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SOME EXPERIMENTAL STUDIES ON ITOH'S STRIATED ELECTRICAL DISCHARGE FIGURES. PART I.

By

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CONTENTS.

I. Introduction	87
II. The properties of the dark radial canal	89
III. The various figures confined by the various materials on the dielectric surface	92
IV. The figures on the rotating dielectric surface	99
V. Some relations among the constants which determine the size of the figure	102
VI. Summary	108

§ I. INTRODUCTION.

A peculiar striated electric discharge figure has been precisely investigated since several years ago by Dr. Itoh in this Institute, on which many important papers⁽¹⁾⁽²⁾⁽³⁾⁽⁴⁾⁽⁶⁾⁽⁷⁾⁽⁸⁾⁽⁹⁾⁽¹⁰⁾⁽¹¹⁾ have already been published by him. We will briefly describe the apparatus and the characteristics of Itoh's electric discharge figure. The apparatus is schematically shown in the following diagram :

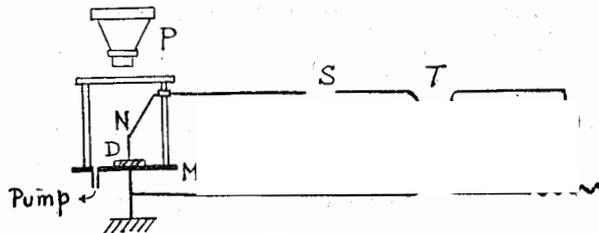


Fig. 1.

- | | |
|--|-------------------------------|
| T : High tension transformer (60 cycles) | D : Circular dielectric plate |
| S : Variable needle spark gap | M : Brass plate |
| N : Needle | P : Photographic camera |

This figure on the dielectric disc has such a characteristic feature that a number of striae radiate at equal angles to each other from the center of the dielectric disc on which the needle point just touches. The relation among the number of the striae, the size and the constant of the dielectric substance is empirically expressed by the following formula⁽⁹⁾

$$N = k \cdot G\sqrt{C}$$

where k = the harmonic number such as 1, 2, 3,

G = the function due to the gas in the discharge vessel.

C = the apparent capacity due to the size and the constant of the dielectrics. In case the dielectric substance is a circular plate having D cm. diameter and L cm. thickness, and if K is the dielectric constant along the stria, the apparent capacity of this dielectric disc is expressed by the following formula

$$C = \frac{K\pi \frac{D^2}{4}}{4\pi L}$$

As there has been little discussion on the mechanism to produce such an astonishing striated electric discharge figure on the dielectric surface, we have made some experiments to elucidate the mechanism of this figure and to make clear some essential natures of this figure, though their results have not yet led to a satisfactory conclusion. The investigation of the mechanism of this figure is important of itself and is also useful to explain the Lichtenberg figure and other similar discharge phenomena. Seeing this striated figure, it may be supposed that there must exist some characters similar to the Lichtenberg figure.

It will be im... re must be split into striae which are s... ed. As the first step for this purpose, the properties of the dark canal between any two striae were experimentally investigated by various methods.

Next, in order to ascertain how these striae are attracted to the dielectric surface, we carried out some experiments by using a rotating dielectric disc.

§ II. THE PROPERTIES OF THE DARK RADIAL CANAL.

Some properties of the dark canal between any two striae of the discharge figure were investigated by the following various methods.

1. By means of the spectrograph.

For the purpose of examining whether the ultra-violet ray exists in these dark canals, we take a small quartz spectrograph made by Adam Hilger. Though we expose these dark canals for several hours through the uviol glass window of the vessel, no ultra-violet ray seems to be recognized.

2. By means of the photographic film.

In order to ascertain the existence of large quantities of the ultra-violet ray in these dark canals, placing a photographic film under the uppermost glass disc which consists one part of uviol and the other of ordinary window glass as shown in Fig. 2, we expose it under the electric discharge for about 0.5 second.

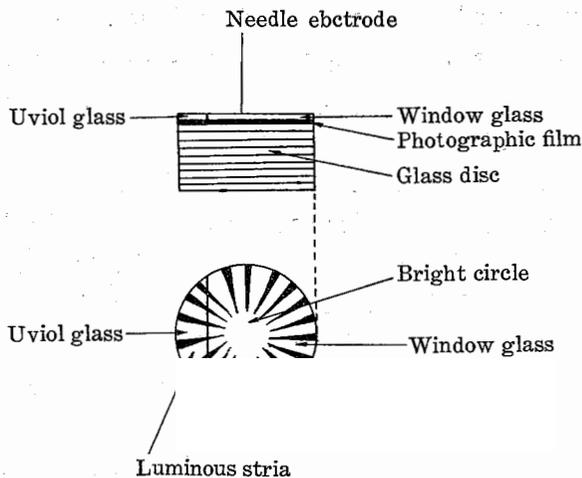


Fig. 2.

But from this film it is difficult to note any different sensitivity between the uviol glass plate and the ordinary one.

3. By heating effect.

Making the striated electric figure display for some adequate time on an ebonite plate instead of glass plate, we find that the black portions under the luminous part alone turn gray due to heating (See Fig. 3).

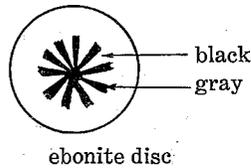


Fig. 3.

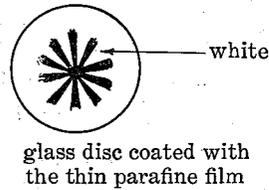


Fig. 4.

