Electric Discharge in Inhomogeneous Field.

By

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Contents.

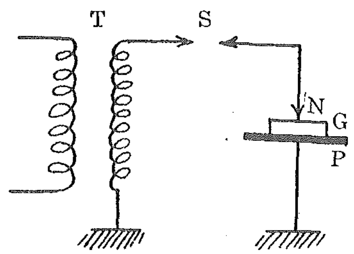
Abstract.

In this paper we describe these phenonena[1]; the occurrence of electric discharge in the inhomogeneous electric field between the needle and the plate electrodes[2], the rectification of high tension A.C. by means of asymmetric electrodes, and[3] the occurrence of a circular spark which is generated chiefly by means of a small needle spark gap inserted in series to the electric circuit.

To obtain the circular spark, the existence of a series spark gap is by all means necessary. We have found differences between the stage with and without the series gap. The current is rectified positively or negatively as the length of the series spark gap is varied, and the relation between the circular spark and the Lichtenberg figure has been discussed.

I. Introduction.

We put a glass plate between a needle and a plate electrode made of copper or brass, and insert a needle spark gap S in series to this apparatus. If we connect this circuit to the terminals of a high tension transformer as shown in Fig. 1, the glim discharge will start from the needle electrode and spread over the surface of the glass plate. With increasing voltage, however, a brilliant radial discharge will start from the needle electrode. If the area of the glass plate is sufficiently large, the spark may not reach the edge of the glass plate. The spark discharge will start radially from the needle electrode, and leaving the needle the discharge will form tree-like branches, the tips of which will fade away. Further, by increasing the voltage or the length of the spark gap, the number of these white sparks decrease and the sparks change into a violet discharge branching near the column of the spark. The discharge in this stage will become much more branchy than the previous discharge. If we increase the gap length further, the radial branches will gradually shorten and will become very branchy.



N ; needle electrode
G ; glass plate
P ; metal plate
T ; transformer (max. 40 KV)
S ; needle spark gap

Fig. 1.

Again by increasing the spark gap length further the branches will turn tangentially at a certain distance from the needle, and stretch to meet with one another, so that they will form a beautiful circular spark with the center at the needle electrode.

The process of producing the circular spark, which we have described before, seems to be simple, but it is necessary in practice to adjust the series gap S delicately from the stage where the violet brush discharge begins to branch in a tangent, to the stage where the circular sparks occur.

There is only one gap length at which the spark becomes circular, and even with a very small deviation, the from of the circular spark begins to get out of shape.

After this stage, as the gap is made longer, the number of tangential branches of the spark becomes less and less, and at last the discharge stretches radially and branches off.

With increasing the gap length still further, the discharge at the gap ceases so long as the voltage is the same as before.

The needle electrode N used in this experiment, is an ordinary sewing needle. Its tip should be sharp as possible, for if we use a needle whose tip has become dull or torn off by using several times, we can not secure a perfect circle. At the same time, as stated later, it is necessary that the contact between the glass plate and the metallic electrode beneath it is sound, so there must not exist any clearance between them. The material of the plate electrode (copper or brass) has no effect on the phenomena, but it is proper that the electrode be polished as brightly as possible, like a mirror. In order that the contact between the upper glass plate and the plate electrode should be sound, it is preferable to use ordinary thin tin-foil inserted between them. Fig. 2 shows a circular spark on the glass plate by means of a photograph taken from the side of the needle electrode. Fig. 3 shows a state where the circular spark is perfect.

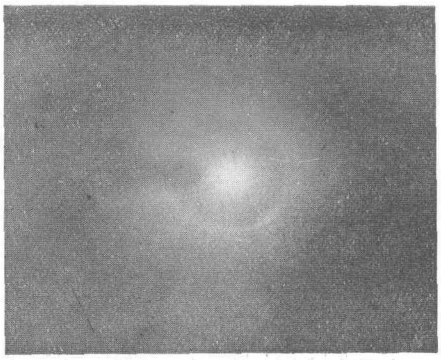


Fig. 2.

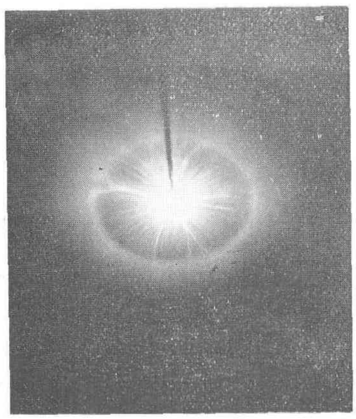


Fig. 3.

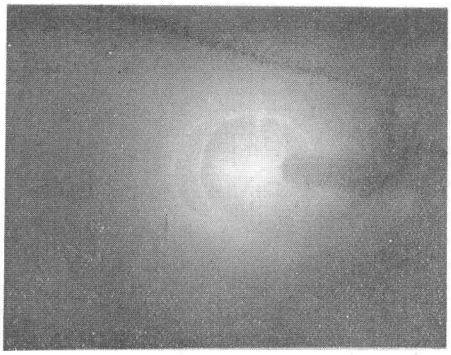


Fig. 4.

In Fig. 4 there exist double circles whose centers are different from each other, one of which is the image reflected by the surface of the plate electrode. Fig. 6 shows the stage where we can not gain a perfect circle in consequence of the fact that the contact of the lower side of glass plate is imperfect.

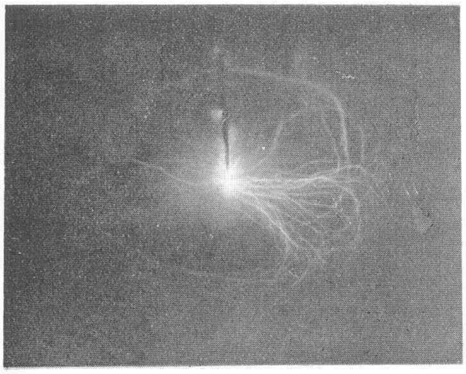


Fig. 5.

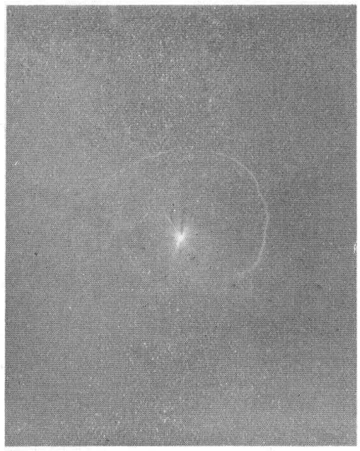


Fig. 6.

II. The method of showing the trace of the circular spark by means of fine powder.

As the circular spark, of course, is visible, so by bringing the photographic camera close, we can get a satisfactory photograph in a moment, but it is dangerous to install a camera too near to the high voltage.

On the other hand, it is inconvenient to set the camera vertically with the glass plate placed horizontally, and also if one uses this method, the diameters can not be measured by scale directly. In preceding studies where we set the camera vertically at a certain distance from the plate, the actual diameters of the circles are deduced from the diameters of the circles on the photographic plates. But now, we have found a more convenient method as follows. If we switch out the electric circuit after the discharge, allow the transformer oil to flow on it, and leave the plate for a little while, the trace of the circular spark becomes apparent. Accompanying this circle, traces of radial spark appear from the needle tip to the circle.

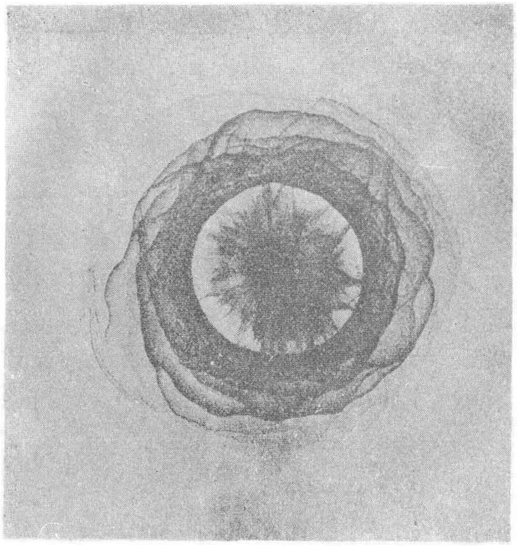


Fig. 7.

This method is convenient for measuring the diameter, but a photograph can not easily be taken. Therefore, we adopted the following method. After a circular spark discharge has been kept for several minutes, we switch out the voltage, sprinkle fine nickel-ammonium sulphate powder on the surface of the plate, remove the upper layer of the powder by tapping it on the floor two or three times vertically, and thus get a figure such as that shown in Fig. 7.

From Fig. 7, one knows how frequently the circular spark discharges occur and the stability the inside circle. In the preceding papers we reported that if we used glass of a certain thickness and regulated the length of the series gap and the voltage of the electric source, we obtained only one circular sparking discharge. But really at the same voltage as before and at a very small length of gap S, another circle consisting of a single spark was obtained. This spark leaves a circular trace which surrounds the boundary of the disc-formed positive brush discharges radiated from the needle electrode.

By more exact observations, we know that the discharge starts radially from the needle electrode as the center, and separates right and left at the boundary of the circle of the corona-discharge and turns round. However, this discharge is different from that shown in Fig. 3, and is rarely perfectly circular. This circle is larger than the circle given in Fig. 3, and corresponds to the outer circle of Fig. 7.

Next, keeping the electric source constant, we increased the length of the series gap gradually from zero over the stage where we obtained the first imperfect larger circle, until we obtained a perfect violet discharge. Thereafter if we switch out and sprinkle on the fine powder, we obtain besides these large and small circles another larger circle having a vague boundary enclosing the two circles. Though we experimented several times, we always obtained these three circles similarly.

This outer larger circle is invisible, during the discharge, but the case is not clear. Judging from figures obtained by fine powder, we can generally classify the sparks in three circles. However, of these circles, the smallest is mainly considered as the circular spark. Fig. 5 shows the imperfect circle occurring with the small gap length.

III. Stroboscopic observation.

If we use a shutter rotating at a synchronous speed with the frequency of the electric source of 60 cycles per sec., we can observe the instantaneous positive or negative phenomenon upon the glass plate separately. It is interesting to observe the circular spark with this apparatus. We rotate the disc having two sectors by means of a single phase synchronous motor coupled mechanically with a direct current shunt motor. At the speed of 1800 r. p. m., we cause the phenomenon to be seen through the sectors stroboscopically. Then, having previously selected the two positions through which the positive phenomenon of the needle electrode alone or negative phenomenon alone can be seen, we will call them the positive and negative sides respectively. Next, adjusting the series spark gap we observe the discharge phenomena by using this apparatus.

