Studies on Discharge.

By

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Abstract.

SECTION I. CURRENT-VOLTAGE CHARACTERISTICS.

The surface charge on the surface of the insulating material has an extraordinary effect upon the discharge phenomena in high voltage engineering. In the first section, the current-voltage curves are measured using needle and plate electrodes, on which various kinds of insulators are laid. If the current is measured increasing the voltage gradually from zero to a certain value and then decreasing the voltage to zero again, a loop of a current-voltage curve is produced. The current of ascending voltage is larger than that of descending, and the difference of these values of current is the greater, the stronger the residual surface charge on the insulator surface. Especially in case of the ebonite plate, the residual surface charge has an extraordinary effect upon the current-voltage characteristics. Its polarity and that of the needle electrodes are equal, so that the potential gradient of space near the needle decreases and the corona disappears provided that the amount of surface change reaches a certain value. After a certain time, however, the residual charge discharges, so the potential gradient becomes so great that the corona appears and the current increases again. Owing to the above reasons, the current and corona vary with a period of from 8 to 10 seconds.

SECTION II. SURFACE CHARGE FIGURE.

A method of detecting the surface residual charge on the ebonite surface is given. The positive and negative charge can be detected by dusting the surface with, (for instance), a mixture of resin and red lead. The figure obtained by this method is termed a surface charge figure,

The experimental results of a surface residual charge by means of a ballistic galvanometer and the surface charge figures are thus compared.

SECTION III. SURFACE CHARGE FIGURE BY THE IMPULSE VOLTAGE.

As the diameter of the surface charge figure by impulse voltage is proportional to the maximum value of the applied impulse voltage, the figure can be used for the measurement of impulse voltage.

In case of impulse voltage also, the positive and negative figures are quite different in shape and in colour. Therefore, this method can be used in place of the Klydonograph.

SECTION IV. SPARKOVER BETWEEN NEEDLE AND PLATE ELECTRODES THROUGH A SMALL HOLE IN EBONITE PLATE.

The sparkover of needle and plate electrodes through a small hole in ebonite plate is described. The experimental results and the theory of probability of ionisation path are compared.

SECTION V. THE MECHANISM OF SPARKOVER BETWEEN NEEDLE AND PLATE ELECTRODES.

The polarity effect of needle and plate electrodes in case of impulse voltage is described. It is due to the space charge, which changes the potential distribution between the electrodes during the spark over.

The potential distribution at sparking is measured by means of the surface charge figure, and it is shown that it is quite different from that calculated electrostatically.

I. Current-Voltage Characteristics.

The surface charge on the surface of insulator plays an important rôle in high voltage electrical engineering, and it has various effects upon the breakdown voltage and current-voltage characteristics of a system including electrodes and dielectrics.

The current-voltage curves of needle and plate electrodes, on which a plate insulator is placed as shown in Fig. 1, are measured by means of a sensitive mirror galvanometer. The connection diagram is shown in Fig. 1. In the figure, V is a voltmeter for the low tension side; T is a high tension

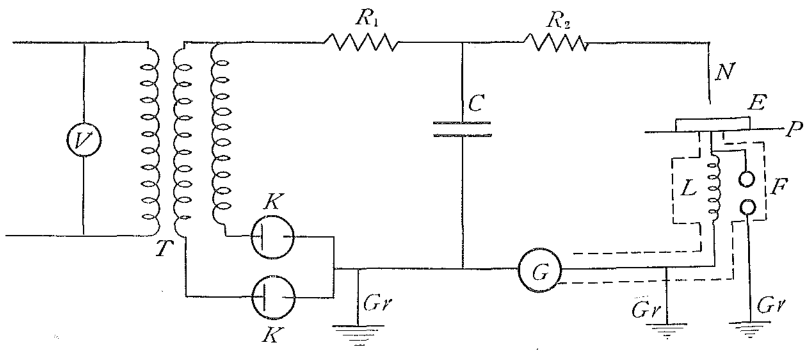


Fig. 1.

testing transformer of 100 KV; K, K are kenotrons; R_1 and R_2 are water resistances, C is a high tension condenser of 0.0354 M.F.; G is a mirror galvanometer; N and P are needle and plate electrodes to be tested respectively; E is the plate insulator; and L and F are self-inductance and small sphere gap respectively. L and F constitute a protective device for the galvanometer against the over current in it. The dotted lines in the figure show a metal box and tin foil for the protection of leakage of current.

If the current is measured increasing the voltage gradually from zero to a certain value (near the break down voltage) and decreasing to zero again, a loop of a current-voltage curve is produced. Its area depends upon the quantity of residual surface charge on the surface of the insulator and upon the character of the surface. It is the larger, the larger the quantity of surface residual charge and the greater the power of adhesion of the charge on the surface.

