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Brush and Glow Discharges of Electricity and the Formation of Spark.

BY

Usaburo Yoshida and Hideki Hirata.

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I. Brush Discharges.

In the previous investigations[1] carried out by one of the writers on the figures produced on photogrophic plates by electric discharges, regular cathode—and irregular anode—figures were observed. A photographic plate was laid on a sheet of tin foil, and when the two electrodes placed on the plate were placed in contact momentaneously with the cathode and the anode of an influence machine respectively, fine images of brush discharges were impressed on the plate. The cathode figure consisted of regular branches which radiated outward from the cathode and terminated rather regularly. On the other hand, the anode figure consisted of many branches which radiated also outward from the anode, each branch changing its path irregularly and have divided into further branchlets in an irregular manner, and these branchlets terminated also irregularly in sharp points. It was also noted that an anode branch consisted of two parts, namely a more intense portion near the electrode and a weaker portion farther away.

When one of the electrodes on the photographic plate was connected by means of a conductor with the tin foil under the plate, a brush discharge was produced only at the other electrode, which was not connected with the foil. When this latter electrode was anode, an anode figure was obtained at this electrode. Experimenting under such conditions, it was observed that the spark did not yet pass between the electrodes, though the ends of the weaker parts of some

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1 U. Yoshida, Mem. Coll. Sci. Kyoto, 2, p 105, and 315, (1917).

anode branches reached the cathode. A spark discharge seemed then to pass between the electrodes, only when an intense portion of an anode branch reached the cathode which was connected with the tin foil under the photographic plate.

In a cathode branch, no such two portions of different natures as those in an anode branch were detected. And a spark discharge seemed always to pass between the electrodes when the end of a cathode branch reached the anode which was connected with the tin foil under the plate.

Let us now consider the brush discharges which take place in the air at atmospheric pressure. The cathode and the anode brush discharges appear at each electrode of an influence machine separately if the distance between them is properly increased and the electric capacity between them is not large.

The appearances of the brushes thus obtained are different in positive and negative discharges. According to K. Wesendonck[1] the appearance of a positive brush was very similar to that of a tree; beginning from its start at the anode, it was divided into several branches which were also subdivided into many weak branchlets. As to a negative brush he also noted that it did not show any branching with a spherical cathode of not a large diameter.

In the present experiment a two-plates-influence-machine of Wehrsen type was used. When the two metallic spherical electrodes of one or two centimetre in diameter were separated to a proper distance, and when the electric capacity between them was made small, positive and negative brushes might be made visible at each electrode separately with a non-luminous region between them. Under such experimental conditions, negative brushes of a reddish purple colour issued from the cathode at that portion of its surface, in most cases, just opposite the anode, and approaching more toward the anode they become diffused more and more and at last terminated in a diffuse boundary. They never showed any regular branching as in the case of a cathode figure on a photographic plate, or any irregular branching as in a positive brush. On the other hand the positive brushes issued from the anode at the portion of its surface just opposite the cathode and showed their characteristic irregular branchings as noted by K. Wesendonck. It was especially noticeable that a positive brush consisted of two parts, namely a more intense part of reddish purple tint

1 K. Wesendonck, Ann. d. Phys. u. Chem., **30**, p. 1, (1887).

nearer to the anode and a weaker part of bluish purple colour farther away as was observed in an anode-discharge-figure on a photographic plate.

Now, one of the two spherical electrodes before mentioned was replaced by a plane electrode of about 10 cm. in diameter and about 1.5 cm. in thickness, which had a smooth edge. The capacity between the electrodes was made small, so that it was more favorable for brush than for spark discharge to take place. Under such experimental conditions brush discharges took place only at the other spherical electrode, and no kind of visible discharge was detected at the plane electrode. When the two electrodes were held at a sufficient distance apart, positive brushes which issued from the spherical anode did not reach the plane cathode, and no luminosity was detected in the region extending from the ends of the positive brushes to the surface of the cathode. Decreasing the distance between the electrodes, gradually a state was reached such that though many fine branches of weak intensities of positive brushes reached the plane cathode yet no spark passed between the electrodes. By yet approaching the electrodes, another state of discharge is reached such that sometimes a spark passed between the electrodes, and sometimes many brush discharges appeared also successively from the anode. In this state of discharge many intense branches of positive brushes extended to the region adjacent to the front surface of the plane cathode, but it was never observed that these intense branches extended to the cathode itself without causing a spark to pass along any one of their paths. This difference of nature between the weaker part and the stronger one of the positive brush is quite similar to that observed in the case of a positive brush on a photographic plate.