Now, if we gradually increase the width of the series spark gap from zero and keep the voltage of the source constant, we can observe a stage where the needle electrode is always negative.

When the length of the series spark gap is zero or extremely small, a brilliant single spark starts from the needle tip, along only one direction, then separates right and left and goes around along a circle which corresponds to the boundary of the positive glim disc seen from the positive side.

When we observe the positive side of the sparking, a violet and disc-formed glim discharge only occurrs, and sometimes violet positive sparks having tree-shaped branches start from one or more points. These tree-shaped positive discharges start at the moment when the voltage is too high, but while the voltage is low, a corona alone appears. At the same time, along the leading wire between the needle electrode and the electric source, there appeared a negative corona which looks like a train of rain drops, just as occurred when the leading wire is negatively charged. It seems that the phenomenon is caused by the rise of voltage of the negative side and happens because the negative current is choked while the positive impulse current flows intermittently. Further, if we slightly enlarge the series gap, the glim discharge occurs in the positive side similarly as before, but the positive spark appears no more and the negative corona appears still on the leading wire.

In this stage, as stated precisely later, the current is almost rectified positively. At the negative side there exist no evident peculiarities, but the brilliant sparks become more luminous and more numerous. Further, if the series gap is shortened gradually and slowly, then the circular spark appears. At the positive side, a somewhat reddish glim discharge starts intermittently from the needle tip, and narrow positive brush discharges start impulsively from the needle. However, if a circular spark is obtained as a perfect circle by adjusting the series gap, these impulsive sparks are extinguished.

At this stage, a perfect circular spark consisting of a violet brush discharge occurs at the negative side, while a positive corona glows luminously, looking as if water were poured on the leading wire. On the other hand, when the positive rectification occurs, it looks as if rain drops were hanging along the leading wire. At this stage, the polarity of the current changes. From these facts, one may insist that the circular spark occurs quite at the negative side of the needle. In order to study whether the circular spark depends solely on the negative voltage, we have used a kenotron and charged the needle negatively, and thus have obtained a much more beautiful perfect circle than the one obtained by alternating voltage. Consequently we know that the positive voltage does not take any part in this phenomenon.

In the next place, if we enlarge the series gap further, the negative brush bending tangentially, tends to turn radially, and at its tip we can observe a brush phenomena similar to the streamers of the Lichtenberg negative figure.

It seems that, so far as the negative brush discharge is concerned, the above described discharge phenomenon is the same one which was described by Toepler(4) and considered by him to be due to the so-called "degree of rise of impulsive voltage." It is not sure, however, whether the degree of rise of the impulsive voltage in the present discharge coincides quantitively with that given by him, or not. Roughly speaking, we can conclude from the oscillogram that at the stage where the spark of the brush discharge bends tangentially from its primary radial direction, the degree of the voltage-rise gradually falls, and the number of impulse voltage during negative half cycle increases. Next, the radius of the circular spark discharges coincides exactly with the values of "L_0," given[5] by Toepler.

The relations between the thickness of glass plates, the diameter of circular sparks and the terminal voltage are experimentally given in the following Table I, and the relations between the diameter of the circle and the voltage drop at the glass plate are shown in Fig. 8. Fig. 8a and Fig. 8b shows the figures on the positive and negative sides obtained stroboscopically.

TABLE I.

Thickness of glass plate in mm	Series gap in mm	Voltage in KV	Circular Spark dia. in mm	Great circle when rect. carr. max.	Ampere.
1.6 mm	9–10 mm	29	26.5		0.16–0.15
,,	0.5 mm	34.4		56.5	0.12
1.67	10.5 mm	26	26.75		0.75
1.81	13.5 mm	27.5	33.5		0.6
,,	3.5	33 KV		50	,,
2.08	17.	34	36.9		0.5
,,	0.6	42.5		51.75	0.72
3.14	14.5	34.3	42.8		0.63
,,	1.25	40		37.75	0.64
3.66	14.5	40	46		0.93
,,	8.5	,,		50.75	0.95
3.92	16.25	40	45.75		0.92
,,	12.	45		39	0.67
4.13	16.50	45	47.5		0.9
,,	5	47.5		79	0.93
6.30					
,,	2.5	50		89	0.66

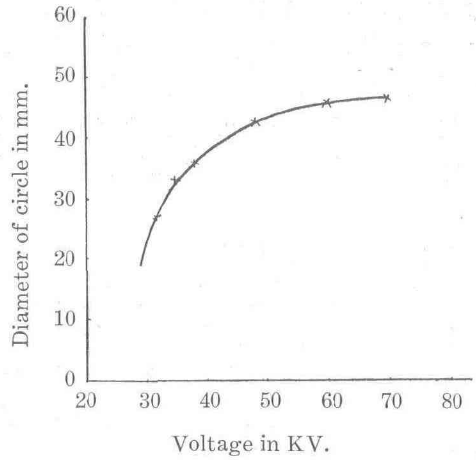
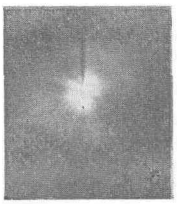


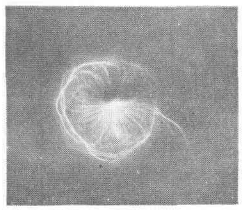
Fig. 8.

A



Positive

B

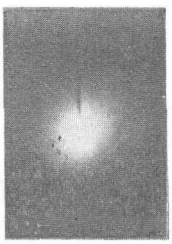


Negative.

Series gap length 14 mm.

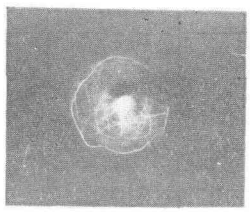
Fig. 8a.

C



Positive.

D



Negative.

Series gap length 4 mm.

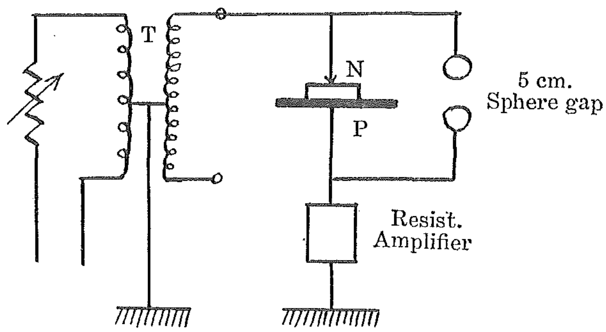
Fig. 8b.

For measuring the voltage, we used two spheres of 5 cm dia., one of which was earthed.

IV. The case where no series spark gap is contained in the circuit.

It seems that the presence of a series gap is a necessary condition, in order to obtain a circular spark.[9]

It seems necessary to study experimentally what characteristics of the circuit containing a glass plate exist in the circuit without a series spark gap and how the presence of a spark gap varies the characteristics of the circuit. For this purpose, we used the connection, shown in Fig. 9 and investigated the relation between the

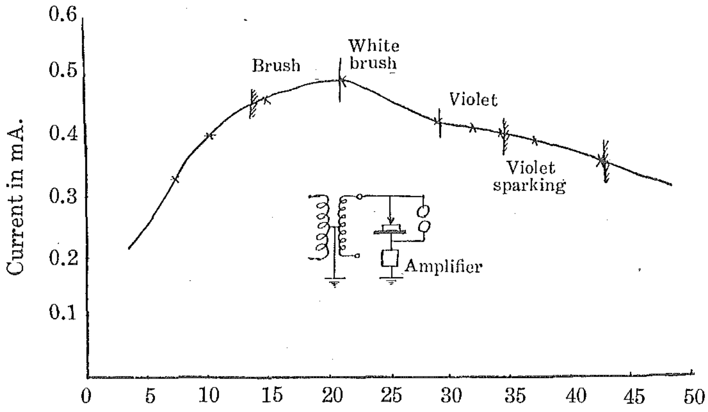


T ; transformer (max. 40 KV)

Fig. 9.

voltage at a glass plate and the current through it. As the current through the glass plate is very small and contains waves of steep and high frequency, it is desireable to measure the current with the thermo-ammeter, but nothing was at hand unfortunately. Therefore, using an Abraham's resistance-amplifier made by Carpentier Co. and amplifying the current by one stage only, we could read the relative length of the current with the milliameter. Fig. 10 is obtained, when the voltage is gradually raised using a 40 KV transformer and a 1.6 mm. glass plate.

From the stage where the corona does not start from the needle electrode, the current increases gradually with the increasing of the applied voltage.



Voltage between plate and needle in KV.
R. H. 86% Temp. 18°C.

Fig. 10.

If we increase the current further, till its maximum value is reached, then a single brilliant spark occurs intermittently from the needle.

This stage corresponds exactly to the larger circle described previously. Raising the voltage further, we obtain a brilliant spark discharge starting from the needle in all directions, but it is remarkable that the current decreases.

The discharge sound becomes louder and louder with the increase in voltage. Raising the voltage still further, we observe that the violet sparks start towards the boundary of the glass plate and bridge over the electrodes, but the current decreases very much.

We carried out a similar experiment, varying the thickness of the plate and the voltage of the source, and obtained the relation shown in Fig. 11. When the loud spark discharge marches towards the boundary of the plate, the same as before, the current became less, and when a single spark stretches further, beyond the glowing part sorrounding the glim discharge around the needle, the current reaches its max. value, thereafter decreasing slowly and gradually with the increasing voltage.

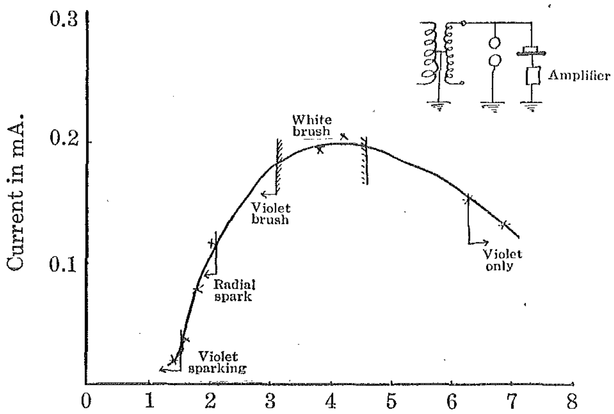
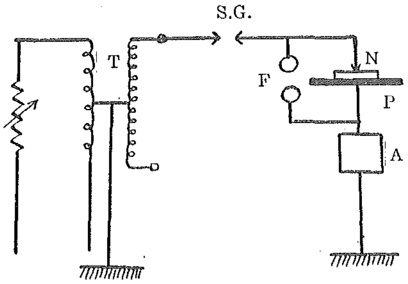


Fig. 11.