The ebonite plate E is laid on the plate electrode as shown in Fig. 1, and the loop of current-voltage curve taken, which is shown in Fig. 2. In case of the ebonite plate, the surface residual charge remains so well on the surface of ebonite that it has an extraordinary effect upon the loop. The full and dotted lines in Fig. 2 show the maximum and minimum values of the oscillatory current respectively. Owing to the following reason, the current is oscillatory. The polarity of residual charge is equal to that of the needle electrode, therefore, if the amount of the residual charge reaches a certain value, the potential gradient of the space near the needle electrode so decreases that the corona around the needle disappears. After a certain value, however, the residual charge discharges, and the potential gradient becomes great enough so that the corona appears and the current increases

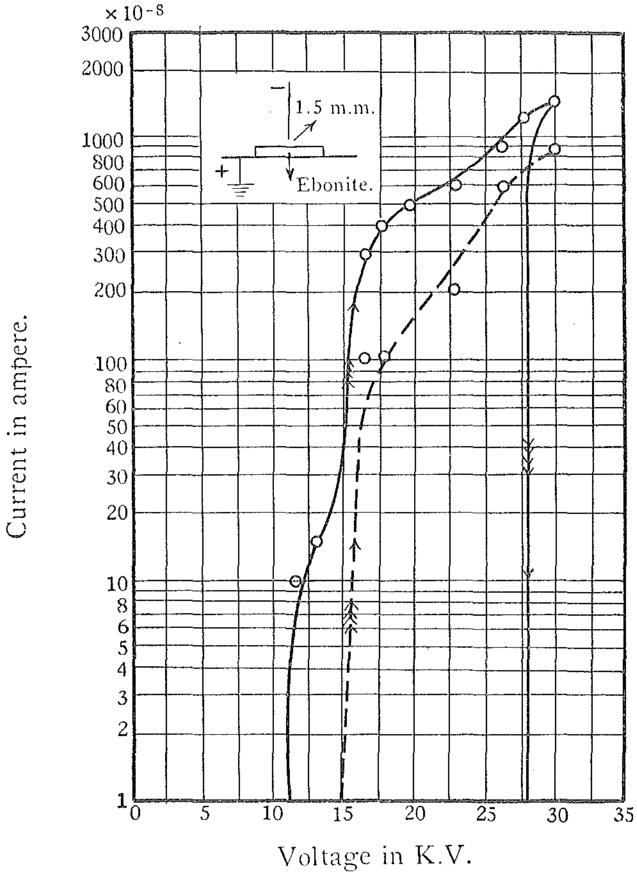


Fig. 2.

again. Owing to the above reasons, the current and corona change with a period of from 8 to 10 seconds.

If there is used a glass plate in place of the ebonite one, there is produced a loop of current-voltage curve, whose area is very much smaller than that of the ebonite. These results show that the charge does not remain so well on the glass plate as on the ebonite plate.

II. Surface Charge Figure.

As was described in the previous section the surface charge remains very well on the surface of ebonite plate, for instance, in a very dry atmosphere it remains more than 10 days.

A method of detecting the surface residual charge on the ebonite surface is given. The positive and negative residual charge can be detected by dusting the surface with the following mixture of fine powder after the application of the voltage.

(1) about 90% of resin and about 10% of red lead.

(2) about 50% of resin and about 50% of lead acetate.

(3) about 50% of sulphur and about 50% of red lead etc.

If a negatively electrified ebonite surface is dusted with the first kind of fine powder, the positively electrified red lead will stick to the surface, while the negatively electrified resin can be easily detached; so that if the powdered surface is blown upon the resin will come off while the red lead will remain, thus the surface will be coloured red. If a positively electrified surface of ebonite plate is treated in this way it will become yellowish white in consequence of the resin sticking to it. For simplicity, such a figure gotten as above stated, is termed a surface charge figure. The surface charge figure is one kind of Lichtenberg's figures, and it is quite different from Lichtenberg's second figure, which is obtained by strewing the fine powder on the surface of the insulator before the application of the voltage.

First there is placed an ebonite plate (thickness 3 mm.) of 15 cm × 15 cm on the plate electrode, and the needle electrode on the ebonite plate at right angles as shown in the figure. Then there is applied the potential difference between the electrodes the needle being the positive pole, and after a few second the voltage is taken off. If the surface of ebonite is dusted with the fine powder after the application of the voltage, a positive surface charge figure is obtained. A negative surface charge figure can be obtained by applying the negative potential to the needle electrode. As these positive and negative figures have a special feature and colour, the difference between them can be distinguished very easily.

After the application of A.C. voltage for a few seconds, dusting the ebonite surface with the fine powder, a surface charge figure is obtained as shown in Fig. 3. In this figure, the root like radial part is yellowish white, i.e. a positive figure, and the outer ring formed part is red, i.e. a negative figure.

The surface charge figure is not due directly to the intensity of the electric field, but to the residual charge. As a verification of this fact, there can be obtained a surface charge figure by the following method. Two ebonite plates in contact with each other are placed between plate electrodes, which are connected with the high voltage A.C. source. After the application of the voltage of about 30 KV. for a few minutes, the inner surface of the ebonite plate is dusted with the fine powder, and an irregular surface charge figure is obtained as shown in Fig. 4.

It is not possible to get clear surface charge figures on a glass plate, porcelain, paper, etc., but on ebonite plate, resin cake, sealing wax, etc., it is possible.