Next, reversing the signs of the poles, a similar observation on negative brushes from the spherical cathode was made. In this case the boundary of the end of a negative brush was not well defined as was stated before, and it was not possible, of course, to speak about its end definitely. But the observation showed that a spark seemed then to pass between the electrodes, only when a weak diffuse luminosity at the end of a negative brush occupied the whole space up to the plane anode. This nature of negative brushes is similar to that of a cathode branch on a photographic plate.

In the case of the discharge figures on the photographic plate, an explanation of their formation based on the consideration of ionisation by collisions of positive ions and electrons with gas molecules was given by one of the writers. In that case the condition that the ions on the photographic plate were attracted by the tin foil under the plate was, of course, taken into account; and especially the formation of the fine regular cathode branches was considered to be due to that condition. In the case of brush discharges in the air at atmospheric pressure this condition is absent. But essentially the same consideration as before seems to be applicable in explaining the main features of positive and negative brushes in this case.

Now a gas will be ionised by collisions of positive and negative ions and electrons with the molecules of the gas. Among these the electrons will be more efficient ionisers than the others which have a greater mass; and the luminosity at the ends of positive and negative brushes will be due to the ionisation by collisions of electrons with the molecules of the air.

The electrons at the end of a negative brush will be supplied by the ionisation by collisions of positive ions with cathode or air molecules near the cathode, and also by the ionisation by collisions of electrons with the air molecules in the region between the cathode and the end of the brush. The electrons at the end of a negative brush thus formed will be repelled by the cathode, and at the same time the positive ions will be attracted toward it. Consequently at the end of a negative brush a great number of electrons will be in excess, and the potential gradient in front of the negative brush will become so large that the molecules of the air are ionised by the collisions of these electrons. The prolongation of a negative brush will occur in such a manner. As the electrons at the end of a negative brush are many in number they will repel each other with considerable force. This combined with the rapid mobility of electrons seems to be the cause of the fact that the end of a negative brush is diffused in its boundary.

Next, in front of the anode, the electrons will be attracted toward it. When the strength of the electric field attains a certain value, they will ionise the air molecules in their journey to the anode, and many positive and negative ions and electrons will be formed. The electrons thus set free will also be attracted toward the anode, and ionise the air by their collisions with its molecules. The positive ions thus formed and left behind will not diffuse immediately, and will retain their positions for a short time owing to their slow mobility.

Consequently in the neighbourhood of a positive brush thus formed, wherein a great number of positive ions is present, the intensity of the electric field may become very strong. If some electrons, which come from the cathode or elsewhere, should happen to be in such field they will also ionise the gas by their collisions with its molecules in their journey to the anode branch mentioned above. And by the same process as described above, the prolongation of an anode brush will take place. Considering in this manner, the peculiar nature of a positive brush, that it has many fine irregular branches toward the cathode seems to be easily understood; because the formation of these branches is primarily due to the presence of electrons which would initially be few in number and distributed rather irregularly.

Next, the well known fact that the positive brush is longer than the diffuse negative brush may be explained in the following manner. At the end of a fine positive brush the positive ions, and at the end of a diffuse negative brush the electrons are in excess respectively. Among these the electrons, owing to their rapid mobility, will diffuse more readily by their mutual repulsions, and the density of the negative charge at the end of a negative brush will be liable to become rare. This will have the effect that a stronger electric field may be established more easily in the neighbourhood of the end of an anode branch. And this is more favorable for the positive brush in its prolongation than for the negative.