V. The circuit containing a series gap.

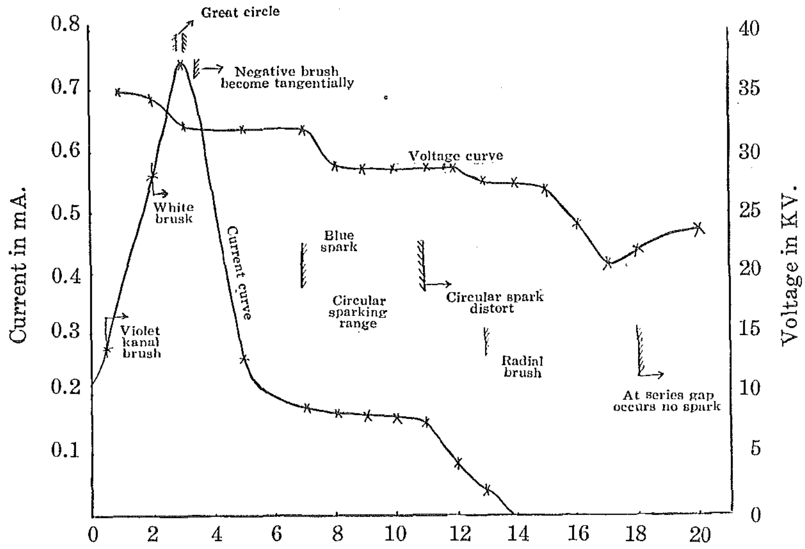
Inserting a spark gap only in series with the glass plate in the apparatus, as shown in the previous figure, we repeated similar experiments, keeping the voltage of the secondary side of the transformer constant by varying the width of the series spark gap. In order to obtain a circular spark, this method is more convenient than the method of varying the voltage directly.

Using the apparatus shown in Fig. 12, we have obtained the relation shown in Fig. 13. In this case, the phenomenon is nearly



S. G. Series gap.
A. Amplifier.

Fig. 12.



Glass plate 1.6 mm. in thickness. Dia. of circle 2.65 cm.
Const. terminal voltage 35 K.V. Great circle 5.55 cm.

Series gap length in mm.

Fig. 13.

the same as in the former experiments. At the gap length of about 3 mm., a positive corona starts from the tip of the needle, and a single negative radial spark starts intermittently.

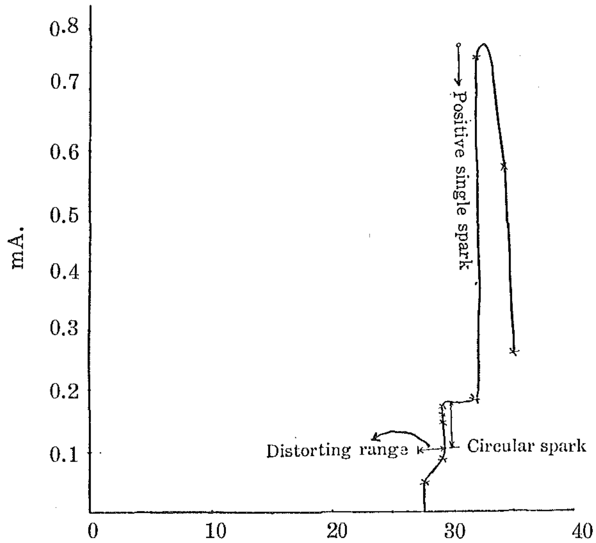
When the current attains its maximum value, the spark separates right and left at the boundary of the disc-formed corona discharge and goes round to form a circle. With a further gap increase, a violet spark starts, but the current decreases suddenly. After this stage, a weak violet brush occurs besides the brush discharge above mentioned.

Owing to the small capacity of the transformer used, the colour of the brush was violet.

Later a high tension transformer of 15 K.V.A. was used, then the brush discharge did not become violet, but an ordinary brilliant brush discharge occurred. As this brilliant brush is composed generally of more narrow canals than a positive one, and the aspect of the branches is similar to the Lichtenberg figure, we could easily judge these to be nothing but a negative brush. Further, adjusting the gap S, the positive brush disappears gradually and we obtain the negative brush discharge only, but hereafter the current and the voltage remain nearly the same during a certain range of variation in the gap length.

Next, enlarging the gap still further, the negative brush branches tangentially, the circular spark is obtained, and then the circle begins to go out of shape, the current decreases suddenly, reaching lastly its minimum value. The voltage changes in manner similar to the current. The relation between the voltage and current is shown in Fig. 14. The circular spark appears during the range of the gap length where the voltage is constant and the current is from about 0.07 mA. to 0.16 mA.

Delicate regulation of the series gap is especially important for obtaining a fine circular spark.



Total voltage 35 KV. Dia. of circle 2.65 cm.

Voltage between plate and needle in mm.

Fig. 14.

In Fig. 14 the circular spark appears near 27 KV., where the current amounts to about 0.125 mA. But in Fig. 10, the brilliant spark has already disappeared at 27 KV., and the violet brush discharge is going to start. At this stage the current amounts to about 0.42 mA. Comparing Fig. 10 with Fig. 14, one sees that in the former case, voltage and current change continuously and slowly, but in the latter case they change very sharply. This difference is due to the fact that the voltage becomes impulsive and some amount of charge remains on the surface of the glass for the later.

We may find the fact that there is a space charge on the glass plate.

We may consider that some charge remains on the glass plate oon after the individual discharges, though never for a long time as in the case of ebonite plate.

VI. Rectifying phenomena.

According to Toepler,[21] [22] [23] if the "Glimmanfangsspannung" differs from the "Funkenspannung," the spark discharge voltages are generally lower in the case where the needle is positive, than where the needle is negative. Contrary to this, if the former two "Spannungen" are the same, the spark discharge voltages are lower in the case where the needle is negative than in the other case. These relations hold even if we apply D.C., impulse, or A.C. voltage to the spark gap consisting of needle and plate electrodes.

Now, in order to investigate how the current rectified by adjusting the series spark gap, we have experimented with the connection, shown in Fig. 15, in which for measuring the direct current, we insert a D.C. galvanometer whose natural frequency is sufficiently large.

Now, using a glass plate of 1.6 mm. thickness and applying a voltage of 29 KV. as the electric source, we investigate the spark discharge by gradually increasing the length of series spark gap

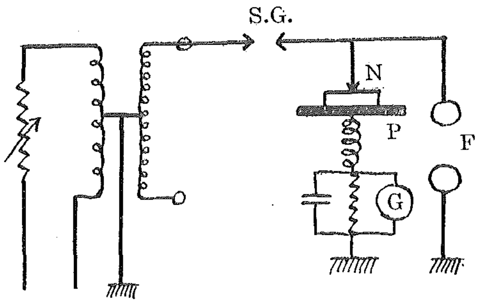


Fig. 15.

from zero. As far from the zero of needle gap length, the rectified amount become larger and larger till it reaches the max. value. Thereafter, the increase of gap length causes the negative brush to change suddenly violet.

After this stage, the current is rectified at the negative sign so rapidly that the deflection of the galvanometer becomes out of scale at that moment. It seems that the rectification becomes most active and stable. At this moment the circular sparking phenomenon occurs.

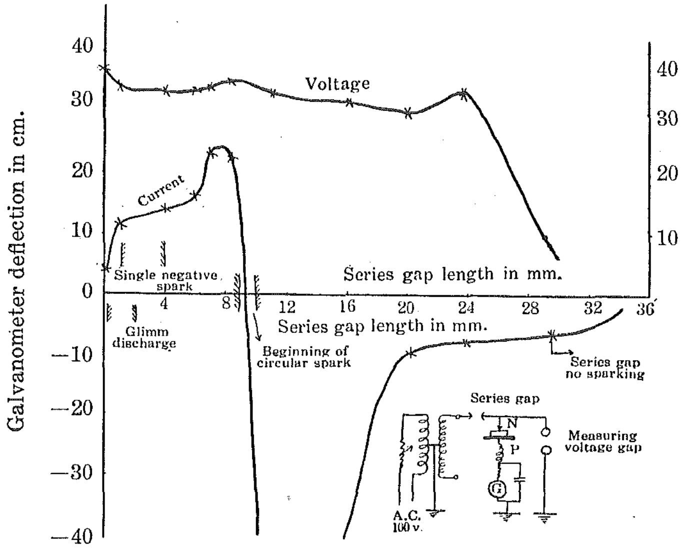


Fig. 16.

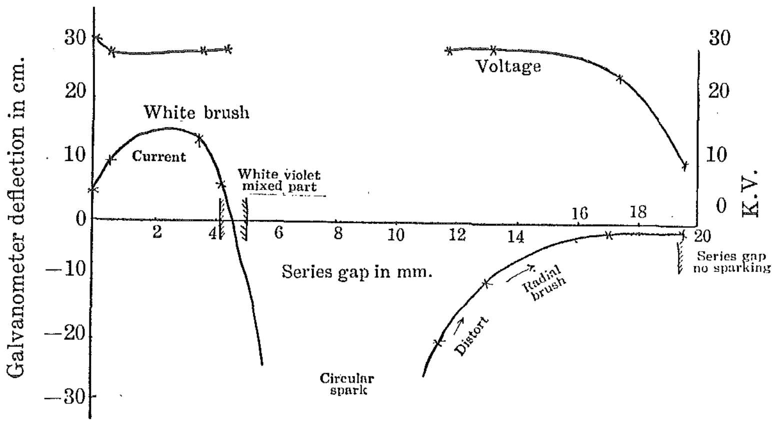
The gap in this stage where the current changes from positive to negative, as shown in Fig. 16, was about 5 mm. in length.

The negative brush tends to be stable with increase in the degree of rectification, though initially the brush discharge pushes out tangentially. In the moment where the maximum rectification takes place, the circular spark occurs. Thereafter, the increase of series gap causes the radial discharge again, and the current decreases gradually.

By increasing the gap length further, the spark at the gap hardly starts and it is not evident whether the rectification is positive or negative.

Next, using a glass plate of 3.14 mm. thickness, we performed similar experiments obtaining the results illustrated in Fig. 17. In this case using the thick glass plate, we must raise the voltage of source correspondingly. At the spark gap about 10 mm. in length the rectification changes from positive as shown in Fig. 17.

Further, making use of the connection shown in Fig. 18, we make the secondary voltage steep by inserting 50 ohms in the primary of the transformer (150 KV.) and by inserting an inductive



Thickness of glass plate 3.14 mm.
Constant terminal voltage 37 K.V.

Fig. 17.

