Onset Studies of Positive Point-to-Plane Corona in Air at Atmospheric Pressure

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Positive point-to-plane corona studies in air have been continued with special emphasis on pre-onset region. Oscillographic and photographic studies show two kinds of current pulses occurring below onset voltages. Both types of pulses can be observed by inductive effects on a plate placed near the gap and by the ion currents produced. At lowest voltages for counting action, pulses lasting for about 0.003 second are recorded on the oscillograph and are accompanied by a glow around the point as described by Trichel for steady corona. These correspond to the regular corona process continuing for several thousand bursts after which space charge modification of the field causes extreme likelihood of extinction. At voltages approaching corona onset, streamers are observed which extend far out into the gap and which can propagate only into a space-charge-free gap. The steady corona process is normally initiated by one of these streamers. The mechanism for both bursts and streamers is shown to involve space charge intensification of the field. Streamer propagation and stable burst corona both depend on photoelectric ionization in the gas. Streamer length is found to depend primarily on point size and for very fine needle points no distinction can be made between bursts and streamers. By the use of a shielding screen to cut out the electrostatic pulse produced by a streamer or a group of bursts, it was possible to determine the number of ions produced. This was found to be approximately 5×10^9 ions per cm of visible streamer, and about 2×10^9 ions in an average burst pulse. The time necessary for positive ions produced by a streamer to cross the gap was measured and found to be of the order of 10^{-3} second, and to vary with gap geometry in a way consistent with the minimum time between two consecutive streamers. Considerable photoelectric ionization was found to occur at the plate as much as 2.15 cm ahead of the visible streamers. Streamers occurring just prior to spark breakdown of the gap are associated with the pre-onset streamers. In this case the higher voltage near breakdown gives the high field necessary for streamer propagation despite space charge modification of the field by the stable corona process.

Introduction

As a result of observations by Loeb, that the positive point-to-plane corona consisted of many individual streamers, an extensive study of positive and negative point coronas has been undertaken in these laboratories. Previous papers by Kip[1] and Trichel[2,3] in these laboratories have investigated the current-voltage characteristics of positive point corona, the nature of the negative corona, and the essential characteristics of positive point-to-plane corona. The last investigation concerned itself with what was termed the burst corona. Subsequent improvement of technique and facilities have now made it possible to investigate the appearance and nature of the streamers in the two regions in which they occur. It is the purpose of this paper to consider streamer formation and the attendant phenomena.

Apparatus and Technique

The experiments were carried on in air, with gap geometry as described,[1] using hemispherically-ended wires of 0.5; 1.0; 2.0; and 4.7-mm diameters, made of platinum or brass. Steel needles were also used in some of the experiments. A 25-kv transformer supplied power through a half-wave rectifier and filter condenser. The voltage is stabilized by a saturable reactor stabilizer which provides the accurate voltage control necessary in these experiments.

Observations were made by photographs of the discharge itself and by photographed oscillograph records of the electrical impulses generated by the discharge. The impulses may be studied by two kinds of oscillograph pick-up, one the detection of the electrostatic pulse due to the appearance of charge (+ions) in the gap, and the other the detection of the ion currents collected at the plate. Fig. 1A shows the inductive method of detecting the electrostatic pulse with a metal disk placed in the vicinity of the gap. The disk is connected to the oscillograph and is shielded by a paper box to prevent the collection of ions by the disk. Fig. 1B shows the second method of pick-up where the voltage drop produced across a resistance in series with the plate is observed on the oscillograph.

[1] A. F. Kip, Phys. Rev. **54**, 139 (1938).
[2] G. W. Trichel, Phys. Rev. **54**, 1078 (1938).
[3] G. W. Trichel, Phys. Rev. **55**, 382 (1939).

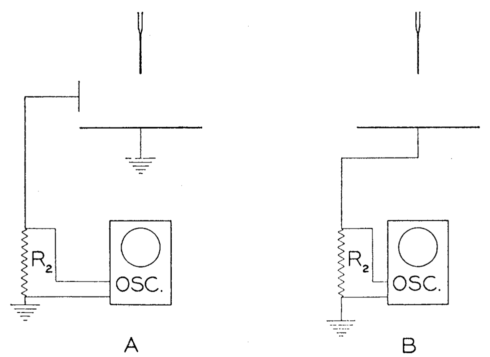


FIG. 1. A, Inductive method for detecting electrostatic pulses from corona with oscillograph. B, Method for detecting ion current and electrostatic pulses from corona with oscillograph.

