Some Applications of the Surface Charge Figure.

Dr. Ing. **Y. Toriyama** and **U. Shinohara.**

Abstract.

Using the surface charge figure, the next three problems are investigated.

1. Potential distribution along the coil.
   In this problem, it is ascertained that in general Wagner's theory is correct.
2. The wave form of the impulse voltage.
   Formerly, Dr. Binder obtained only the wave front of the impulse voltage, but the total wave form can be measured by present method.
3. The spark lag.
   One of the measuring methods of the spark lag is shown. This method is very accurate and the time lag of 10^{-8} sec. in order or the shorter time lag can be exactly measured.

I. Introduction.

In this paper, there is shown the application of the surface charge figure in the study of the impulse voltage; for instance, the problems of the coil subjected to the impulse voltage and some properties of gaps, etc..

II. Surface Charge Figure.[1]

The surface charge figure is similar to Lichtenberg's dust figure. Instead of the photographic plate of the Klydonograph, there is used the ebonite plate; and after the application of the impulse voltage, a fine powder is sprinkled over this ebonite plate (Fig. 1). Then there is obtained the clear figure as shown in Fig. 2.

If the plate of the other kinds of insulating materials are used, the clear figure can not always be obtained, but the ebonite or the sealing-wax plate gives good results.

1) Y. Toriyama, Journal of the institute of Elec. Eng. of Japan. No. 484–485.

When the positive or negative impulse voltage is applied on the ebonite plate respectively, there is obtained the surface charge figures as

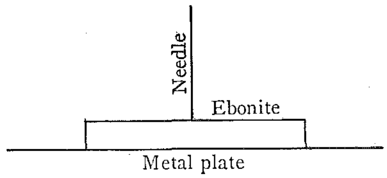


Fig. 1.

shown in Fig. 2. Looking at this figure the following facts are evident, i.e., the shape of the positive figure is distinctly different from that of the negative figure, moreover the size of the positive figure is very much larger than that of the negative.

Next, is explained the reason of the attainment of this surface charge figure. On the application of the impulse voltage, the molecules of air on the ebonite plate are ionized, and the electrons are moved towards the needle electrode, but the positive ions remain on the ebonte plate. This is also the case when the positive voltage is applied to the needle electrode; but when the negative voltage is used, the positive ions move to the needle electrode and the electrons remain on the ebonite plate. Namely, the surface chage figure is due to the residual charge. Therefore, if the fine powder, as for example the mixture of resin and red lead, is sprinkled on the ebonite plate, it is decidedly easy to distinguish the positive figure from the negative; i.e. the positive figure is yellowish white, but the negative figure is red.

Hence, from the surface charge figure, it is known whether the applied impulse voltage is positive or negative.

When the oscillatory impulse voltage is applied, the combination of the positive and negative figures, as in Fig. 3, is obtained.

If the terminal of the needle and the metalic plate electrode are changed, also there is the same kind of figure obtained as in the former case. Therefore, the aspect of the oscillatory impulse voltage can be found out.

Next, to be found out is that the relation between the maximum value of the applied impulse voltage and the radius of the surface charge figure is always a straight line. Hence the maximum value of the impulse voltage can be measured fairly accurately with this surface charge figure. And this figure is obtained for such fast impulse voltage as 10^{-8} sec. in order, but in this case the number of the radiated twigs of the figure are decreased considerably.

III. Potential Distribution Along the Coil.

Up to this time, the problem of the coil has been studied by many authors. The many results obtained can be divided into two classes, i.e.

1. The critical frequency does not exist on the coil.
   (Lenz,[2] Rogowski,[3] Gothe,[4] etc.)
2. The critical frequency may exist on the coil.
   (Wagner,[5] Rüdenberg,[6] Böhm,[7] etc.)

Then, Gothe tried to find out the critical frequency of the coil experimentally, but his efforts came to nothing. But Böhm found out the critical frequency of the transformer experimentally. Hence, Steidinger[8] thought as follows.

The critical frequency does not always exist; i.e. it does not exist in the coil of single layer winding, but in coils which have iron cores, as in case of the transformer. Consequently, whether the critical frequency exists or not, depends on the properties of the coil.

Then, the investigation is made using the surface charge figure to find out whether the critical frequency exists or not in the coil of single layer winding; and how when the impulse voltage is applied on the coil, the potential along the coil is distributed.

The conclusion of the experiments made are as follows. The critical frequency exists even in the coil of single layer winding.

Gothe calculated the value of critical frequency from the formula of Wagner's theory and also examined it experimentally, but he failed to find out the true value. Perhaps, the frequency, he used, did not reach to the required value. Wagner's theory is perhaps suitable on the whole, but is never a perfect theory. Therefore, this theory does not absolutely

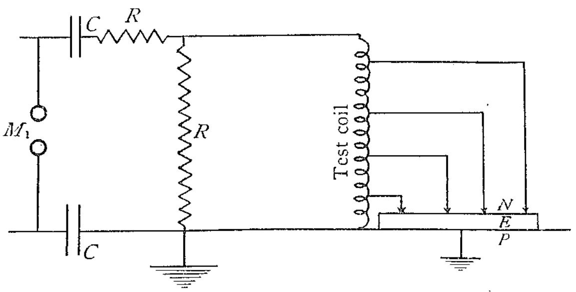
2) Ann. d. Phys. 43 s. 749.
3) Arch. f. Elek. Bd. VII s. 17 u. s. 240.
4) Arch. f. Elek. Bd. IX s. 1, 1921.
5) E. u. M. 1915. Arch. f. Elek. Bd. VI s. 201, 1917.
6) El. Schaltvorgänge; E. u. M. 1914 s. 729.
7) Arch. f. Elek. Bd. IX s. 341, 1921.
Arch. f. Elek. Bd. V s. 383, 1917.
8) Arch. f. Elek. Bd. XIII s. 237, 1924.

correspond to the experimental value. For instance, his theory has a defect in the handling of the capacity. The potential distribution along the combination of condensers (or a string of suspension insulators) varies with the frequency of the applied voltage. But Wagner's theory does not take into consideration this fact.

