Some Experiments on Lichtenberg Discharge

By

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Abstract

(1) The size of discharge-figures alters with the varying positions of a resistance which is inserted in series with the lead to the electrode. This phenomenon seems to be due to the superposition of not only an advancing wave but also of the waves reflected at some junctions in the circuit. From the experimental results, it is found that the time of the impulse wave-front in our cases is about 2.3×10^{-8} secs. Some other experiments on the Lichtenberg discharge are also described.

(2) The effect of self-induction upon Pedersen's short time-measurement is described, and it is shown that by this method (under certain conditions) small inductions from about 0.7 to 40 microhenries can be measured.

(3) A method for measuring a short time interval by using a low pressure tube is suggested.

1. Introduction

Most of the experiments described in the following paper were carried out with the electrical connections shown in Fig. 1. An electrode A is placed on the sensitive film of a photographic plate P which is covered underneath with an earthed metal plate B. R_0 is a shunt resistance, C_0 a Leyden jar, G a spark gap, and I an induction coil.

Fig. 1

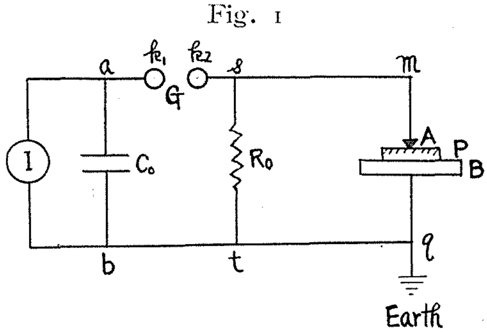


Diagram of the circuit for ordinary discharge figures

If an electric impulse resulting from a spark at G reaches the electrode A, a discharge-figure is impressed on the Plate P, and the figures thus obtained depend upon the sign of the impulse. It is, however, an interesting fact that the size of figure varies with the length of the lead $GsmA$. P. O. Pedersen[1] investigated this point by changing the lengths of the wires $k_2 m$ and $b q$, keeping all other conditions as constant as possible. By this means he found that the size of the discharge figure increased with the increase of the length of the lead wire, and argued that the size of the discharge figure varied with the duration of electric impulse applied to Lichtenberg gap A. He calculated the duration τ by the formula

$$\tau = \frac{2.GA}{v} \text{sec.} \tag{1}$$

where v is the velocity of light. J. C. Street and J. W. Beams[2] found the same phenomenon by using an apparatus which was essentially similar to Fig. 1, except that the Lichtenberg gap APB was replaced with a spark gap of low capacity. They suggested that the potential-rise at the end of a long lead results from the interference between the advancing wave and the wave reflected at the spark gap G.

Convinced that this phenomenon has something still left to be investigated before it is satisfactorily solved, the writer carried out some experiments with an apparatus in which a resistance was inserted in series with the connecting wire to the electrode A (Fig. 1), and found that the size of the discharge-figure varies also as the position of the resistance is shifted, even though the length of the lead-wire is kept constant. It seems to the writer that this phenomenon is essentially the same as that described above and that it is due to nothing but the total effect of the impulse waves which are produced there.

2. The Size of the Discharge-Figure and the Series Resistance inserted in the Lead

The writer has investigated the relation between the size of the figure and the position of the series resistance R with the arrangement as shown in Fig. 2, where R is a pencil of 135 ohms and 12 cms. in length. The length of sA was kept constant at 5 ms. throughout the experiment.

1. P. O. Pedersen: Vidensk. Selsk. I, 11, 3, (1919).
   „ „ „ „ VIII, 10, 3, (1929).
2. J. C. Street and J. W. Beams: Phys. Rev. **38**, 416 (1931).

Fig. 2

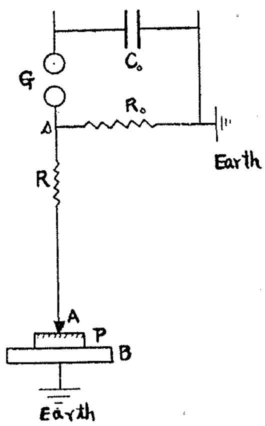
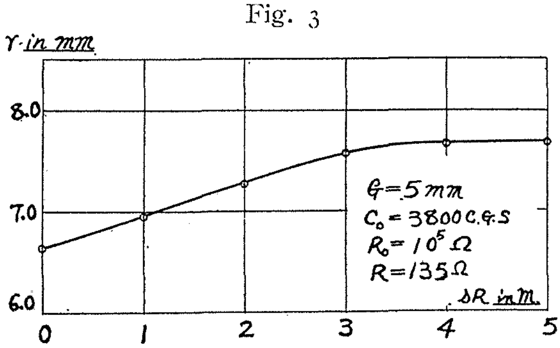


Diagram for measurement of the effect of series resistance upon the size of the discharge figure

The results of the experiment are given in Fig. 3; in which the abscissa indicates the position of R reckoned from s, and the ordinate indicates the radius r of the negative figure. The curve in this figure tells us that the position of the series resistance R bears a close relation to the size of the discharge-figure, and that r increases linearly with the length sR up to approximately 3 ms.; after that point r begins to increase very slowly. Similar experiments carried out for the positive discharge-figure brought the same results as those described above, though accurate measurement of r was accompanied by great difficulty owing to the irregular outline of the positive figure caused by the presence of the series resistance.[1]

The discharge of the condenser through our circuit will generally be oscillatory, but the damping of the oscillations will be considerable, for the losses due to R_0, R, G etc. are great. However, even if an oscillation occurring in the main circuit influences the size of the discharge-figure, the position of R should have no effect upon it. This phenomenon may be explained chiefly by the fact that impulse waves are produced by the reflections of the advancing wave at some points in the circuit. For an illustration, let us consider the cases of the superposition of two simple impulses.