It is already mentioned that there are two parts of different natures in a positive brush: one of stronger intensity and the other of weaker intensity further away from the anode. Among these the stronger branch is always accompanied by a weaker branch as its continuation at the end. This fact is also observable clearly in the case of brush discharge on a photographic plate. Moreover, when the potential difference between the electrodes is moderately decreased, the stronger positive brushes disappear entirely, and the brushes of weaker intensity alone are visible at the anode. Judging from these facts it seems natural to consider that the weaker brush appeared previously at the anode and then the brush of stronger intensity is formed along the path made by the former.

In the case of brush discharges on a photographic plate it was assumed that the weaker part of a positive brush was the path of the ionisation by collisions of electrons with the molecules of the air, and that the ionisation by collisions of positive ions with air molecules occurred in the branches of stronger intensity. When once a branch of the positive brush of weaker intensity is formed momentaneously by the ionisation by collisions of electrons with the molecules of the air, the electrons and the negative ions thus formed are attracted toward the anode, and the positive ions are left behind. Though the air in that branch will be in a condition, by the previous ionisation, that it might be more easily ionised by the collisions of electrons with its molecules, yet the intensity of the electric field in that branch will be so much reduced by such distribution of ions that it is insufficient to cause the ionisation by collisions of electrons with air molecules in it.

When the potential of the anode is gradually raised, the positive brush of weaker intensity grows more, and its length and the number of branches are increased. In this state of its growth, many negative ions and electrons produced at the end of each branch of the brush are attracted and move toward the anode. And in their journey to the anode most of them will move along the paths made by the previous ionisation by collisions of electrons with air molecules, that is along the branches of the weaker brush, because the potentials in every branches are higher than those in their immediate neighbourhood due to the presence of the excess of positive ions in every parts of the branches. Consequently the gas in the branches will be more easily ionisable by the collisions of electrons and of positive ions with its molecules at least due to the increase of their temperatures by the rapid movements of electrons along them. Moreover the electric force in a branch in the immediate neighbourhood of the anode will be tolerably increased by the accumulation of negative ions and electrons toward the anode, and the gas in this strong electric field will be ionised by the collisions of positive ions and electrons with its molecules. And ionisation which occurs in this place will be more vigorous than those at the ends of the weaker positive brush before mentioned, because the gas in this place is in a more easily ionisable state and the number of electrons which ionise the gas in this place will be larger than those at the former. The negative ions and electrons produced at the ends of the weaker brush, are attracted toward the anode along the branches of the weaker brush; and by the accumulation of many of these negatively charged particles a strong electric field will be established in the place just in front of the group of a large number of position ions formed by the previous intense ionisation. By the ionisation by collision of positive and negative ions and electrons with the gas molecules in this place, a large number of electrons and positive ions will also be produced. The electrons and the negative ions being attracted toward the anode, the group of a large number of positive ions thus produced will be pushed away; and the same process being repeated as before the ionisation by collisions of positive and negative ions and electrons above noted will take place successively along the branches of the weaker positive brush. This process of comparatively vigorous ionisation will be accompanied by the emission of light of stronger intensity, and the fact that the stronger part of the positive brush follows along the paths of the weaker ones seems to be explained in such way.

In the case of a positive brush on a photographic plate, some cases were observed where a stronger branch of the positive branch made way, in some part of its path, across the neighbouring weaker branches. This will perhaps occur also in our case, and the irregularity of the path of the stronger branch will be increased by this condition.

When once a stronger branch of the positive brush is formed, the gas in this branch will be in an easily ionisable state, at least, due to the increase of its temperature. And the process of ionisation by collisions, at least of electrons with its molecules, will last for a short time after the formation of the stronger branch so far as the potential of the anode does not fall below a certain value.

Thus assuming the nature of the stronger branch of a positive brush the fact that the spark discharge is caused by the arrival of this branch to the cathode seems to be explained easily. In a weaker branch of a positive brush, the process of ionisation by collisions of electrons with the molecules of the air takes place only momentaneously at the instant of its formation, and no more after its formation as was considered before. Moreover, the ionisation by collisions of positive ions with the molecules of the air does not occur in that part. If the weaker branch of a positive brush is of such a nature, the mere arrival of it at the cathode will not cause the spark dischage to pass between the electrodes as was observed in the present experiment and also in the case of a brush discharge on a photographic plate.

