Figures produced on Photographic Plates by Electric Discharges.

By

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(Received Nov. 24, 1916.)

Of dust figures, known as Lichtenberg's figures, produced on non-conducting plates by electric discharges, many investigations have been made.

Brown[1], however, used photographic plates instead of the powdered non-conducting plate of Lichtenberg's figures, and obtained beautiful figures. He placed a photographic plate upon a sheet of tin foil connected to one terminal of the secondary of an induction coil, and the end of the wire connected to the other terminal was put upon the sensitive film. When one single discharge was caused by breaking the mercury-break by hand, beautiful figures were obtained after developement. As to the figures thus obtained Brown says "...... when the terminal on the plate was negative, the figure consisted of beautiful sharply defined symmetrical palm-like fronds on irregular stems branching out from the center where the wire rested, together with a mass of less distinct irregular straggling lines also branching outwards. When the terminal of the wire was made positive, the figure consisted of irregular branchings sharply defined except near the center."

A little earlier than Brown, E. L. Trouvelot[2] obtained similar figures by a similar method.

In 1896, Nürnberg[3] obtained similar figures with the leyden jar.

Though, since then, similar results have been obtained by Blümel[4] and Nipher[5] by similar method, investigations under various conditions are wanting; and consequently it is not clear why the figures are produced. The writer has experimented under various conditions; and has undertaken a rough explanation of the formation of the figures.

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1 Phil. Mag., **26**, 502, (1888).

2 C. R., **107**, 684, (1888). 3 Beiblätter z. d. Ann. d. Phys., **20**, (1896). 4 Beiblätter z. d. Ann. d. Phys., **22**, 596, (1898). 5 Beiblätter z. d. Ann. d. Phys., **35**, 1106, (1911).

In the following, the subject is treated, for the sake of clearness, in three parts: 1 mode of discharge; 2 formation of the photographic impression; 3 an explanation of the formation of the figures, and the transition from brush discharge to spark discharge.

1. Mode of Discharge.

The apparatus used is represented in the annexed figure. In this figure, *C* is a condenser which is charged with an influence machine, *B* a photographic plate placed upon a sheet of tin foil *A*, *E* and *F* spark gaps, *G* an ebonite rod, and *H* a metal rod connected to the tin foil. When the spark gaps *E*, *F* were brought in contact, a glow of discharge, produced on the sensitive film of the plate about the electrode *D*, could be seen; and a discharge figure was obtained after developement. Positive and negative figures were produced on the same plate when the electrode *H* was disconnected from the tin foil and placed upon the plate. When an induction coil, instead of the influence machine, was used, no condenser was inserted. To determine the sign of the electrodes a light-glow-oscilloscope was connected in series in *CE* or *CF*.

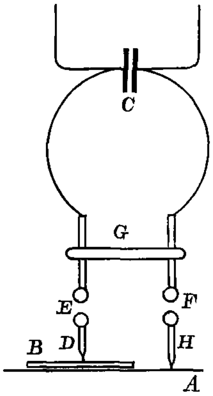


Fig. 1 is a discharge figure obtained with point electrodes connected to both the terminals of an influence machine. The cathode figure consists of regular, sharply defined, straight branches, radiating outwards from the point of the electrode with regular sharply defined intervals between them, their terminals being nearly on the circumference of a circle whose center is the point. The breadth of each branch continuously decreases as we recede from its end to the electrode.

On the other hand, the anode figure consists of sharply defined, irregular branches radiating outwards from the electrode; each branch changes its path irregularly and is divided into further branchings in an irregular manner; it is also irregular in its breadth and its length, and terminates in a sharp point. These characteristic properties of the anode figure will be more clearly seen in Fig. 3. Generally speaking, the extension of the anode figure is greater than that of the cathode figure.

Fig. 2 and 3 are figures obtained when stronger discharges than in the case of Fig. 1 had taken place. On the whole, these resemble the figures obtained by Brown, but there are no irregular branches near the electrode in the cathode figure as is seen in Brown's figure. Perhaps, as will be noted later, these may be of the anode type, due to an oscillation in the secondary of the induction coil used by Brown.

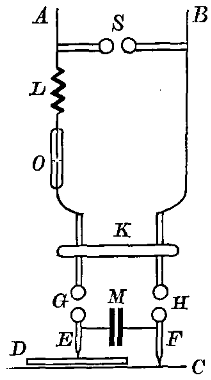
The principal differences between the figures represented in Fig. 2 and the cathode figure in Fig. 1 are that the former suffered deformation by the appearance of some strong branches, and that further fine branchings occurred.

It is worthy of note that, before the further branching takes place, the intensity in a branch is greater on its sides than in its central portion. This is always observed in cathode figures when further branching of a branch occurs. In the anode figure represented in Fig. 3, the characteristic properties observed in Fig. 1 are more clearly seen, and moreover it is interesting to note the appearance of many stronger branches near the electrode and several small anode figures with independent origins whose formation can not be explained.