In the next place, the residual surface charge on the ebonite plate is measured by means of a ballistic galvanometer[1] using a plate electrode of 8 cm. diameter or 2 cm. diameter. The experimental results of the ballistic galvanometer method and those of the surface charge figures are

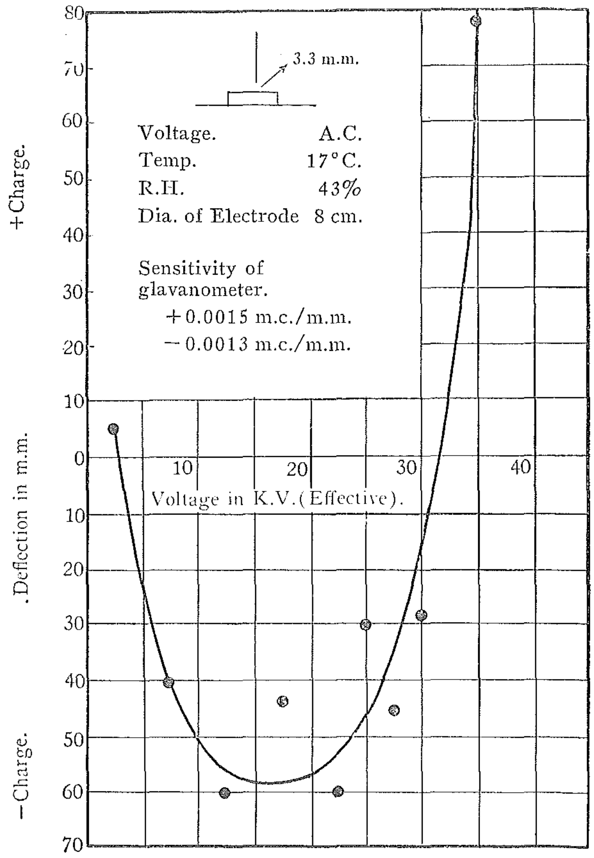


Fig. 5.

1) T. Nishi: A.I.E.E. 1920 Nov.

compared, and it is found that these two results agree with each other. Fig. 5 shows the relation between the deflection of the ballistic galvanometer and the applied A.C. voltage. As can be seen in the figure, the negative charge increases with the applied voltage up to about 18 K.V., and then decreases to zero at about 32 K.V. Above 32 K.V. the galvanometer deflects to reverse side. Corresponding to this experiment, the surface charge figures are obtained. Up to about 15 K.V. only a red negative figure is obtained, however, above 15 K.V. yellowish white radial positive figure in a red ground is obtained. Owing to above facts, the deflection of the ballistic galvanometer decreases above 20 K.V.

The fact that the galvanometer does not deflect at about 32 K.V. does not mean that there is no residual charge, but that the negative and positive charges under the electrode are equal to each other.

III. Surface Charge Figures by the Impulse Voltage.

The connection diagram of the impulse generator used in the experiment is shown in Fig. 6. In the figure, V, T, C_1, K, K and W_2 denote the same things as in Fig. 1; M_1 are sphere electrodes of 5 cm. diameter; W_1 is a non-inductive resistance (140,000 ohms water resistance); C_2 is a high tension condenser of 0.0177 m.f.; N is a needle electrode; E is an ebonite plate on which the surface charge figure is obtained; and P is a copper plate electrode. If the voltage of the transformer is raised gradually, M_1 sparks over once, and a single impulse voltage is applied at the terminals of W_1, i.e. N and P.

If after the application of impulse voltage using needle N as a positive pole, the surface of the ebonite plate E is dusted with the fine powder, then

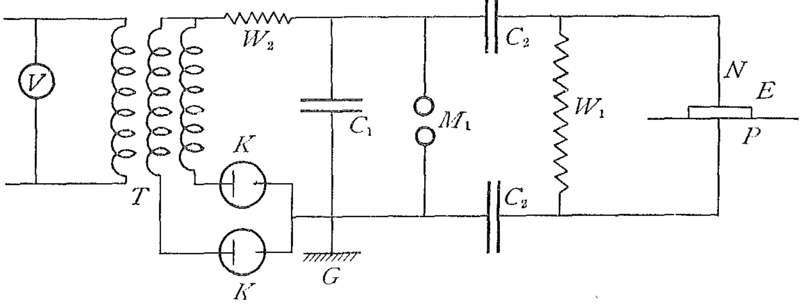


Fig. 6.

a positive surface charge figure is obtained. An example of the positive figure is shown in Fig. 7, and that of the negative figure in Fig. 8.

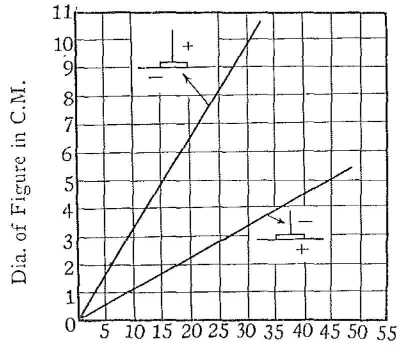
As there is a clear distinction between positive and negative surface charge figures, and as the diameter of the figure is proportional (as shown in Fig. 9,) to the maximum value of the applied impulse voltage, so the figure can be used to measure the maximum value and polarity of the impulse voltage.