When a metal, with a comparatively large curvature such as a thin wire, was used as the cathode, a few short negative brushes were seen to issue from its surface. As these brushes glowed steadily, the process of the ionisation by collisions of electrons with the molecules of the air would be taking place simultaneously in all portions of these brushes in contrary to the case of the weaker positive brushes where the ionisation by collisions of electrons was supposed to occur in a rather pulsatory manner at the moment of their formations. When a spherical cathode of larger diameter than a centimetre was used under the present experimental conditions, the negative brushes were never steady, but the fact that the spark discharge was caused by the arrival of the end of a negative brush to the plane anode seems to suggest that the ionisation by collisions of electrons is taking place simultaneously in every portion of this brush.

II. Glow Discharge.

When the spherical electrodes of one or two centimetres in diameter are separated at a proper distance, the capacity between them being reduced, positive and negative brush discharges are visible at each electrode respectively. Next, when the distance between the two electrodes is further increased, one may observe that an entirely different phenomenon of discharge takes place at the anode. The positive brush disappears entirely and the surface of the anode which is just opposite to the cathode is now covered with the thin film of a pale violet glow. This Phenomenon is called the positive glow discharge.

In regard to the question, in what circumstances the glow discharge takes place, many investigations have been made. But, so far as the writers are aware, this question is not definitely answered, and its nature remains still unexplained.

According to K. Wesendonck[1] the positive brush was easily converted to a glow discharge by the effect of blowing the air against the former. The writers repeated this experiment and observed that this effect was especially noticeable when the air was blown by a bellows.

As this effect of blowing the air against the brush seemed to the writers to be due to a rapid diffusion of great numbers of positive and negative ions and electrons in the brush, the opinion was immediately entertained that a uniform supply of a great many electrons toward the anode might be favorable to the phenomenon of the glow discharge.

By using a plane cathode and a spherical anode of one or two centimetres in diameter as the electrodes of an influence machine, and by reducing the capacity between the electrodes, only the positive brush discharge was made visible at the spherical anode by properly

1 K. Wesendonck, Wied. Ann., **40**, p. 481, (1890).

adjusting the distance between the electrodes. Next, when the air in the region between the electrodes was ionised by the passage of β and γ rays from radium bromide, the positive brushes disappeared instantaneously, and the surface of the spherical anode which was just opposite to the cathode was now covered with the thin film of a glow discharge. When the sample of radium bromide was taken away the brush discharge reappeared instantaneously, and the glow disappeared at that very moment. This was just as was expected. The same phenomenon was observed also with a spherical cathode, but with a little more difficulty, because the negative brush which issued from the spherical cathode called forth a dense accumulation of negative ions and electrons toward the narrow central portion of the surface of the anode which is just opposite to the cathode. It was already stated before that the phenomenon of glow discharge was easily observed at the spherical anode when the spherical cathode was separated at a comparatively long distance from the anode. In this case, negative ions and electrons from the negative brush would have to diffuse themselves in a wider area, and their distribution in front of the anode would be rather uniform.

When an infinite number of electrons of uniform distribution were present in front of the anode, the positive brushes, if once formed at the surface of the anode, would be enormous in number; and consequently the electric fields at their ends would not be so strong as in the other case where they were few in number. This circumstance would be unfavorable. to the prolongation and consequently to the formation of the brushes. And the process of the ionisation by collisions of electrons with the air molecules would be confined to the region just in front of the anode, as was observed in the case of the anode glow discharge.

In order to illustrate the fact that the uniform supply of electrons to the anode is favorable to the formation of the anode glow, the photograph Fig. 1 is presented. In this case, two wires of about one millimeter in diameter were stretched, about four centimetres apart, parallel to one another, and served as the cathode and the anode of the influence machine respectively. At the beginning of the discharge the negative brushes, which were very short in this case and appeared like luminous points, flickered here and there on the surface of the cathode wire, and the anode glows also changed their places on the surface of the anode wire simultaneously. But after a short while, these short negative brushes became steady, and the anode glows appeared also steadily on the surface of the anode wire just opposite to the negative brushes. In Fig. 1, the three separate luminous points are the images of three such steady negative brushes, and the three luminous threads, which occupy the positions just opposite to the former three are the images of the corresponding anode glows. The length of a luminous thread of the anode glow depends upon the distance between the two wires, the former increasing with the latter.