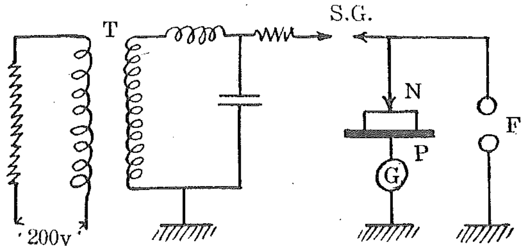
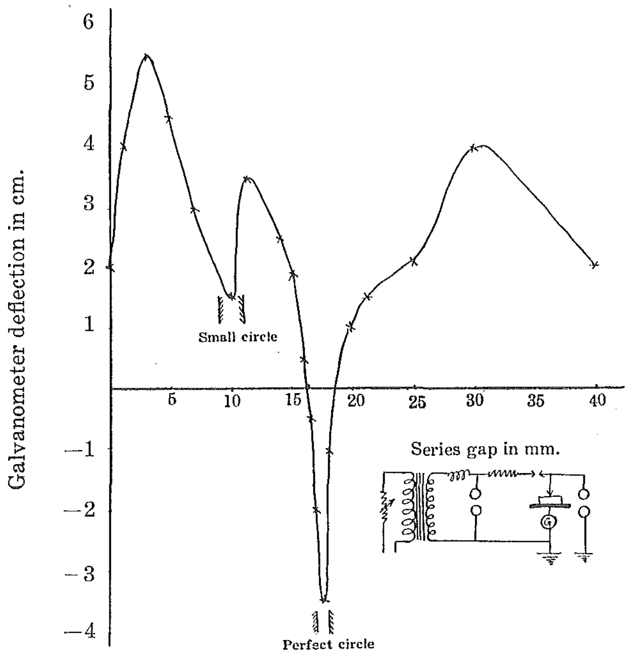


Fig. 18.

coil in series and spheres 25 cm. dia. in parallel as electrostatic capacity. The results are shown in Fig. 19. In this case, the range of the gap where the current is positively rectified, is wide and the quantity of rectification is also large compared with the former experiment.



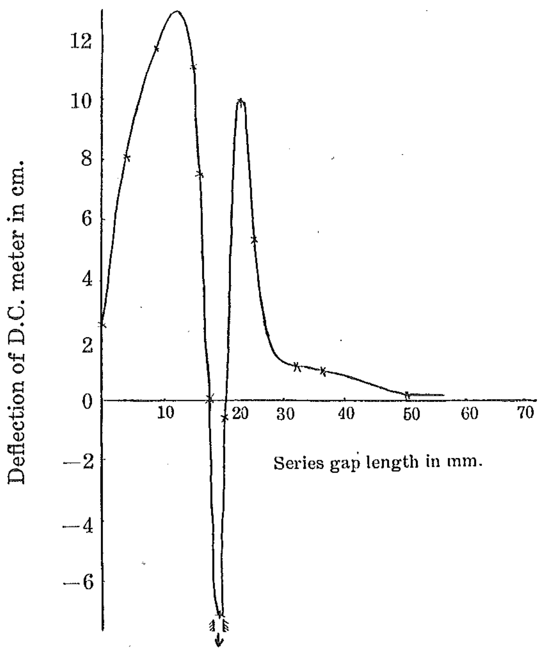
Total voltage 41.5 K.V.
Glass plate 3.2 mm. in thickness.
Shunt resistance 10. ohms.

Fig. 19.

The stage where the sign of the rectification becomes negative happens when the gap length lies between 16 and 19 mm. This range is narrower than in the former experiment.

In the stage where the negative rectification is at its maximum the circular spark takes place, too, but it is observed that the form of the spark is not perfectly circular. Indeed, by the stroboscopic method, we can observe that in this stage the positive brush discharge develops much more than the former case.

Similarly the results obtained using a glass plate of 4.5 mm. thickness, are given in Figs. 20 and 21.



Glass plate 4.5 mm. in thickness.
Total voltage 46.5 K.V.
Shunt resistance 10 ohms.
Perfect circular spark.
Terminal voltage 41.5 K.V.

Fig. 20.

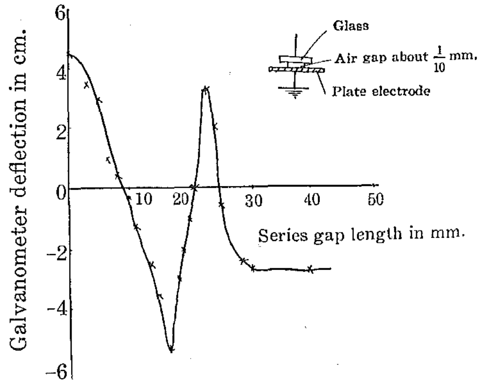


Fig. 21.

In the former case, the current is rectified negatively in an 18—20 mm. range of gap length, but when an air layer exists, the range becomes larger, that is, the effective range of gap length is 10 mm.—20 mm. Furthermore the presence of the air film makes the circular spark imperfect and generally irregular.

The experiments suggest, that there exists a close relation between the negative rectification and the circular sparking phenomenon. Further, one may conclude from the experiments using the connection in Fig. 18 that the impulse voltage is necessary for causing these two phenomena.

VII. Oscillographic observations.

Now we use a glass plate 4.5 mm. in thickness and insert a tin-foil between the glass plate and plate electrode, to get close contact. The currents and the voltages are measured as we vary the length of the series gap.

As the voltage to be applied to the element of the oscillograph for measuring the voltage wave, we adopt the voltage of one part of the electro-static capacities connected in parallel with the terminals of the glass plate as shown in Fig. 22.

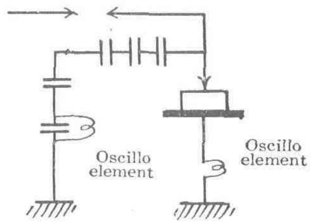


Fig. 22.

At zero width or near zero of the series gap, as stated before, the current rectified positively, but from oscillograms as shown in Figs. 23 and 24, we find that the current flows intermittently only in a small part of each cycle. The voltage-time curve is somewhat sinsoidal as shown in Fig. 25 where the spark gap is 18 mm. in length.

The sine wave in the oscillogram gives both time range and polarity (positive or negative). When the circular spark begins to appear with a certain width of the spark gap, the impulse currents are larger and larger and more numerous than those obtained at zero gap length. The first impulse is larger than the following ones and the series of three impulses is repeated at each cycle.

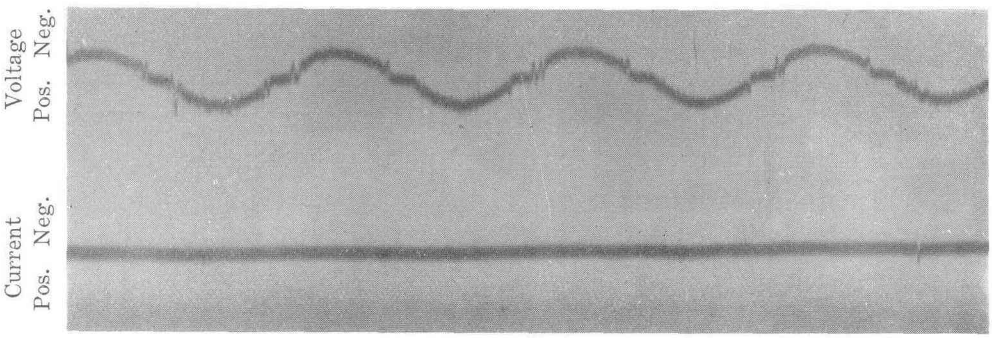


Fig. 23. ×3/2

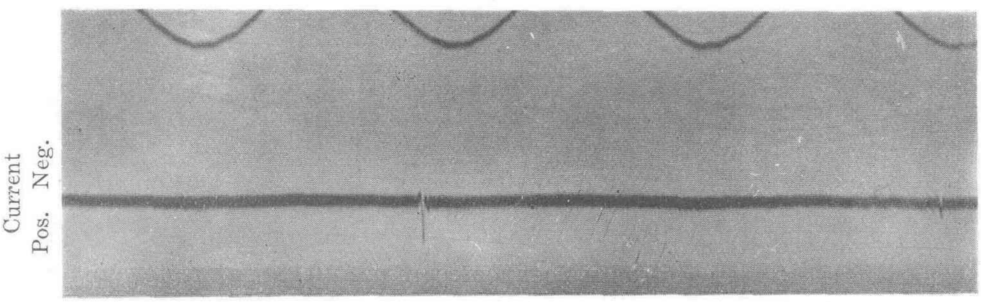


Fig. 24. ×3/2

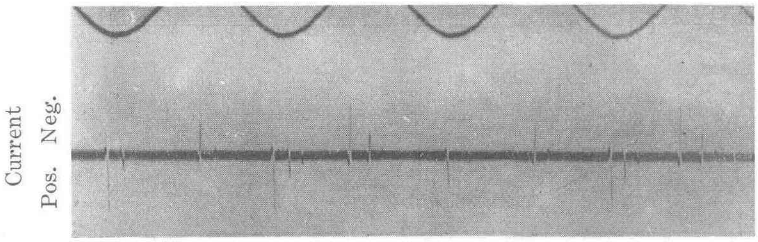


Fig. 25. ×3/2

The magnitudes of both positive and negative impulses are nearly equal.

If we suppose that some charge remains in the last stage of the cycle and is to be neutralised by charges of opposite sign due to the head of the following cycle, then it is reasonable that the voltage in phases are depressed and that a large amount of current is following at the beginning of the cycle (as the neutralizing current).

Fig. 26 shows the current where the perfect circular spark appears. In each half cycle appear two impulsive currents, the negative impulsive currents being much larger than the positive ones.

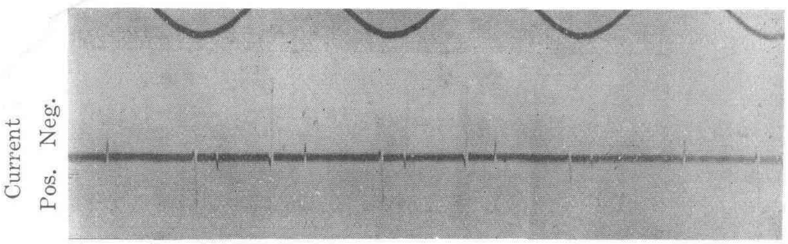


Fig. 26. ×3/2

Fig. 27 shows the voltage and current simultaneously.

We insert the electrostatic capacity in parallel between the needle and plate electrodes in order to measure the voltage wave, but the circular spark is somewhat distorted. The voltage wave is quite distorted and has many impulse waves successively.