Fig. 3



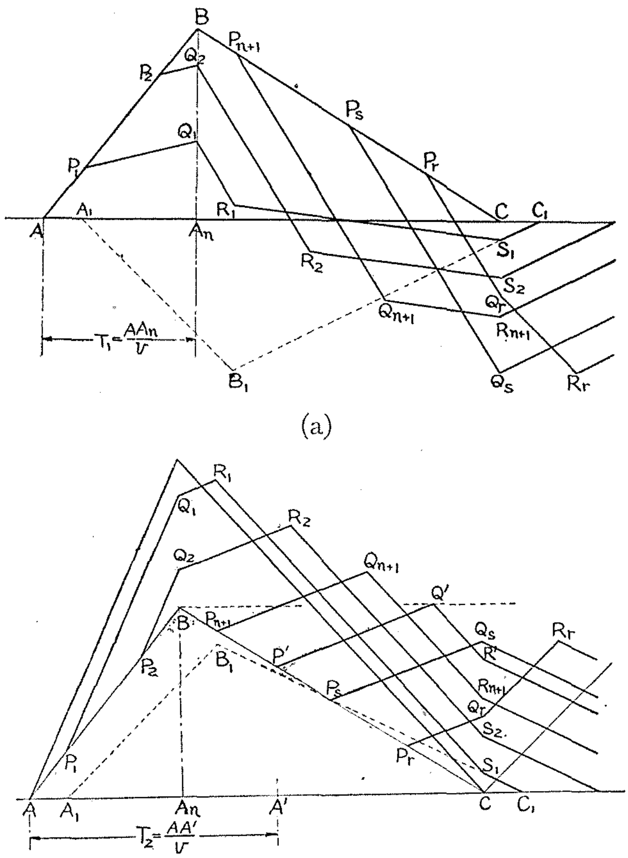
Relation between the range of negative figure and the position of series resistance

In Fig. 4 (a), let us assume that ABC is an advancing triangular wave and $A_1B_1C_1$ the wave reflected at a point in a distortionless circuit; the durations of these two waves being equal to each other,

1. T. Terada: These Memoirs, A, 13, 281 (1930).

and their crests reversed. Then, the form of the resultant wave can be shown graphically by the curve $AP_1Q_1R_1S_1C_1$. The height of the crest of the resultant wave increases with the increase of the length AA_1 until it assumes the full length of the wave front. If the length of AA_1 becomes greater than that of the wave front, the maximum

Fig. 4



Superposition of triangular impulses

height of the crest of the resultant wave is always the same as BA_n, which is the height of ABC. Even if the advancing and reflected waves are respectively single sine waves, the result is the same as that described here.

Fig. 4 (b), in which all the notations stand for the same meanings as those in Fig. 4 (a), represents the case where the wave crests are of the same sign. In this case, the crest of the resultant waves is highest when AA_1 is equal to zero; but it decreases gradually with the increase of the length AA_1 until A_1 reaches a certain position A'; and after that, the maximum height (BA_n) remains always constant. If, in this case, the advancing and reflected waves are single sine waves and their amplitudes and the durations are equal to each other, the amplitude of the resultant wave will decrease gradually until the phase difference between them reaches 120°, which can easily be calculated.

The wave form in the present experiment will not be so simple as those described above in that the discharge of the condenser C_0 in Fig. 2 will generally take a form of damped oscillation. However, it seems not to be unnatural to consider roughly that the form of the first impulse wave is a happy medium between the triangular and single sine waves. If so, both the illustration and consideration tried above may be applied to the explanation of the results shown in Fig. 3.

In our case, there were some junctions in the circuit (Fig. 2), at which the reflections would occur. In order to investigate the resultant effect of the waves reflected at G and s upon the size of the discharge-figure, the writer took many discharge-figures keeping $RA = 1$ m. in the cases (a) $C_0 s = 0.5$ m., $sR = 4$ ms. and (b) $C_0 s = 3.5$ ms., $sR = 1$ m. From these, it was found that the size of the discharge-figure in the case (a) was a little (about 5.4%) greater than that in the case (b). However, this discrepancy in both cases was too small to explain fully the character of Fig. 3. Therefore the existence of some other wave-reflection was thought to bear a more important relation to the proper solution of the present problem.

(i) Firstly, the reflected wave at R will be reflected again at the condenser C_0, and then will come to the electrode through the resistance R. If the advancing potential wave which travelled first through the resistance R is negative, then the potential of the doubly reflected wave should be positive because of the large capacity at C_0. In that case, the negative potential at the electrode A will be reduced by that doubly reflected wave, and the height of the crest of the negative potential at the electrode A will increase with the time $\frac{2C_0R}{v}$ until the time T_1 shown in Fig. 4 (a), where v is the propagation-velocity of the wave along the wire.