Actually, this method picks up both the electrostatic signal and the ion current, but by introducing a shielding screen above the plate as shown in Fig. 2, the electrostatic signal may be cut out, so as to observe only the ion current pulse.

The oscillograph used is particularly suited to these experiments by virtue of its two stages of amplification, giving a sensitivity of 0.05 volt/inch on the screen, and by virtue of a single sweep circuit making it possible to observe and photograph separate events which would otherwise be superposed on each other on the oscillograph screen.

The radioactive source used to provide external ionization was an old radon ampule. Intensity of ionization in the region of the gap was regulated by moving the source to various distances from the gap, from a minimum of a few centimeters to over a meter away.

Experimental Results

With the radioactive source in the vicinity of the gap, as the voltage applied to the point is gradually increased, the field in the intense field region immediately surrounding the point eventually becomes great enough for electrons falling into the positive point to multiply as they travel. That is, α, Townsend's coefficient of electron multiplication, becomes large enough for each radioactively-produced electron to produce an avalanche of electrons, the magnitude of the avalanche depending on $\int Edx$ taken over the distance x, where E, the electric field, and therefore α, which depends on E, has a value large enough to produce multiplication. The maximum size of these single avalanches at potentials below the onset of stable corona vary from 10 to 10^4 electrons for various point sizes, and are too small to detect with the limited sensitivity of the oscillograph. As the voltage is increased, with the oscillograph placed in the plate circuit as in Fig. 1B, pulses begin to appear on the oscillograph, lasting up to about 0.003

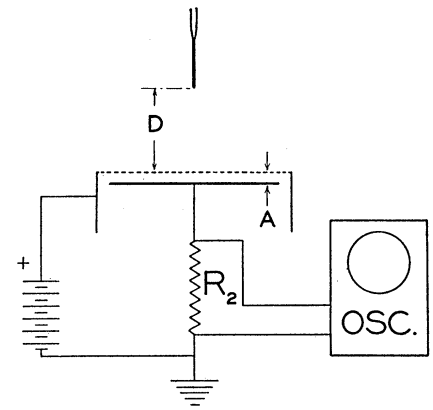


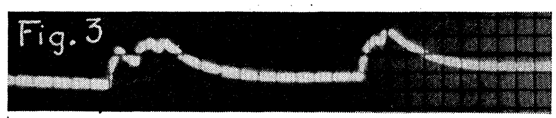
FIG. 2. Shielded plate for detecting ion current pulses with oscillograph.

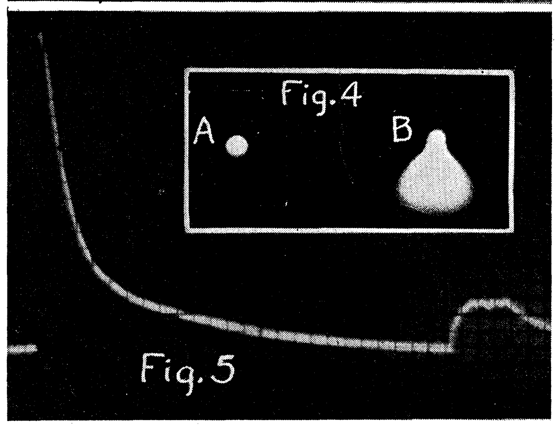
second, increasing in magnitude with increasing voltage from the smallest observable on the screen up to a size such as is shown in Fig. 3. With these pulses there is associated a glow around the point exactly similar to the glow which occurs in the stable corona process above onset voltages. A photograph of such a glow caused by many groups of bursts is shown in Fig. 4A. These pulses thus correspond to the initiating of self-maintaining corona by the external ionization, but because of the limited voltage applied, after the process has continued for about 0.003 second, accumulated space charge so weakens the field around the point that the process stops. The pulses are thus composed of many ($\sim 10^3$) unresolved separate discharges, partially resolved on the oscillograph by Trichel, and termed by him *bursts*. If the shielding screen is placed above the plate, the irregularities in the pulse disappear and one gets only the smooth pulse due to the collection of positive ions whose duration corresponds to the duration of the group of bursts, as modified by diffusion.

As the voltage is further increased, in addition to the bursts, there appear intense pulses on the oscillograph such as are shown in Fig. 5, where an intense pulse and a group of bursts appear on the same picture. Associated with these large pulses are faint streamers which penetrate far out into the gap and which make an audible noise. These will be termed pre-onset streamers, and a photograph of many of these is shown in Fig. 4B.