Figs. 28 and 29 show the voltage and current where the length S is 19 mm.

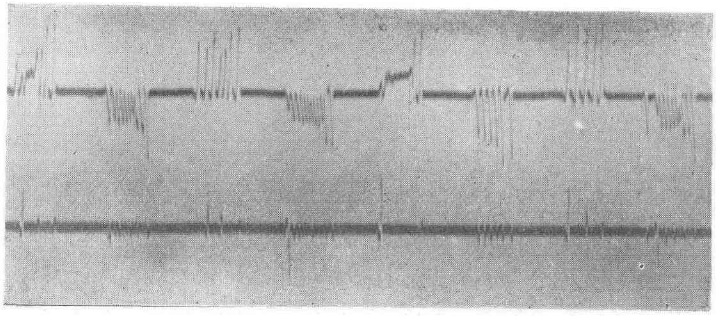


Fig. 27. ×3/2

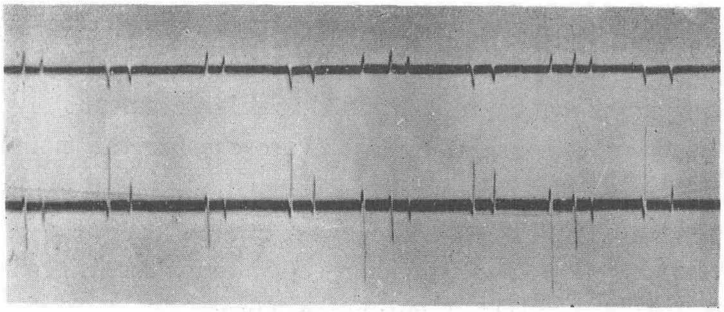


Fig. 28. ×3/2

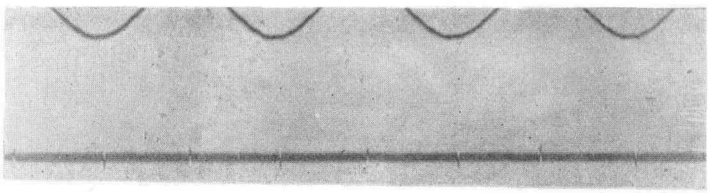


Fig. 29. ×3/2

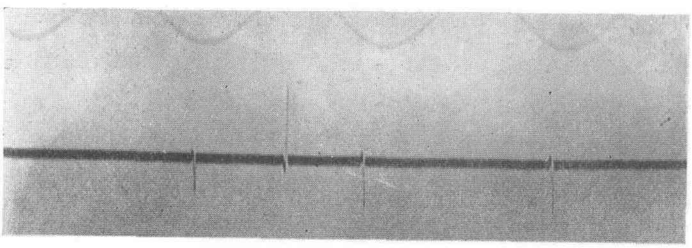


Fig. 30. ×3/2

Near this stage, the circular spark goes out of shape gradually and the voltage wave differs from that in Fig. 29.

In Fig. 30 the gap length has been enlarged to about 50 mm. In Fig. 31 the gap length is 84 mm. We see that a large impulse appears in every several cycles.

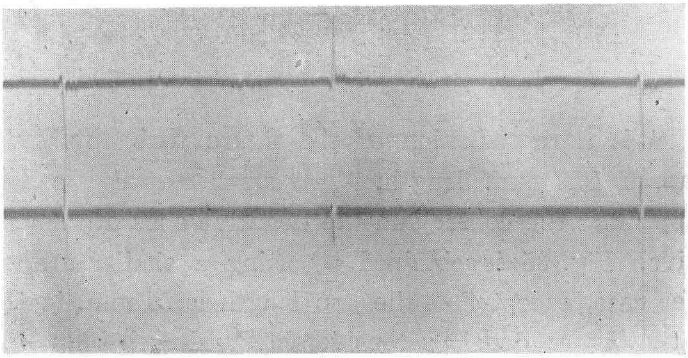


Fig. 31. ×3/2

VIII. Lichtenberg Figure.

Using the same apparatus as in the former experiment, the author next investigated the circular spark, concerned with Lichtenberg Figure. Putting the Photographic plate on the electrode, keeping its film side upward, we have closed the circuit for a short time and obtained the results shown in Fig. 32.

This figure is similar to the positive Lichtenberg Figure using an induction coil as electric source. This perhaps shows that the photographic plate is charged very slowly by the voltage accompanying many impulse waves. We have also tried the same experiment using the connection shown in Fig. 33, in which a glycerin or water rheostat is inserted parallel between the needle and plate electrodes.

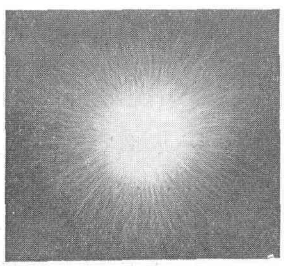


Fig. 32. ×2

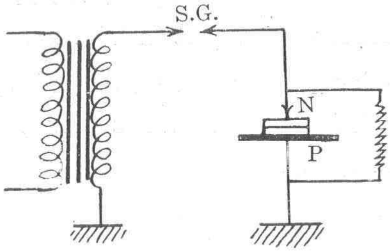
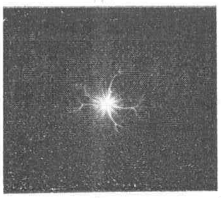


Fig. 33.

Fig. 34 is a reproduction of the figure thus obtained with a series gap of 19.7 mm. length. The small negative and positive figures appear at the center and the negative ones are smaller than the positive. Fig. 35 is obtained by using a similar connection to the former case, except that the gap length is 25 mm. in this case. The negative figure develops considerably and each branch at three or four spots. We can not see any corresponding development of the positive figure. Again Figs. 36 and 37 show the figures obtained in a similar manner, the gap length being 30 mm. and 35 mm. in length respectively.



×2

Fig. 34.

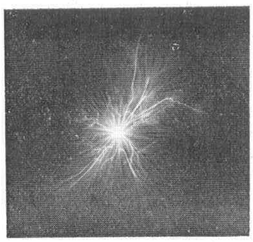


Fig. 35. ×2

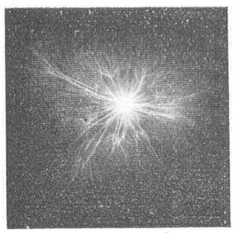
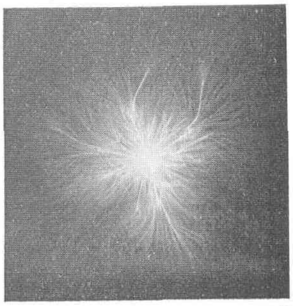


Fig. 36. ×2

The negative figure becomes very large, but the positive figure remains as before.

In Fig. 38, we can observe that the negative brushes bend somewhat tangentially, but the positive figure becomes larger.

Between Figs. 37 and 38, there exists the stage where the first branches of the negative figure bend tangentially and meet with each other to form the circular spark. As it is difficult to switch



×2

Fig. 37.

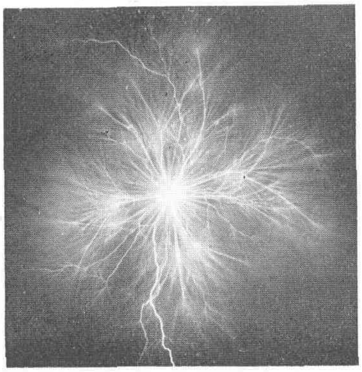


Fig. 38. ×2

in just in time (for obtaining the perfect circular spark, after we have found the stage where the circular spark just appears) one figure (Fig. 38) is selected from among several as the stage where the circular spark occurs. In Fig. 39 the gap is fairly wide open, the positive figure develops largely as does also the negative figure, and the first branch starts almost radially only near the starting point. If we trace the faint part of the figure, we may find the faint large circle as a whole.

Briefly speaking, up to a certain length of series gap, the negative figure develops actively, then the spark bends tangentially near

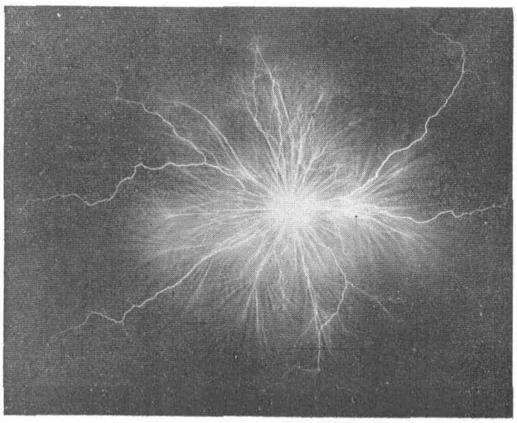


Fig. 39. ×2

the first branching point of brush discharge and then lastly the smooth circular spark occurs.

For the larger gap length, the spark stretches radially farther.

The positive figure becomes larger and larger with increasing gap length, but the negative figure becomes the largest at a certain gap length and then decreases gradually. Enlarging the gap further, we obtain the positive figure only but negative figure (Fig. 32). If we observe the discharging phenomena on the glass plate through the stroboscopic shutter, we see that the negative figure does not appear and the current is perfectly rectified positively.

The negative needle electrode of the series spark gap as shown in Fig. 43, looks somewhat swollen. Moreover, if the gap is enlarged, the positive spark starts intermittently once in every several cycles, as shown in Fig. 41.

Fig. 42 is the figure obtained at the instant, when the ionization develops from the positive electrode and the spark is going to jump

Fig. 40.

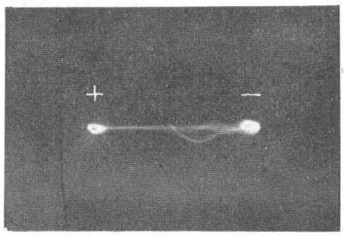


Fig. 41.

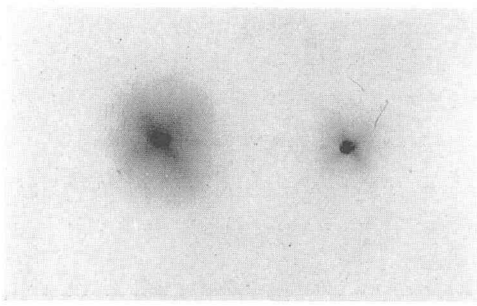


Fig. 42.

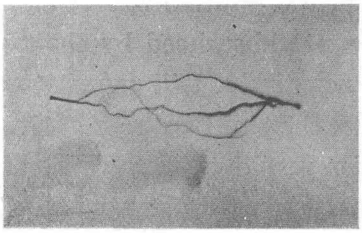


Fig. 43.