Next, is described the experimental results. The coil used has the following dimensions.

Length of coil=41.2 cm. Number of turn=136.
Diameter of coil=9.0 cm. Inductance=341.4 Henries
Distance between two neighbouring wires=3 m.m.

And the single layer cotton covered wire (B. & S. No. 24) is wound on the cylindrical form of pressphan. The maximum values at each 10 turns of the coil are measured simultaneously by means of the surface charge figure. (See Fig. 4).



M_1 : Sphere gap. C : Condenser.
R & R' : Water Rheostat. N : Needle Electrode.
E : Ebonite plate. P : Metalic plate.

Fig. 4.

If the end of the coil is grounded, Fig. 5 is obtained by the application of positive impulse voltage and Fig. 6 by negative impulse. From these two figures, it is known that the oscillation occurs at each point of the coil.

The distribution of the maximum voltage along the coil is shown in Fig. 7. This shape of curve is due to the distributed inductance and capacity of the coil.

If the impulse voltage of the rectangular form is applied, the potential distribution along the coil is shown by the equation.

$$p_x = P\left[1-\frac{x}{l}-2\sum_{1}^{\infty}\frac{\sin b_x\, x \cos \beta_x\, t}{b_x\, l\{1+(b_x\, l)^2\delta\}}\right]$$

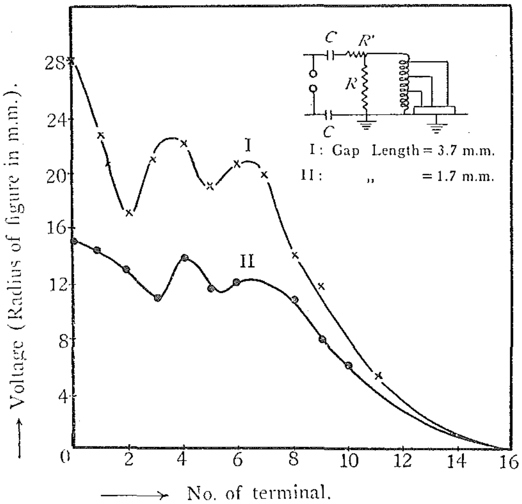


Fig. 7.

where
$$x=1,\ 2,\ 3,\dots\dots$$

$$b_x=\frac{x\pi}{l},\qquad \delta=\frac{K}{l^2C}$$

$$\beta_x=\frac{b_x v}{\sqrt{1+(b_x l)^2\delta}}$$

K: Capacity between adjacent windings.
C: Capacity between earth and unit length of the coil.
l: Length of the coil.
x: Any position on the coil.

Plotting this in curve, it is found out that this formula agrees in the main with the experimental results.

Next there is applied a steeper impulse voltage than in the former case, Fig. 8 is obtained. Looking at this figure, oscillation occurs at both ends of the coil, but the potential is zero at the center. This is nothing else than the standing wave.

If there is applied a still steeper impulse voltage then instead of Fig. 8, Fig. 9 is obtained. In this case, the impulse wave travels in the coil, which acts only on the combination of condensers. However, during the travelling of this impulse wave, the wave front becomes flat. Hence the inductance of the coil has an influence upon the wave, and oscillation occurs.

The frequency at this boundary is nothing else than the critical frequency. Thus the critical frequency of coil exists in the coil of single layer winding. Hence, Wagner's theory is correct on the whole.

Next, the earth plate is placed under the coil, and the capacity between earth and coil is changed. In this case, if a fairly short impulse voltage is applied, the amplitude of the oscillation becomes larger but the aspects of the voltage distribution are the same generally speaking.

Next, open one end of the coil and apply the impulse voltage. In this case, the reflection occurs at the open end, and voltage distribution becomes as shown in Fig. 11.

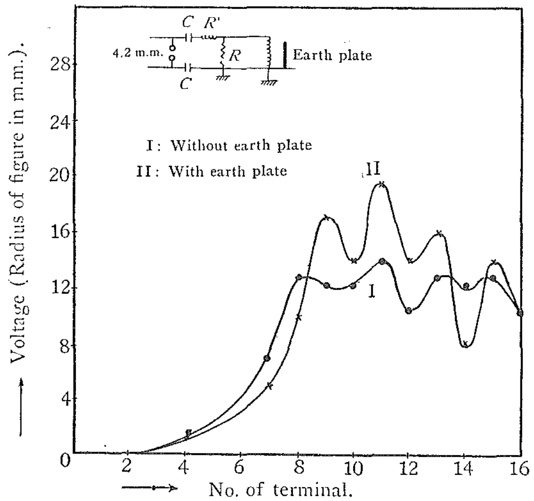


Fig. 10.