Replacing the ebonite plate, we again lay upon it a glass plate coated with a thin paraffine film and under the same condition as just above, we find that the portion under the luminous part becomes tarnished due to heating, but the other part still remains unchanged (See Fig. 4.).

4. By means of the secondary dust figure.

If a fine powder such as lycopodium powder is uniformly sprinkled over the surface of the glass disc, the electric discharge figure is remarkably different from the ordinary figure and also sometimes the electric wind blows this light powder off. On the contrary, if we fill the powder so as to move freely in a thin air layer between the upper two discs separated around their edges by rubber packing, we find that the discharge figure is not conspicuously altered. Therefore we make the experiment using the arrangement shown in Fig. 5. When the discharge takes place, this powder begins to move to the outer edge. After a few seconds the powder is ranged radially on the surface of the disc as in Fig. 6. We may call the figure thus obtained the secondary dust figure. In spite of the fact that the streamers of the figures thus obtained sometimes clearly coincide with those of the upper luminous radial figure, the explanation of the various properties of the radial figure of the dust

potential on the plate is analogous to the appearance of the map of Mt. Fuji in which its valleys correspond to the dark canals. The validity of this comparison will be verified by experiments in 1 and 2 of § III.

§ III. THE VARIOUS FIGURES CONFINED BY THE VARIOUS MATERIALS ON THE DIELECTRIC SURFACE.

1. The case where a thin wire is put radially on the dielectric disc.

Laying a piece of thin wire on the circular glass plate radially from its center, we obtained another radial figure with a triangular dark space along the wire. Glancing at this figure, it will be at once noticed that the farther end of the wire becomes a new pole from which another figure is generated (See Fig. 8.).

The cause of the formation of this dark space is easily explained as follows: the propagation velocity of the striae of these figures along the dielectric surface attains the order of 10^7 cm./sec. or less, while that on this thin wire is estimated to be in the order of light velocity. As the propagation velocity of electric charges in the conductor is very large compared with that over the dielectric surface, the wire AB is considered to be in equipotential line in the present case. Thus the electric field along AB becomes so much steeper that the equivalent distance through AB between two electrodes is shortened by the length AB. The distribution of the field intensity

through AB is indicated by the full line of

distribution without AB

ted line. Therefore

the value of this equipotential is considered as a certain value between potentials at A and B without this thin wire. Since the potential at A on the wire is lower than in its neighbourhood, the striae passing near A may be concentrated into A on the wire

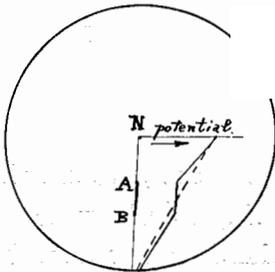
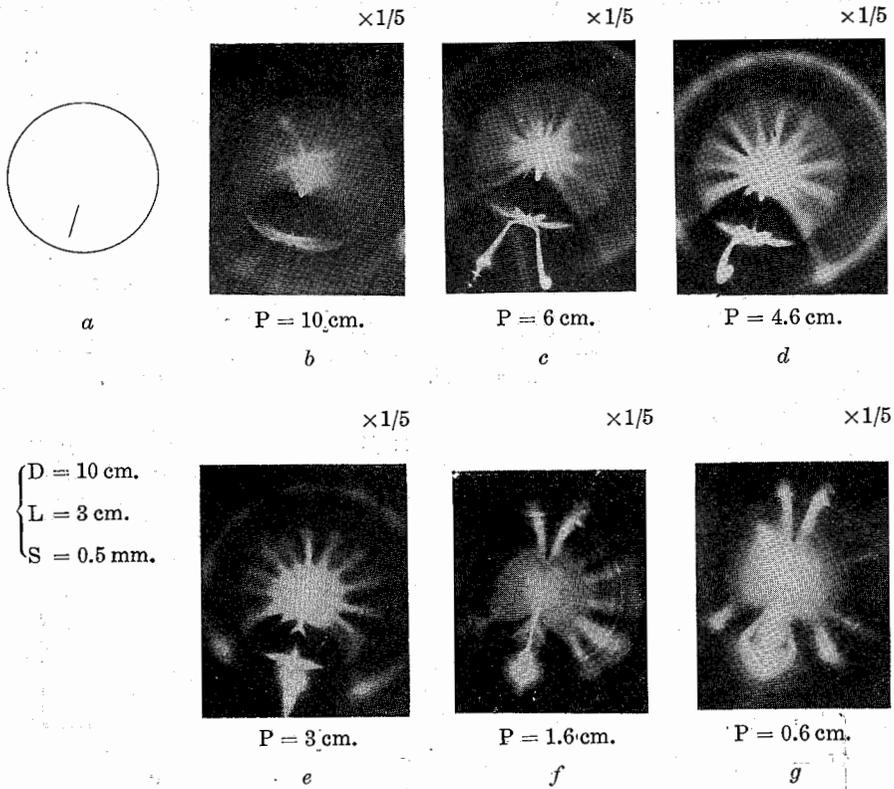


Fig. 7.

and therefore its shadow or the dark space will appear as shown in Fig. 8, c. Since the potential at B is higher than in its neighbourhood, new striae spread over the surface along the direction of the large potential difference from B.