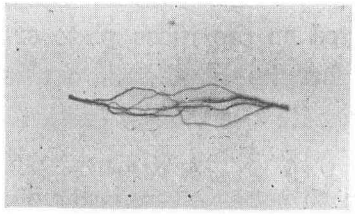


Fig. 44.

to the negative electrode. The long rod-formed spark stretches from the tip of the positive electrode.

In the Fig. 44, we show the discharge at the series gap in the stage where the positive and negative brush discharges are equal in size. Fig. 40, shows the case where the gap length is shortened to 15 mm, accompanying a little by an arc.

IX. Consideration of the construction of the circular spark.

The aspects of brush discharge on the glass plate vary according to the length of the series gap. We choose, for convenience' sake, the following three stages among them:

1. The case where the series gap is zero or extremely small.
2. The case where the series gap has medium opening i.e. the current is rectified negatively.
3. The case where the series gap has wide opening i.e. the current is rectified positively.

Case 1.

Judging from the foregoing oscillograms (Fig. 23), we know that the voltage wave is not too much distorted from the original form.

As the series gap is small, the spark starts comparatively easily. Besides, as the glass plate has an electrostatic capacity, the voltage applied to the plate becomes impulsive, but it seems that the voltage must not reach too high a value.

Now we consider the case where the needle electrode is positive.

According to Yoshida's theory[6] on the positive figure, electrons situated on the glass plate or in the neighbourhood by chance and also charging at the plate electrode negatively, will march towards the needle electrode N and will produce the positive and negative ions from neutral gas molecules by ionization resulting from collision along the path towards the needle electrode, When the potential difference of electrode is fairly high, the ionization by collision of the positive and negative ions with the neutral gas molecule is most active in the neighbourhood of the needle electrode N, and as the velocity of the positive ions is very small, about 1/1000 of the velocity of the negative, they seem almost to remain as a space charge and hence the potential gradient at the needle electrode N becomes lower and lower, so the most effective ionization, i.e. the maximum potential gradient, may shift towards the plate electrode because the positive space charge remains after the ionization.

Therefore, at this stage, one of the terminals of the D.C. galvanometer being earthed and the other free (even though the galvanometer is separated about one meter from the leading wire of the galvanometer terminal), the positive current flows, carrying this space charge.

The charge remaining on the surface of the glass plate in the neighbourhood of the needle is positive, but the amount is not very large. If we raise the voltage, the ionizing effect due to collision of the positive ions develops actively and thus positive ions are generated in the neighbourhood of the needle electrode forming a corona circle which is clearly visible to the naked eye.

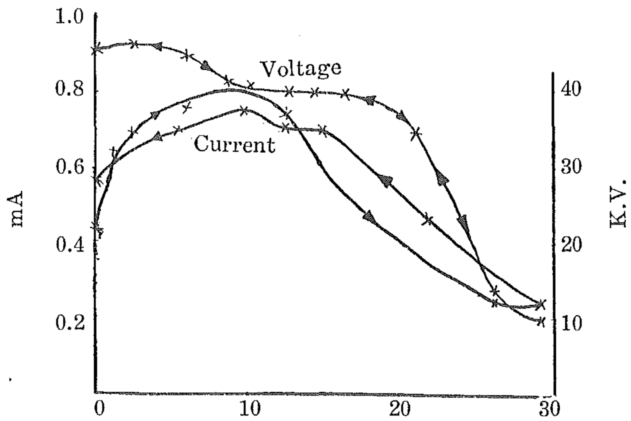
Next, we consider the negative side of the needle under the same circumstance. The positive space charge situated near the needle in the last half cycle, will be neutralized by the opposite polarity of the negative needle, but in order to neutralize the positive space charge situated along the outer boundary of the corona circle, the brush starts radially from the needle and if it stretches directly to the outer boundary, it can not push out of the boundary circle and so branches in two directions right and left, along the positive residual charge remaining from the last half cycle and turns around the electrode N to form a circle.

Case 2.

The current is negatively rectified at this case and when the rectification attains its maximum value, the circular spark occurs. As stated before, this happens when the series spark gap is larger than the one in case 1.

The voltage pulsates more and more violently, and does not hold the original form of sine wave. By every pulsation of the voltage, a pretty large amount of space charge is accumulated on the surface of the glass between the needle and plate electrode.

Glass plate 2.17 mm. in thickness.



Series gap length in mm.

Fig. 45.

The circumstances may be clearer from the characteristics of the voltage and current shown in Fig. 45, and also from the fact that when one terminal of the ballistic galvanometer is grounded and the other is left free, if we bring this free end near to the electric field, the current through the galvanometer becomes negative, too. Thus we may well suppose that when the circular spark occurs, a large quantity of the negative charge must flow from the tip of the needle N towards the atmosphere. That is the reason why the impulse of the voltage wave is depressed at the beginning of a cycle while predominant for the current cycle.

Then supposing that the charge left on the surface of glass may be negative also, we have discharged the residual charge along the trace of the circular spark on the glass plate through a ballistic galvanometer immediately after the spark discharge. But we have found that this charge was not negative, but positive.

Though this experiment was repeated many times, we could always get the same results. The quantity of this charge was much larger than that left when the needle was positively charged. We suppose, therefore, that this charge is not the one starting directly from the needle, but exists only along the circle after the ionization by collision. Really, in the other parts, excepting in the trace of the circular spark, there exists some negative charge. According to Toepler, the negative brush is bent tangentially within a certain limit of $\frac{dV}{dt}$, the brush of the first pulsating voltage creates a discharging path and the following brushes go along the same path traced by the preceding one. We can consider then as follows: when the needle is negative, the electrons flow out radially from it and the positive ions generated by the collisions assemble near the needle N and the potential gradient near the needle N rises more and more. The further the electrons are from the needle, the weaker the potential gradient becomes accumulating the positive charge near the needle.

With the development of ionization by collision, the negative ions are repulsed by positive ions at a certain distance from the needle N, and they may stay almost as a space charge. The potential gradient in this part of the glass becomes lower and lower, and at last the potential gradient along the circle increases by the accumulated positive ions, and consequently the ionization by collision occurs more violently in this direction.

This is why the positive charge remains circularly at a certain distance from the needle N, and the negative bent figure appears.

Case 3.

In this case, the gap S is comparatively large. When the spark bridges over this gap, the voltage wave becomes pretty steep, and is applied to the glass plate in the inhomogeneous field between the needle electrode and the plate electrode. If the needle electrode is positive, the voltage of the brush discharge on the plate may be generally low, and the current rectified positively. Accordingly when the needle is positive, the potential gradient displaces gradually from the needle to the plate, and the positive brush grows large.

X. Circuit containing a rheostat parallel to the discharge system.

In the preceding section, we have described the rectification of A.C. by our peculiar discharge circuit.

Now, we insert a rheostat consisting of glycerin in glass tube about 70 cm. in height in the circuit shown in Fig. 33.

If the total applied voltage is kept constant and the thickness of the glass plate varied, then we can have a relation between the series gap length and the break-down voltage as in Fig. 46. From Fig. 46, we can see that the spark-over voltage increases together with the thickness of the glass plate.

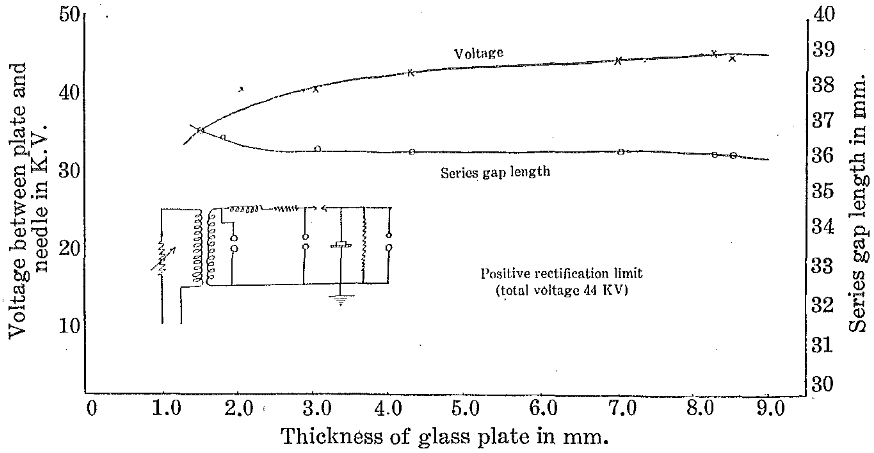


Fig. 46.

Next, using a glass plate 8.5 mm in thickness, varying the sparking length of the series gap and adjusting the voltage between the plate and needle electrodes, we have gotten relations between them as shown in Fig. 47;

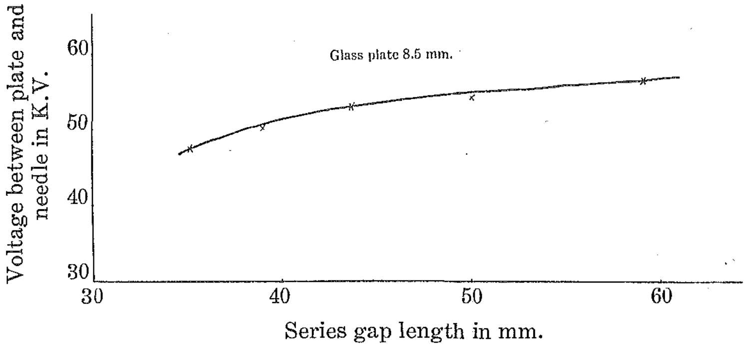


Fig. 47.

Therefore, the larger the length of series gap, the higher the voltage between the needle and plate electrodes. This fact comes perhaps from the fact that the voltage becomes impulsive by increasing the series gap length and the capacitive action of the glass plate is considerable.

Using a water rheostat instead of the glycerin tube rheostat, we have gotten Fig. 48, that is, the relation between the rectification and the thickness of the glass plate.

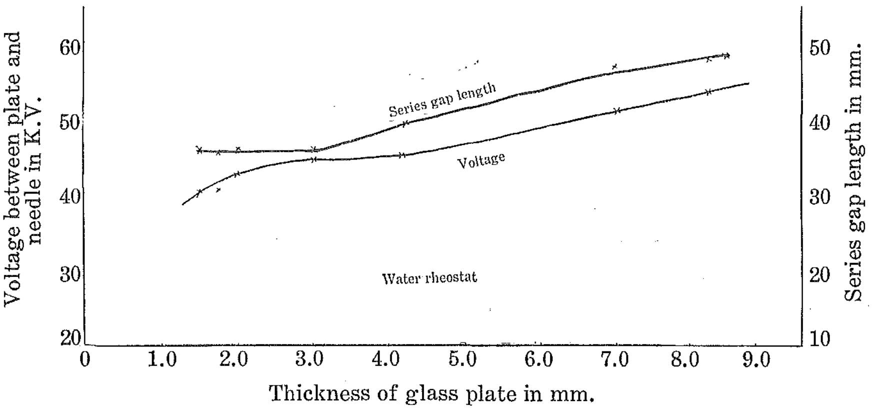


Fig. 48.