The amount of the error of this method is nearly equal to that of the sphere electrodes, so that it is very convenient to use this figure in place of Lichtenberg's figure on the photographic plate. Moreover, this method has two merits; i.e. the figure can be taken in the light room, and the ebonite plate can be used many times, provided it is cleaned.

The maximum value of the first and second waves of a damped oscillatory impulse voltage can be measured obtaining the two figures by changing the connection of N and P reversely.

In the next place, taking the figure and varying the distance d between the needle N and the ebonite plate E, if the distance d reaches a certain value, the surface charge figure disappears on account of the given impulse voltage. If this distance is termed d_0, it is larger for a positive than for a negative figure, in case of d being 3.0 cm. is shown in Fig. 10.

The surface charge figure can not only be obtained on the upper surface of the ebonite plate, but also on the under surface simultaneously. The under surface figure is termed the secondary figure.



Impulse voltage in K.V.(Max.).
Fig. 9.

The secondary figure is not so regular in shape as the upper surface charge figure, and the polarity of the surface residual charge of the upper and under surface ones are opposite. The positive and negative secondary figures are shown in Fig. 11, A, B.

IV. Spark over between Needle and Plate Electrodes through a small Hole in Ebonite Pate.

In this section the mechanism of the sparkover between the needle and plate electrodes is described. The connection diagram of the experiment is shown in Fig. 12. In the first place, the distance between needle N and plate P is adjusted so as to spark over, for the first time, for every

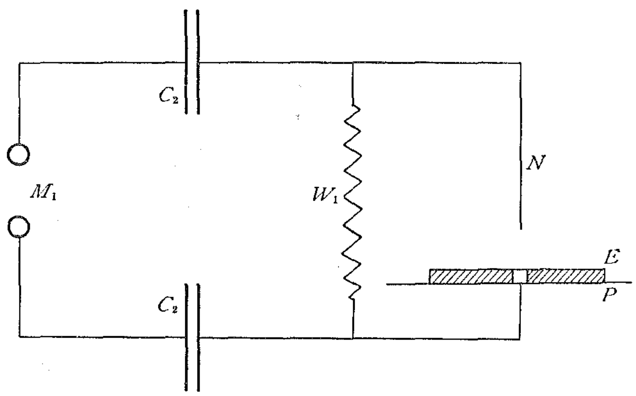


Fig. 12.

definite impulse voltage without ebonite plate E. For simplicity, such a distance is termed critical gap length. Then the ebonite plate E with a small hope is so placed that the center of the hole is situated just under the needle.

If there is no hole in the ebonite plate, a surface charge figure as shown in Fig. 13 is obtained by applying an impulse voltage of 28 K.V. using needle N as the positive pole. In the figure, the center of the figure like a star is an intersection of the ionisation path and the surface of the ebonite plate. If there is a small hole in the ebonite plate, and the earliest and the greatest ionisation path falls into the hole, the spark-over occurs. In this case it is not possible to see any surface charge figure on the surface. However, if the earliest ionisation path does not fall into the hole, the spark over does not occur, and the surface charge figure is seen as shown in Fig. 14 and Fig. 15.

In short ,the numbers of spark-overs through the small hole depend upon the probability of the falling of the earliest and largest ionisation path into the small hole.

50 times of impulse voltages are applied between N and P using needle N as the positive pole, and the numbers of spark-overs are observed for each hole. The radius of the hole is varied from zero to 7 m.m. The experimental results and the theoretically calculated results are shown in Fig. 16.

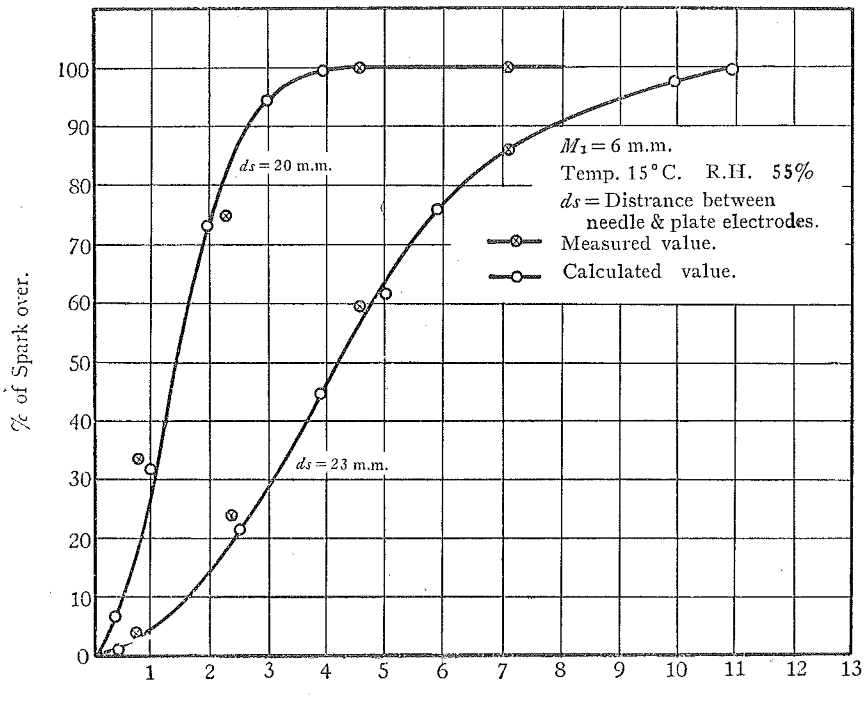


Fig. 16.