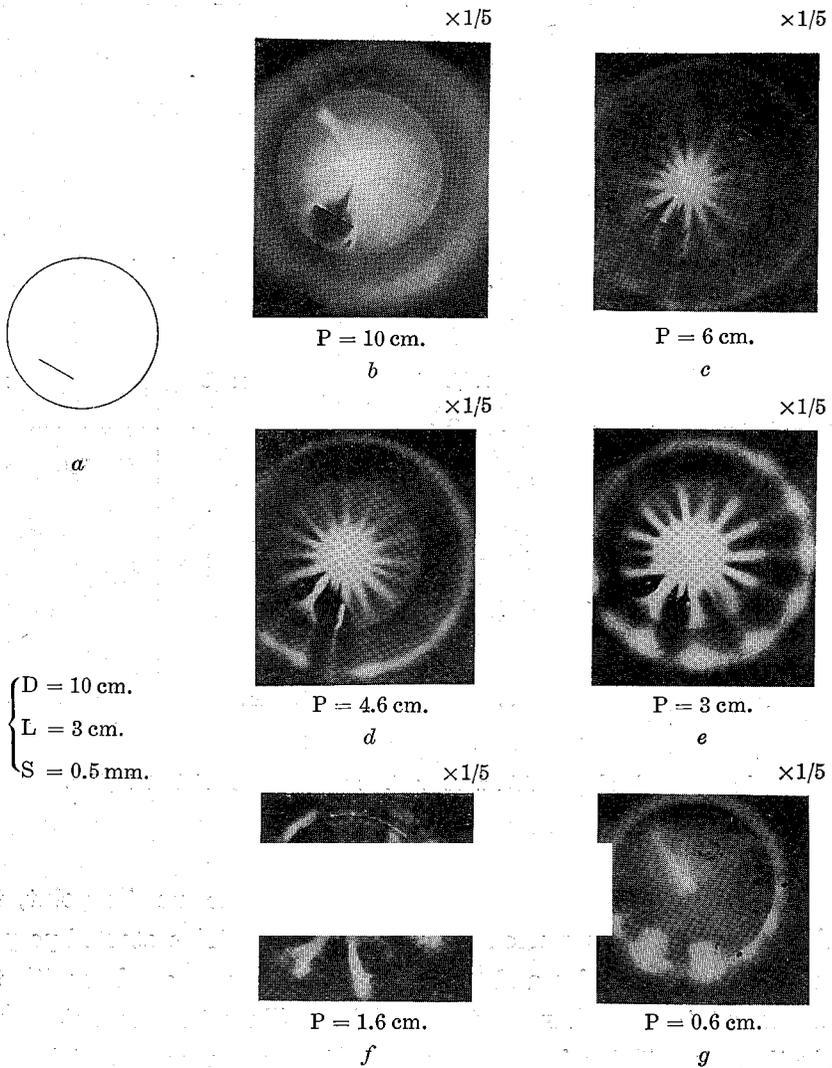
Figures confined by a thin wire on the surface of the dielectric disc.

Fig. 8.

If one end of the needle point, the striae started from the needle point, the striae started perpendicularly from the wire and their velocities become smaller with the increase of the number of the collision. Since the amount of the ionization by collision is very small in the space where striae encounter each other, these parts appear as the dark lines as shown in Fig. 13, b.

2. The case where a thin wire is put tangentially on the dielectric disc.

Next, putting the thin wire on the glass disc tangentially to the radial direction at a certain distance from its center, we obtain a figure as shown in Fig. 9. Since the potential difference between the



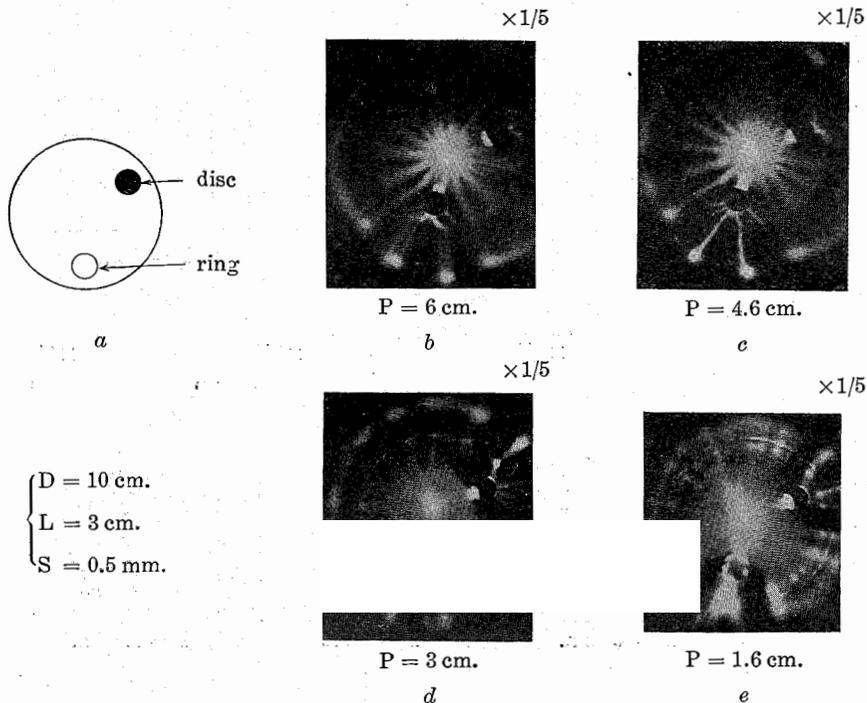
Figures confined by a thin wire on the dielectric disc.

Fig. 9.

electrodes is larger at high pressure than at low, the disturbance of the striae at the ends of the wire is comparatively larger at the high air pressure (Fig. 9, b.). However, if the pressure of the air is reduced these effects must be small on account of the smaller potential difference between the two electrodes. Especially at low pressure less than a few cm. the luminous striae pass through this thin wire without causing any disturbance.

