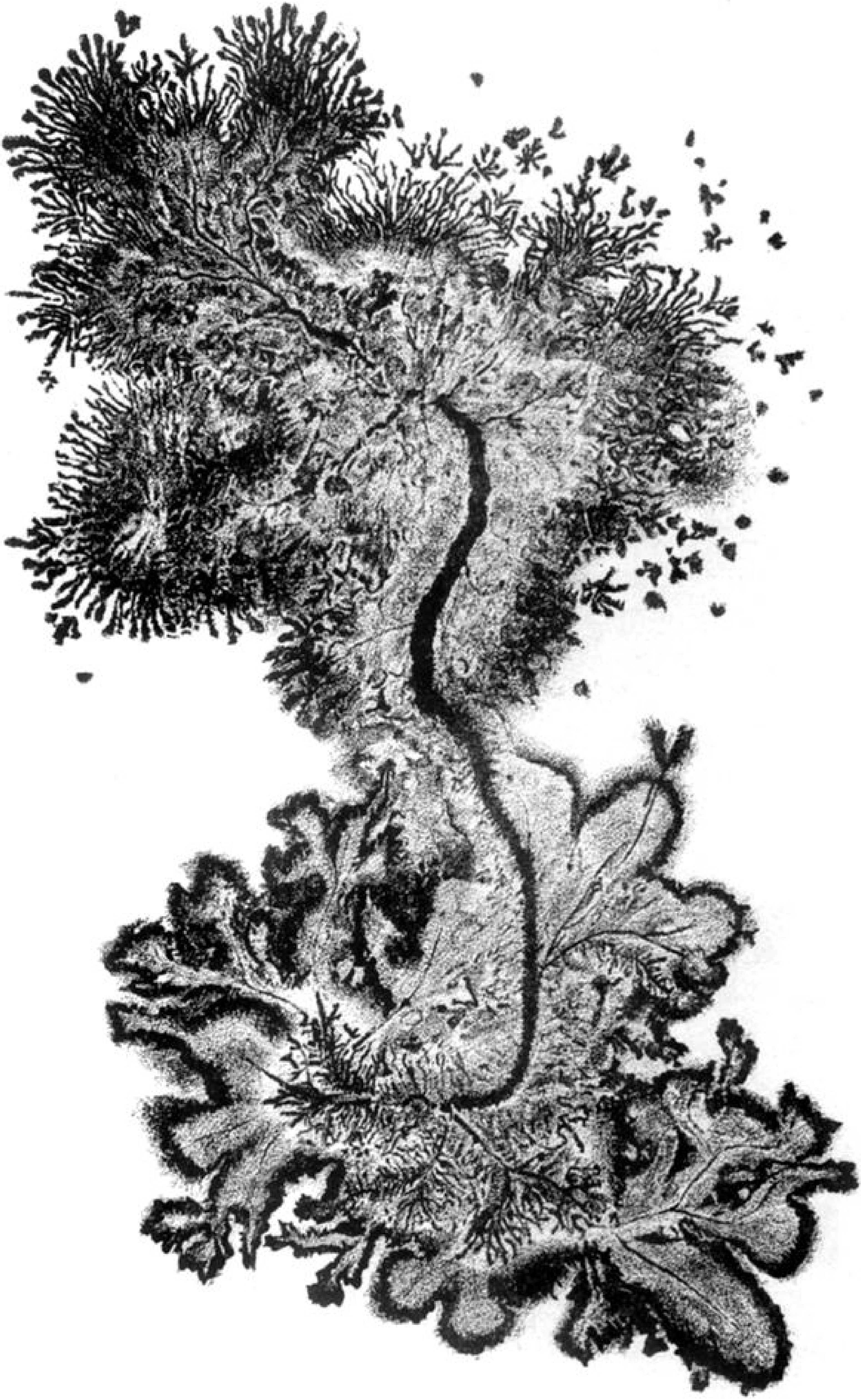
FIG. 2.



Enlargement of tentacles.

FIG. 4.