(ii) Secondly, we must take into account the effect of the other wave which was first reflected at the electrode A and then at the resistance R. If the advancing wave is negative as before, the doubly reflected wave coming to the electrode A should be negative too (see Sec. 3 of this article). In this case, it leads us to expect that the crest of the negative potential at the electrode A increases with the reduction of the time $\frac{2RA}{v}$ until the time is reduced to zero from the value T_2 shown in Fig. 4 (b).

Now, if the crest of the negative potential at A results from the superposition of the primary advancing wave and these two reflected waves (i) and (ii) as mentioned above, it will be understood that the crest of the resultant potential wave increases in height as C_0R becomes longer, until the value of $\frac{2C_0R}{v}$ reaches T_1, which is smaller than T_2; and that when C_0R is further lengthened, the height of the crest is very slow in increasing, for there is left only the effect of the wave (ii) since the effect of the wave (i) needs no longer be taken into account (see Fig. 4).

S. Mikola[1] gives the following formula for the relation between the radius r of the discharge-figure and the real spark potential V,

$$r=a_1\sqrt{V-V_0} \quad \text{for the positive figure} \tag{2}$$

and

$$r=a_2(V-V_0) \quad \text{for the negative figure} \tag{3}$$

where V_0 is the smallest potential difference capable of forming a figure, and a_1 and a_2 are constants. Admitting this relation, we may duly expect the size of the discharge-figures to enlarge with the length of C_0R or sR. Hence the results shown in Fig. 3 seem to be fully explained.

Now, if this explanation of the curve in Fig. 3 is accepted, we can calculate the time T_1 of the wave-front by using the formula

$$T_1=\frac{2C_0R}{v} \tag{4}$$

where $C_0R=C_0S+SR$. In our case, the increase of the size of the discharge-figure practically ceased when the length sR was about 3 ms. (see Fig. 3). Therefore, by giving to C_0s and sR the actual values 0.5 m. and 3 ms. respectively, we get

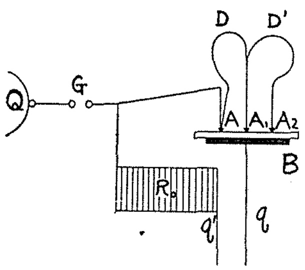
$$T_1=2.3\times10^{-3} \text{ secs.} \tag{5}$$

1. S. Mikola: Phys. Zeit., **18**, 158 (1917).

3. Size of the Discharge-figure obtained at the Ends of two Branch-leads

About sixty years ago, W. V. Bezold[1] investigated the size of Lichtenberg dust-figures obtained with a long lead under various experimental conditions. We now quote one of his arrangements.

Fig. 5



W. V. Bezold's arrangement

In Fig. 5, Q is an electrical machine; G, a spark gap; R_0, a Ruhmkorff induction-coil used as a return-conductor; P, a horizontal plate of well-insulating glass covered underneath with earthed tin foil B; and A, A_1 and A_2, electrodes connected by two wires D and D'. Bezold noticed that if the lengths of D and D' were suitably chosen, for example, $G=4.3$ mms., $AG=50$ cms., $D=620$ cms., and $D'=810$ cms., the dust-figures obtained at A and A_2 were both large, whereas only a small star appeared at A_1.

In accounting for this phenomenon, he says, "If electric waves are impelled along a wire and forced to return along the same path after reflection at the end, the advancing and reflected waves would interfere and so give rise to phenomena analogous to those observed in organ-pipes. The observations already described point distinctly to such an analogy, and we may venture to compare the positions of the wire in which maximum and minimum figures appear with the antinodes and nodes."

The place of the reflection of the electric wave is not confined, however, to the electrodes A, A_1, A_2; but it takes place also at G and some other parts of the connection. To find the effects of such reflections, the writer carried out the following experiments.

In Fig. 6, $A_1 s A_2$ is a flat loop of No. 19 wire 10 ms. in length; $k_2 s$ is a feeder of 2.5 ms.; and s denotes a feeder tap which can be attached to the loop at any point. With this apparatus, discharge-figures at the electrodes A_1 and A_2 were obtained at the same time by varying the position of the tap s over the loop.

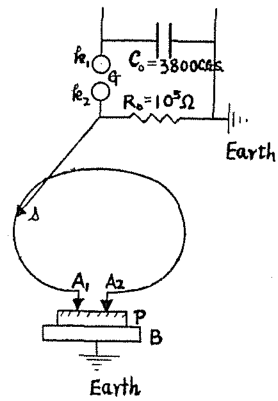
The photographs reproduced in Fig. 1, Plate I represent the negative figures which were obtained when the path-difference was 2 ms.:

1. H. Hertz: Electric waves (Translated by D. E. Jones) p. 54 (1893).

the photograph (a) at the electrode of the shorter branch, and (b) at that of the longer branch. The photographs in Fig. 2 in the same plate were obtained when the path-difference was 9 ms.: the photograph (a) at the electrode of the shorter branch; and (b) at that of the longer one. In these figures, two peculiar features are noticeable: one is that the positive branches appearing within the negative figure gave rise to the "reversal-like phenomena[1]" though they are too faint to be reproduced clearly; and the other that some fan-shaped negative figures appeared at the outside of the primary negative stems in the figure obtained at the electrode of the shorter branch when the path-difference became 3 ms. or more.