Fig. 4 was obtained with an induction coil when a few make and break discharges had taken place. On the whole, in their characteristic properties, both cathode and anode figures resemble the anode figure obtained with the influence machine, but in details they are different. In the cathode figure its irregular, finer branches make a denser group of smaller extension than that of the anode, and there are many branches which run in directions perpendicular to the radial directions.

Fig. 5 was obtained when a little stronger discharge than in the case of Fig. 4 had taken place. At its cathode, the cathode figure get with the influence machine appeared together with the cathode figure in Fig. 4. As it is ambiguous with regard to the distinction between cathode and anode in Fig. 4 and 5, for several make and break discharges occurred, it is better to test with a single make or a single break discharge. Fig. 6 was obtained with a single break discharge which was caused by breaking the mercury-break by hand.

In this figure also, both cathode and anode figures greatly resemble the anode figure produced by the influence machine. In the cathode figure, it is seen that many branches run in directions perpendicular to the radials, as observed in Fig. 4 and 5. Inserting a light-glow-oscilloscope in series in the circuit, and observing by a rotating mirror, the discharge was really seen to be oscillatory. The cathode electrode is one which was cathode at first; and the anode electrode is one which was anode at first. As, in the next period of oscillation, the electrode which was cathode at first will become anode, an anode figure will be produced from this electrode at this stage. Are the cathode figures in Fig. 4, 5 and 6 not anode figures thus formed? To test this point further, I experimented with oscillatory discharges from the influence machine. The annexed figure indicates the arrangement taken. In this figure, L denotes a self induction, O the light-glow-oscilloscope, M a condenser, and S a spark gap.



After A, B were connected to both the terminals of the influence machine, the spark gaps G, H were respectively brought in contact. After a single spark had passed through the spark gap S, the plate was developed. The figures thus obtained are represented in Fig. 7 and 8. Fig. 8 was obtained at the electrode which had been cathode before a spark had passed through the spark gap S, and Fig. 7 when the sign was reversed. In their characteristic properties, both figures have much resemblance respectively to the cathode and anode figures obtained with a single discharge of the induction coil.

Before the spark had passed through the spark gap S, a weak glow was visible only at the negative pole of the oscilloscope, but just when the spark passed through S, an intense glow appeared at both the poles. Though this intense glow could not by a rotating mirror be resolved as an oscillatory discharge, yet, it was doubtless one of short period, because the self induction and the capacity used were small. The reason why the cathode figures obtained with the influence machine did not appear in the above oscillatory figures is probably that cathode figures with the influence machine always have less extension than the anode figures. Consequently we may say that there is a distinct difference between the cathode figure which is composed of regular branches and the anode figure which is composed of irregular branches.

Next, using electrodes of various forms, various discharge figures were obtained with influence machine. Fig. 9 and 10 are respectively the cathode and anode figures got with cylindrical electrode. In these figures, cathode branches end abruptly on a regular continuous outline as usual, and leave a small circular free portion in the center of the electrode, but the irregular anode branches end irregularly, and do not leave any regular free space at the center of the electrode as that of the cathode branches.

The points where the branches seem to start from the electrode are never regularly distributed, but when an electrode with many regularly distributed small studs along the contour of it, was employed, all the anode and cathode branches seem to start from the studs where electric force was intense. Fig. 11, 12, 13, etc. are obtained with such electrodes.

In Fig. 11 a circular-disc-electrode was used, and in Fig. 12 and 13 a crossed-plate-electrode was used. From these figures we see that all the regular cathode branches, which do never interfere with each other, leaving sharply defined regular dark intervals between them, seem to start at right angles to the contour of the electrode. The facts observed in the case of the point electrode with regard to the mode of branching and of the distribution of intensity in a branch also may be clearly seen in these figures. In Fig. 14, the electrode used consists of a circular cylinder and a smaller concentric disc, both of which were connected to the cathode of the influence machine. The branches which radiated from the disc and those which radiated from the inside of the cylindrical electrode never interfere but leave dark circular portion as their boundary.

Now with regard to the directions of the cathode branches which radiate outwards from the electrode, Fig. 11 and 14 seem to show that they represents the directions of the lines of force due to the electrode; but if we recollect the figure represented in Fig. 2, where a stronger discharge than in the case of Fig. 1 occurred, we shall be led to think that there is considerable repulsion between neighbouring branches. In order to test this point, cathode figure Fig. 15 was taken. This figure was produced when a cathode discharge took place on a photographic plate under which a wooden plate coated with tin foil was placed in the position indicated by the rectangle. Near the electrode the direction of all branches is nearly perpendicular to the contour of the electrode; but, as the branches go a little forward, these above the tin foil grow longer and longer than those under which there is no tin foil, and the latter change their direction continuously by the repulsion due to the former.

The fact that all cathode branches terminate on continuous curves seems to indicate that all branches of a cathode figure start from the electrode and go forward simultaneously, repelling each other with considerable forces. In the cathode figure Fig. 12, each branch which radiates from the neighbouring two sides of a corner is straight along almost its whole path, except in a little portion at its end where it curves a little along the dark boundary of the branch which is the bisector of the angle of the corner. In the anode figure Fig. 13, all branches which seem to radiate from the neighbouring sides of a corner terminate nearly on the bisector of the angle of the corner in an irregular manner.