Both individual bursts and streamers are characterized by far greater ionization than is possible in an avalanche. Thus both must depend on a mechanism involving the space charge intensification of the electrostatic field. That is, the first avalanche of electrons leaves a positive ion column out from the point with an enhanced field at its tip. Ultraviolet light produced during the electron avalanche has meanwhile produced more electrons out in the gas by photoelectric ionization and these electrons make new avalanches as they fall into the intensified axial field of the extended point. This process repeats until diffusion of the ions, possible branching, and the naturally lower fields far out in the gap cause self-propagation to stop. There is then a time of relaxation necessary before another streamer or burst can propagate from this region, this time being the time necessary to restore the original high fields. Then if negative ions or electrons are present, a new streamer or burst can occur. It is to be noted that while the time of relaxation for streamers is of the order of 0.001 second, the bursts, which require smaller fields, can occur at the rate of 10^6 per second, by spreading laterally over the point surface as shown by Trichel, due to the lower fields necessary, which allows for new bursts despite incomplete clearing of the space charge.

It is important to note that all evidence indicates that the pre-onset streamers can occur *only* into a cleared gap, that is, one in which there are no space charges. In fact it is probable that not only do streamers require a certain starting field at the point, but furthermore they cannot propagate unless the tip of the streamer finds itself in a field which exceeds some minimum value. As soon as either a pre-onset streamer or burst pulse fouls the gap with space charge, the streamers cannot form. Hence after the first streamer, the space charge prevents the development of another streamer until the gap is cleared. However, a streamer may be followed immediately by bursts, since streamer propagation is so rapid as to allow very little lateral spread of the space charge over the point surface, and therefore fields sufficient for the production of bursts initiated by photoelectrons may exist over at least part of the point surface. Thus at slightly higher voltages, the streamer





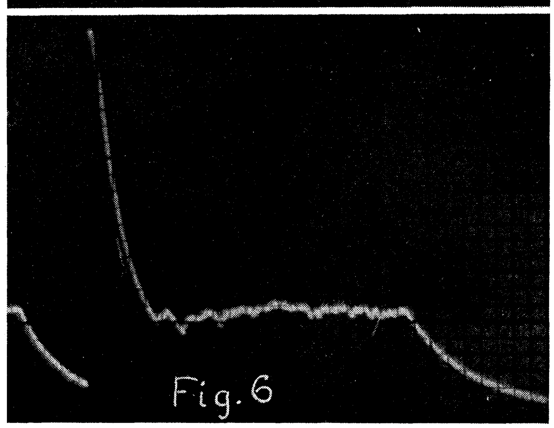


FIG. 3. Pulses of burst corona as shown on oscillograph, using pick-up method 1B. Duration of pulse is 0.003 second.

FIG. 4. A, Glow around point caused by a series of burst pulses. This is similar to the glow in stable corona. B, Picture of many pre-onset streamers. Five-minute exposure at *f*-2, with radioactive source near gap to produce streamers.

FIG. 5. Oscillogram of a streamer and a burst pulse, using pick-up method 1B.

FIG. 6. Oscillogram of streamer with plateau, using pick-up method 1B. Plateau is due to burst corona initiated by and immediately following streamer.

oscillograph may show a plateau as shown in Fig. 6. In this case the streamer is choked off as before, but in spite of the modification of the field around the point by the ions from the streamer, the field is great enough so that these ions can initiate a burst pulse or, if the voltage is high enough, the streamer will initiate stable burst corona. In fact, under most gap geometries, stable corona is always initiated by one of these streamers. An exception to this is the case of very fine needle points, which will be discussed later. These initiating streamers have previously been noted and termed a brush discharge[4, 5] but largely ignored owing primarily to the extremely narrow voltage range in which they can occur, and because they occur only as the initial stage of stable corona.

The variation of streamer length with gap geometry is shown in Fig. 7, where streamer length is plotted against the radius of curvature of the hemispherical points for 3- and 6-cm gaps.

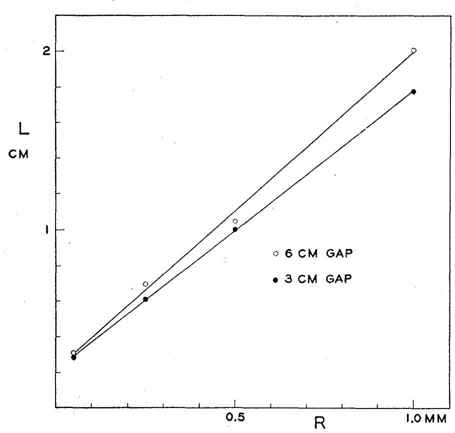


FIG. 7. Length of visible pre-onset streamers plotted against R, the radius of curvature of the point, for 3- and 6-cm gaps.