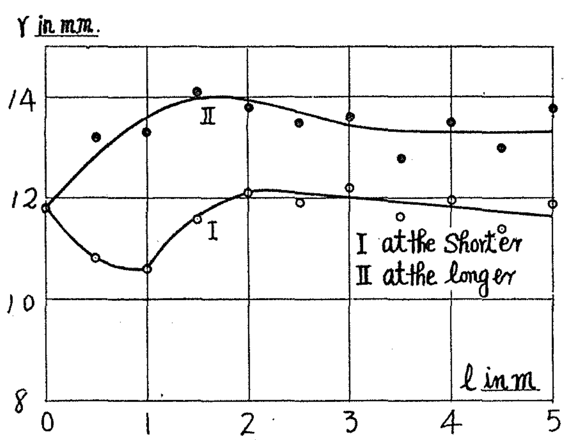
The origin of this fan-shaped negative figure seems to be the same as that which P. O. Pedersen[2] obtained with a long lead. The occurrence of the fan-shaped figure was practically independent of the length of the feeder $k_2 s$, but greatly depended upon the electrical conditions at the end of the longer branch. For example, it made no appearance when the end A_2 was connected to the earth

Fig. 6



Diagramatical representation of the electrical connections used in measuring the change in the size of the discharge-figure

Fig. 7



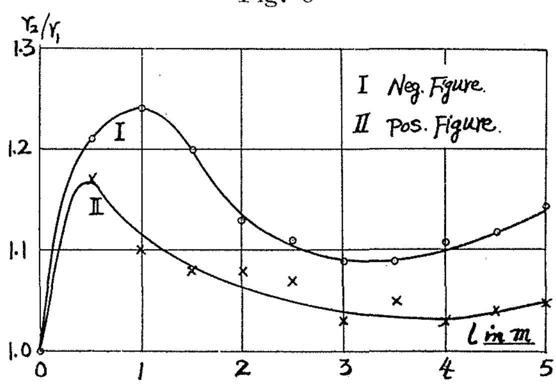
Relation between the range of negative figures and the position of the tap

1. U. Yoshida: These Memoirs A, 2, 315 (1917).
U. Yoshida and J. Tsutsumi: These Memoirs A, 12, 217 (1929).
T. Terada: These Memoirs A, 14, 219 (1931).
2. P. O. Pedersen: loc. cit. (1919).

through a water resistance of about 10^3 ohms. Consequently, it is suggested that the fan-shaped figure was produced by the impulse reflected at the end of the longer branch; and consequently that the reflections at A_1 and A_2 had a direct influence upon the sizes of the discharge-figures obtained at both ends respectively; and also that the sign of the impulse was not reversed by the reflection of the Lichtenberg electrodes A_1 and A_2. As to the formation of such a figure, the writer will dwell upon that later.

Now, curve I in Fig. 7 shows the relation between the size of the negative figure obtained at the electrode of the shorter branch and the length l of the lead wire from the middle of $A_1 s A_2$ to the tap; and curve II that between the size of the negative figure at the longer branch and l. In the former, the size of the discharge figure is extremely reduced when the path-difference $2l$ becomes 2 ms., after then gradually increases up to its maximum value; while in the latter, the figure becomes great at the very first, and then is reduced in its size very gradually. If we plot in a curve the relation between l and the ratio of the size of its two figures obtained at both ends A_1 and A_2, we shall obtain a curve rising more or less abruptly to a peak at $l=1$ m. as shown in curve I in Fig. 8. The same relation for the positive figure is shown by the curve II in Fig. 8.

Fig. 8



Relation between the ratio of the sizes of discharge-figures and the position of the tap

The peculiarity of the curves shown in Fig. 7 and Fig. 8 can hardly be fully explained by a standing wave caused by the interference of the advancing and the reflected waves which, in turn, are produced by the reflections at the electrode A_1 and A_2 respectively. It is true that the wave reflected at the electrode A_2 (or A_1) affects the size of the discharge-figure obtained at A_1 (or A_2). However, we must take into consideration moreover the waves reflected at the point s, G, and the condenser C_0; the discharge-figure obtained at the electrode A_1 or A_2 will have a size corresponding to the maximum potential produced at the electrode in question, which results from the superposition of the impulse waves considered above. Let us assume for the time being that these waves are simple harmonic with the same period. Then the maximum amplitude of the resultant wave will depend upon the position of the tap s, and there may be some positions of the tap s at which the maximum and minimum values of the maximum amplitude of the resultant are caused. Though, in the present case, the actual wave-form of the impulses is not such a simple one, yet such a simplification throws a good deal of light on their qualitative character.