Let P be the probability of falling of the earliest and the greatest ionisation path (or falling of the spark) into the unit area, on the ebonite surface, at r from the center of the hole (see Fig. 17). Then P is given as follows.[1]

$$P=\frac{1}{\pi k^2}e^{-\frac{r}{k^2}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

1) U. Yoshida: The Denkihyoron. 1928 Sep.

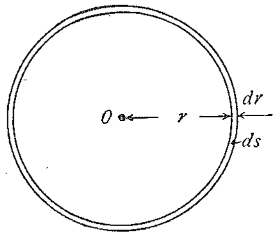


Fig. 17.

where k^2 is a constant for given electrodes and gap length.

Then, the probability of the falling of the ionisation path into the elementary area ds is as follows.

$$Pds=\frac{2r}{k^2}e^{-\frac{r^2}{k^2}}dr$$

Therefore, the probability of the falling into the circle of radius r is

$$\int Pds=\frac{2}{k^2}\int_0^r re^{-\frac{r^2}{k^2}}dr$$

Let

$$e^{-\frac{r^2}{k^2}}=x$$

and integrating there is found

$$\int Pds=[1-e^{-\frac{r^2}{k^2}}]=R\ldots\text{say} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

If the numbers of the applied impulse voltage are expressed by N (in this case $N=50$), the numbers of spark-overs are

$$NR=N[1-e^{-\frac{r^2}{k^2}}] \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

or

$$\log(N-NR)=\text{Const.}-\frac{r^2}{k^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The value of k^2 can be calculated from this equation and the experimental results.

The calculated $N\ R$ from eq. (3) is shown in Fig. 16. As is seen in the figure, the experimental and calculated results agree.

The manner of spark-over in case of the needle N being the negative pole is quite different from that of the needle used as the positive pole. In the case of critical gap length, the spark-over occurs through the hole for every time of the application of the same impulse voltage.

The critical gap length of the positive needle is greater than that of the negative needle. It seems that the causes of the differences are due to the difference between the modes of ionisation of the positive and negative needles. In the case of the negative needle, the ionisation path occurs just under the needle, and the surface charge figure of critical gap length is shown in Fig. 18.

V. The Mechanism of Spark Over between Needle and Plate Electrodes.

If the impulse voltage is applied between the needle and plate electrodes using the former as the positive pole, the electrons produced by the ionisation by collision move towards the needle, and the positive

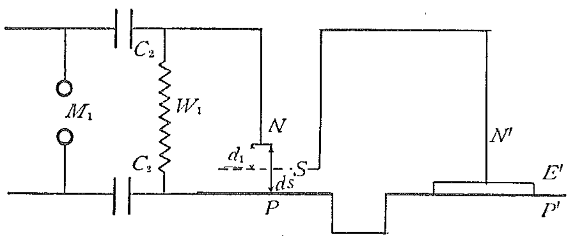


Fig. 19.

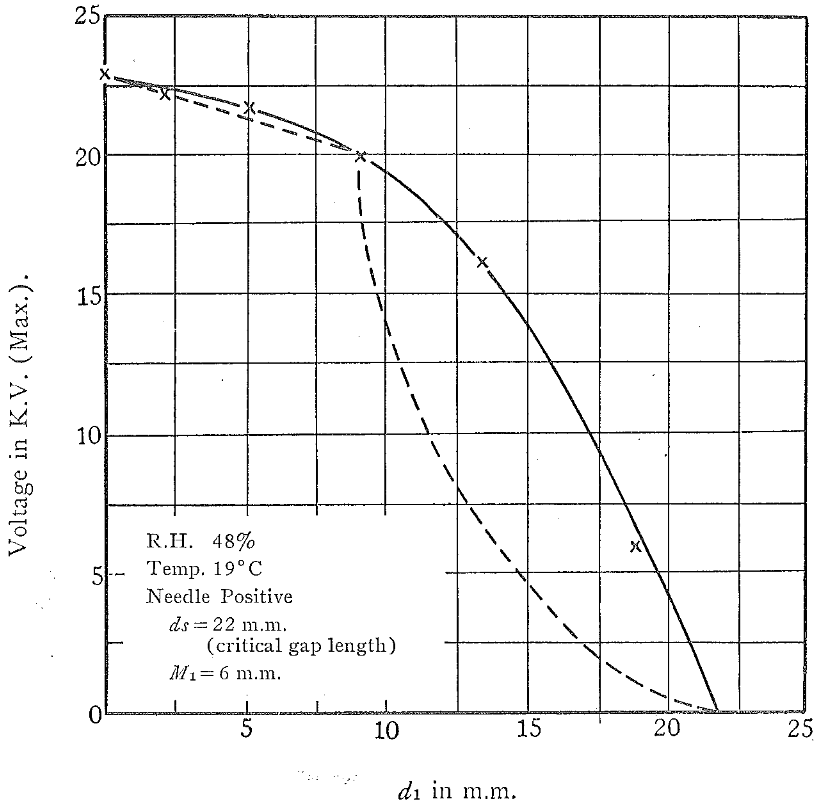


Fig. 20.

ions towards the plate electrode. However, owing to the fact that the velocity of electrons is about 1000 times greater than that of positive ions, the positive ions remain at the end of the needle, so that the high potential gradient at the end of the needle is weakened by the positive space charge. Therefore, the region of high potential gradient moves from the needle towards the plate in time, and the ionisation by collision proceeds along the ionisation path. According to the above reason, the potential gradient between the electrodes is very much larger at certain moments than gradient calculated electrostatically.