Consequently, with regard to the formation of the cathode figure, it seems to the writer as if the branches start from the points on the electrode where the electric force is intense, and go forward with nearly equal velosity, leaving sharply defined intervals between them, and repelling each other with considerable force, and finally terminate abruptly on the regular boundary of the figure.

Next the writer investigated the change of the nature of the discharge figures with regard to the height of the sensitive film above the tin foil. Fig. 16 is a cathode figure on a Kodak film, the height of its sensitive film above the tin foil was about 0·15 mm; while with ordinary plate it is about 1–2 mm. The figure consists of very, very fine regular branches, and the intervals between them are also very sharp and fine.

When the height of the sensitive film was increased by placing glass plates or an ebonite plate under the photographic plate, the branches became large and the intervals between them became diffused. Fig. 17 was obtained when an ebonite plate whose thickness is about 1 cm. was placed between the photographic plate and the tin foil which was connected to the positive pole of the influence machine.

Fig. 18, 19, and 20 are anode figures obtained with various heights of the sensitive film above the tin foil. In Fig. 18 the height is least, as a Kodak film was used. Fig. 19 was obtained with a common plate; and in Fig. 20 an ebonite plate whose thickness was about 1 cm. was placed between the plate and the foil, and consequently the height is greatest in this case. From these figures we see that the anode figures become smaller in extension, and that their branches become finer and end more regularly as the height is reduced.

So far as the writer has experimented, the various features of the discharge figures seem to be unaffected by the metal used as electrode, the metal placed under the photographic plate, and the kind of photographic plates.

2. Formation of the Photographic Impression.

With regard to the question as to whether the result obtained was due to a photographic effect of the luminosity of the discharge, or to some more direct action of the discharge on the film, Brown[1] took the latter view. For, according to his experiment, the luminosity of the discharge alone was too weak to produce such fine figures; and, when the discharge was taken with the two terminals on the back or uncoated side of the plate, a photographic effect on both sides of the film was observed.

When the discharge on a photographic plate was observed with the naked eye, only the intense portions of the branches showed their structures, the weak portions of continuous luminosity never showing their details; but, if viewed through a lens, the discharge represented all its details as is depicted on the photographic plate. Moreover, these features of the discharge are not confined to a photographic plate, but can be seen on a glass plate when the luminosity of the discharge is viewed through a lens. This shows that the sensitive film plays, at least, no essential part in the formation of the figure, except that the latent image of the luminosity of the discharge which occurred along its surface is produced in it.

When the discharge was taken with either electrode on the back or uncoated side of a common plate, only a cloudy photographic impression of the branching discharge on the back of the plate was obtained on the back of the sensitive film; but when a Kodak film on a glass plate was used, instead of the common plate, a clear impression of the branching discharge on the back of the film was produced on the back of the sensitive film. And as, in either case, the luminosity of the discharge could be seen on the back of the plate or the film, there seems to be no objection, as far as the above experiment is concerned, to considering that the photographic impression on the back of the sensitive film was made by the luminosity of the discharge on the back of the plate.

In favour of his view, Brown mentioned the fact that he obtained

1 Phil. Mag., **26**, 502, (1888).

a photographic impression on the outer surface of the sensitive film when the discharge took place on the back of the plate which had been placed with its sensitive film downward on a sheet of tin foil. But, if two thin and small glass plates were placed between the sensitive film and the metal plate so that an air space was left between them, the luminosity of the discharge could be seen between them, and a photogtaphic impression be obtained on the outer surface of the sensitive film. Considering this, there is no reason to believe that the luminosity of the discharge did not appear between the film and the foil in the Brown's experiment, and consequently that any direct action produced such an impression on the photographic plate without the intervention of the luminosity of the discharge.

In resumé, so far as the writer has experimented, the sensitive film plays no essential part in the formation of the figure, and it is natural to consider that the photographic impression of the discharge figure is produced by the photographic action of the luminosity of the discharge which occurs along the surface of the sensitive film.

3. An Explanation of the Formation of the Figures, and the Transition from Brush Discharge to Spark Discharge.

If we assume that the luminosity of the discharge is due to the ionisation of molecules of gas, the discharge figures obtained will be the path of the ionisation; and, therefore, in the explanation of the figures we need only to consider the path of the ionisation of the gas molecules produced by the electric discharge.

J. J. Thomson, in his theory of the conduction of electricity through gases, regarded the spark discharge as originating in the ionisation of the gas by moving ions, the small negative ions—the corpuscles—being more efficient ionisers than the positive ones, which have a greater mass. And, as the original source of these ions, he considered the ionisation due to the collision of positive ions with the gas molecules near the cathode or with the cathode itself.

As to the difference between the minimum potential for positive and negative points when the electric discharge occurs from a point he says, "...the minimum potential difference is determined by the condition that the electric field near the electrode should be strong enough to enable the positive ions to produce an adequate stream of corpuscles. Now when the point is the cathode the positive ions have two opportunities of producing corpuscles, (1) by impact with the electrode, (2) by impact with the molecules of the gas; while when the point is the anode only the second of these is available; this would have the effect of making the minimum potential required for point discharge greater."