Comparing this case with the one shown in Fig. 46, the voltage-rise due to the thickness of the glass plate is larger than the one shown in Fig. 46.

This is because, the water rheostat having a smaller resistance than the glycerin tube, the charge on the glass plate is carried away through the former more than through the latter and only the steep impulse voltage is impressed on the glass plate. In the preceding section we have stated that, though we used the alternating voltage as an electric source in that experiment, the spark-over voltage exists on the positive needle side only.

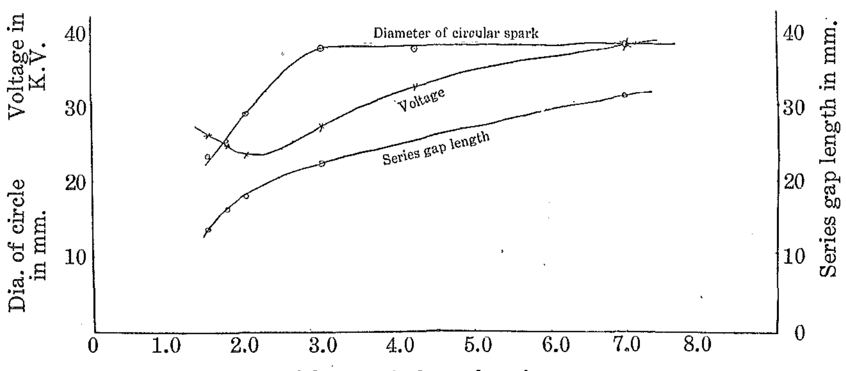


Fig. 49.

In the process where the series gap length is varied to gain the break-down voltage, there exists only one point where the circular spark appears. Therefore one obtains the relation shown in Fig. 49 by using the fine powder to indicate the diameter of the circle.

As shown in Fig. 49, the length of the series gap becomes larger with the increase in the thickness of the glass plate initially and then thereafter, the length of the gap increases lineally with it, but the diameter of the circle increases steeply up to a certain constant value.

Thereupon observing that in the inhomogeneous field built up between the needle and plate electrodes, more favourable rectification is attained by inserting the rheostat parallel with it, we consider that this fact may be due to the effect of carrying off the slow charging current on the glass plate through the parallel rheostat.

XI. Discharge in the atmosphere directly.

Figs. 46, 47 and 48, above mentioned, show the cases where the current is positively rectified to a considerable extent. In the case where the circular spark appears as shown in Fig. 49, the current is considerably rectified negatively.

Up to this, we have described the discharging phenomena on the surface of glass plate and its polarity effect in the inhomogeneous field. However, in order to investigate the phenomena which appear in the space between the plate and needle electrodes, we impress the alternating voltage between the two electrodes directly without inserting a glass plate between them. That is, we have gotten similar experimental results to those obtained by Toepler and Marx. If we apply the alternating voltage to this circuit, "Funkenanfangsspannung" exists only in the positive side of the needle electrode.

In the range where the distance between the needle and plate electrodes is rather long, the negative spark appears no more with full regulation of the voltage or the series gap length.

We have ascertained these facts by the stroboscopic method. Within the range of the distance of the plate-needle-electrodes from 40 mm. to 120 mm., the spark appears only when the needle is positive but in the range less than 30 mm., the spark can be obtained when the needle is negative as well as positive, by increasing the length of the series gap and raising the applied voltage.

In the case where the negative spark appears together with the positive one, the terminal voltage rises fairly as shown in Fig. 50.

If the distance between the plate and needle electrodes increases, then both the positive and the negative break-down voltage rise together, but the negative "Anfangsspannung" rises more rapidly by increasing the distance between the plate and needle. These results coincide with those obtained by Toepler.

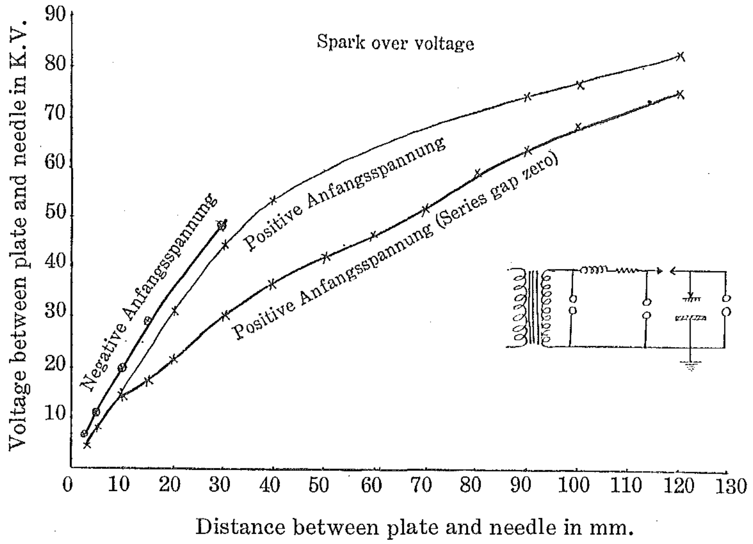


Fig. 50.

Next, the spark when the needle is positive using a kenotron in the circuit (Fig. 51) is shown in Fig. 52, and when negative in Fig. 53. These indicate how the break-down voltage between the plate and needle electrodes varies when no series gap is employed.

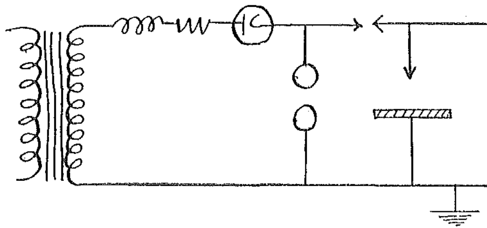


Fig. 51.

Fig. 52 indicates the trace of the positive "Funkenanfangsspannung" which is irregular in the range of small gap length. This fact is explained by the occurrence of the residual charge ac-

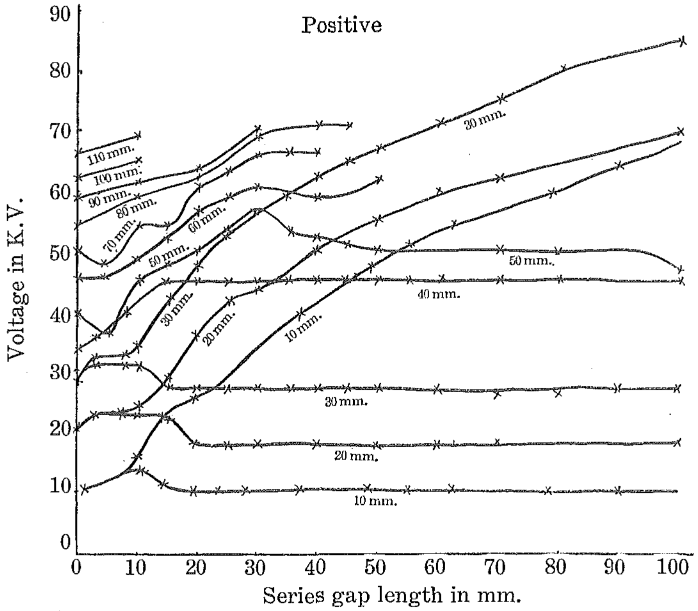

Positive
Voltage in K.V.
Series gap length in mm.
110 mm.
100 mm.
90 mm.
80 mm.
70 mm.
60 mm.
50 mm.
30 mm.
20 mm.
10 mm.
50 mm.
40 mm.
30 mm.
20 mm.
10 mm.

Fig. 52.

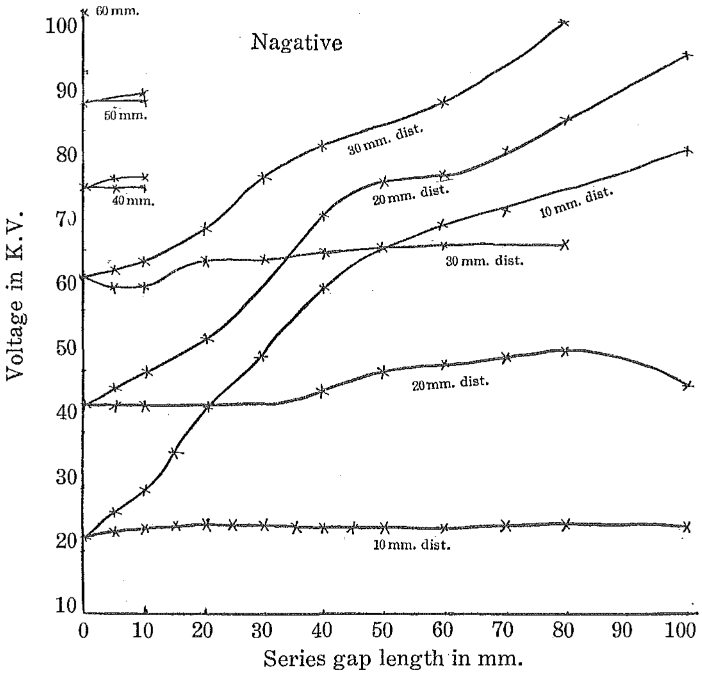

60 mm.
Nagative
50 mm.
40 mm.
Voltage in K.V.
Series gap length in mm.
30 mm. dist.
20 mm. dist.
10 mm. dist.
30 mm. dist.
20 mm. dist.
10 mm. dist.

Fig. 53.

cumulating in the space between the needle and the plate after the discharge. "Funkenanfangsspannung" between the plate and needle and the total voltage, are marked in the figure at each 10 mm. interval in the range of distance between the plate and needle from 10 mm. to 110 mm.

One may consider that the break-down voltage between the plate and needle must be constant against the various lengths of series gap, even if the length of the gap is varied from zero to a great value. But the experiment, on the contrary shows that the voltage increases together with increasing the series gap length and the distance of the plate and needle.

