An Investigation of a Point Discharge in a Magnetic Field.

By Oscar William Silvey.

Since the announcement of the magnetic deflection of the electric arc and of the path of the particles of a vacuum tube discharge, there has been some investigation of the electric discharge in a magnetic field at atmospheric pressure.

Among the first of these investigations was that of Precht,[1] who found that when a spark passed transverse to the lines of force in a magnetic field, between a point anode and a blunt cathode, there was a deviation of the path of the spark, especially from the middle portion of the spark gap to the cathode, the spark increased in brightness, and there was a decrease in the fall of potential between the electrodes. Also, if the electrodes were separated farther until a brush discharge existed between them, the stream showed a deflection, the potential between the points decreased, and the brush often changed into a spark discharge, when the electro-magnets producing the field were excited. In case of the glow discharge, where there existed a small brush at the anode and a bright spot on the cathode, with the intervening space dark, the spot moved up or down according to the electrodynamic laws, when the field was magnetized first in one direction and then in the other.

In case a point cathode was used with a blunt anode, the spark was deflected and the potential raised, when the magnet was excited the spark discharge being often changed to a brush.

[2]H. E. Schaeffer has recently studied the effect of the magnetic field on the spark discharge of an induction coil in each of the following types of spark:

"1. The spark obtained when neither capacity nor self-induction had been introduced into the secondary circuit of the induction coil.

"2. The spark obtained when a capacity of 0.005 to 0.012 microfarads had been introduced into the secondary circuit.

[1] J. Precht, Wied. Annalen (66-4, pp. 676, 697), 1898.

[2] H. E. Schaeffer, Astro-Physical Journal (28, pp. 121-149), Sept., 1908.

"3. The spark obtained when a capacity of .0005 to .012 M. F. and a self-induction of 0.003 henrys has been introduced into the secondary circuit."

In this study it was found that "when the magnetic field was parallel to the spark length, the first type of spark presented two sheets of vapor in the form of spirals. In a field at right angles to the spark length this vapor is in the form of two semicircular sheets, one being on each side of the spark gap in a plane perpendicular to the direction of the magnetic field.

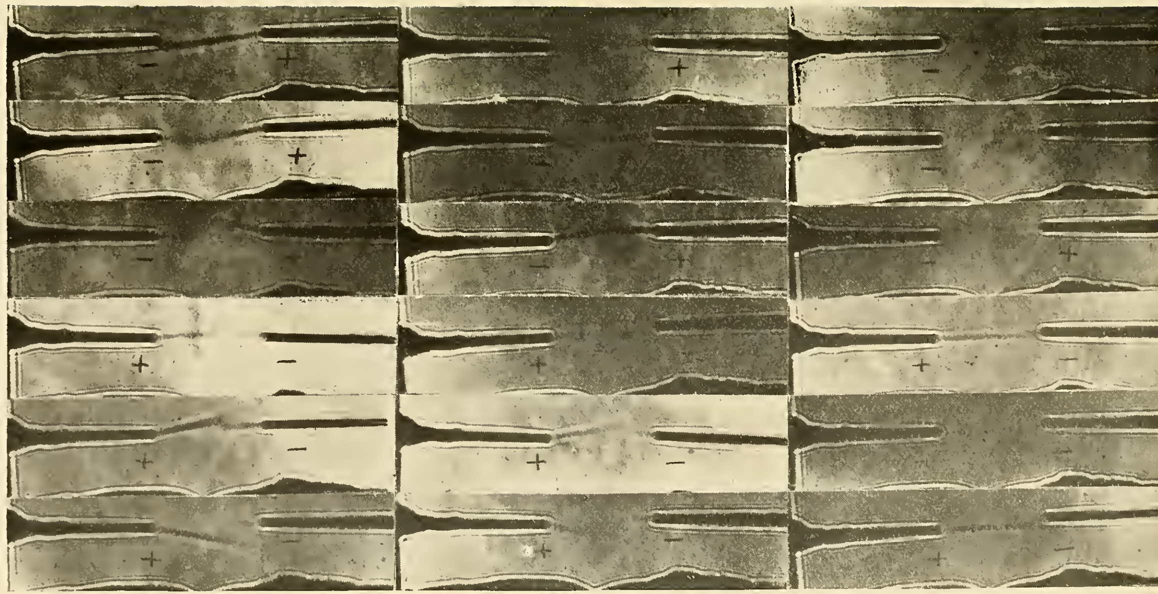
"In the second type of spark (if the capacity did not exceed .002 M. F.) and in the third type brilliant spiral threads in a parallel field and brilliant circular threads in a transverse field took the place of the spiral and circular sheets respectively. In the first and second types of spark the bundle of threads across the gap could not be deflected by a magnetic field of 12,000 gausses. In the third type the metallic vapor and the threads across the gap were deflected in a very strong field and in a manner analogous to that of the circular and spiral threads. Reversing the direction of the magnetic field, or that of the current through the primary of the induction coil, changes the position of the sheets and of their ends. Decreasing the current through the primary or lengthening the spark gap sufficiently, causes one sheet or one set of threads to disappear."