As no luminous discharge takes place at any portion of the anode surface where no such glow discharges are detected, we may infer that the electric field in this portion is not so strong as to cause the ionisation by collisions of electrons with the air molecules; and that in the other portion of the anode surface where the glow is visible it is strengthened by the accumulation of negative ions and electrons toward the anode.

If the uniform supply of a great number of electrons to the anode is favorable to the formation of the anode glow discharge as was considered before, any other condition, on the contrary, which is injurious to the uniform distribution of ions and electrons will be more favorable for the formation of the positive brush than for that of the anode glow. According to Wesendonck[1], an anode glow discharge was easily converted to a positive brush one by spreading metal powders on the surface of the anode or in the region between the electrodes.

In the preceding paragraph we have stated that the glow discharge took place at the anode when a great number of electrons of uniform distribution was supplied to the anode. But this is never always the case. By using a plane cathode and a spherical anode as was stated before and reducing the capacity between them, the distance between them and the rotation of the influence machine were so adjusted that, when the air in the region between them was ionised by the passage of β and γ rays from a sample of radium bromide, the discharge at the anode occurred in the form of a glow. Next, when the intensity of the electric field in front of the anode was increased to a certain amount by increasing the speed of rotation of the influence machine or by decreasing the distance between the electrodes, a reddish purple "luminous point" appeared in the pale violet luminous film of the glow on the surface of the spherical anode just opposite to the plane cathode where the electric field was strongest. In this state of discharge a few positive brushes also sometimes ap-

[1] K. Wesendonck, l.c.

peared at the anode. And it is especially noticeable that these positive brushes started always from the "luminous points" mentioned above. This was already observed by K. Wesendonk[1] and he called this "luminous point" "der Zündstoff eines Funkens." When the capacity between the electrodes was increased, the positive brushes which had started from the luminous points of the anode glow were converted to the spark discharges as was noted by Villard and Abraham.[2]

Here it must be remarked that the positive brush which started from a luminous point of the anode glow was always the stronger part of the positive brush before mentioned. A luminous point of the anode glow, thus being the starting point of a stronger positive brush, seems to be of the same nature as the latter. If the intensity of the electric field at a point on the front surface of the anode, where the glow discharge is taking place, is increased to a certain value, the positive ions in the glow will ionise the air at that point by their collisions; and much denser positive ions will be set free at this point than at the other portion of the glow. As these dense positive ions thus set free at this point are pushed ahead, they are in the same state as those at the end of a positive brush; and a positive brush will start from this point just as in the case of the prolongation of a positive brush.

M. Toepler[3] investigated the glow and the brush discharge, etc., quantitatively. Taking the distance between the electrodes and the current as the abscissa and the ordinate respectively, he determined the domain of existence for each kind of discharge. According to him the positive brush assumed the domain of a stronger current than that of the anode glow. The writers are of opinion that the difference of current intensity is rather a consequence of the difference between the natures of the glow and the brush discharge and not the direct cause of the formation of either of them.

III. Spark Discharges.

B. Walter[4] investigated the mechanism of the formation of a spark due to an induction coil by using the method of a moving photogra-

[1] K. Wesendonk, Verh. d. D. Phys. Ges., p. 514 (1912).

[2] Villard and Abraham, l.c.

[3] Toepler, Ann. d. Phys., **2**, p. 560, (1900).