3. The case where various shaped conductors are put on the dielectric surface.

If we put conductors of various shapes on the glass disc, we have sometimes obtained beautiful figures due to the disturbance of the original field. The form and colour of these figures can be much varied by adjusting the width of the series gap and the air pressure.



Figures confined by a small disc and a small ring on the surface of the dielectric disc.

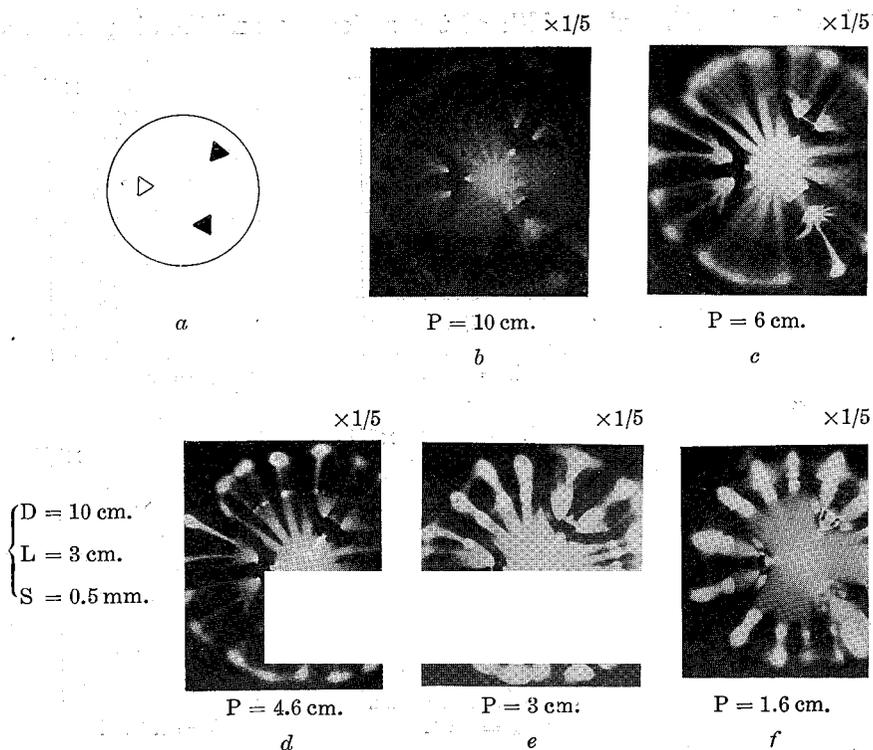
Fig. 10.

As the first example, if a small metal ring and a small disc are placed on the plate at a certain distance from the needle point, we obtain the figure shown in Fig. 10.

Next, placing small thin equilateral triangular conductors on the glass plate, we obtain a figure as shown in Fig. 11.

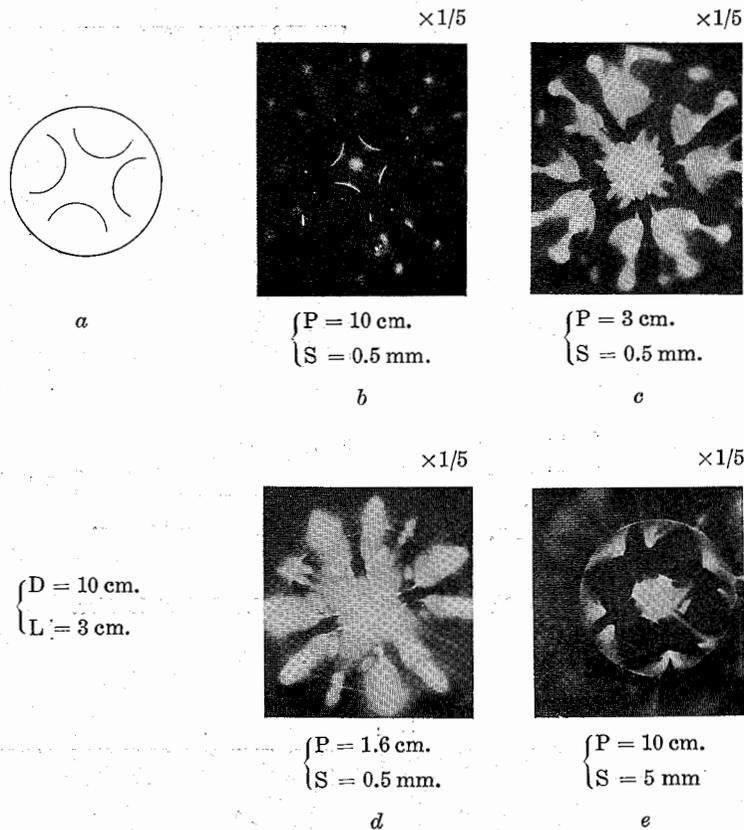
Thirdly, placing four quadrant shaped wires in such a position as in Fig. 12, a., we obtain beautiful figures as in Fig. 12, b, c, and d. Fig. 12, e shows the electric figure with a large gap length.

Lastly, when cross wires whose intersecting point coincides with the needle point of the electrode are placed on the disc, a beautiful figure as shown in Fig. 13, b appears.



Figures confined by a small triangle on the surface of the dielectric disc.

Fig. 11.



Figures confined by four wires of quadrant shape on the dielectric disc.

Fig. 12.

4. The case where fine powder is strewn.

In order to examine how the silver granules on the photographic plate affect the Lichtenberg experiment is carried out. If fine glass powder is uniformly strewn on the surface of the glass disc, ordinary Itoh's figure having rather smooth striae changes into a figure with many branches such as that of the positive Lichtenberg figure as shown in Fig. 14. Of course the needle electrode has positive polarity in each case.