The different parts of the deflected spark were analyzed by the spectroscope, and it was found that the "Circular sheet of the first type of spark gave a spectrum of nitrogen bands, while the central threads showed that of the metallic lines and the air lines. The second type gave the same spectrum of bright air lines, and fainter metallic lines, for both circular threads and central threads. The third type showed the same spectrum (air lines) for all metals used as electrodes. The spectrum of the circular threads showed the arc lines in addition to the air lines."

By means of a rotating mirror, the velocity of the circular threads of the spark was determined, and from this a value for $\frac{E}{M}$ calculated.

Prof. A. L. Foley[1] passed transversely through a long tube which served as a pinhole camera an electric discharge and observed that when a photographic plate was placed at the opposite end of the tube from the pinhole, the plate after exposure showed a shadow picture of a stream

[1] Not yet published.



No. 1. No. 2. No. 3. No. 4. No. 5. No. 6.

A. B. C.

No. 1. Current first direction; magnetism (none).
No. 2. " " " " 1st direction.
No. 3. " " " " 2d "

No. 4. Current second direction; magnetism (none).
No. 5. " " " " 1st direction.
No. 6. " " " " 2d "

between the points which were used as electrodes. The picture of this stream was surrounded by interference or diffraction fringes, in some ways resembling the fringes about the solid points themselves.

The principal object of the present investigation was to study the effect of a magnetic field upon this stream and to study the character of the particles composing it.

The apparatus used was that constructed by Prof. Foley and Mr. Haseman for the investigation of interference fringes about a point discharge, air streams, and vapor streams. It consisted of a wooden tube 6.87 meters long (Fig. 1). One part 20.3x20.3x230 cm. was made to telescope over another part 15.2x15.2x457 cm. This provided a means of separating the two parts for adjusting the points and magnets. Another portion (E., Figs. 1 and 3) containing a plate holder (F) was made to fit over the end. The tube was painted a dead black inside, and at intervals screens (Fig. 9) were placed throughout the tube so that no light would be reflected from the sides. An opening was made in the lower side of the tube beneath the points and through this opening a magnet was introduced so that the lines of force were perpendicular to the direction of the line of discharge. During the latter part of the experiment a similar opening was cut in the top of the tube and a second magnet placed above the first one so that like poles faced each other. Figs. 4, 5, 6 and 8, show the successive attempts to increase the field strength. The end of the tube (C) was closed by a cap which shut out all light except from a pin hole, as shown by Fig. 2. A circular disc with holes of various sizes provided a means of regulating the amount of light. A is a 90° arc lamp, the crater of which is focussed on the pin hole by the lens B.

Light was shut out of the tube by placing a piece of black card board in front of the pin hole. When a photograph was to be taken, if the discharge was a silent or brush, the slide (S) was drawn from over the plate, and after the tube had come to rest, the card board was removed until the plate was sufficiently exposed. In case of the spark discharge which fogged the plate if exposed too long, the card board was first removed and the exposure made by withdrawing the slide.