Path of incandescent particles at the poles.



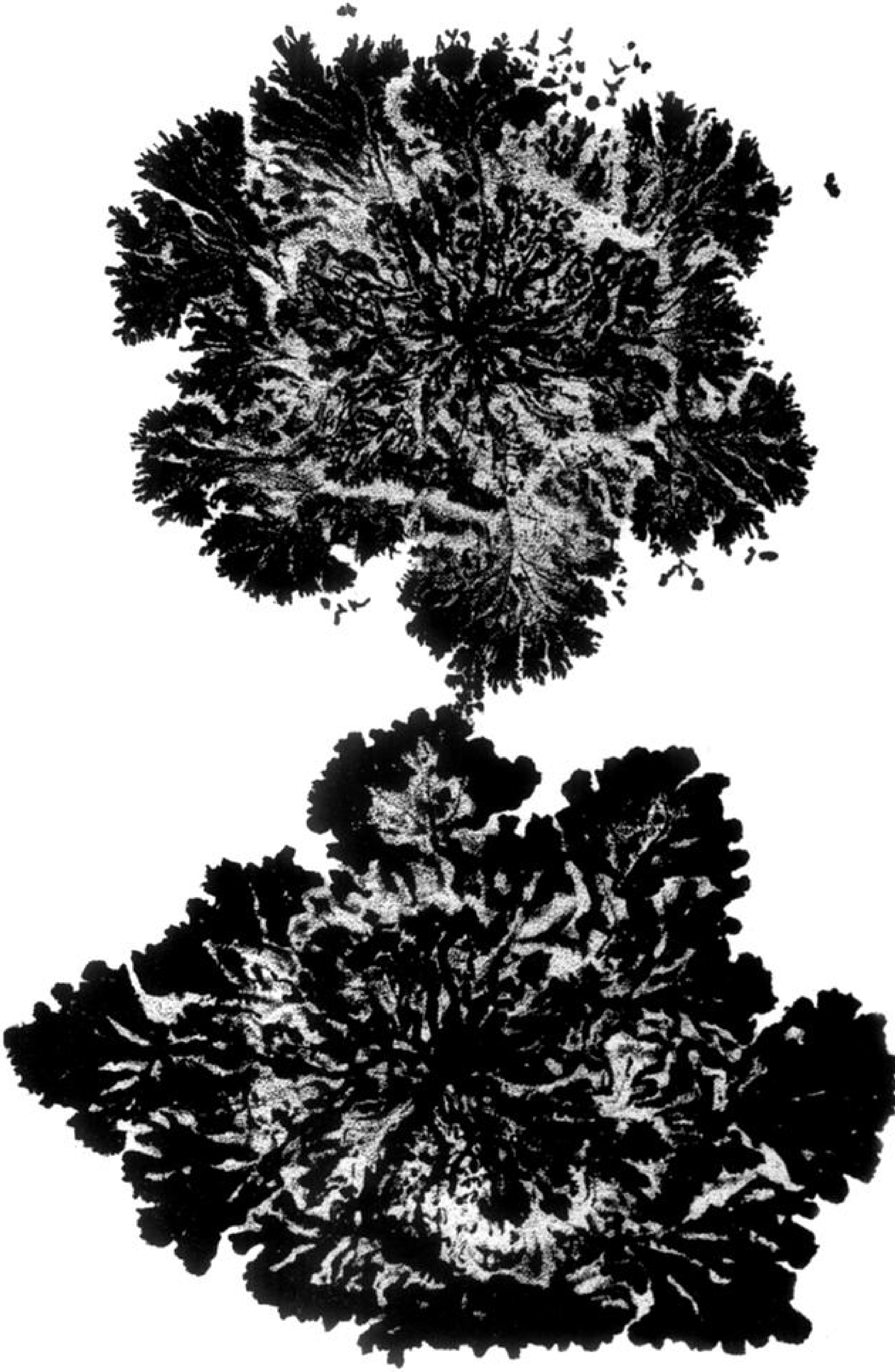


Fig. 1.