Since the streamer length depends primarily on the shape of the high field region of the gap, little variation of streamer length with gap distance is to be expected. It is seen that with large radius of curvature where the high fields extend farther into the gap, the streamers are longer.

Observations with a series of needle points of different sizes show that as the size of the point is decreased, streamers become smaller and smaller and finally there is no distinction between bursts and streamers as shown in the oscillograph pictures of Fig. 8. This is more or less to be expected, since the high field region for smaller points becomes extremely short, in which case the streamers become shorter and shorter, until no distinction can be made between bursts and streamers.

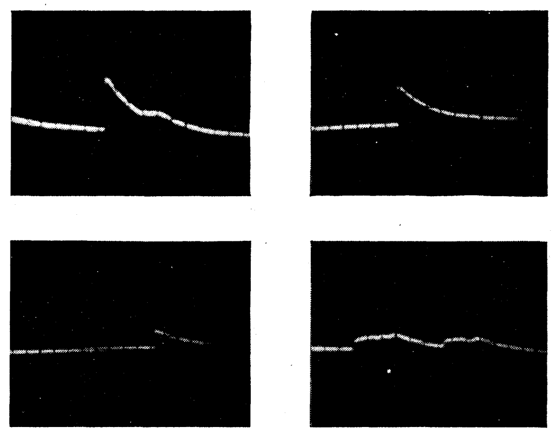


FIG. 8. Oscillogram taken by method 1B, showing decrease in size of streamer pulse with decreasing point size.

Trichel has estimated the number of ions per burst as of the order of 10^7 ions. Using the shielding screen as shown in Fig. 2, it was possible to measure the number of ions produced by either a series of bursts in a burst pulse or by a streamer. A voltage V' was put between the screen and plate such as to draw most of the positive ions through to the plate. Connecting the oscillograph across R_2 in series with the plate, the pulse obtained is caused entirely by the collection of positive ions at the plate. Knowing the sensitivity of the oscillograph, its time scale, and the value of R_2, the number of ions in the pulse can be calculated. This value must be corrected for the fraction of the ions which are collected at the screen. This is done approximately by increasing the gap voltage above onset, where the ratio of steady currents to plate and screen can be measured by a micro-ammeter. This fractional loss to the screen is then corrected for in the calculations. The results of such measurements and calculations show that the number of ions produced is proportional to

[4] M. Toepler, Ann. d. Physik **2**, 560 (1900).
[5] J. Zeleny, Phys. Rev. **3**, 69 (1914); J. Frank. Inst. **218**, 685 (1934).

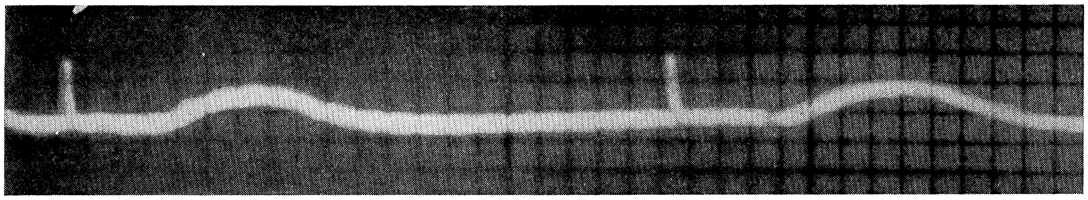


FIG. 9. Oscillogram taken by method 2, with screen moved aside to allow recording of small electrostatic pulse at time of streamer propagation, followed by ion current at plate. Pulses from two streamers are shown.

the length of the streamer, giving approximately 5×10^9 ions per cm of visible streamer. In the normal burst pulse in the same region the number of ions is about 2×10^9. Hence the fouling of the gap by a burst pulse is not very different from that in a streamer.

This last experimental arrangement may be modified to give the time the positive ions formed by the streamer take to cross the gap. Thus if the shielding screen is moved to the side so that a small part of the plate is no longer shielded from the electrostatic pulse, the oscillograph will show not only the pulse due to the ions collected at the plate, but also a small inductive kick will mark the point on the time axis when the streamer occurred. Such an oscillograph picture is shown in Fig. 9 where the time between the inductive pulse and the maximum of the ion pulse is 0.005 second. Fig. 10 shows a plot of this time interval for various points at 3- and 6-cm gap lengths. In such measurements, the distance A and voltage V' are of such magnitudes as to make the time for the positive ion travel through the distance A negligible with respect to the total time interval measured.