The points first used were made of sharply pointed brass pins 0.61 mm. in diameter and 3 cm. long. In the latter part of the experiment the brass pins were replaced by steel millinery needles 0.70 mm. in

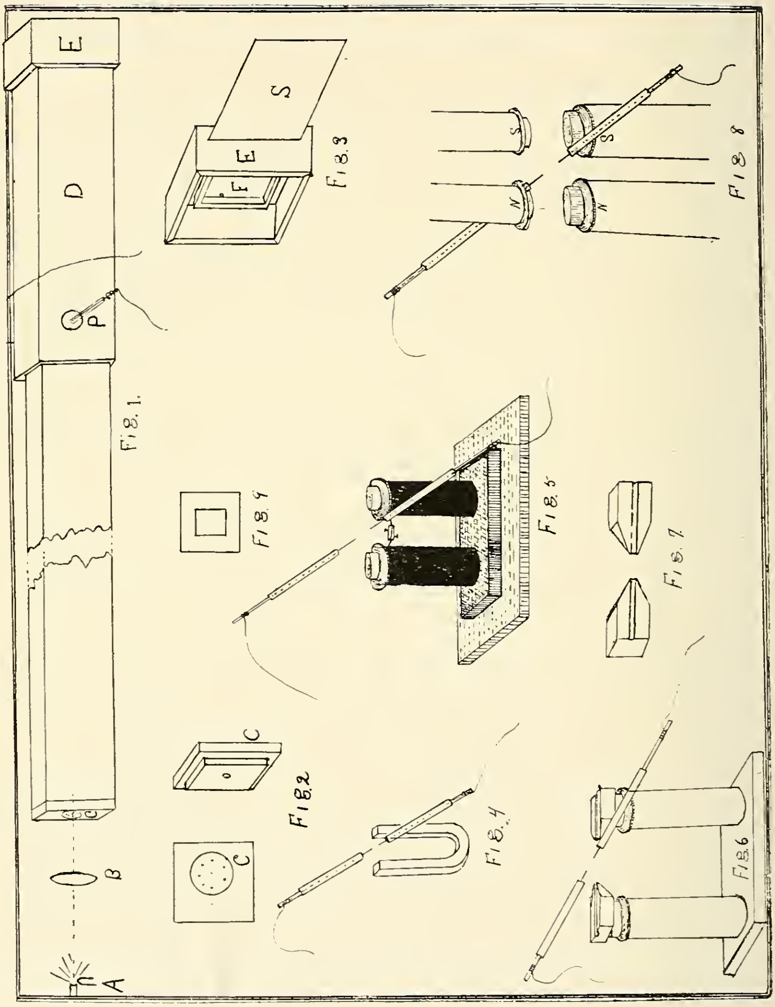


Fig. 1.
A
B
C
D
E
P
Fig. 2
C
Fig. 3
E
F
S
Fig. 4
Fig. 5
Fig. 6
Fig. 7
Fig. 8
N
S
Fig. 9

diameter and 5.2 cm. long. They were soldered into the ends of brass rods 0.5 cm. in diameter. The rods were placed in glass tubes and held firm by sealing wax at the two ends of the tubes. The points were charged by means of a four-mica-plate Wagner static machine (the Leyden jars had been removed), which was run by an electric motor with a rheostat in circuit for regulating the speed. The rods extended through the sides of the camera as shown by (P) Fig. 1, so that the points were near its axis. The points were about 15.5 mm. apart for the first three series of photographs and about 17 mm. apart for the last four series.

For the first series of photographs the magnet extended through the lower side of the tube directly below the points and was placed so that the tops of the pole pieces were about 0.5 cm. below the points. When the separable pole pieces, Fig. 7, were used they were covered with a layer of sealing wax about 3 mm. thick on all sides except the one facing the magnet cores, to prevent sparks passing to the magnet from the points.

As a preparation for the experiment the simpler part of Precht's work was repeated (i. e., apparatus was set up containing one point and one blunt electrode in the same position shown by the points in Fig. 6). The deflection of spark, brush and glow discharge were easily observed in a semi-darkened room when a transverse field was produced by exciting the magnets. Some cases were observed in which the discharge was transformed from one type into another. but no measurements were made of the potential, nor determination made of the signs of the charge on the points to see if they accorded with the results given by Precht.