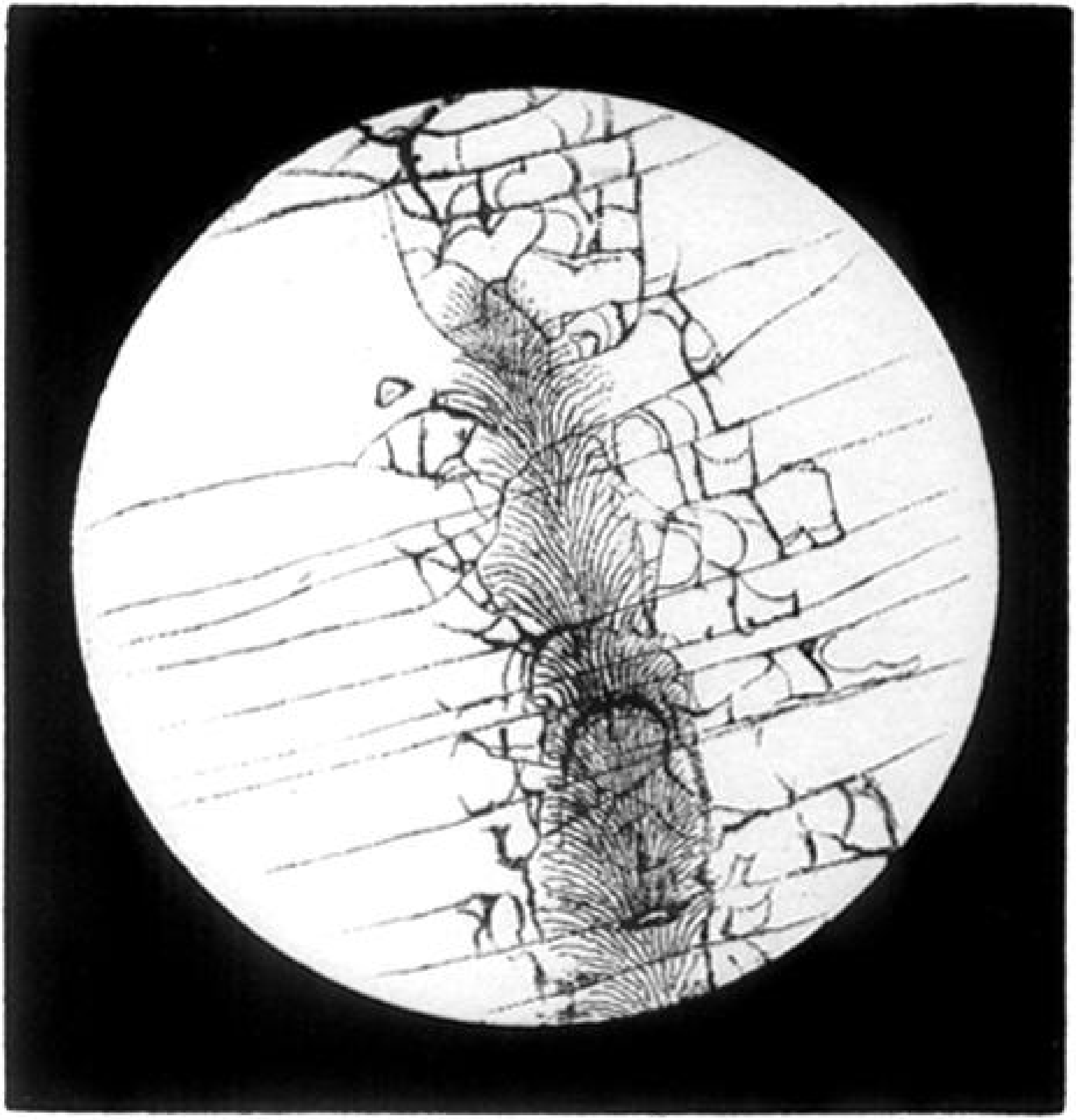


Fig. 2.