We will first consider the size of the negative figure obtained at the electrode A_1 of the shorter branch (Fig. 7, I). Let us assume for simplicity's sake that the lead-wire to the electrode A_1 in Fig. 6 consists of $C_0 s A_1$ and $s A_2 A_1$. According to the writer's opinion described in the preceding chapter, the shorter the path $C_0 s A_1$ the smaller the size of the discharge-figure at A_1 (see Fig. 4 (a)), and the longer the path $s A_2 A_1$ the smaller the size (see Fig. 4 (b)). If the tap s is moved towards the electrode A_1 from the middle of the loop $A_1 s A_2$, $C_0 s A_1$ becomes shorter and $s A_2 A_1$ longer. Consequently, the size of the figure obtained at the electrode A_1 must be gradually reduced. However, when the tap is moved further in the same direction, that is to say, when $s A_2 A_1$ is further lengthened and $C_0 s A_1$ reduced (for example when $s A_2 \geqq 6.5$ ms.), then the growth of the negative figure impressed by the resultant potential at the electrode A_1, which is due to the superposition of the primary advancing wave and the doubly reflected wave from the condenser C_0, will cease before the wave reflected at the electrode A_2 reaches the electrode A_1; and the conductivity of the stem of the negative figure at that time will be very much reduced. Consequently, the impulse wave from A_2, travelling through the narrow conducting passage in the stem with small diffusion of the electric charge, reaches the end of the negative stem, which was previously impressed on the photographic plate P; and thus gives rise to a comparatively high negative potential at that point. This seems to be the cause of the formation of the fan-shaped figure as shown in Fig. 2 (a), Plate I.

If, in that case, the effect of the reflected wave from the electrode A_2 (which has smaller diffusion) is greater than that given by the doubly reflected wave from the condenser C_0, then the size of the figure obtained at A_1 must enlarge. Of course, it is difficult to explain accurately this point unless we know clearly the coefficients of reflection at A_1, A_2, and C_0, the law connecting the change of the resistance at the spark gap with time, and in particular the law connecting the change of the conductivity of the negative stem with time (the relation between the diffusion of the charge and the time). However, as a matter of fact, the linear size of the fan-shaped figure became gradually greater with the increase of the length sA_2. Hence it may be concluded that the increase of the size of the negative figure obtained at shorter branch A_1 when the lead sA_1 was reduced to 4 ms. or less, was due to the increase of the effect of the reflected wave from A_2, which was caused by the decrease of the conductivity of the stem and the reduction of the diffusion of the charge due to the longer duration of $\frac{2sA_2}{v}$.

From the fact that the fan-shaped figure always appeared when the lead sA_2 was 6.5 ms. or more, it follows, by assuming the explanation given above to be correct, that the growth of the negative discharge-figure obtained without the reflected wave from the electrode A_2 practically ceased within the time

$$2\,sA_2/v = 2 \times 6.5/3 \times 10^8 = 4.3 \times 10^{-8}\text{secs.} \qquad (6)$$

The time described above was virtually independent of the width of spark gap G up to 5 mms. or more. The duration of the formation of the discharge figure was investigated some years ago by P. O. Pedersen[1] by means of an apparatus similar to Fig. 1. He connected two open parallel wires at the points m and q respectively and found that the increase of the size of the negative figure obtained at A in Fig. 1 ceased when the lengths of the parallel wires increased to 8 ms. From this fact, he argued that the growth of the negative figure ceased after the lapse of 5.3×10^{-8} secs., a figure which accords with the value given to it by the present writer.

Next, we must consider the size of the negative figure obtained at the electrode A_2 (Fig. 7, II). If the tap s is moved towards the electrode A_1 from the middle of $A_1\,s\,A_2$, the length $C_0\,s\,A_2$ becomes greater and the length $s\,A_1A_2$ smaller. According to the consideration stated in the previous chapter, in this case the reduction-effect due to the doubly reflected potential wave (the wave reflected at A_2 and C_0) decreases (see Fig. 4 (a)) and the increasing effect due to the reflected potential wave ($s\,A_1A_2$) increases when the tap s is moved toward the electrode A_1 (see Fig. 4 (b)). Consequently the potential at the

1. P. O. Pedersen: loc. cit. (1929).

electrode A_2 rises; and as its result, the discharge-figure becomes greater with the increase of the length sA_2 or l up to a certain value as shown by the curve II in Fig. 7.

For the positive discharge-figures, similar experiments were carried out. The character of Curve II in Fig. 8, which shows the results obtained, is similar to that of curve I in the same figure, though the results are comparatively irregular because of the irregular boundary of the positive figure. Consequently, it seems that the explanation in the case ef the negative figure is also applicable in this case. When the path-difference was about 1 m., that is when the longer branch sA_2 was about 5.5 ms. in length, the size of figure obtained at the electrode A_1 of the shorter branch became minimum, and when sA_2 was further lengthened, some longer positive branches appeared in the vacant spaces between the normal branches. From an experiment similar to that done for the determination of the origin of the star of the negative figure, it was found that these longer branches were due to the wave reflected at the electrode A_2. If, from this, the time necessary for the formation of the positive figure is calculated by the method described above, we get the duration of about 3.6×10^{-8} secs., a figure which again accords with the value 3×10^{-8} secs. which P. O. Pedersen obtained by a different method. Lastly, the reason why the measurements of the size of the positive figure were irregular is again due to the fact that, by lengthening the lead sA_2, the positive branches caused by the wave reflected at A_2 are so formed as to fit themselves in irregular order into the vacant spaces between the branches of the figure impressed previously.