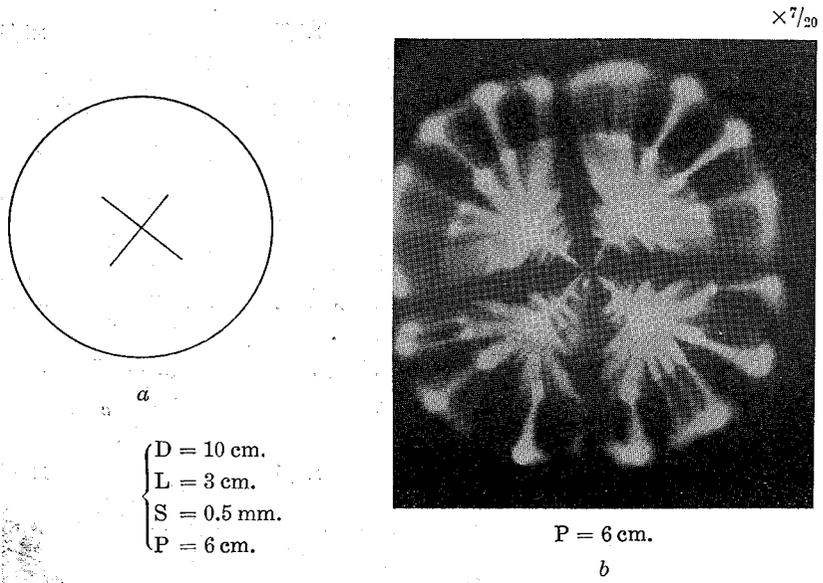


Figure confined by cross wire on the dielectric disc.

Fig. 13.

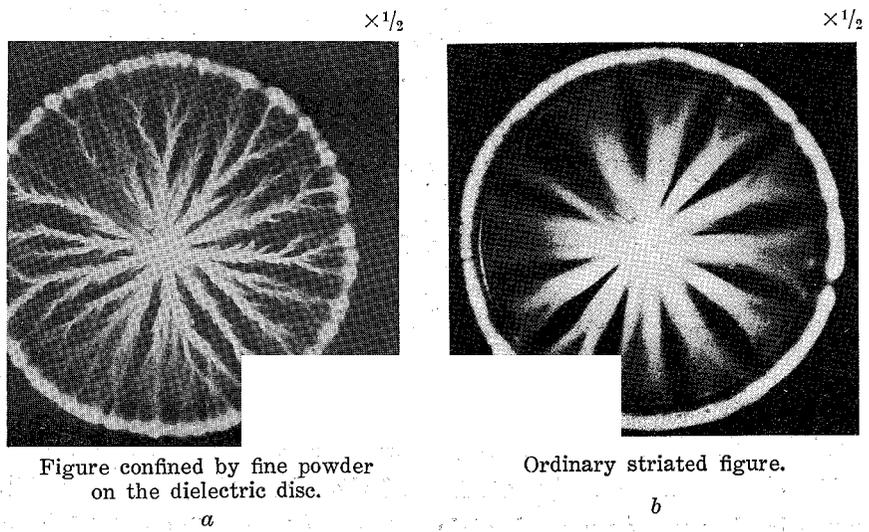

 $\left\{ \begin{array}{l} D = 10 \text{ cm.} \\ L = 3 \text{ cm.} \\ S = 0.5 \text{ mm.} \\ P = 6 \text{ cm.} \end{array} \right.$

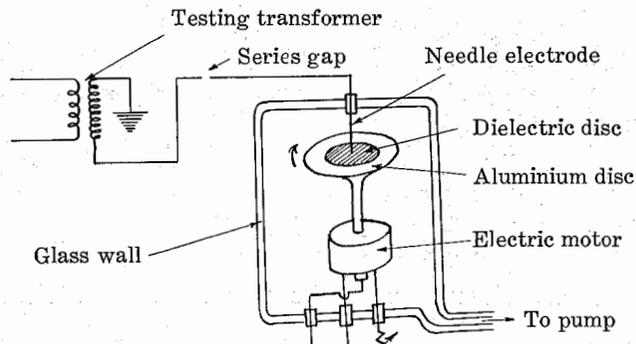
Fig. 14.

Next, using a fine conducting powder such as aluminium powder, a similar branchy figure is obtained, but is not so beautiful as that in Fig. 14.

Creepage current such as high frequent oscillating or impulsive current under the skin effect must flow all over the surface of the discharge vessel. For this reason, the dielectric material operates as the usual conductor. The existence of the creepage current is easily detected by the Johnsen-Rahbeck effect.

§ IV. THE FIGURES ON THE ROTATING DIELECTRIC SURFACE.

The attempt to ascertain if the formation of the striae of these figures is explained by the adsorbed ions on the surface of the dielectric disc, is tried using a rotating disc. Its electrical connection is illustrated in Fig. 15. The rotation of the disc about its centre is regulated by an electric motor in the discharge vessel as shown in Fig. 15.



1. The case where a needle electrode is placed concentrically on the circular plate.

It will be easily observed with a slow rotation that the initial configuration of the figure is fixed on the rotating plate itself as



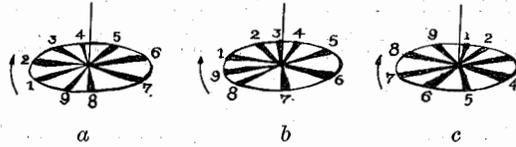


Fig. 16.

shown in Fig. 16, a, b, c. The same result is recognized with rapid rotation by putting a photographic paper under the uppermost glass plate. Fig. 17, is an example. The left photograph is obtained with the rotating disc while the other with the fixed disc. These experimental results give us the knowledge that the striae are fixed on the surface of the disc.