In the case of the negative needle, as the positive ions remain at the end of the needle, so the ionisation by collision does not proceed as in the case of the positive needle. Therefore, when the equal impulse voltage is applied the maximum spark over gap length or critical gap

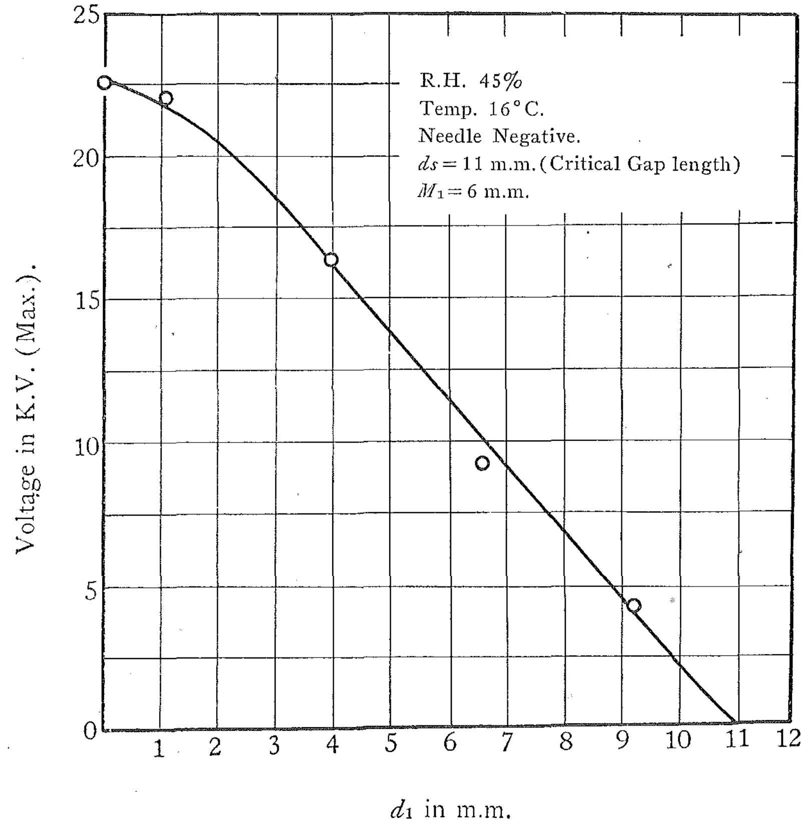


Fig. 21.

length of the positive needle is larger than that of the negative needle.

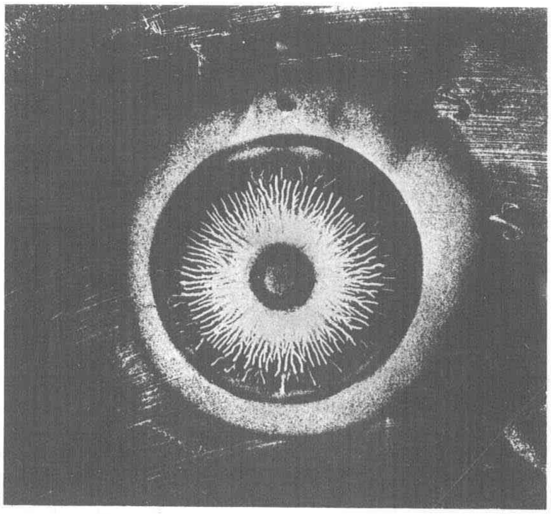
The potential distribution between the electrodes is measured by means of the surface charge figure. The simplified connection diagram is shown in Fig. 19, in which N and P are the needle and plate electrodes respectively; N' E' P' represent the device for obtaining the figure; and the dotted line S is a very thin wire stretched along the equipotential surface. Varying d_1 from zero to d_s there is measured the potential difference between S and P by means of the figure on ebonite plate E'.

The experimental result in case of the positive needle is shown in Fig. 20, in which the dotted line shows the imagined potential distribution at certain moments. As is seen from the experimental results, the potential gradient is quite different from that calculated electrostatically, so that there must be taken into account the space charge in case of impulse voltage. The theory of break down of spark gap standing on the potential gradient calculated electrostatically can not be applied in case of impulse voltage.

The corresponding experimental result of the negative needle is shown in Fig. 21. The polarity effect of needle and plate electrodes by impulse voltage is accounted for by the above stated experiments.

The End.