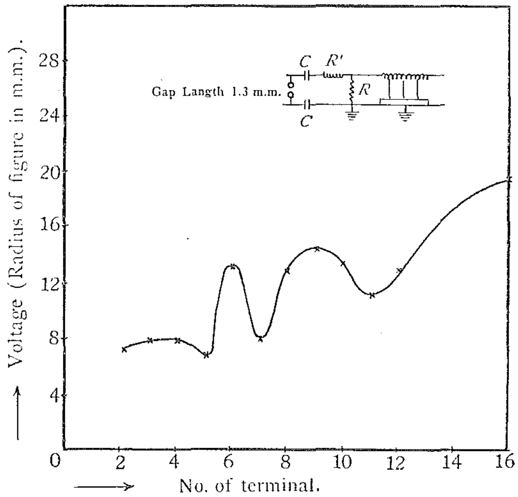


Fig. 11.

If a rectangular wave is applied, the potential at any position of the coil is shown by the equation

$$p_x = P\left[1 - 2\sum_{1}^{\infty} \frac{\sin b_x x \cos \beta_x t}{b_x l\{1+(b_x l)^2 \delta\}}\right]$$

In this case, also in general the correctness of Wagner's theory can be ascertained. In this experiment, the apparatus with which the surface charge figure is taken, has capacity. Hence, the insertion of this apparatus provokes the change of the condition of the circuit; i.e. error is introduced. Therefore, the support of the needle electrode is made from the plate insulator, and the use of metal in any part is avoided. Besides that, an attempt was made to reduce the number of errors introduced by other causes to as small a number as possible.

IV. Measurement of the Total Wave Form of Impulse Voltage.

Formerly, Dr. Binder[9] tried to measure the wave front of the impulse voltage by means of the sphere gap. In this method, he could only find out the wave front and could not obtain the tails of the wave. Using the surface charge figure instead of the sphere gap, there can be found out the total wave form of the impulse voltage, i.e., both the wave front and the wave tail.

If the impulse wave has such form as shown in Fig. 12, there is obtained the positive figure at the front side of the impulse wave (V_1), and the negative figure at the back side (V_2). Next, interchanging the terminals with each other, there is obtained the negative figure at the front side and the positive figure at the back side of the wave.

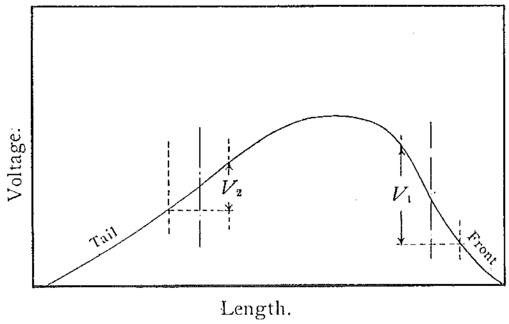


Fig. 12

In general, the size and shape of the surface charge figure are very different depending upon whether positive or negative voltage is used, also the size of the negative figure is very much smaller than that of the positive figure. Hence the voltage at the tail end of the wave can be measured (Fig. 13).

Fig. 14 is the wave form of the impulse voltage which is obtained from the connection as shown in Fig. 15.
When the spark gap is placed as a dotted line as in Fig. 15, the wave form as in Fig. 16 in obtained. (In Fig. 16, the end of the impulse wave becomes large, perhaps, this is due to the fact that Teopler's law is not correct in regard to the extreme end of the spark.)

9) E.T.Z. 1915; 1917, s. 381.

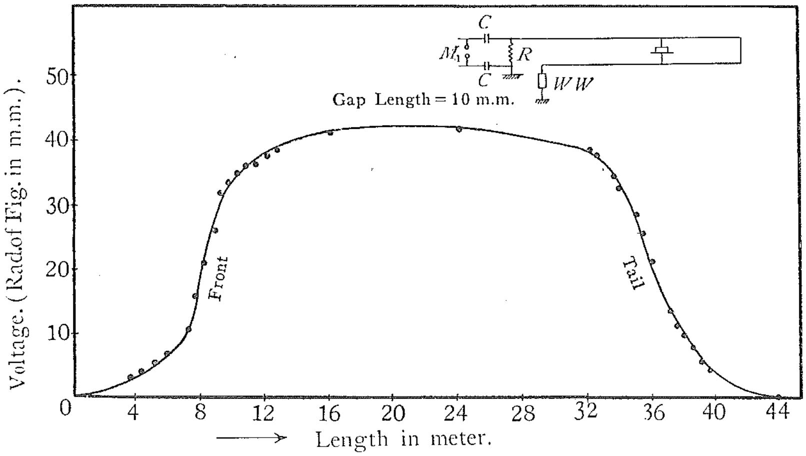
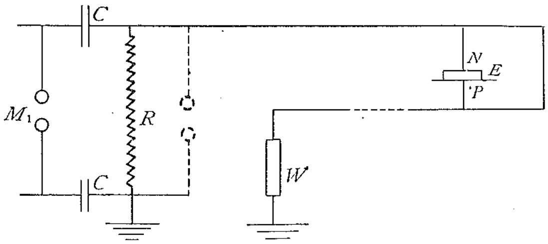


Fig. 14.



M_1: Sphere gap. C: Meirowsky Condenser.
R: Water Rheostat. W: Resistance (equivalent to Surge Impedance of line).
N-E-P: Apparatus for surface charge figure.

Fig. 15.