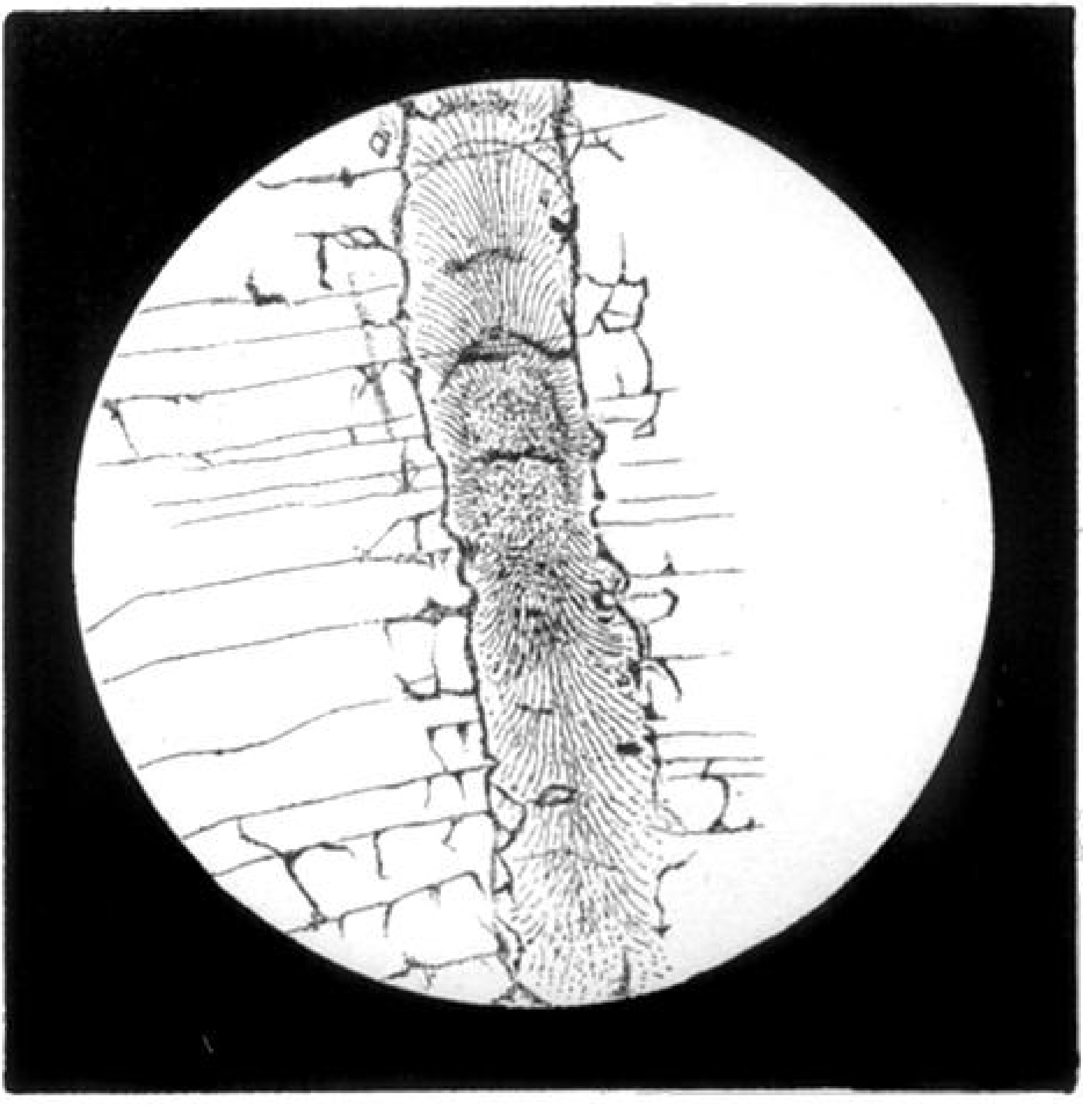


Fig. 1.

Fig. 2.

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