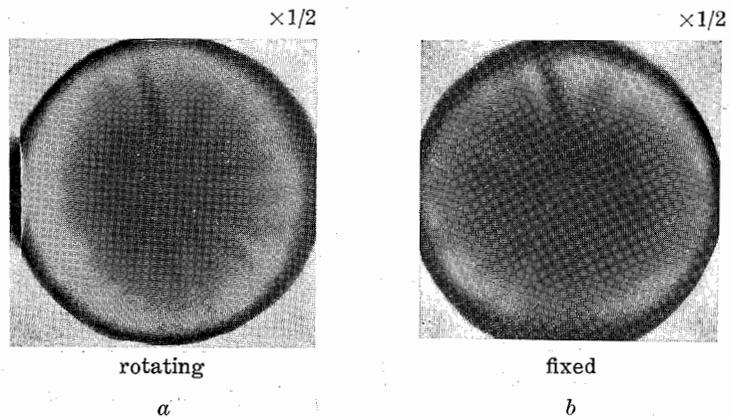


Fig. 17.

2. The case where the needle is placed eccentrically on the circular plate.

Next, if the needle is placed eccentrically on the circular glass plate, the initial luminous figure can not remain the same on account of the asymmetry of the electric field over the surface of the dielectric plate. The change of the configuration by slow rotation does not distort its former luminous figure till the angle of rotation of the disc exceeds a certain value. However, when this angle of rotation exceeds a certain limit, this figure is

perfectly distorted, and a new figure always appears before the preceding one has disappeared in every impulse on a different point of the disc. Therefore with rapid rotation of the disc the luminous striated figure on the disc apparently disappears and the surface of the rotating disc is coated with a uniform brightness.

3. The case where two needle electrodes stand upright on a circular plate.

If two needle electrodes stand upright on a glass plate of circular form, two electric discharge figures quite similar to each other appear around the needle points. According to Dr. Itoh⁽¹¹⁾, the boundary between these two figures on this plate appears as a dark straight line which bisects at right angles the line connecting these two needle points. If we make a phase difference in the electric potential between these two poles by inserting a wire of some length, we can easily measure the propagation velocity of the luminous figure over the surface of the glass disc. The case where

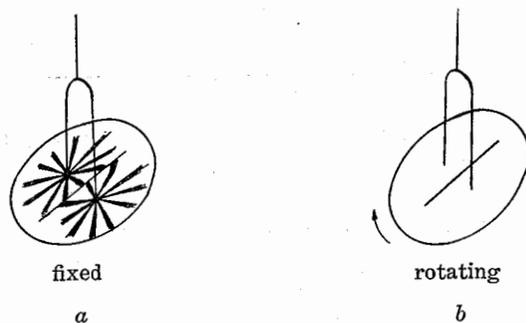


Fig. 18.

two needle electrodes be upright on the dielectric disc is shown we rotate the disc, it is observed that the luminous part is made uniformly bright for the reason stated in case 2 of this section but the dark line always still keeps its former position (Fig. 18, b.). The phenomenon last mentioned is quite natural under the circumstances that impulsive discharges occur intermittently and independently of each other.

§ V. SOME RELATIONS AMONG THE CONSTANTS
WHICH DETERMINE THE SIZE OF
THE FIGURE.

The existence of the spark gap in the discharging circuit is absolutely necessary for the production of these figures; the length of this gap plays an important rôle to change sensitively the fineness and the shape of this figure in various manners. Under such an expectation which there will be some remarkable relationships between the gap length and the size of the figure, we are able to obtain some relations among these factors by using the data of the various previous papers.

1. D_0 - S curve.

At first, we have a relation between the gap length S and the diameter D_0 of the central bright circle from which the striae radiate. It seems that the gap width which must decide the amount

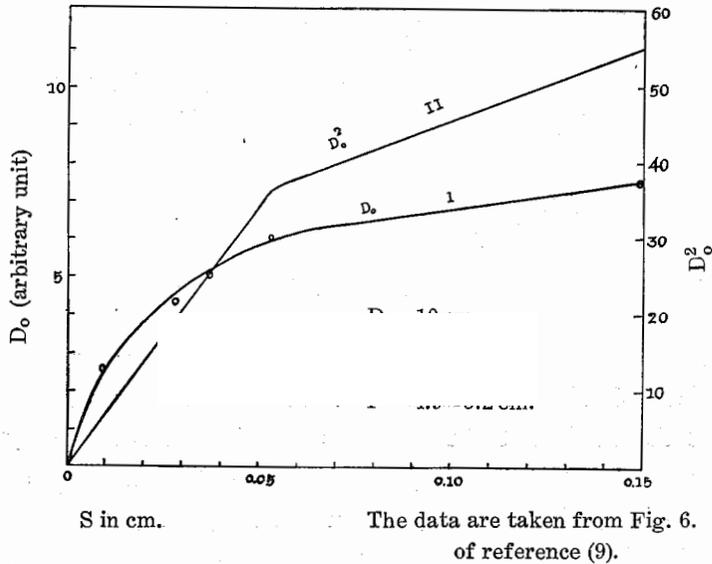


Fig. 19.

of the impulsive voltage within a certain range will control the diameter of the central circle by a simple relation. As the width is increased, the diameter of this circle becomes larger. Therefore from the data in the previous paper⁽⁹⁾, D_o plotted against S are shown in Fig. 19. On the other hand, when D_o^2 is taken instead of D_o , the curve *I* is replaced by curve *II*. This curve is nearly a straight line, except for the greatest width of the gap. From this curve the following relation is empirically determined.

