ELECTRICAL DISCHARGE FROM HOT CARBON.

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THE present article is a continuation of a series of articles which have been published on the electrical discharge through gases caused by bodies at high temperatures. The first one of these gave an explanation of the electric arc. In that article it was assumed that the positive ions in the arc move more rapidly than the negative ones. In the next article it was shown that when ions are drawn out from the arc by a charged body, the positive do indeed have the greater velocity.

In a more recent article an account was given of the discharge from a hot platinum wire. Here also the positive ions under some of the conditions move more rapidly than the negative ones. In this last case it was possible to take one step further, and to give a probable explanation of the greater velocity of the positive ions. Apparently the average velocity of the ions was greatly diminished by the presence about the wire of particles driven off from it, and these particles retarded the movement of the negative ions more than the positive. Some of the particles driven off were either charged negatively from the beginning or else quickly became thus charged. In any case more of them seemed to act as slowly moving negative ions than as positive, and the average velocity of the negative ions was thus made smaller than that of the positive. This explanation was suggested as a possible one by Rutherford¹ before my article on the same subject was completed.

This phenomenon is not as unique as might at first be thought. Rutherford² found that "emanation" from the thorium compounds behaved as if charged positively. Barus³ has reached the conclusion from his work on the diffusion of nuclei that in some cases they may exist in a colloidal state when in a gas. If the platinum

¹ PHYS. REV., 13, 332.

² Phil. Mag. (5), 49, 161.

³ Amer. Journ. of Science (4), 13, 400.

particles driven off from the hot wire are in such a condition we may very properly compare them with the platinum particles which Bredig¹ secured in the colloidal condition when an arc is formed between platinum terminals under water. He found that when a current was passed through such a solution these particles are carried to the anode, as if they were charged negatively, as are indeed many of the particles driven from the hot platinum wire. He also found the same phenomena to exist in the case of other metals. Possibly the colloidal condition of particles when in a gas may be found to be of more common occurrence than has been supposed.

With this knowledge of the ions passing from platinum it seemed most natural to suppose that the greater velocity of the ions drawn from the arc and also those in the arc itself was due to the same cause, namely to particles driven off from the carbon which were either charged negatively from the beginning or became so when surrounded by negative ions. I have, therefore, repeated some of the experiments, using a pencil of carbon instead of platinum wire.

It was not expected that the phenomena would be identical in the two cases, since the particles of carbon which may come in contact with oxygen while they are yet hot will form CO_2 or CO , and since the electrical properties of carbon are no doubt different from those of platinum.

Some of the experiments could not well be repeated with carbon, since the carbon pencil in air commences to burn as soon as it is hot enough to produce discharge, and this decreases the diameter of the pencil. Thus the same amount of current through the carbon will continually heat it to higher and higher temperatures. Therefore no attempt was made to repeat any but the simpler experiments which might have some bearing on the explanation which has been suggested.

These experiments will show that, though the details are in many respects different, the general phenomena are the same with carbon as with platinum, and they make probable the explanation that the positive ions move the more rapidly because the negative ones are loaded with particles driven off from the carbon.

Discharge with Different Currents through the Carbon.—The first

¹ Ztschr. angew. Chem. Jahrgang, 1898, Heft 41, p. 952, Beib. 24, 229.

measurements were those showing the effects produced by varying the current through the carbon, when it was heated in the air. These measurements must of necessity be more or less inaccurate. The carbon not only becomes smaller the longer it is heated, but the temperature is affected both by the amount of current flowing through it and by the amount of combustion at the surface. Still by taking measurements as quickly as possible and by beginning with small currents some idea can be gained of the way in which the rate of discharge depends on the temperature.

The observations given in the following four tables were all taken with the same cylinder about the carbon. The carbon pencil used with the first set was 3.1 mm. in diameter. This gradually became smaller as it was burnt away. In the other three cases the observations were made in a glass cylinder which has already been described¹ and in these cases the carbon pencil was 1.6 mm. in diameter. The diameter of the surrounding cylinder was 4 cm. and

TABLE I.