[4] B. Walter, Ann. d. Phys., **66**, p. 636, (1898); and **68**, p. 776, (1899).

phic plate, and observed that a spark discharge had passed between the electrodes along the path formed by preliminary positive and negative brushes. When a plane and a sphere were employed as the cathode and the anode of an influence machine respectively, the brush discharge appeared only at the spherical anode. By reducing the capacity and the distance between them properly a state was reached such that, in most cases, the discharge occurred in the form of a positive brush at the spherical anode, and sometimes in the form of a spark. Under such experimental conditions, the writers observed that the spark passed then between the electrodes when the end of a stronger positive brush reached the plane cathode. When the signs of the electrodes were interchanged, only negative brushes appeared at the spherical cathode, and under similar experimental conditions as before it was observed that the arrival of the end of a negative brush at the plane anode caused a spark discharge between the electrodes. These facts were already described in a former section. Next when two spheres of one or two centimetres in diameter were used as the cathode and the anode of the influence machine, the positive and the negative brushes were formed at each electrode respectively. Experimenting under a similar condition as before, it was observed that probably a spark passed then between the electrodes when the end of the stronger part of a positive brush had arrived at the end of a negative brush.

Next maintaining the other conditions unaltered, the capacity between the electrodes was increased a little in each of the three cases above mentioned, then the positive and the negative brushes were increased more in length but were reduced in number, that is the time-interval between the two successive brushes was increased. And consequently the spark discharges occurred more frequently than before. When the capacity between the electrodes was still further increased this tendency become more prominent and at last a state was reached when the discharge took place only in the form of sparks, and never in that of brushes. In the case of positive brushes and sparks which occurred in the state of glow discharge at the spherical anode, the same effect of capacity on the manner of discharge was also observed. The fact observed by Toepler[1] that the domain of existence of the spark discharge in his current—spark length—diagram increased contrariwise to those of brush and glow

1 M. Toepler, l.c.

with the capacity, amounts to nothing more than has been stated before. When the capacity between the electrodes was increased, the decrement of the potential difference between the electrodes by the formation of a brush would be smaller, and the brush thus formed would become longer than before. By yet more increasing the capacity, the brush would become still longer. And at last when it was increased sufficiently, all of the brushes would become so long that each brush might always cause a spark discharge between the electrodes. Thus considering, it will be seen that a spark discharge is always preceded by a preliminary brush, and that the former occurs along the path made by the latter as was observed by B. Walter.

If the spark discharge takes place in such a manner, the path of a spark will be different in its form according as it was formed along a positive brush or along the negative. This was really the case, and illustrated by Fig. 2 and Fig. 3. Fig. 2 is the photograph of a spark which passed between a plane cathode and a spherical anode of 1.7 centimetre in diameter of an influence machine, and Fig. 3 was taken when the signs of the poles were reversed. The distance between the electrode was the same in both cases and was about four centimetres. As is evident from these figures, the zigzag spark in Fig. 2 is very different from the rather smooth spark in Fig. 3. This difference of the nature of spark in the two cases seems to be explained easily by the consideration that the zigzag spark in Fig. 2 took place along an irregular positive brush which would have appeared previously at the spherical anode, and that the smooth spark in Fig. 3 occurred along a regular negative brush which would have appeared also previously at the spherical cathode.

When special attention was not paid to avoid the formation of either of the two kinds of brushes, positive and negative brushes appeared generally at each electrode respectively. Among these the irregular fine positive brush is, in most cases, much longer than the diffuse negative brush as was stated and explained before. If a spark discharge occurs in such cases, a major part of its path will be along a zigzag branch of a preliminary positive brush. The zigzag nature of a spark seems thus to be due to this nature of a positive brush.

Now, it is well known that when a spark is branched, the branches point to the negative electrode, as was observed in the case of the spark in the laboratory or in that of the lightning spark. This mode of branching of the spark is entirely identical with that of the positive brush. And the branches of the spark may be regarded as those of its preliminary positive brush.

If the electrodes are not of the same size, the spark length for the same potential difference depends upon whether the larger or smaller electrode is used as the cathode. Thus, for example, Faraday found that the spark length was larger when the smaller sphere was positive than when it was negative. More recently Villard and Abraham[1], on experimenting with the electrodes of a plane and a sphere of various diameters, found that the spark length was larger when the sphere was positive than when it was negative. This may be explained by the consideration that the spark is formed along the path made by a preliminary brush discharge, and that a positive brush is more favorable by its longer extension for the formation of the spark than a negative brush.