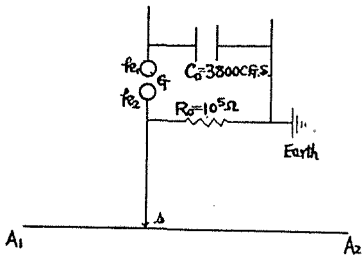
4. Potential Distribution along a Flat Aerial

In Fig. 9, $A_1 s A_2$ is a bare copper wire of 10 ms. in length and 1 mm. in diameter. C_0, R_0 and G have the same meanings as those described before.

About thirty years ago, A. Slaby[1] measured the potential distribution along a wire when an electric oscillation was set up in it, with an experimental arrangement similar to that shown in this figure: one pole of an induction coil was connected to various points along a stretched wire, and the other pole of the coil was earthed or connected to a large capacity. This arrangement differed from the present

1. A. Slaby: The Electrician **49**, 6, (1902).

Fig. 9

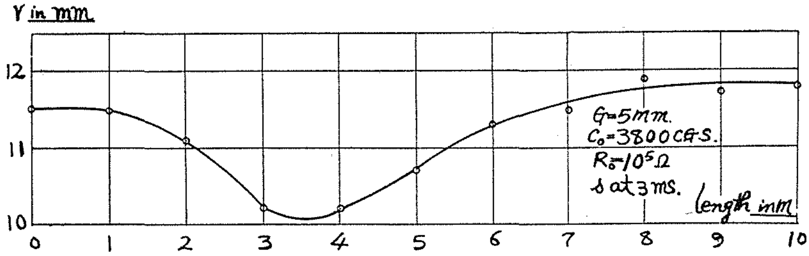


Measurement of potential-distribution along a wire $A_1\,s\,A_2$

arrangement, however, in that it had no shunt resistance R_0 nor condenser C_0. Using a spark-micrometer, he found that the potential loops occurred at the ends and a relative node occurred at the middle of the wire regardless of the position of the tap. However, in the present case, the sizes of the discharge figures obtained at both ends A_1 and A_2 have greatly depended upon the position of the tap s as seen in Figs. 7 and 8. Consequently, in the present case it seems necessary to examine the potential distribution along the system $A_1\,s\,A_2$. First, the size of the discharge figure (negative) obtained at various points along the wire was measured; and in the second place, the measurements were made with two spherical spark-micrometers of 1 cm. in diameter, having a divided head by which the spark lengths down to 0.03 mm. can be measured. In the latter case, one micrometer was fixed at the feeder tap s and the other was moved along the aerial $A_1 s A_2$; then the voltage ratio between both was obtained, the potential at the point s being taken as the unit.

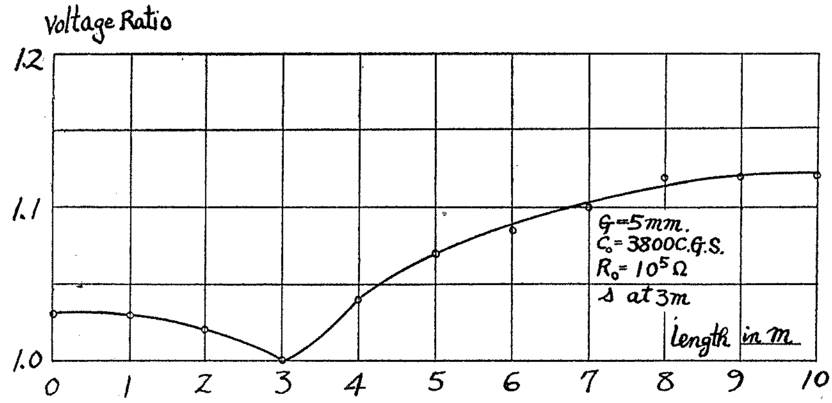
Fig. 10 shows the results obtained with the former method (discharge-figure), and Fig. 11 those obtained with the latter. In both cases the tap s was placed always at a point 2 ms. away from the middle of the aerial. From these, it is seen that the minimum potential appeared at the point s or near it, and the relative maximum potentials at the ends of the wire, the potential at the end of the longer branch being always greater than that at the end of the shorter. These results are different from Slaby's. However, when the shunt

Fig. 10



Range of the negative figure obtained along the system $A_1\,s\,A_2$

Fig. 11

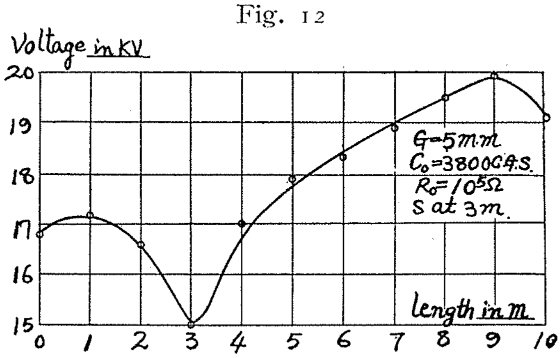


Potential-distribution curve along the system $A_1 s A_2$

resistance R_0 was greatly increased, the capacity C_0 was proportionately reduced; moreover, the sparks were made to occur successively at G. In other words, when the experimental conditions were made to approach Slaby's, the results practically tallied with those obtained by Slaby. This indicates that the results obtained hitherto by the writer's experiments are unable to be explained merely by a pure standing wave.