$$\frac{S}{D_o^2} = \text{constant} \dots\dots\dots (1)$$

or

$$\frac{\sqrt{S}}{D_o} = \text{constant} \dots\dots\dots (1')$$

$$2. \quad \frac{\sqrt{\frac{S}{S'}}}{\frac{D_o}{D'_o}} = 1$$

For the different gap width S and S' , we can respectively write in the following forms using the result of (1').

$$\frac{\sqrt{S}}{D_o} = \text{constant} \dots\dots\dots (2)$$

$$\frac{\sqrt{S'}}{D'_o} = \text{constant} \dots\dots\dots (3)$$

from (2) and (3), the following relation can be obtained.

$$\frac{\sqrt{\frac{S}{S'}}}{\frac{D_o}{D'_o}} = 1 \dots\dots\dots (4)$$

Some data obtained from the previous paper show how the formula (4) is reasonable as shown in Table 1.

TABLE I.

No.	No. of Reference.	P cm.	S cm.	D_o	$\sqrt{\frac{S}{S'}}$	$\frac{D_o}{D'_o}$	$\frac{\sqrt{\frac{S}{S'}}}{\frac{D_o}{D'_o}}$
1	Fig. 14* { 32 33	4.6 4.7	.079 .034	10 7	1.52	1.43	1.06
2	" { 34 35	5.2 5.3	.050 .074	8 10	1.21	1.25	0.97
3	" { 41 42	4.3 4.3	.010 .058	4 9	2.4	2.25	1.07
4	" { 43 44	4.7 5.9	.016 .064	3.4 7	2.0	2.05	0.98
5	" { 54 55	5.9 5.9	.050 .012	6.5 3.4	2.04	1.92	1.06
6	Fig. 11*.	2.8	.019 .037	11 16	1.4	1.45	0.96

	Diameter of the glass disc.	Thickness of the glass disc.
Fig. 14*	10 cm.	1.5 cm.
Fig. 11*	10 cm.	0.496 cm.

These data are taken from Fig. 14* and Fig. 11* of reference (9).

3. D_o - P curve

If the pressure P is increased, naturally, the diameter of the circle will be enlarged. From the many data on this experiment the relation between D_o and P (in cm. of Hg.) is indicated in Figs. 20 and 21. If $\sqrt{\frac{1}{P}}$ is taken instead of P , the curve shows a straight line within the range of the air pressure from 4 cm. to 15 cm.

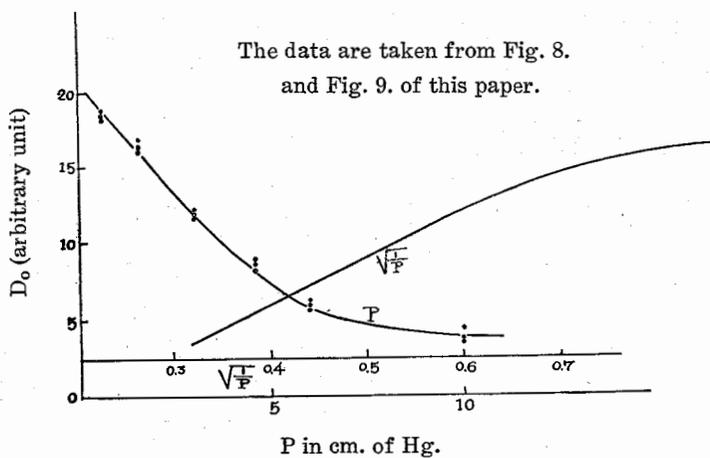


Fig. 20.

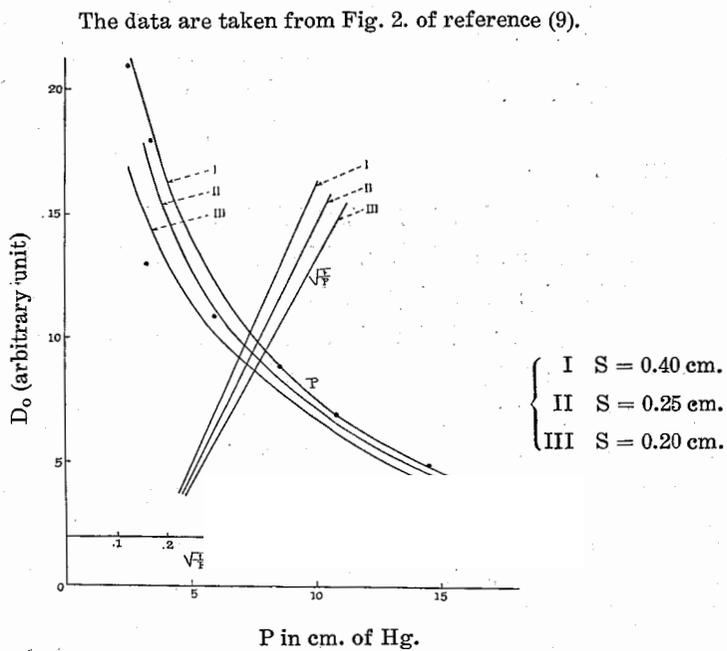


Fig. 21.