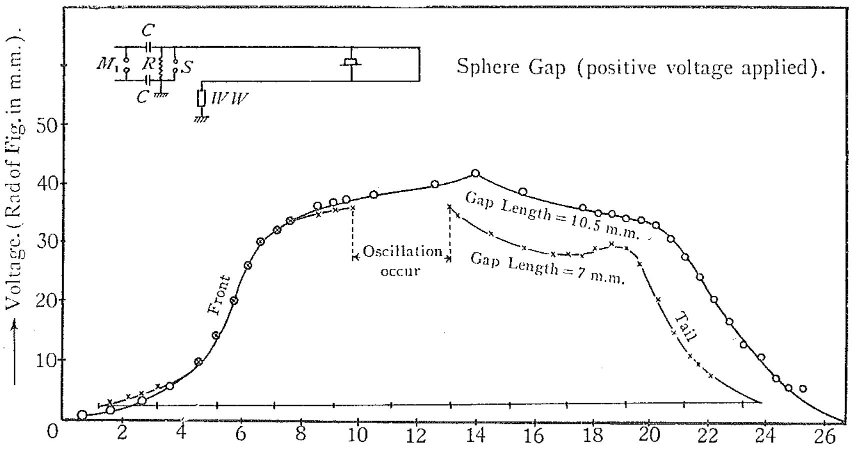


Fig. 16-1.

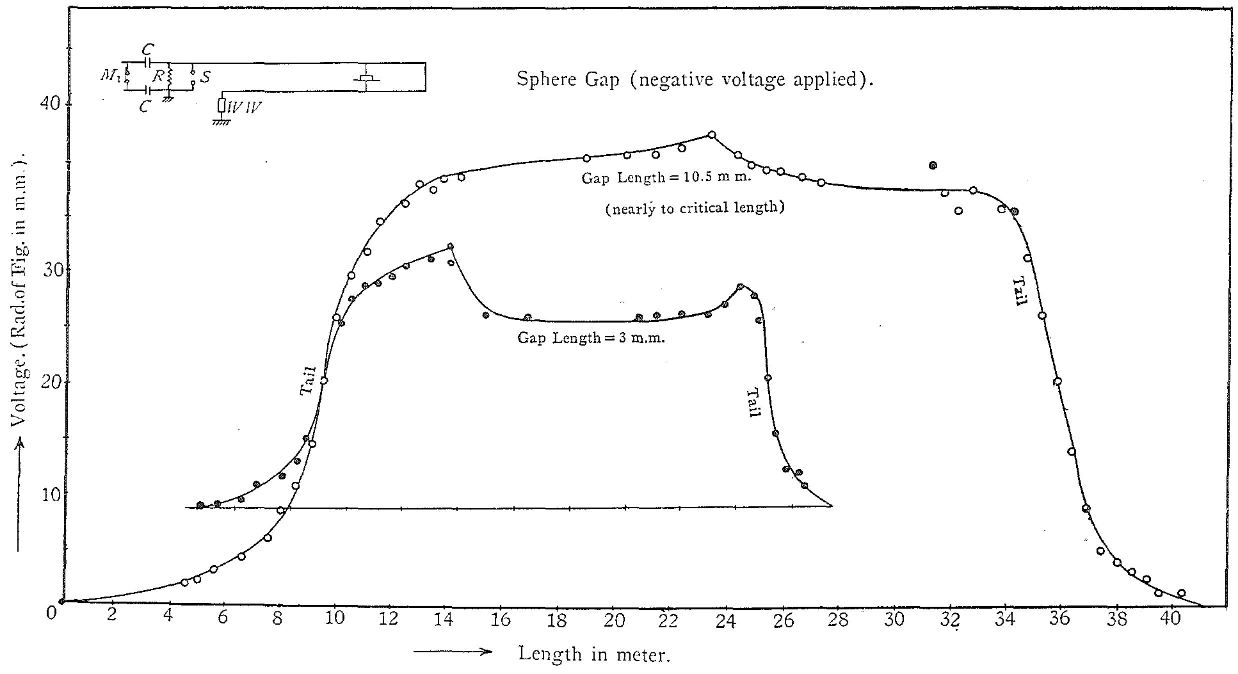
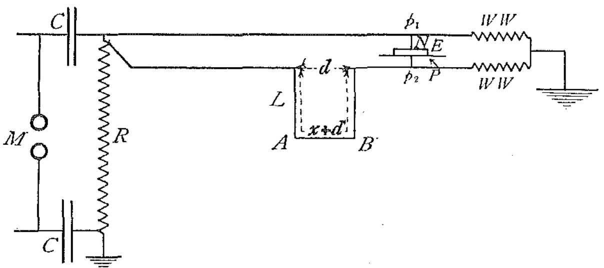

Sphere Gap (negative voltage applied).
Gap Length = 10.5 m m.
(nearly to critical length)
Gap Length = 3 m.m.
Tail
Tail
Tail
C
C
M_1
R
S
W W
Voltage. (Rad.of Fig. in m.m.).
Length in meter.
0
10
20
30
40
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40

Fig. 16-2.

V. Measurement of the Spark Lag.

On the spark lag, various theories and measuring methods have been presented up to date. The following method is one of the fairly accurate measuring methods of the spark lag.

In the connection of Fig. 17, the wire AB is slide on the Lecher wire (L) and the relation between the radius of the surface charge figure (V) and the length of the Lecher wire (x), or time ($T=x/3\times10^{10}$ sec.) is found out.



M: Main gap.
C: Meirowsky Condenser.
R: Water Rheostat.
L: Lecher wire.
AB: Slide wire.
N: Needle electrode.
E: Ebonite plate.
P: Plate Electrode.
WW: Resistance which is equivalent to Surge impedance of line.

Fig. 17.

Next there is substituted the gap to be tested for the Lecher wire, (as in Fig. 18) and the maximum voltage is measured in the same position as before (p_1 & p_2). (The apparatus for the surface charge figure is not moved during the experiment.)