Observations gave evidence that sometimes streamers are repeating, that is, apparently streamers sometimes occur in groups of from two to five. This indicated that under some conditions the ionization produced by a streamer is effective in starting a new streamer after at least most of the space charge is removed from the gap. The arrangement in Fig. 2 was found to enhance this self-repetition and to make possible the verification of the mechanism. In this arrangement it is possible to vary the distance A and the voltage V' between screen and plate. Using the 2.0-mm diameter point with the gap distance D at 3.0 cm, and setting the gap voltage V to the streamer region, it was found that the application of a certain range of voltages V', depending on the distance A, would cause series of up to more than 20 streamers to occur, following each other at a nearly uniform frequency. The frequency of the streamers increased as V' was increased, up to a certain maximum frequency when the streamers cease to occur unless a radioactive source is present to start them. The frequency was investigated as a function of V' and A, where A was varied from 2.0 to 11.5 mm.

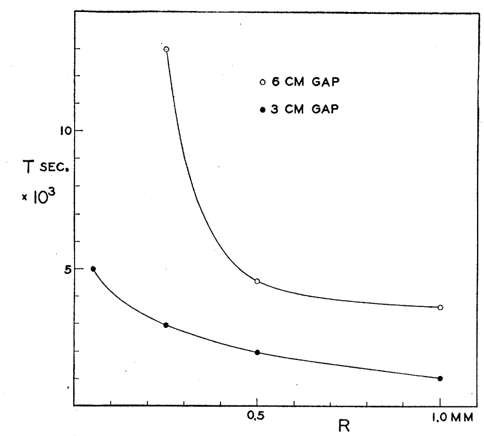


FIG. 10. Time of positive ion transit from streamer to plate *vs.* R, the radius of curvature of the point. Time measured from oscillograms similar to that shown in Fig. 9.

From the nature of the experimental results, the mechanism of repetition must be explained on the following basis, which necessitates photoelectric ionization at the plate by the ultraviolet light emitted by the streamer. Regardless of whether or not the screen is in place, electrons must be photoelectrically produced at the plate and must attach to O_2 molecules almost immediately, to form negative ions. There are also electrons produced in the gas, as will be shown below, but in the region A, the number of these is apparently not appreciable as compared to those produced at the plate, and not sufficient to initiate a new streamer. If D is not too great (~ 3 cm), and the screen is not present the negative ions so produced are swept into the point before the time of relaxation has elapsed and therefore cannot serve to initiate a new streamer. However, with the screen in place, the values of V' and A are such as to give a lower field in region A than would exist without the screen. Under such conditions the negative ions produced at the plate travel slowly enough to allow the main gap to clear, after which the group of negative ions are able to initiate a new streamer as they fall into the point. As the field in region A is increased, the time for the negative ions to pass through A becomes less, and they reach the point sooner, causing increased frequency of streamers until finally repetition ceases when the negative ions are getting into the point before the time of relaxation has elapsed.

The correctness of such an assumed mechanism may be shown as follows. Let t_1 = time for negative ions to travel through A. This will be given by $t_1 = A/kE = A^2/kV'$, where k is the ion mobility and E is the field strength. t_2 = time for ions to cross gap D. This is constant for a given point and gap.

Then if the time between the streamers and the appearance of negative ions at the plate is negligible (as it will be if the ionization is photoelectric), the time between streamers will be $T = A^2/kV' + t_2$, or the frequency of streamers will be

$$F = \frac{1}{A^2/kV' + t_2}.$$

Figure 11 shows a plot of F *vs.* V'/A^2, where A has been varied from 2.0 to 11.5 mm, and V' from 22.5 to 585 volts. The curve drawn in represents the values of F given by the equation when t_2 is taken as 0.001 second and $k = 1.3$ cm/sec. per volt/cm. Considering the wide range of values for A and V' used, the fit is remarkably good, and leaves little doubt as to the validity of the assumed mechanism. The spread of values is most likely due to the difficulty in assigning the exact value of A in each case, together with the difficulty in assigning the exact frequency. It is important to note that this gives proof that photoelectric ionization occurs at the plate, in the most extreme case, 2.15 cm beyond the end of the visible streamer.