Lastly, the potential distribution along the wire $A_1 s A_2$ was again examined when the ends A_1 and A_2 were made to functionate as Lichtenberg needle gaps of the same size and shape respectively. The potential along the wire, irradiated by the radioactive rays, was detected with a spark-micrometer. The width of the spark-micrometer was increased until four sparkings across it occurred per one hundred sparks across G, and this width of the spark-micrometer was taken as a measure of the potential. The feature of the curve in Fig. 12 thus obtained is similar to those obtained without Lich-

Fig. 12



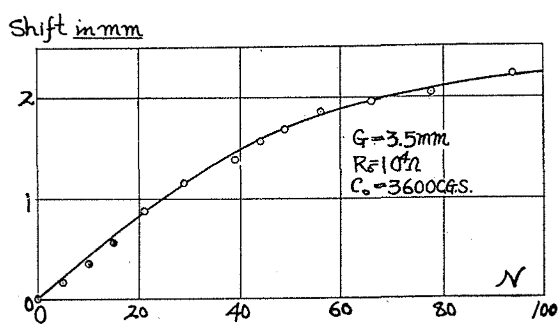
Potential-distribution curve along the system $A_1 s A_2$ with Lichtenberg gaps at both ends tenberg gaps, except that the potential at every point along the wire was generally reduced a little owing to the capacity of the Lichtenberg gap.

5. Method for Measuring a Small Self-inductance

P. O. Pedersen,[1] by using an apparatus similar to that shown in Fig. 6 measured a short time interval from 10^{-9} to 2×10^{-7} secs. Paul Heymans and Nathaniel H. Frank[2] also measured a short time interval from 6.7×10^{-11} to 10^{-7} secs. with similar apparatus provided with a compensating lead. The present writer measured the time interval from 1.7×10^{-9} to 1.6×10^{-7} secs., by using an arrangement similar to Pedersen's. The two electrodes (A_1 and A_2), 3.5 cms. long and 0.5 cm. wide, were so placed that their edges were parallel to each other. During such measurements, it was found that the winding of the lead wire sA_1 or sA_2 (in Fig. 6) had some effect upon the measurement.

In order to investigate this effect more closely, two No. 26 lead wires 8 ms. in length were used in place of sA_2 and sA_1 in Fig. 6. One lead wire—say sA_2—was made to form a half circle in the air, and the other—say sA_1—was wound round a grooved ebonite-bar and dipped in an insulating oil-bath. The diameter of our coil was 2.5 cms. and the number of turns per cm. was 7.44. With this many discharge figures were obtained, and the shift of the meeting line of the two discharge figures appearing at the half-way point between the parallel electrodes A_1 and A_2 was measured. From this shift, we can calculate the retarding time due to our coil by using the calibration curve, which shows the relation between the retarding time and the shift of the meeting line.

Fig. 13



Relation between the displacement of the meeting line and the number of turns of the coil

1. P. O. Pedersen: Ann. der Physik., **69**, 205 (1922).
2. P. Heymans and N. H. Frank: Phys. Rev. **25**, 865 (1925).

The relation thus obtained between the number of turns N of the coil and the shift of the meeting line of two figures from the half-way position of the parallel electrodes A_1 and A_2 is represented in Fig. 13. The meeting line shifts towards the electrode (A_1) which has a larger self-inductance (coil).

Now, though the coil used was a single-layer type, it would have some capacity between the successive turns. The writer examined the effect of the capacity upon the shift of the meeting line with the apparatus shown in Fig. 6, but in this case the lead wires sA_1 and sA_2, having the length of 8 ms. respectively and a spherical capacity of 12.5 C. G. S. or more, were attached at a point 50 cms. apart from an electrode. Since the results of this experiment show that the capacity within the value described here had no effect upon the shift, it may be concluded that the shift as shown in Fig. 13 is mainly caused by the self-induction of the coil. Thus, reversely by this method, we can measure a small difference of self-induction from about 0.7 microhenry, corresponding to 5 turns, to about 40 microhenries corresponding to 94 turns, if we know the size and linear length of the coil wire. When the inductance was too great, the meeting line of the two figures became somewhat vague and the measurement of the shift was difficult. This might be due to the oscillation produced in the coil.[1]

The reason why such a shift was caused by the self-induction may be explained as follows. By the presence of the coil, the wave-front of the travelling wave is changed into flat and the current coming to the electrode A_1 is reduced in comparison with that to A_2. Consequently, the start of the discharge-figure from A_1 will be retarded and the propagation-velocity of the figure[2] will also be reduced.

6. A Method for Measuring a Short Time Interval with Low Pressure Tube

The electrical connection used was similar to that shown in Fig. 6, with the exception that a low pressure discharge tube was used instead of photographic plate P. Two adjustable needle electrodes A_1 and A_2 were made to pass by an airtight connection through the ends of a glass tube 50 cms. in length and 3.5 cms. in diameter

1. T. Terada: loc. cit. (1930).
2. P. O. Pedersen: loc. cit. (1919).

provided with an exhaust arrangement. The position of the ends of the electrodes A_1 and A_2 were determined by means of an attached scale S, by measuring the positions of two movable circular ebonite plates Es fitted in the tube, through whose holes the needle-points were exposed a little as shown in Fig. 14.