The magnets and points were then placed in the tube as described and photographic records made of the discharge. The silent discharge was first studied. To produce the magnetic field a permanent horseshoe magnet was first used, and although it was strong enough to blow out the arc of an arc lamp, the photographs taken showed no deflection of the stream. It was then replaced by an electro-magnet, Fig. 5, later pole pieces, Fig. 7, were placed as shown in Fig. 6, and finally two electro-magnets placed in opposition, Fig. 8, in attempts to produce a field sufficiently strong to deflect the stream. The magnets were weak compared with those used by Precht and H. E. Schaeffer. The field measured only about 1,000 gausses as used in Figs. 5 and 6, and only about 1,500 gausses as used in Fig. 8. None of the photographs taken of the silent discharge showed any deflection when the magnets were excited.

Seven series of photographs were then taken.

A—Is a visible spark discharge.

B—Is a Brush discharge (a violent stream extended about 0.8 cm. from the positive point. The negative point showed only a bright speck).

C—The glow or silent discharge. (Nothing was visible between the points in the darkened tube. Each point showed a bright speck.)

D—Spark discharge representing the highest speed of the machine and highest potential between the points.

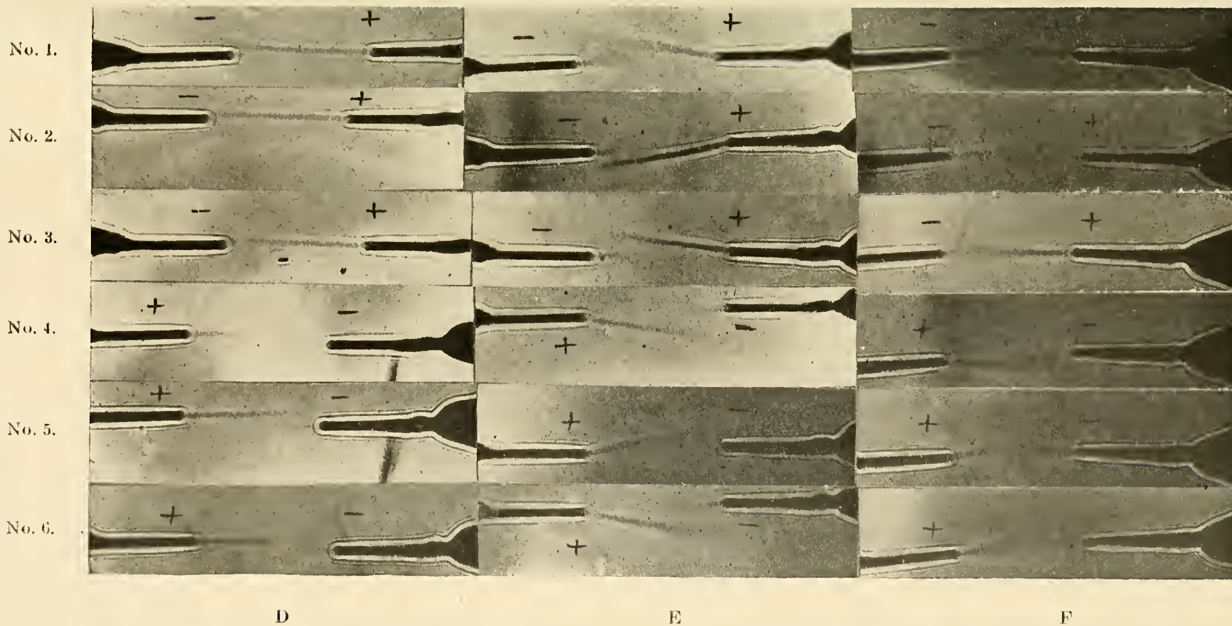
E—Spark discharge, representing the lowest speed of the machine at which a visible spark passed between the points. A lower speed would have caused the spark to change to brush.

F—Silent discharge, same as C.

G—Silent discharge, same as C. Deflected by a stream of air issuing from below the points.

The different series in decreasing order of their potential as represented by the relative speed of the machine are D, A, E, B (C, F or G). Series A, B and C were taken with magnet and pole pieces as represented in Fig. 6. The magnetic field strength was about 1,000 lines per sq. cm. in the region of the points. The points were 15.7 mm. apart. Series D, E and F were taken with the magnets as shown in Fig. 8. The magnetic field strength in the neighborhood of the points was about 1,500 lines per sq. cm.