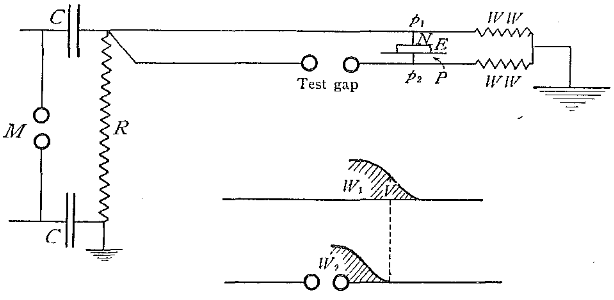


Fig. 18.

Hence there can be measured the time lag from the experiment with Lecher wire, i.e. from relation (V-T).

If it is necessary to measure the time lag accurately, we must find out the wave form of the two impulse waves W_1 and W_2, and trace the position in such a way that the voltage difference of the two impulse waves W_1 and W_2, will correspond to the voltage V.

The experimental results are the following. Fig. 19 shows the relation between the radius of the surface charge figure and the time lag, which is obtained by using the Lecher wire.

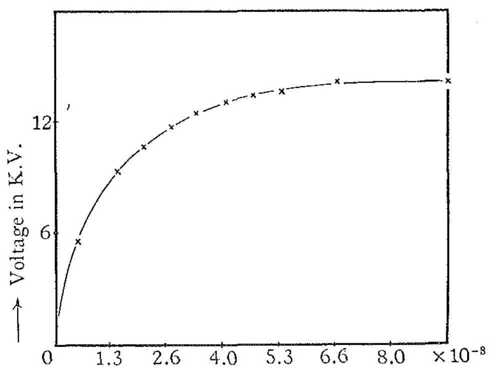


Fig. 19.

For the sphere gap, there were obtained the following experimental data.

Relative humidity 34%
Room temperature 18°C.
Diameter of sphere gap 19.4 m.m.
Max. voltage (2.8 cm. radius of figure) 8 K.V.

	Gap Length in m.m.	Time Lag in Seconds
Illuminated by mercury lamp (Distance between gap & lamp 7.5 cm.)	0.5	1.3×10^{-9}
	1.5	3.0×10^{-9}
	2.8	1.0×10^{-8}
	4.0	1.4×10^{-8}
	5.0	1.9×10^{-8}
Not illuminated by mercury lamp	1	2.5×10^{-8}
	2	5.3×10^{-8}
	3	10.0×10^{-8}

Plotting this data in curve, Fig. 20 is obtained.

This method is very well suited for the measurement of the time interval which is smaller than 10^{-7} sec. in order. But using the flat impulse voltage, this method is also accurate for the time lag which is larger than 10^{-7} sec. in order.

But, if it is necessary to test the spark gap of the larger time lag, it is better to compare this gap with the standard sphere gap which is tested by the method above mentioned. The connection diagram is shown in Fig. 21. In this case, it is necessary to know the wave form of each impulse waves (W_4 & W_4).

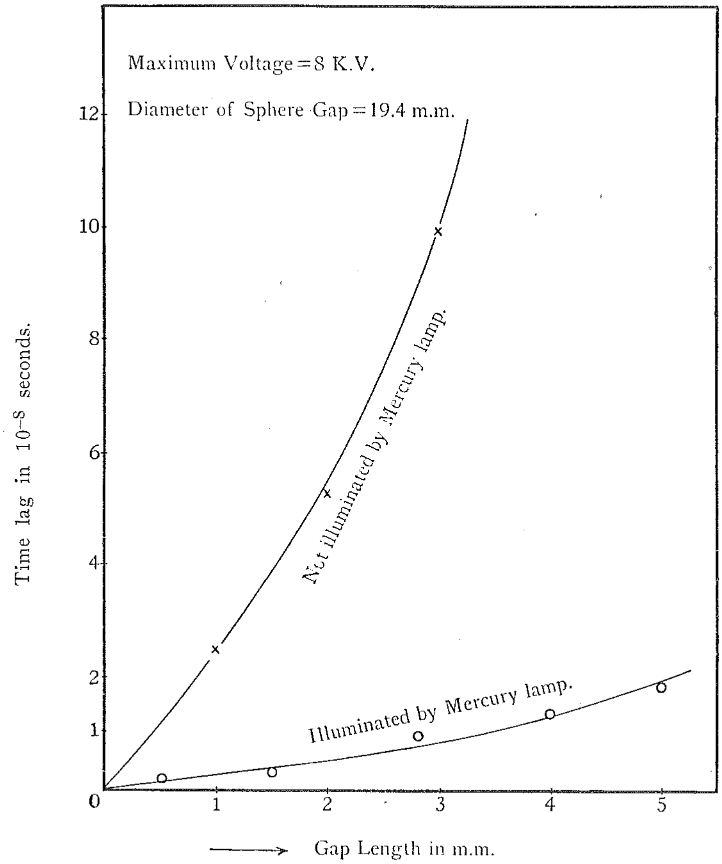


Fig. 20.

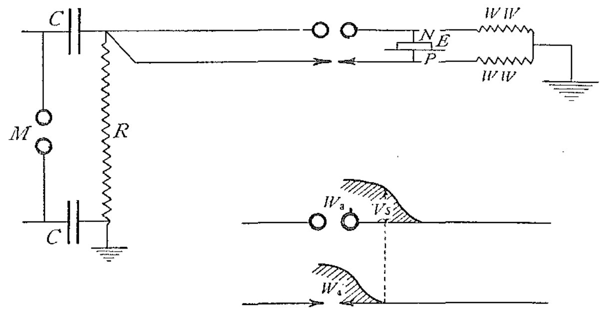


Fig. 21.