4. N-D curve.

Lastly, the distribution of the number of striae along the radial direction over the surface of the glass plate is obtained by means of a rotating divider whose centre coincides with the needle point. Fig. 22 shows that the number⁽¹³⁾ of striae is linearly proportional to

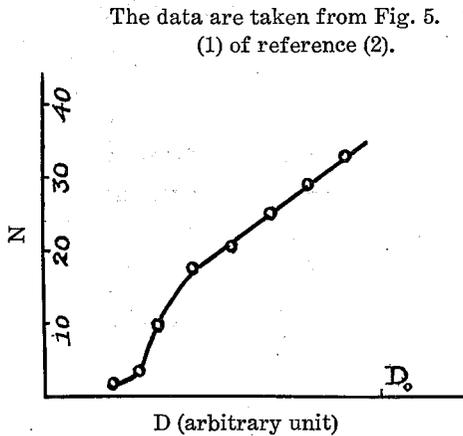


Fig. 22.

the distance from the centre. Also we notice that the distance between any two striae of these figures can not exceed a certain limit which depends on the discharge conditions. Therefore if the distance between two striae exceeds these critical values, the striae are obliged to decompose so as to satisfy the above property. The same property appears in the case of the parallel striated figure.

5. D-A curve.

In order to determine the potential distribution on the surface of the dielectric disc we place a thin wire radially on the surface of the dielectric disc and displace it radially from the needle point towards the periphery of the disc. A new figure starts from the farther end of this thin wire as started in 1 of §III.

The variation of the size of this figure is indicated in Fig. 23. We will represent the area of the central part of this figure as A and the distance between the nearest end of the thin wire as D . The value of A is taken from the photograph of Fig. 23. Next if we take \sqrt{A} instead of A in Fig. 24 the relation is represented by a straight line.

On the other hand, the writer has recently noticed that these relations (1, 2, 3. of this paragraph) could be explained by assuming that the electric charge under a certain condition has properties similar

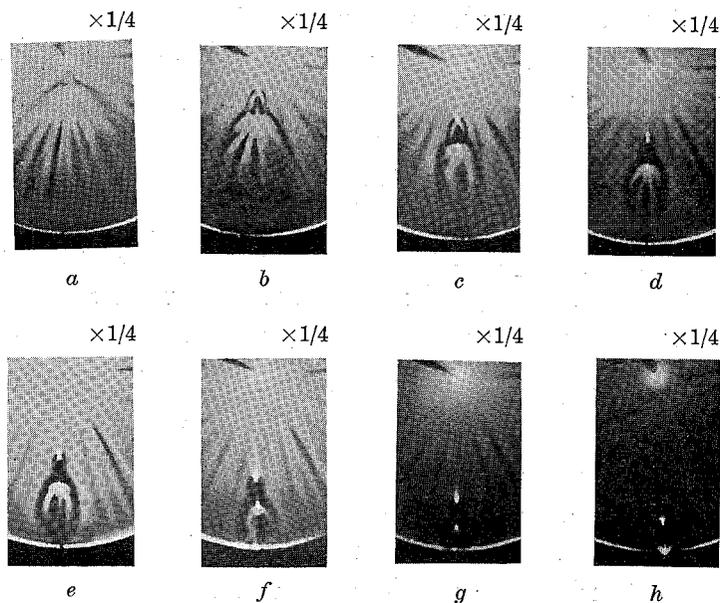


Fig. 23.

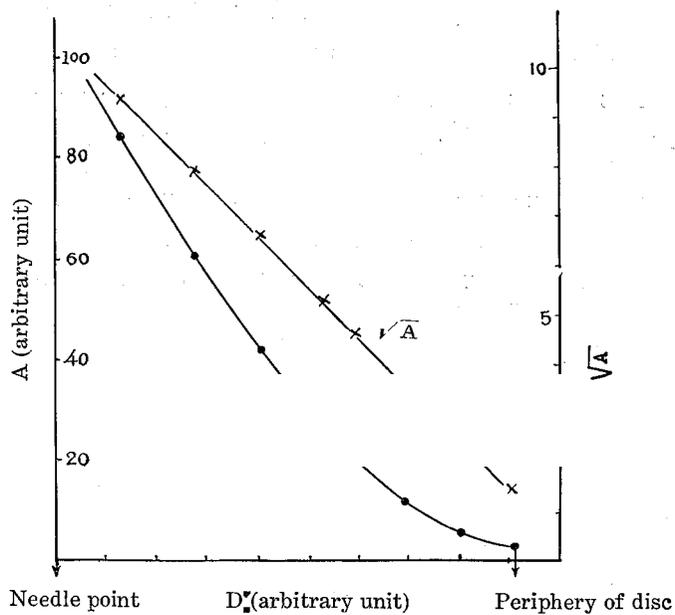


Fig. 24.



to such things as the surface tension and the viscosity of liquid, but at present this assumption does not seem to be sufficient to explain quantitatively all phenomena of these surface discharges.

§ VI. SUMMARY.

1. The potential distribution of these figures on the dielectric disc shows good analogy with the appearance of the map of Mt. Fuji in which its valleys correspond to the dark canals.

2. Placing the various shaped conducting or insulating materials on the insulating disc, sometimes beautiful electric discharge figures appear on that disc as results from the disturbance of the original electrostatic field by these auxiliaries mentioned.

3. When the fine powder is uniformly strewn over the discharge surface, the figure on that dielectric surface reveals an appearance similar to that of the positive Lichtenberg figure on a photographic plate.

4. In the case of the rotating dielectric disc, we observe some interesting phenomena about the striae of this electric figure.

5. It is shown that the size of the central bright circle of these figures depends on the gap width and the air pressure.

In conclusion, the present writer wishes to express his hearty thanks to Prof. Y. IKEDA for the continual guidance given to carry out this work and also to Dr. Itoh for valuable suggestions.

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