Now, in our experiment, this consideration of the case of electric discharge from points may be applied; and an explanation of the principal properties of the discharge figures was undertaken by the following assumptions: (1) in a cathode branch, the ionisation in its end portion is caused by the collisions of negative ions with the gas molecules, and the original source of these negative ions is supplied by the ionisation due to the collisions of positive ions with the gas molecules in the neighbourhood of the cathode, or with the cathode itself; (2) in an anode branch, also, the ionisation in its end portion is caused by the collisions of negative ions with the gas molecules, and the ionisation due to the collisions of positive ions occurs in the portion nearer to the anode.

If the potential of the anode is increased sufficiently, the negative ions, which were present just before the formation of the photographic impression by the ionisation commences, will be pushed toward the portions of the electrode where the electric force is strong, and will ionise the gas molecules with which they collide. The negative ions thus produced will also do the same thing; and many positive and negative ions will be produced. The group of positive ions, which will be left behind as the negative ions are pushed toward the anode, will now act as a portion of the anode; and, repeating the same process as before, further branching and elongation of the anode branch will take place. With this explanation, the properties of the anode branches (that they are irregular in their branchings and elongations, and that their branches end in sharp points) will be immediately understood; because the formation of these branches is due to the presence of negative ions which would be distributed irregularly.

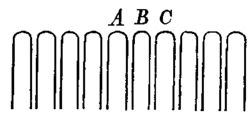
When the height of the sensitive film from the tin foil is reduced, the electric force along the film becomes smaller; and, consequently, the range in which the ionisation occurs becomes smaller as is seen in Fig. 18.

An explanation of the formation of the cathode figure. When the electric force at a point on the cathode reaches a certain intensity, a short spark passes from this point to the air a little distance away.

Along the path of this spark ions will be produced, positive as well as negative, and the positive ions will be attracted toward the electrode, while the negative ions will be driven away. The prolongation of a branch thus formed will be caused by the ionisation of the negative ions which are driven away from the cathode, as was assumed before. These negative ions on the surface of the sensitive film will be attracted downward by the attraction of the positive charge on the tin foil, and their motion will be retarded as if they suffer a kind of resistance. When many such branches are produced from the cathode on the sensitive film, there will be a portion of least electric force between any two neighbouring branches.

The electric force which acts on the negative ions on the side of a branch will be nearly perpendicular to the side of the branch along the surface of the film, and will be very small due to the repulsion of the charge on the neighbouring branch and the resistance caused by the attraction of the opposite charge on the tin foil ; and therefore the kinetic energy of the negative ions gained under the electric field will become insufficient to ionise the gas molecules before they reach the region of the least electric force between the neighbouring two branches. The property of the cathode branches that they leave sharply defined intervals between neighbouring branches seems thus to be explained.

Next an explanation of why the further branching of a cathode branch occurs will be given. Let *A*, *B*, *C* etc. be the ends of cathode branches before further branching takes place. At the end of any branch the attraction of the tin foil on the negative ions will be greater in its central portion than on its side portion; and, therefore, the resistance which will retard the motion of the negative ions on the end of the branch will be greater in its central portion than on its sides ; and consequently the negative ions on the side portion of the branch will go further and further forward than in its central portion, and at last the branch will be split into two. In Fig. 15, 14 and 21 many such branches can be seen.



When the breadth of a branch is comparatively great, the attraction on the negative ions in its end, due to the tin foil, will be strong and nearly constant in all portions excepting the sides where it will decrease abruptly. And when a certain stage of its elongation is reached, the end of the branch will bulge out at the sides, leaving the central portion unaffected as indicated in the annexed figure. The repulsive forces which act on the negative ions at various points at the end of the branch thus formed, will be stronger or weaker according as the convexity of the boundary at that point is greater or smaller, or the concavity is smaller or greater. In its next stage the branch will grow out in its central portion as indicated by the dotted line in the figure. Consequently, when its further growth occurs, the branch will at last split up into three. If the branch is still broader, the central branch will also split up into two or more, and consequently, further branching of a branch into many branchlets will take place, as is seen in many cathode figures.

The variation of the intensity of the attraction of the tin foil upon negative ions at various points on the boundary of the end of a branch will be greater when the distance between the sensitive film and the tin foil is reduced, and when the branch is long. This is the reason why the cathode branches become finer as the distance between the sensitive film and the tin foil is reduced, and why the further branching of a branch occurs at a certain distance from the electrode.

Lastly, in order to study in what stage of the brush discharge a direct spark will pass, the writer placed two electrodes on the sensitive film, one being connected to the tin foil under the plate. When the two electrodes were brought into contact respectively to both the terminals of the influence machine, a discharge figure was obtained only at the electrode which was not connected to the tin foil.

When this was cathode, cathode figures were produced at this electrode, as represented in Fig. 21 and 22. In Fig. 21, where no direct spark discharge occurred, the cathade figure did not reach the anode. But in Fig. 22, when a direct spark occurred, the boundary of the cathode figure seemed to have been in contact with the anode. On many figures, not given here, the writer could not observe where no direct spark occurred when the cathode branches reached the anode.