The six numbers of each series, A, B, C, D, E and F, were taken in succession as rapidly as possible, it requiring 20 or 30 minutes to complete the series. In the photograph the longer stream is the one from the positive terminal and the shorter one the stream from the negative electrode. If the positive stream is from right to left it is designated as "first direction," if from left to right, as "second direction." Nos. 1, 2 and 3 then show current in the "first direction," while Nos. 4, 5 and 6 show current in the "second direction." If the magnets were excited so that the direction of the lines of force were from the front to the back of the photograph (i. e., after correcting for the reversal in direction caused by printing from the plate), the direction of magnetism is designated as "first direction," and those with the lines of force from back to front of the page are designated as magnetized in the "second direction."



No. 1. Current first direction; magnetism (none).
No. 2. " " " " 1st direction.
No. 3. " " " " 2d "

No. 4. Current second direction; magnetism (none).
No. 5. " " " " 1st direction.
No. 6. " " " " 2d "

Following then this plan, Nos. 1 and 4 show the current when the magnets are not excited. Nos. 2 and 5 show the current in a field of the "first direction," and Nos. 3 and 6 show it in a field of the "second direction." It may be observed from the photographs that the streams in series A, B, D and E are deflected as if they were flexible conductors bearing a current, in so far as direction of deflection is concerned, thus indicating that the stream is one of charged particles.

But some characteristics of the photographed stream are hard to explain on the theory that the air is ionized and that the stream consists of charged particles. The glow discharge and the negative stream in all cases show no deflection in a field of 1,500 gausses. Also the stream goes in a straight line after leaving the point instead of following a curved path to the opposite electrode, and there seems to be no connection or joining of the negative and positive streams. In some ways it acts as the air and vapor streams investigated by Professor Foley and Mr. Haseman. In case of the silent discharge, where the machine was run at its lowest possible speed and the potential was the lowest, the stream retains the same size as far as it can be traced. In series B there is not much change in the width of the stream. Series E shows the stream growing broader as the distance increases from the electrode. Series A shows a still greater broadening and D an even greater dispersion. The greater pressure in the stream no doubt accompanies the greater potential difference, and therefore accompanies the greater dispersion of the stream, as was shown to be true in case of air and vapor streams by Professor Foley and Mr. Haseman. Series E and B show a greater deflection than any other series, and since B was the highest potential brush discharge and E the lowest potential spark discharge which could be obtained without a transformation of the type of discharge, these few photographs indicate that the greatest magnetic deflection is produced when the discharge is on the verge of changing from one type into the other. Enough photographs were not taken to verify this, however.

It will be observed in Nos. 1 and 4 of the series E that the stream does not always pass along a line directly between the points, even when the discharge takes place outside a magnetic field. In the observations made such cases were in a minority, the discharge as a rule passing directly between the points or nearly so. The cause of its deviation in these few cases was not learned.

Also, very often when adjusting the speed to obtain photographs for series B and E the discharge would change from one type to the other when the magnets were excited. Precht found that this was the case, but these observations can hardly be compared with his, since point electrodes were used in this case, while he used one point and one blunt electrode. In all cases observed where a change occurred, if a brush discharge in a nonmagnetic field passed above or below a line directly between the points as shown by the spark discharge E, 1 and 4, and the magnets were excited to deflect the stream in such a way as to make the path of discharge shorter, it changed to a spark discharge. Or if a spark discharge passed directly between the points and was deflected it changed to a brush. In all observed cases (possibly 25 or 30) the transformation could be explained by the change of distance.

The series G shows the effect of an air current on the path of discharge. The air current was led into the camera through the bottom side by means of a glass tube 2.25 cm. in diameter so that the mouth of the glass tube was 2.2 cm. below the points, and flowed at the rate of about 1,200 c. c. per second. Nos. 1 and 3 show the discharge without the air current, and Nos. 2 and 4 show deflection by the air current. It differs from the deflection produced by the magnetic field in that the greater deflection here is with the negative stream. This indicates that the pressure is not as great in the negative stream as in the positive, which agrees with the work of [1]S. Arrhenius, who measured the torsion produced by a suspended wire cross with points bent at right angles to point in the same direction and found that the torsion produced by the negatively charged wire was less than the positively charged wire, which was more clearly shown the lower the potential. (Note—It was intended to show a photograph with current in second direction, deflected by an air current. G 4, which should have shown this, shows a current in the same direction as G 2, which was due to a reversal of polarity of the machine. The error was not observed until the apparatus was torn down.)