However, for the series gap distance of about 20 mm. in these data, the spark-over voltage is lower than in the case where the distance is zero. Therefore, the fact that the positive break-down voltage is lower than the negative, is favourable to the positive rectification of the alternating voltage and so is also the fact that the negative break-down voltage at the gap of 20 mm. increases with increasing length of the series gap. We have found also that at the distance of about 20 mm. between the plate and needle, the most favourable rectification of A. C. voltage occurs. The break-down voltage increases with increasing series gap length as shown in Figs. 52 and 53.

Keeping the distance of the plate and needle constant, the more the spark-over voltage increases, the more the voltage becomes impulsive. However, the time which is needed for the impulse voltage to pass through it, must be sufficient to ionize the space.

The over-voltage of the impulse wave has remarkable influence on the discharge, when the needle is positive and the distance of the plate and needle is great.

Really, a sufficient time is needed to establish the ionization of gas in the space, and if the time interval of the impressed voltage is short, a sufficient higher voltage is necessary than in the static case, for continuing the ionization by collision.

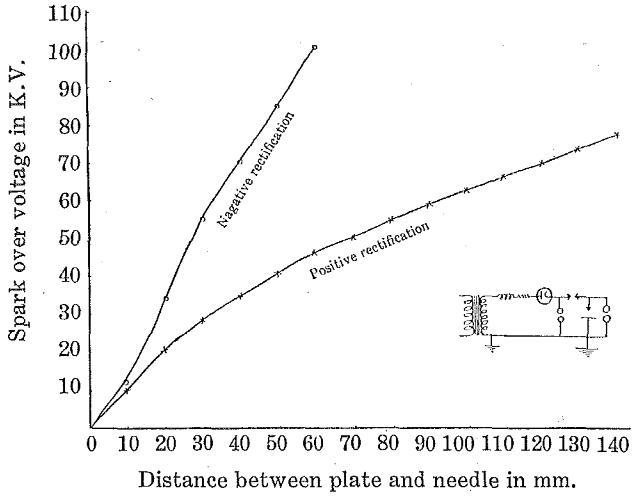


Fig. 54.

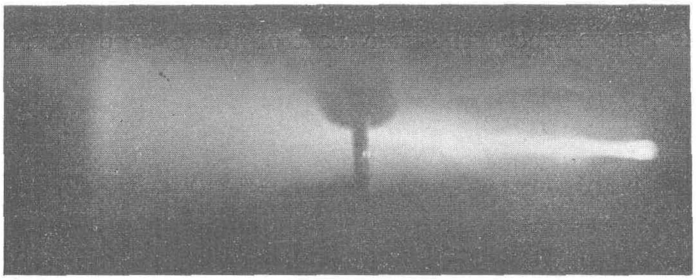
Fig. 54 illustrates the positive and negative "Funkenanfangsspannung" in the case where the series gap is zero in length. It is the same as the results obtained by Toepler and Max.

XII. Effect of inserting solid media between the plate and needle.

Fig. 55 shows the "glim" discharge just before the break-down of air happens between the plate and needle keeping the needle electrode positive. The black body at the middle of the figure is a metal ring insulated by the ebonite.

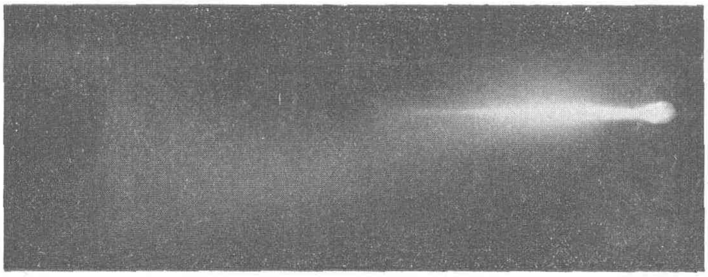
When this metal ring was inserted midway in the line between the plate and needle, the "Glimmlicht" converged into the hole of the metal ring. We see from this fact that the charge from needle to the plate, is repelled by the positive surface charge on the metal surface.

Next, shifting the metal ring outside the central line between the needle and plate, an upper concaved "Glimmlicht" is gotten as shown in Fig. 56. This may be explained in just the same way as the above.



Distance 120 mm., Positive needle. ×3/2

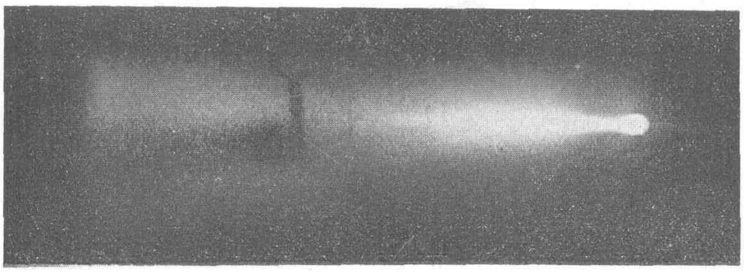
Fig. 55.



Distance 120 mm., Positive needle. ×3/2

Fig. 56.

Next again, if the ring is approached near the plate the shadow produced by the metal ring can be observed as shown in Fig. 57.



Distance 120 mm., Positive needle. ×3/2

Fig. 57.

If the ring is brought still nearer with its center coinciding with the central line between the plate and needle, it is found that only the "Glimmlicht" in the space vanishes out except that a very small violet "Glimmlicht" appears only at the tip of the needle. Thus one learns the course where the main part of the charge passes, or the place where ionization by collision due to the positive and the negative ions is active.

As the most intense ionization by collision i. e. the maximum potential gradient occurs at this place, if we disturb this part of the electric field by inserting the metal ring, the "Glimmlicht" must disappear from this place, otherwise the "Glimmlicht" should concentrate in this place. This is shown in Fig. 58.

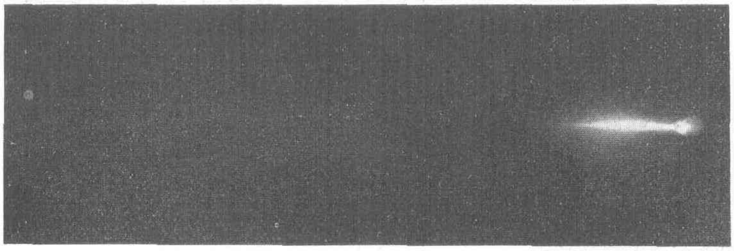


Fig. 58. ×3/2

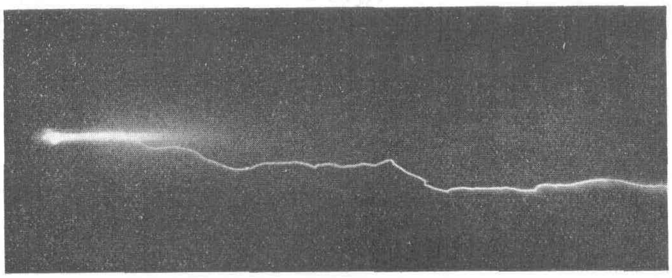


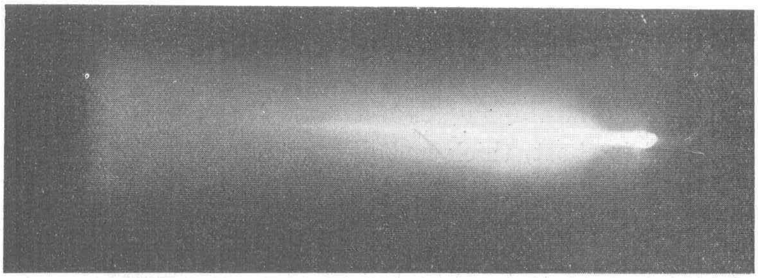
Fig. 59. ×3/2

Fig. 59 illustrates the case where sparking occurs between needle and plate. From the figure, we can see that the light is faint at the needle and very dense near the plate.

If the ionization by collision of gas in the neighbourhood of positive needle is more active than in other cases, and a long conductor is inserted in the direction of the gap near the positive needle, the spark must occur.

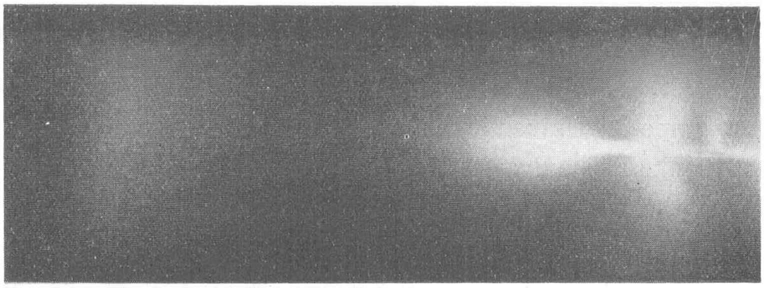
But actually, a dim "Glimmlicht" appears only about the circumference of the conductor placed near the negative plate, and then the spark occurs.

Next, Figs. 60 and 61 show the results gotten without and with the series gap. The "Glimmlicht" occurs not only from the tip of the needle, but also from all parts of the electrode. The positive



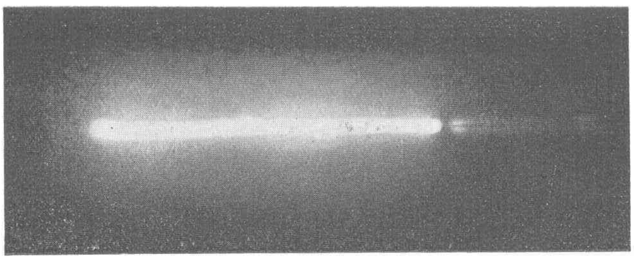
Distance 110 mm., Positive needle, No series gap. ×3/2

Fig. 60.



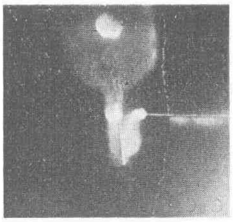
Distance 110 mm., Positive needle, Series gap. ×3/2

Fig. 61.



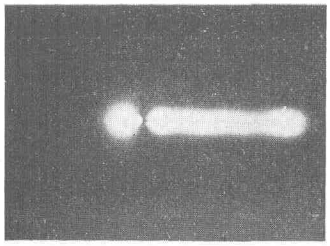
Negative needle, Positive plate. ×3/2

Fig. 62.



Negative needle.
Positive plate.
Distance 70 mm.

Fig. 63.



Negative needle.
Positive plate.
Distance 70 mm.

Fig. 64.

"Glimmlicht" is short, thick and dim in its middle position when series gap is used but it appears in the form of a rod when none is used. Fig. 62 shows the electric arc at the needle when an insulated conductor is put to the tip of the needle. It will be explained by the fact that the potential gradient of this part is great. Fig. 64 is the negative "Glimmlicht" instead of the positive.

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