On the other hand, when the sign of the electrode was reversed, anode figures were produced, as represented in Fig. 23, 24 and 25. In Fig. 24, no direct spark occurred, though the end of some branches reached the cathode. This will be explained, if we consider, as was assumed before, that the ionisation by positive ions does not occur in the end portion of an anode branch, for to make a direct spark pass between the electrodes, the ionisation by positive ions should occur near the cathode as was pointed out by J. J. Thomson. On the other hand, if the ends of cathode branches reach the anode, a direct spark will pass, for every cathode branch has its original source of ions in the neighbourhood of the cathode by the collisions of positive ions, as was assumed before.

In conclusion the auther's sincere thanks are due to Prof. T. Mizuno for the interest he has taken in the work.

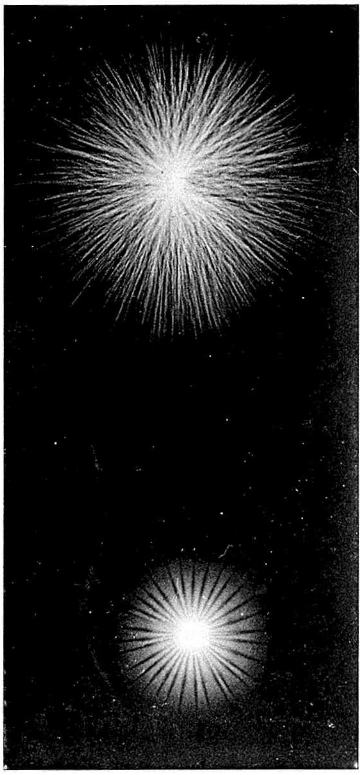


Fig. 1

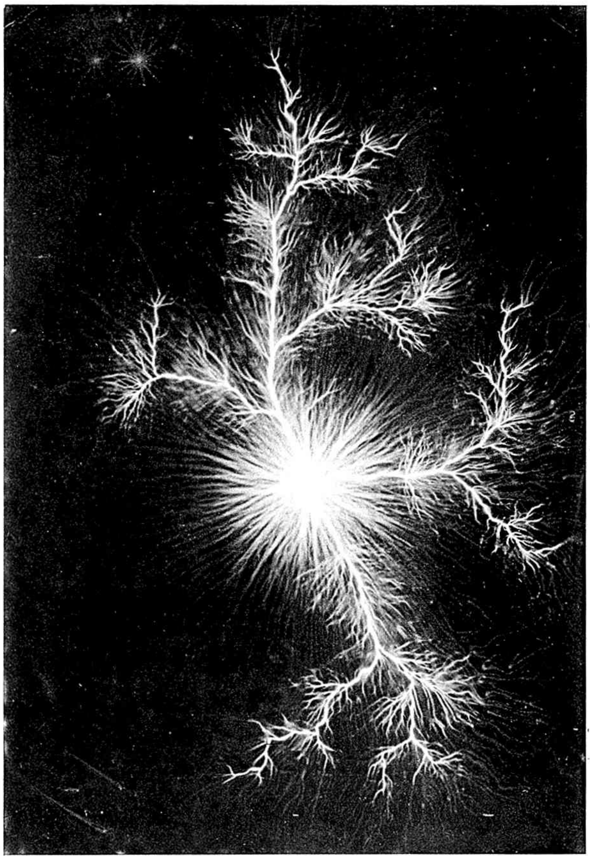


Fig. 3

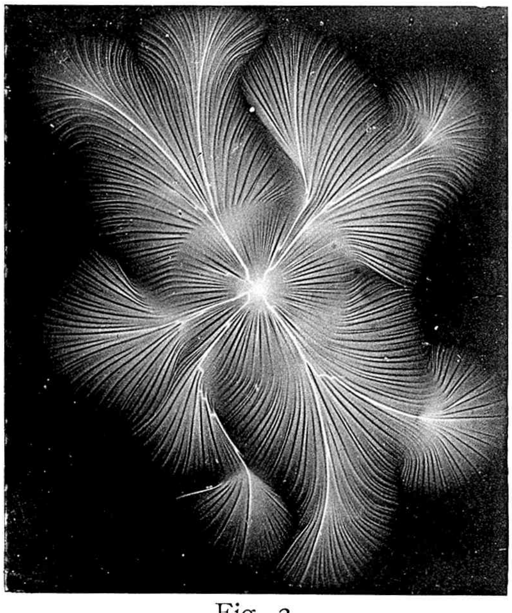


Fig. 2

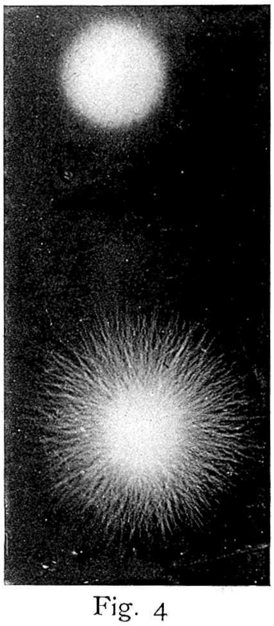