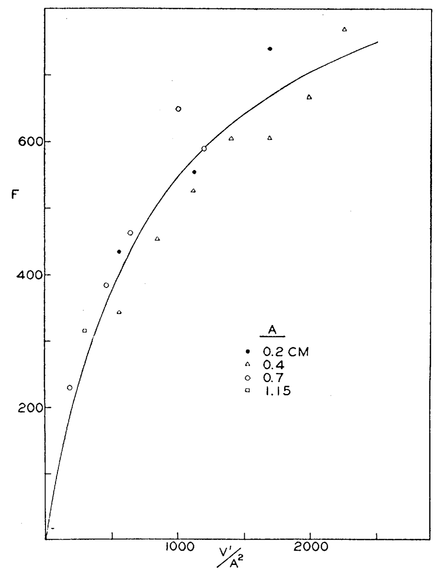


FIG. 11. Frequency of streamer repetition plotted against V'/A^2 for various values of V' and A. Curve drawn in is theoretical value, assuming k, the negative ion mobility $= 1.2$ cm/sec./volt/cm, and $t_1 = 0.001$ second. 3-cm gap, using 1.0-mm radius point.

Verification of this mechanism for larger gap distances becomes increasingly difficult, because with larger gaps there is some chance of repetition without the screen present, since ions formed in the gap begin to take long enough to reach the point for the relaxation time to elapse, and also, the photo-ionization at the plate rapidly becomes weaker as the gap increases, until the process finally stops.

Proof of photo-ionization in the gas (which is hardly necessary in view of the known mechanism of streamer propagation) is obtained if, for the same point, the gap is reduced to 2.0 cm. In this case the visible streamers get completely across to the screen, but do not penetrate and one would expect heavy ionization in the gas in region A. This is shown to be the case by the fact that varying V' no longer changes the frequency of repetition, which means that repetition does not depend on ions formed at the plate, but on those formed throughout region A. However, if zero or reversed voltage is applied between screen and plate, the ions formed do not get out into the gap and repetition ceases.

The foregoing experiments with repeating streamers provide the explanation of the action of fine needle point streamers. With fine points there is considerable evidence for repetition. Groups of 4, 5 or more streamers are often seen on the oscillograph. This can be explained by the fact that for small points the high field region is more radial and much more concentrated around the point. The field is much weaker around the gap where photo-ionization can occur than for larger points, with the result that the negative ions formed travel much more slowly towards the point, allowing the time of relaxation to pass before they all reach the point, while the streamer space charge projected towards the plate is swept out nearly as fast as before.

Still another way to obtain repeating streamers is to put a high resistance (of the order of 10^9 ohms) in series with the point. With this, when a streamer propagates, the electrons falling into the point lower the point potential instantaneously until the charge leaks through the resistance. The effect of this lowered potential is to increase the time of relaxation and also increase the time taken by the photoelectrically produced negative ions to fall into the point. The effect on this latter time is greater, so that with the series resistance the gap is effectively cleared by the time the negative ions reach the point, giving repetition of the streamers. In the early work of Toepler,[4] the same effect was produced, because the voltage was supplied by an electrostatic generator of limited capacity. Thus Toepler noted that the positive glow discharge was preceded at lower voltages by a brush discharge, which must now be interpreted as a series of repeating pre-onset streamers, brought about by the lowering of the point potential by each streamer. That this is the actual mechanism is shown by the fact that with the high resistance in the point circuit, if the electrostatic pick-up is above the gap and near the point, a negative pulse is seen, instead of the positive pulse which occurs when the pick-up is placed near the gap. This negative pulse gives proof that there is considerable actual lowering of the point potential.

An additional effect of a series resistance in the point circuit is that if the resistance is of the order of 10^8 ohms or more, the streamer length is decreased. A resistance of 2.4×10^9 ohms decreases the length of the streamers by about 25 percent. This is to be expected in view of the mechanism of virtual self-extension of the positive point by succeeding avalanches of electrons leaving behind positive ions. As each avalanche of electrons falls into the point it causes a lowering of the potential of the point, and the consequently lowered fields cause extinction of the streamer before it attains its normal length. If the streamers were not decreased in length it would indicate that streamer propagation was so rapid that there was not time for electrons to reach the point before the streamers stop propagating. This is consistent with the very rapid propagation of electrons up ionized streamer channels observed by Schonland and Collins,[6] Allibone and Meek,[7] and especially Snoddy, Dietrich and Beams.[8]