Contrary to the case above mentioned, K. Wesendonck[2] observed that, in the case of a pure spark where no trace of a brush or a glow was detected, the effect of the dissimilarity of the two electrodes on the spark length was absent. This seems to the writers to be the effect of a large capacity which K. Wesendonck applied between the electrodes to avoid the appearance of any other form of discharge than spark. But, a further investigation is of course needed on this point.

Lastly it is especially interesting to note that the sparking potential between the electrodes is higher when a spark occurs in a state of positive glow discharge at the surface of the anode than when it takes place in a state of positive brush discharge or in that of a non-luminous discharge at the anode as was observed by M. Toepler[3] and Villard and Abraham[4]. According to the writers' view, the spark which takes place in a state of glow discharge at the anode is also preceded by the appearance of a positive brush, and the spark passes along the path made by this preliminary positive brush. It has been already mentioned that a positive brush which appeared in a state of positive glow at the anode started at a "luminous point" in the glow at the anode; and this "luminous point" was considered, in that case, to be due to the ionisation by collisions of positive ions with the molecules of the air. When a positive brush did not accompany

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1 Villard and Abraham, C.R., **153**, p. 1200, (1911).
2 K. Wesendonck, Wied. Ann., **38**, p. 222, (1889).
3 M. Toepler, Drude Ann., **7**, p. 477 (1902).
4 Villard and Abraham, C.R., **130**, p. 1286, (1910).

a positive glow, the ionisation by collisions of positive ions with air molecules which took place in a stronger part of the brush, was considered to be caused by the fact that the electric field in every portion of a weaker part of the brush was strengthened by the accumulation of many positive and negative ions and electrons in a narrow space. Now, in the case of a " luminous point " in the positive glow, this condition is absent, and a higher potential difference between the electrodes was needed to cause the ionisation by collisions of positive ions with air molecules in a portion of the positive glow, that is to form a " luminous point " in the glow which was a " Zündstoff eines Funkens " as was named by K. Wesendonk.

Summary.

1. The natures of a positive and a negative brush discharge, and especially the parts played by them in the formation of a spark discharge were investigated.

2. The stronger part and the weaker part of a positive brush were different in their natures. The latter was a pilot of the former, and the arrival of the end of the former at the cathode or at a negative brush caused a spark discharge between the electrodes.

3. An explanation of the formation of the negative and the positive brush was undertaken by the consideration of the ionisation by collisions of electrons and of positive ions with the molecules of the air.

4. The conditions under which the positive glow was formed were examined, and it was observed that a uniform supply of a great number of electrons toward the anode was favorable for the formation of the positive glow.

5. A positive brush which appeared at the anode in a state of positive glow discharge was observed to start at a " luminous point " in the positive glow. As a spark took place along a preliminary brush discharge, this " luminous point " was also the starting point of the spark at the anode, and this " luminons point " was called by K. Wesendonk " der Zündstoff eines Funkens."

6. An explanation of the various features of a spark discharge was attempted on the ground that a spark passed between the electrodes along the path made by a preliminary brush.

The writers' hearty thanks are due to Prof. T. Mizuno for his interest in this research.

Fig. 1.

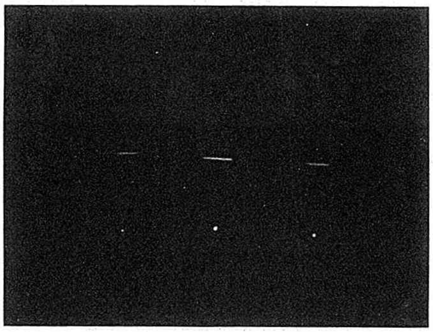

Fig. 2.

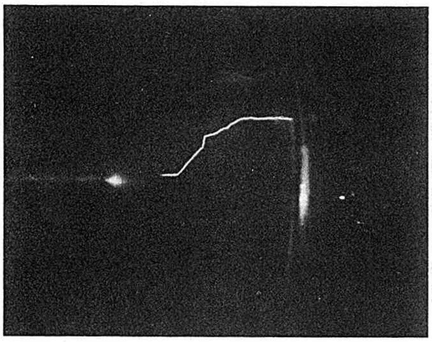

Fig. 3.