Fig. 14

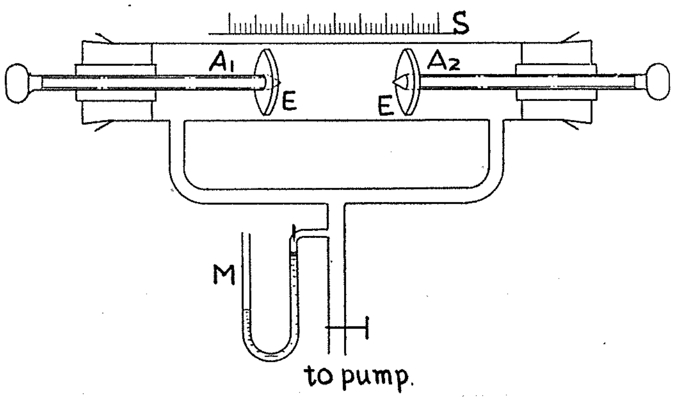
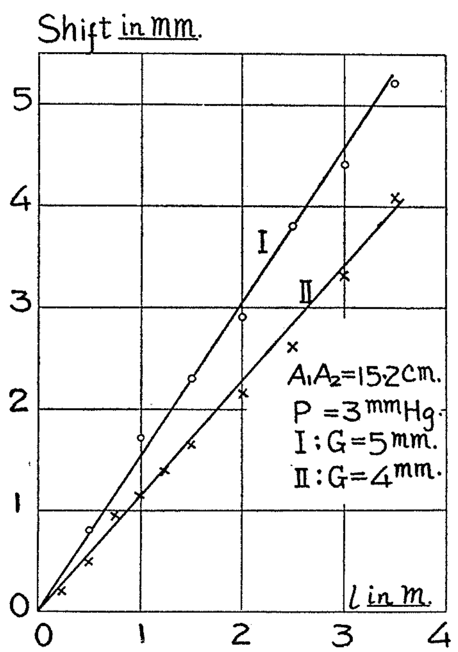


Diagram of low pressure tube

If the wire sA_1 was equal to sA_2 (see Fig. 6) and the sparks occurred at G with an interval of about one second, two discharges emitted by the electrodes A_1 and A_2 were observed to meet at the middle of the electrodes and a dark zone appeared there. When the needle point of the 'finder' (composed of a metallic needle of 5 cms. or more in length attached at one end to an ebonite handle, the latter being held by the hand) was moved to the middle of the dark zone by sliding it along the outside wall of the tube, brush discharges were seen to appear uniformly around it. If the path-difference became greater than 1.5 ms. or more, the dark zone became so diffused that it was difficult to determine the position of the middle of that zone with the naked eye. However, in this case, the point corresponding to the middle of the dark zone could be determined clearly by means of the finder. In such a way, it was found that the meeting zone was displaced from the half-way position of the electrodes A_1 and A_2 towards the electrode of the longer lead-wire providing that the amplitude of the electric impulse was sufficient.

Fig. 15 shows the relation between the shift of the meeting zone in question and the path-difference between the two lead wires, this figure was obtained for the negative impulse when the wire $A_1 s A_2$ was 4.5 ms. in length and the pressure of the vacuum tube was about 3 mms. of Hg. By means of the curves given in that figure, the writer could measure the short time interval from 3×10^{-10} to 10^{-3} secs.

Fig. 15



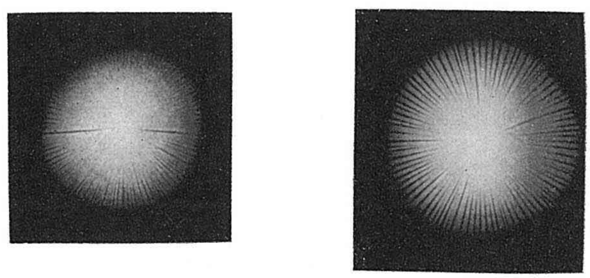
Relation between the shift of dark zone and the path-difference

The writer wishes to express his sincere thanks to Professor U. Yoshida of Kyoto Imperial University for his constant advice and most helpful criticism.

Plate I

Fig. 1

Path difference = 2 ms.

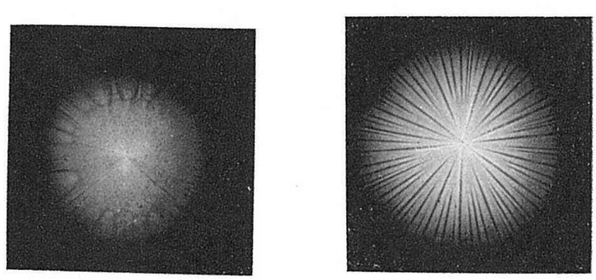


(a) Shorter branch

(b) Longer branch

Fig. 2

Path-difference = 9 ms.



(a) Shorter branch

(b) Longer branch