Since the photographic intensity of the streamers is weak, it has so far been impossible to get pictures of less than about 50 streamers more or less superposed on each other. A single streamer picture would be highly desirable, since it would show whether or not the streamers are forked, as might be expected in view of the mechanism of their propagation. There are, however, two lines of evidence for forked streamers. It is seen that the streamers shown in Fig. 4 all start vertically downward in a narrow column and then spread out. This spreading out indicates at least that the streamers bend rather sharply, and it is certainly more reasonable to explain the bending by a branching of the tracks. Perhaps better evidence for forked tracks comes from the cloud chamber pictures of single pre-onset streamers taken by Gorrill in this laboratory, and those of breakdown streamers (see below) of Bradley and Snoddy,[9] Raether,[10] and Nakaya and Yamasaki,[11]

[6] B. F. J. Schonland and H. Collins, Proc. Roy. Soc. **A143**, 654 (1934).
[7] T. E. Allibone and J. M. Meek, Proc. Roy. Soc. **A166**, 97 (1938).
[8] L. B. Snoddy, J. R. Dietrich and J. W. Beams, Phys. Rev. **52**, 739 (1937).
[9] C. D. Bradley and L. B. Snoddy, Phys. Rev. **47**, 541 (1935).
[10] H. Raether, Zeits. f. Physik **94**, 567 (1935).
[11] U. Nakaya and F. Yamasaki, Proc. Roy. Soc. **148**, 446 (1935).

which show considerable branching, both near their beginning, as suggested by Fig. 4, and also near the end of the track, where 4 or 5 branches may occur. The failure to observe branches visually in such streamers is doubtless because of their feeble intensity.

As has been stated earlier, the pre-onset streamers can occur only in a cleared gap, and therefore cease as soon as stable burst corona sets in. However, at voltages approaching values near those for spark breakdown of the gap, streamers similar in appearance to the pre-onset streamers may appear. In this case the voltage has been so much increased that in spite of the space charge modification of the intense field region of the gap by the stable burst corona process, fields are great enough to allow streamer propagation. For a 0.5-mm diameter point, with a 6-cm gap, pre-onset streamers occur at 5.4 kv. Breakdown streamers appear above 40 kv. These streamers are unaffected by external ionization provided by a radioactive source, since the stable corona provides a continuous source of ionization. The minimum length of these breakdown streamers depends on gap geometry as in the case of the pre-onset streamers, but for a given size of point, the breakdown streamers are much longer than the pre-onset streamers. Thus for a needle point with 0.05-mm radius of curvature the minimum length of the breakdown streamers is approximately twice that of the pre-onset streamers. The length of the breakdown streamers is found to be decreased by a high series resistance, as was the case for onset streamers, presumably for the same reason, as explained above.

In contrast to the pre-onset streamers, whose occurrence is limited to a narrow voltage range, breakdown streamers persist from the voltage at which they begin up to spark breakdown. Under some gap geometries this range may be quite large, and may allow the measurement of the length of streamers as a function of applied voltage. A typical case was studied using the 0.05-mm needle point with a 6-cm gap distance, and eventually spark breakdown occurs. With larger points, the minimum length may be equal to the gap distance and breakdown may occur at once upon the appearance of the breakdown streamers. These streamers are the primary mechanism of spark breakdown in all cases. As soon as the streamers reach the plate cathode with enough intensity to form a cathode spot giving a copious supply of electrons, the discharge becomes unstable, a return stroke occurs, and spark breakdown ensues.

The similarity of pre-onset and breakdown streamers can be shown by the phenomena occurring near the corona point distance, that is, the gap below which spark breakdown occurs without the appearance of stable corona. The variation of this distance as a function of point size was investigated and given previously.[1] At the time these experiments were carried out, it was found that under certain conditions, stable corona could be maintained with gaps less than the corona point distance; namely, if enough resistance was placed in the gap circuit so that spark breakdown would be extinguished by the *IR* drop in the resistance, it often happened that after a spark, stable corona would occur and would continue through a considerable voltage range before breakdown again occurred. Present knowledge of the pre-onset streamers makes this easily understood. At less than the corona point distance, the pre-onset streamers reach completely across the gap with such intensity as to insure the production of a cathode spot and consequent spark breakdown. Since these streamers are the inevitable precursors of stable corona, spark breakdown necessarily takes place. However, if the spark is choked off by a series resistance, the ions in the gap prevent immediate repetition of another streamer, and at the same time allow for the initating of stable corona. Thus both types of streamers are found to produce spark breakdown in the same way, and the short gap phenomena are completely explained.