Series H shows photographs of the points when the poles of the machine were placed close enough for a spark to pass between them. It was found that when a spark passed between the poles of the machine there was a violet stream (brush) between the points. This violet stream did not usually pass directly from one point to the other, but was curved with

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[1] S. Arrhenius (Annal. Phys. Chem. 63, pp. 305-313), 1897.

No. 1.

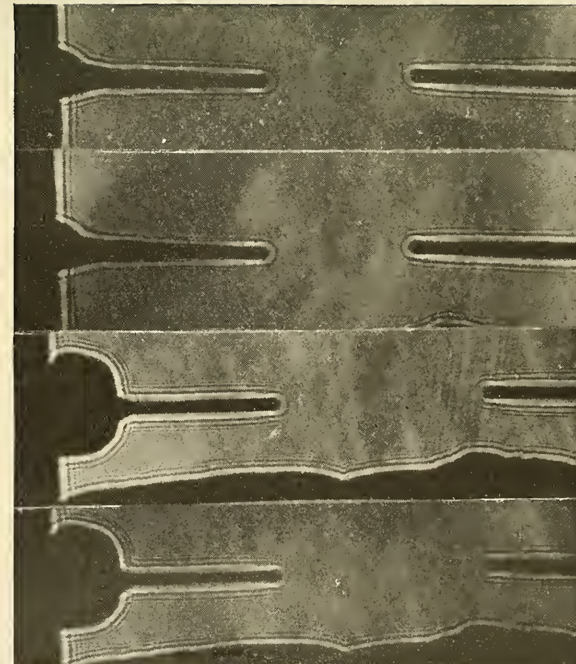
No. 2.

No. 3.

No. 4.

G

Nos. (1 and 3) G. Without air stream.
Nos. (2 and 4) G. With " "



H

H. Spark between poles of the machine, violet brush between points.

the two ends connected to the needles, not always at the points. When the magnets were excited there was no deflection observed in a field of 1,500 gausses. The photographs taken show nothing between the points.

Before putting on the cap containing the plate to take the photographs in series D a pencil drawing was made of the general form of each spark as seen from the end of the tube. Fig. 10 is a blue-print taken from these drawings, which shows that the direction of the spark as it leaves the electrode has the same direction as the photographed stream.

The width of the streams was measured in the proximity of the point with a micrometer microscope, and it was found that the width was independent of the potential between the points. The measurement was made between the outer edges of the central dark band. It will also be noticed in series D that the negative stream is almost as plain and almost as long as the positive stream.

The photographs of series E show plainly the interference fringes as described by Professor Foley. Although no special pains were taken to show these fringes in any of the work, one or two can be seen on each photograph.

SUMMARY OF RESULTS.

1. The positive stream between the points for a spark or brush discharge was deflected by a magnetic field as low as 1,000 gausses, the direction of deflection being in accordance with electro-dynamic laws.

2. The stream for glow discharge and the negative stream in any case were not deflected by a field of 1,500 gausses.

3. The direction of the photographed stream for a spark discharge as it leaves the point is the same as the visible direction of the spark.

4. The size of the stream at the points is independent of the potential between the points.

5. The stream was deflected by an air current, the negative being deflected more than the positive.

6. The stream for the high potential spark increased in width as the distance from the point increased, while the stream for the glow discharge retained its original size as far as it could be traced.

7. Some of the data indicate that the stream photographed is one of the ionized air particles, the stream as a whole having an index of refraction different from that of the surrounding air, due to its pressure.

If this is the case, however, the silent discharge stream and the negative stream should have been deflected also. This might possibly be done with a stronger field. Also, the stream, if it consists of charged particles, should terminate on the opposite electrode, which is very seldom the case.

The above investigation was suggested by Professor Arthur L. Foley of Indiana University. I wish to thank him and Professor R. R. Ramsey for their helpful suggestions during the course of the investigation.

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No. 1 D.

No. 2 D.

No. 3 D.

No. 4 D.

No. 5 D.

No. 6 D.