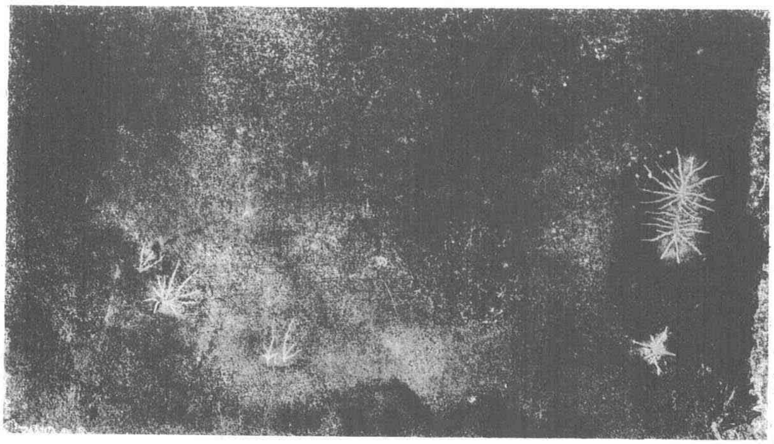
Fig. 3.



Voltage. A.C. 12 K.V. (effective value).

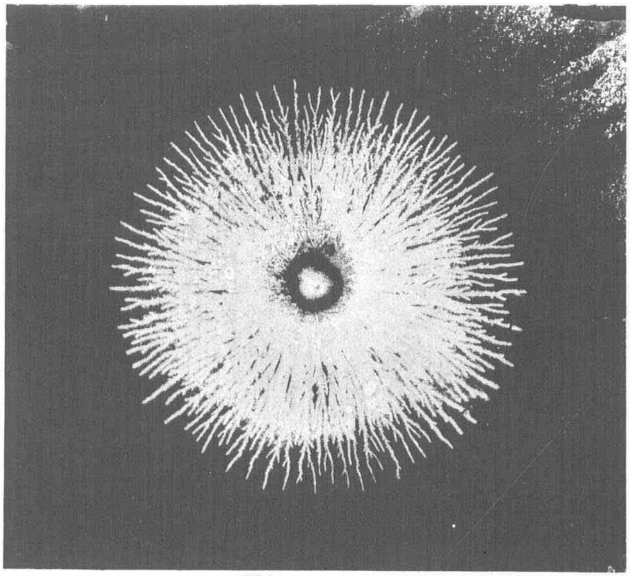
Temp. 21°C R.H. 33%

Fig. 4.



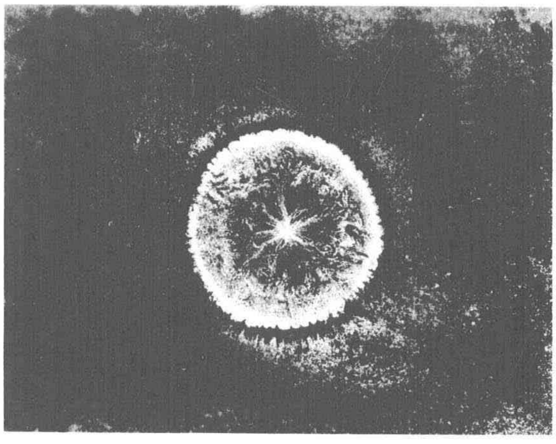
Voltage. A.C. 30 K.V. (effective value).
Temp. 17°C R.H. 41%
Surface charge figure on the inner Surface.

Fig. 7.



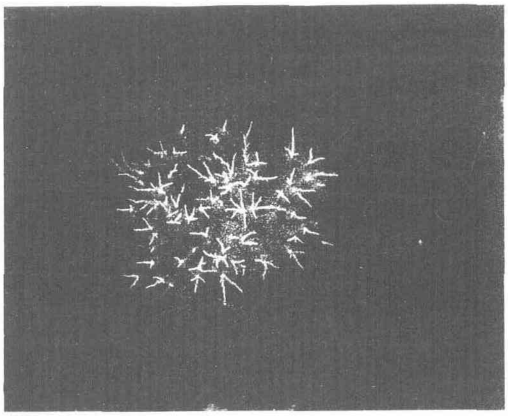
Impulse Voltage. 23 K.V. Max. Value.
Positive Figure.
Temp. 18°C R.H. 56%

Fig. 8.



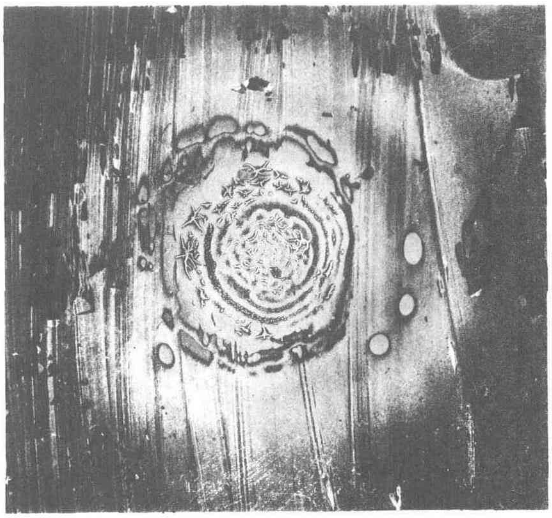
Impulse Voltage. 33.5 K.V. Max. Value.
Negative Figure.
Temp. 18°C R.H. 56%

Fig. 10.