In conclusion, the author wishes to express his gratitude to Professor Loeb for his hearty support and guidance and valuable assistance in interpretation during the carrying out of these researches.

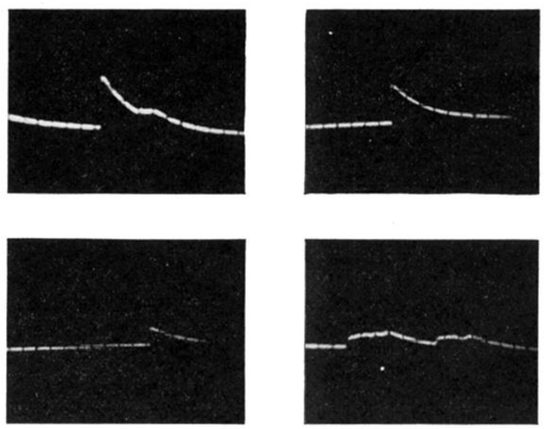


FIG. 8. Oscillogram taken by method 1B, showing decrease in size of streamer pulse with decreasing point size.

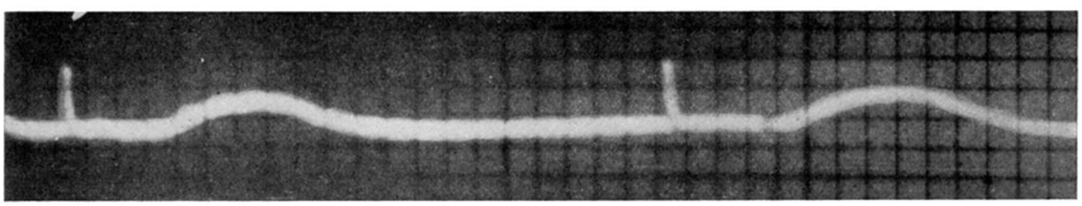
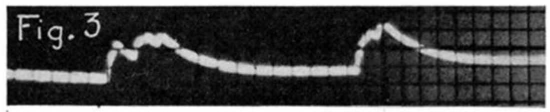
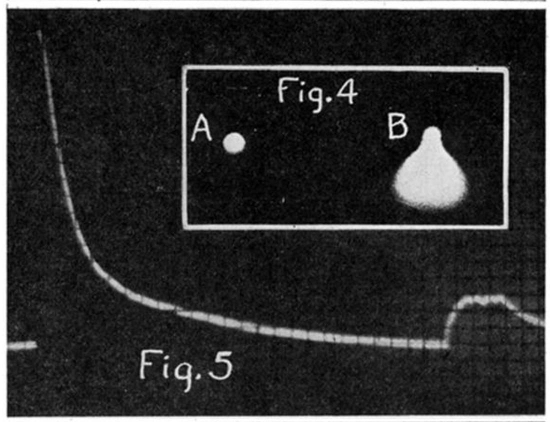


FIG. 9. Oscillogram taken by method 2, with screen moved aside to allow recording of small electrostatic pulse at time of streamer propagation, followed by ion current at plate. Pulses from two streamers are shown.





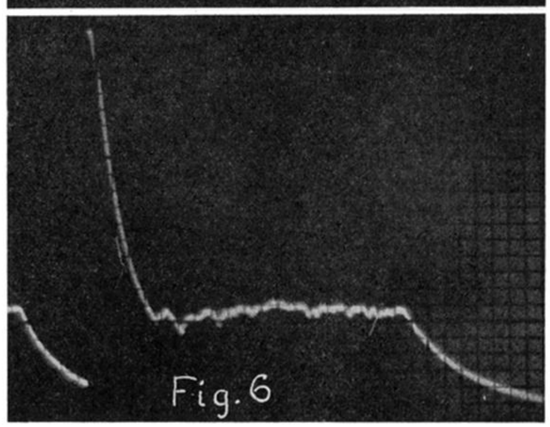


FIG. 3. Pulses of burst corona as shown on oscillograph, using pick-up method 1B. Duration of pulse is 0.003 second.

FIG. 4. A, Glow around point caused by a series of burst pulses. This is similar to the glow in stable corona. B, Picture of many pre-onset streamers. Five-minute exposure at *f*-2, with radioactive source near gap to produce streamers.

FIG. 5. Oscillogram of a streamer and a burst pulse, using pick-up method 1B.

FIG. 6. Oscillogram of streamer with plateau, using pick-up method 1B. Plateau is due to burst corona initiated by and immediately following streamer.