The comparison of this method with Pedersen's method[10] of measurement of spark lag is as follows.

(1) In Pedersen's case, the capacity of the electrode for obtaining the Lichtenberg's figure has an effect upon the sparkover voltage and spark lag of the gap to be tested, but in this case, the resistance *W W* has no effect upon the gap, because the resistance of *W W* is equal to the value of surge impedance.

(2) In the former case, the displacement of the intersection of two Lichtenberg's figures is an order of few m.m., but in the latter case, the diameter of the surface charge figure is up to 10 cm. or more. Therefore, this method is more accurate than Pedersen's.

VI. Conclusion.

For the study of impulse voltage, the surface charge figure is a great convenience. Because, when the sphere gap is used for the measurement of the impulse voltage, this gap needs some energy to spark over; and after this phenomena, the circuit is very disturbed. Besides that, the decision as to the maximum value of the impulse voltage is a troublesome task.

Therefore, in the study of the problem concerning the impulse voltage, the Lichtenberg's figure is a commendable instrument.

But, the ordinary Lichtenberg's figure is obtained with the photographic plate, therefore the complicated process of the photograph is necessary. But the process of obtaining the surface charge figure is very simple

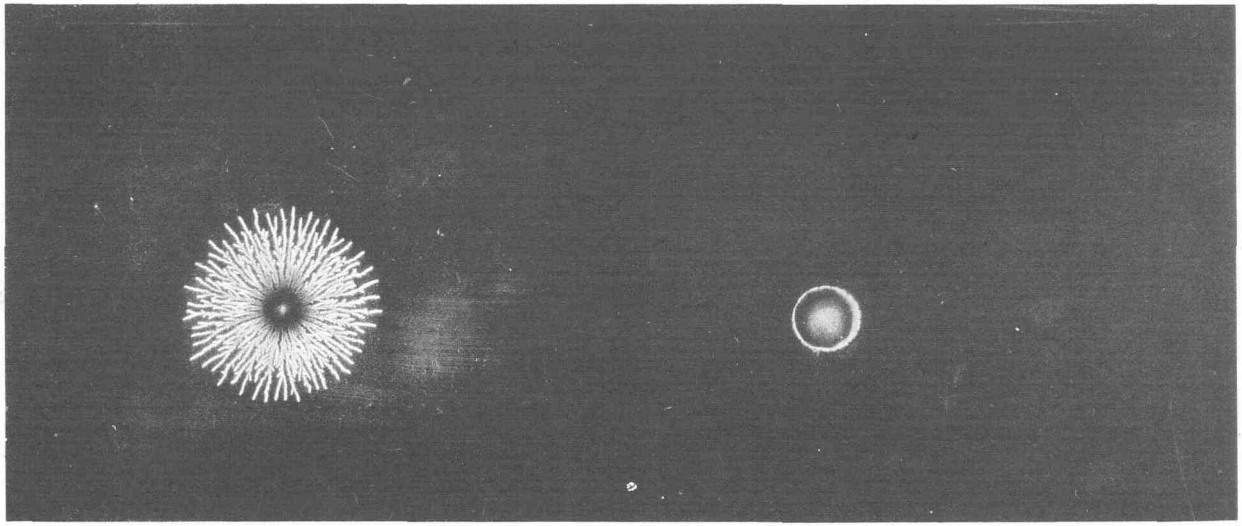
10) P. O. Pedersen, Ann. d. Phys. 71, 1923; 75, 1924.

and several dozens of figures per hour are easily obtained, and thus the aspect of the impulse voltage is found out immediately. If the ebonite plate is wiped with alcohol, a single sheet of ebonite plate can be used many times.

Hence the utilization of the surface charge figure is a very economical process.

The end.

Fig. 2.



Positive. Negative.

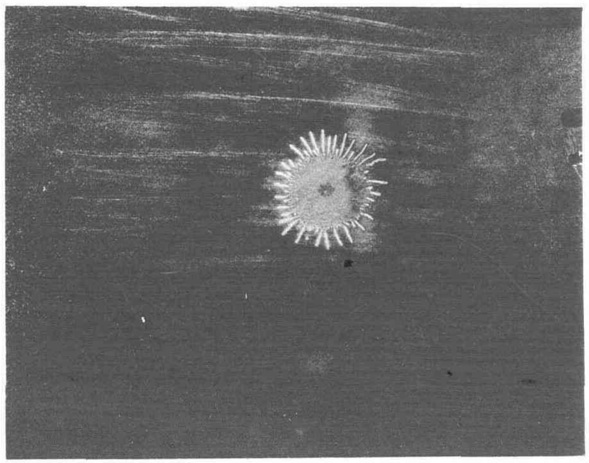


Fig. 3. Oscillatory impulse.