Fig. 4

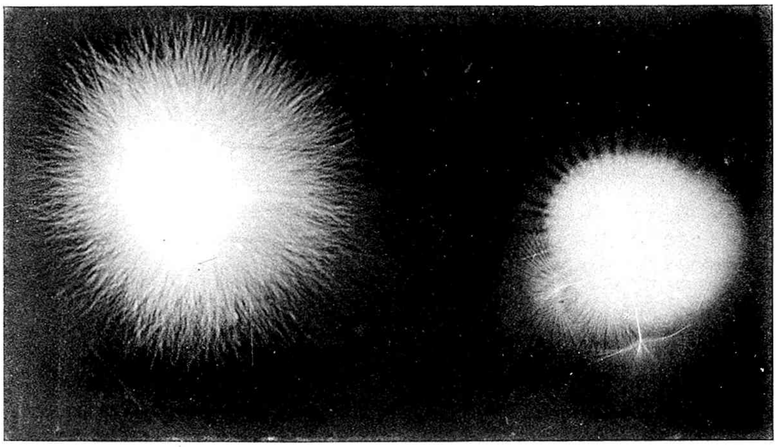


Fig. 5

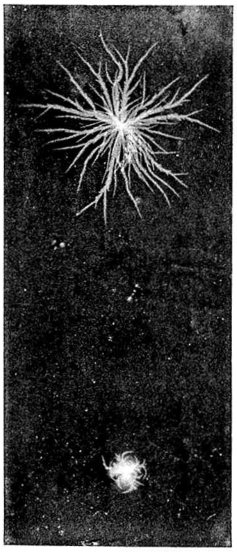


Fig. 6

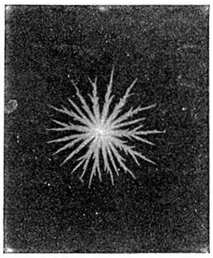


Fig. 7

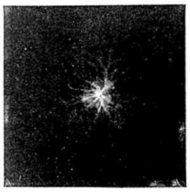


Fig. 8

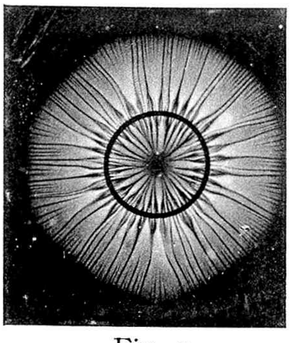


Fig. 9

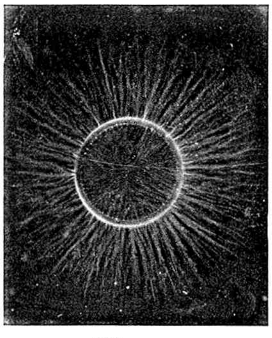


Fig. 10

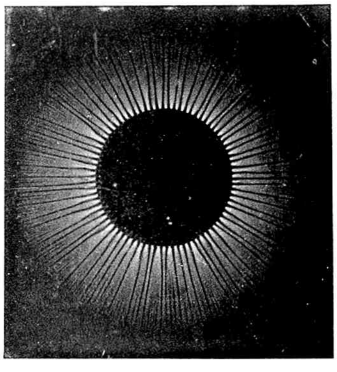


Fig. 11

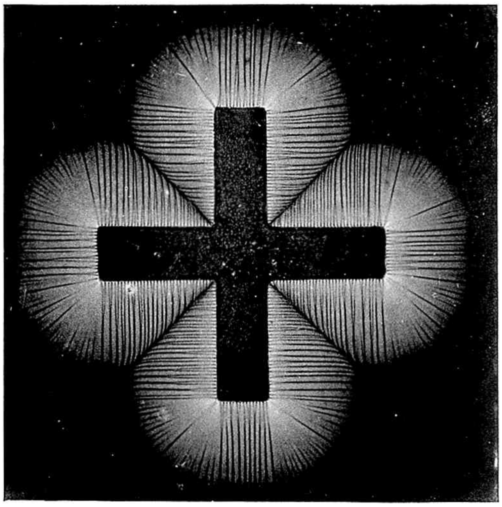


Fig. 12

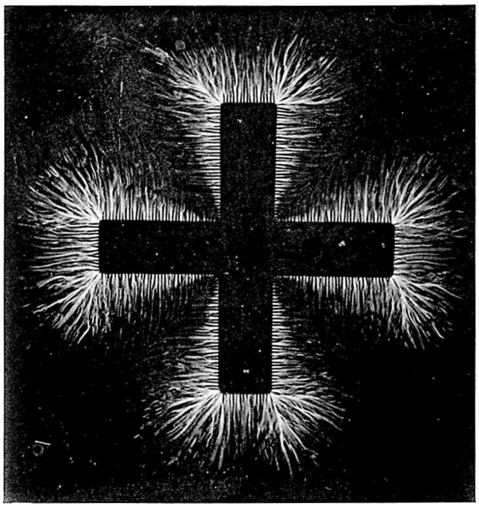


Fig. 13

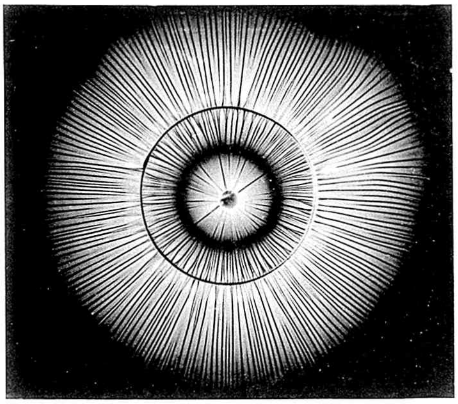


Fig. 14

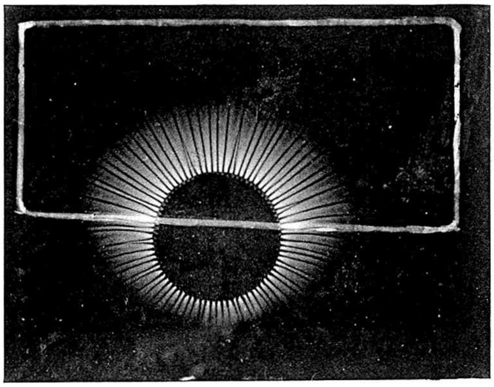