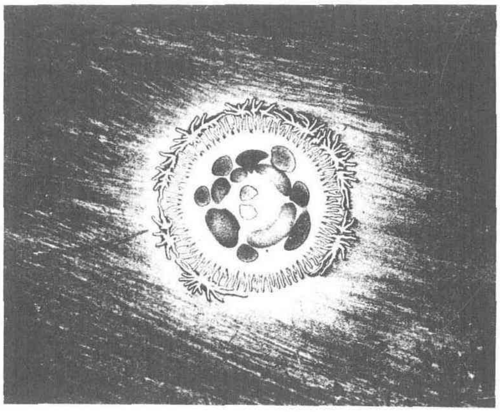
Impulse Voltage. Max. Value. 28 K.V.
Gap $d=30$ m.m.
Positive figure.
Temp. 18°C R.H. 56%

Fig. 11, A.



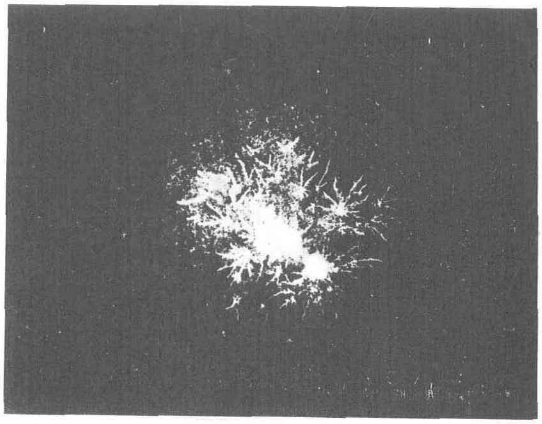
Impulse Voltage. 23 K.V. Max. Value.
Positive secondary figure.
Temp. 18°C R.H. 37%

Fig. 11, B.



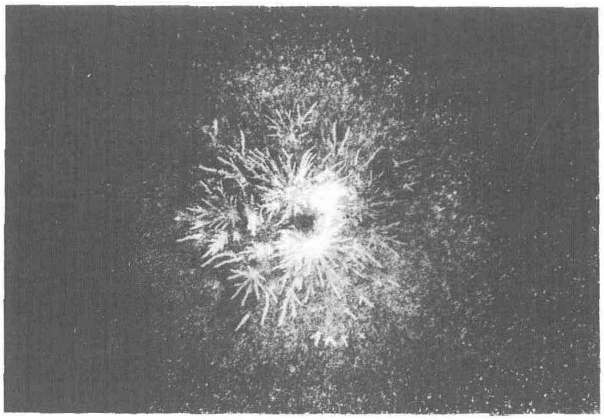
Impulse Voltage. 33.5 K.V. Max. Value.
Negative Secondary Figure.
Temp. 18°C R.H. 37%

Fig. 13.



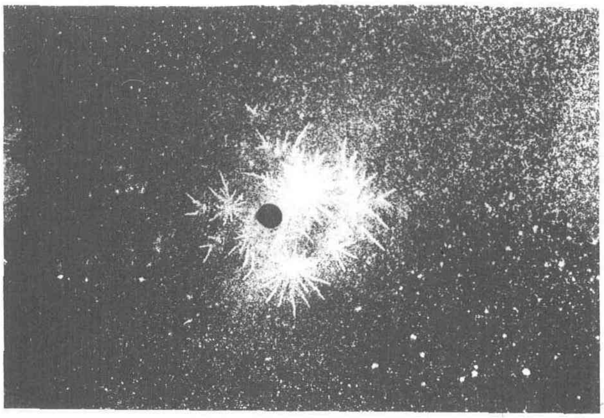
Impulse Voltage. Max. Value. 28. K.V.
Positive Figure.
Distance bet. N and P = 23 m.m. (critical gap length).
Temp. 16°C R.H. 55%

Fig. 14.



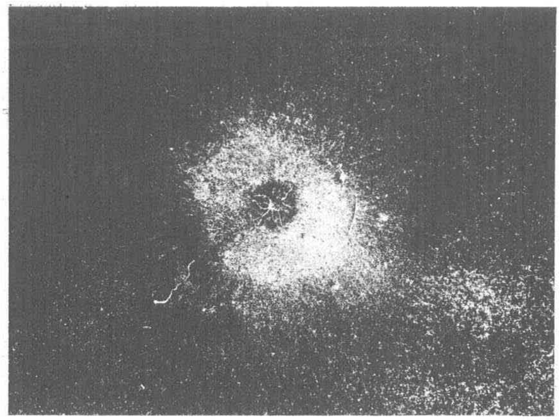
Impulse Voltage. Max. Value. 28 K.V.
Positive Figure.
Distance bet. N and P = 23 m.m.
Dia. of hole = 1.6 m.m.
Temp. 18°C   R.H. 52%

Fig. 15.



Impulse Voltage. Max. Value. 28 K.V.
Positive Figure.
Distance bet. N and P = 23 m.m.
Dia. of hole = 4.8 m.m.
Temp. 18°C   R.H. 52%

Fig. 18.



Impulse Voltage. Max. Value. 28 K.V.
Negative Figure.
Distance bet. N and P = 11 m.m. (critical gap length).
Temp. 16°C R.H. 55%