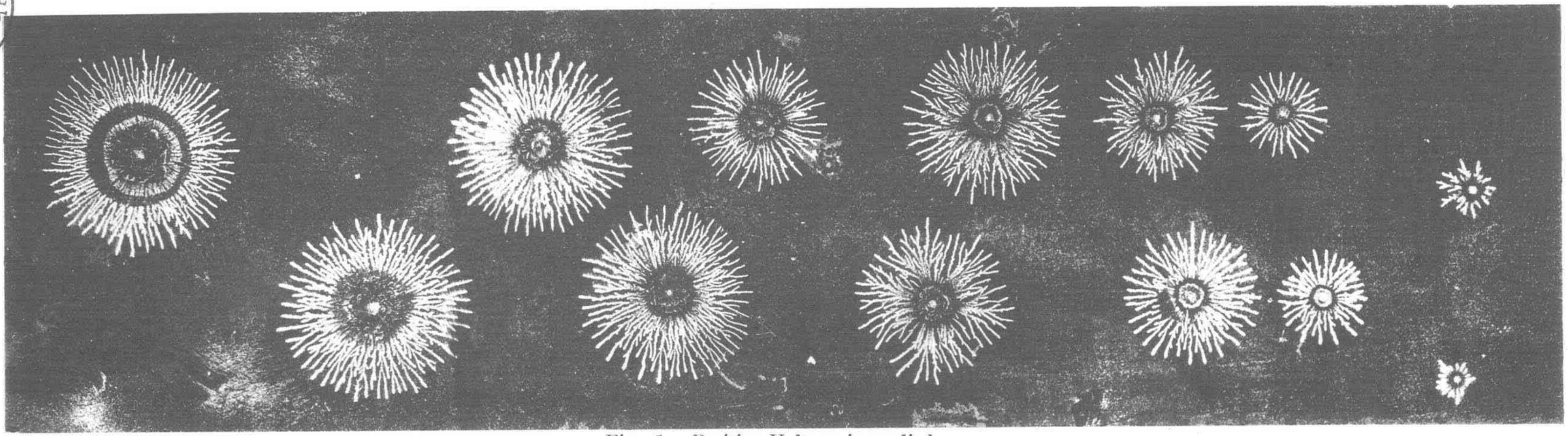


Fig. 5. Positive Voltage is applied.

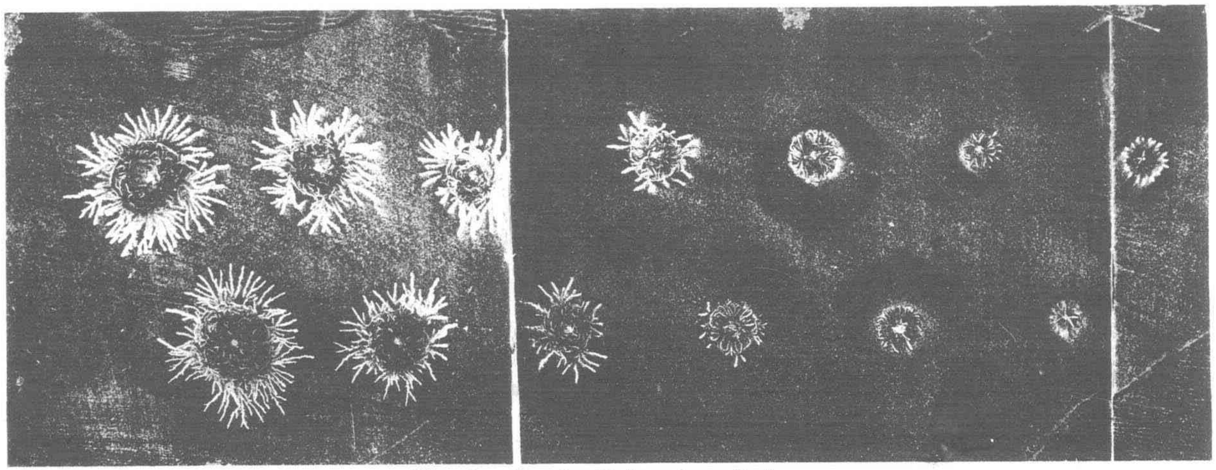


Fig. 6. Negative Voltage is applied.

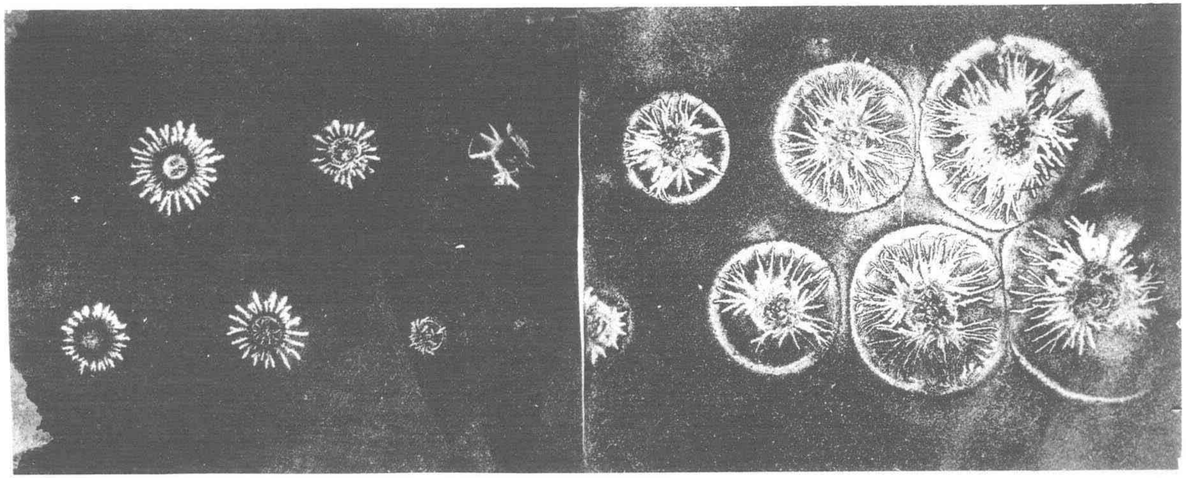


Fig. 8.