Fig. 15

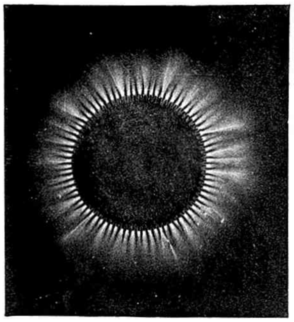


Fig. 16

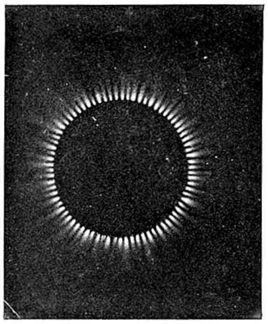


Fig. 17

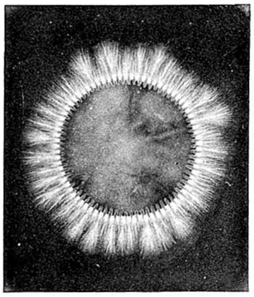


Fig. 18

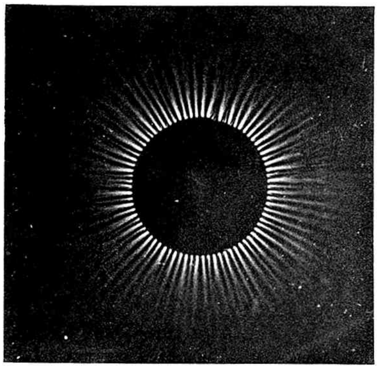


Fig. 19

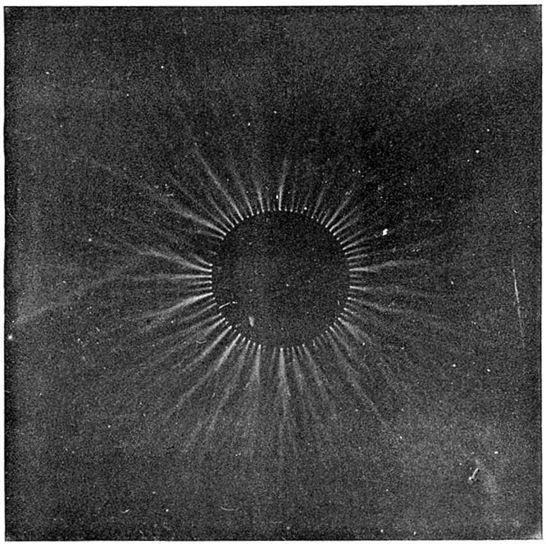


Fig. 20

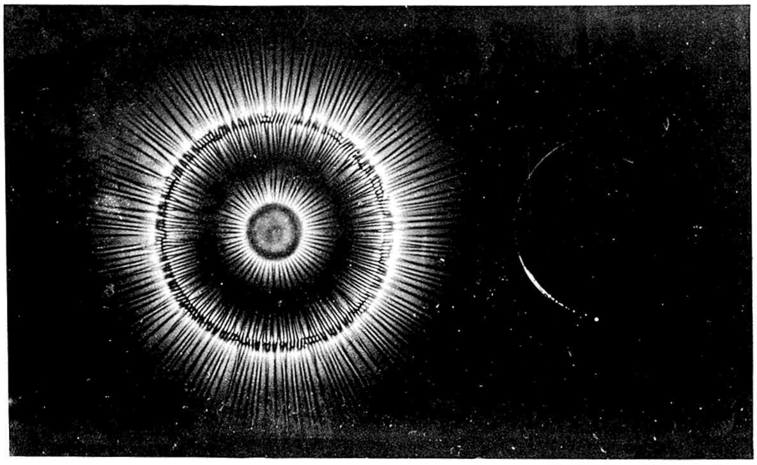


Fig. 21

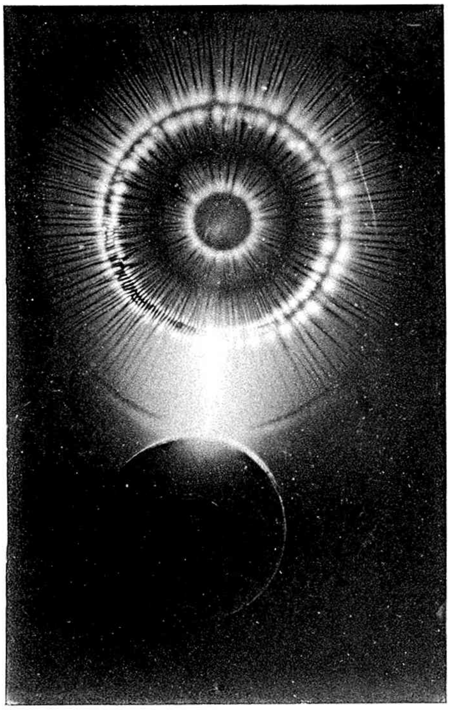


Fig. 22

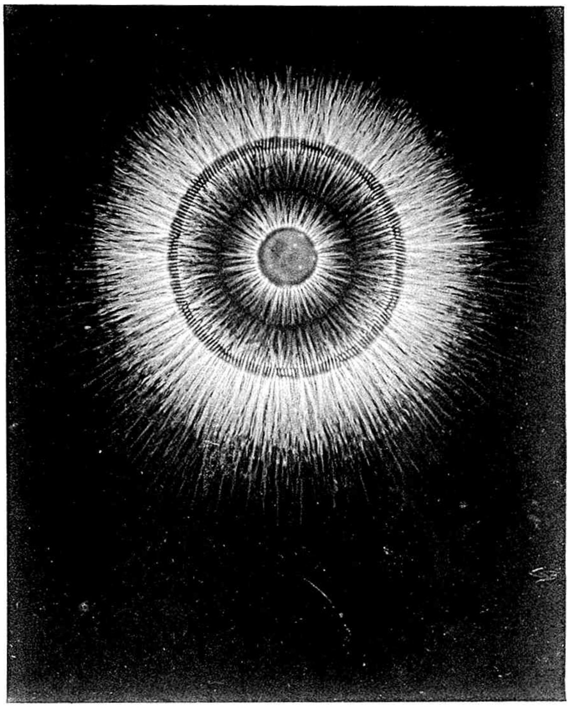


Fig. 23

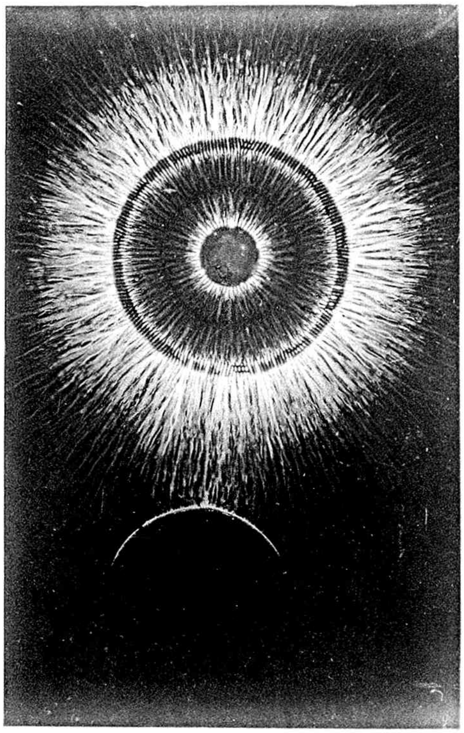


Fig. 24

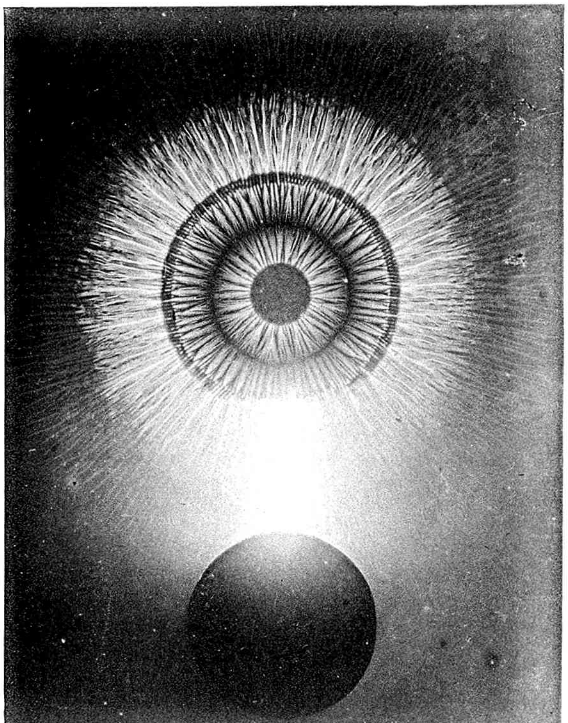


Fig. 25