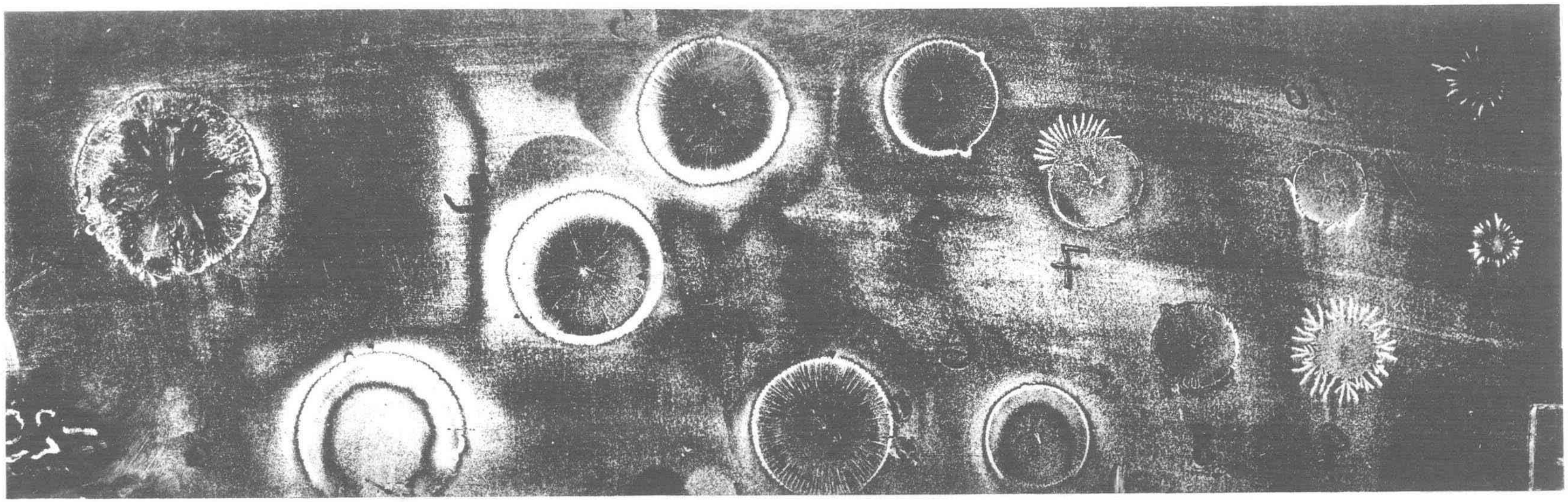
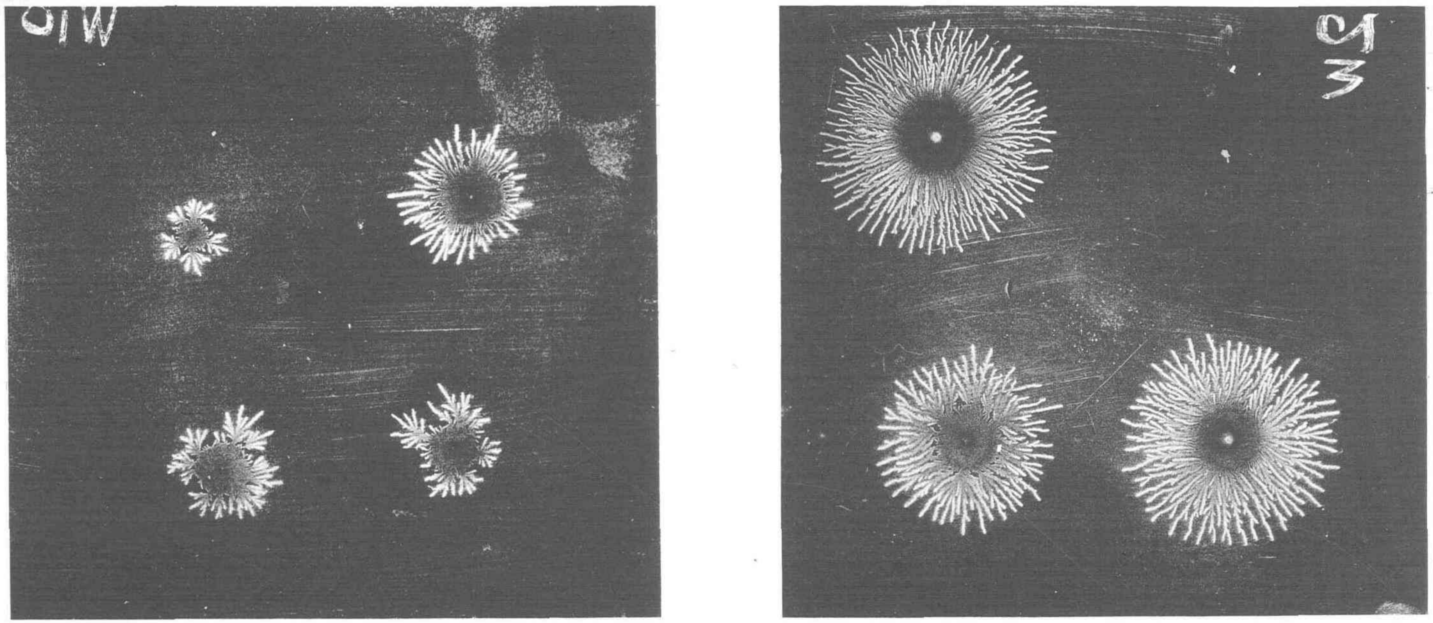


Fig. 9.

Fig. 13.



Combined figure of Positive and Negative figures.
(V_1 is negative, V_2 is positive.)