Current through Pencil.	Positive Discharge	Negative Discharge.
8.5	7.3×10^{-9}	
9	42	
9.5	29	29×10^{-9}
10	17	19
11	12	13
12	6.8	7.8

the length 5 cm. In each of the tables column 1 gives the current in ampères flowing through the carbon pencil. Column 2 gives the rates of discharge in ampères when the carbon was charged positively, and column 3 those when it was charged negatively. The observations were made in the same way and with the same instruments that have been described in connection with measurements on the discharge from platinum wires.

Table I. gives the observations taken with the carbon in air. The potential difference between the carbon and the surrounding cylinder was in this case 35 volts.

¹ PHYS. REV., 14, 242.

After taking the data as given above the current was diminished somewhat and the discharge was found to increase, showing that the smaller rates of discharge were indeed due to higher temperatures and not to the wasting away of the carbon pencil.

As seen in the table the positive discharge commences before the negative. It was, however, difficult to compare these with certainty, since combustion began at nearly the same temperature as that at which discharge commenced and with the beginning of combustion there was a rapid rise in temperature. To test this further a device which has already been described¹ was used for reversing the direction of the current about once per second. By these means the surrounding cylinder receives first positive and then negative discharge and the average potential would indicate which of these was the larger. When this was used it was found that the cylinder became charged positively as the carbon first began to glow. But when the amount of current sent through was increased the average potential of the cylinder became a few volts below zero. This fully confirms the data given in the table. The positive discharge first occurs, but the negative becomes the larger at higher temperatures.

When we compare this with the discharge from platinum wires, we see that in both cases the positive discharge first occurs and that in both cases both the positive and negative discharges pass through maxima. The two cases are different in that with the platinum the negative discharge requires much higher temperatures than the positive, while with the carbon only a little higher temperature appears to be needed. They are also different in that with the carbon the negative soon becomes larger than the positive. The fact that the positive and negative begin with nearly the same amount of current is partly due to the combustion which begins at this point. The other differences will be considered later.

The rate of discharge was found to vary approximately as the square of the potential difference.

Discharge within an Enclosed Tube. — When observations were made of the rate of discharge within an enclosed tube it was found that the phenomena were the same as those observed under similar

¹ PHYS., REV., 12, 139.

circumstances with platinum. The rates of discharge with different currents are given in Table II.

TABLE II.

Current through Pencil.	Positive Discharge.	Negative Discharge.
4	9×10^{-10}	
4.5	6	
5	2.4	
7	1.2	3.6×10^{-10}
8	1.3	6
10	1.1	6
11	1	4

The rates of discharge are here very much smaller than in open space and show that here also particles are driven off which collect on the ions and retard their motion.

Discharge in a Vacuum.—When we pass to the discharge in a

TABLE III.

Current through Pencil.	Positive Discharge.	Negative Discharge.
4.5	3.9×10^{-7}	
5	12	
6	26.7	
8	33	
9	40	1.9×10^{-7}
10	41	10
11	45	45.5
12	43	143
13	47.5	510
14	60	1370

vacuum we find an even more complete parallel with the phenomena with a platinum wire. The data are given in Table III. for the discharge at approximately 1 mm. of mercury pressure.

With larger currents the tube and the connections became hot so quickly that it was not practicable to carry the observations further. To judge from the appearance of the carbon it had with the largest current about the same temperature as the filament of the ordinary incandescent lamp when used at its normal candle power.

As with platinum wire the positive discharge first begins to pass from the carbon, but after the negative once starts it quickly sur-

passes the positive. The negative discharge becomes very much larger with the carbon than it did with the platinum, possibly because higher temperatures may be reached. The phenomenon here is essentially that known as the Edison effect. It has been shown by Edison, Preece,¹ and Fleming² that in an ordinary incandescent lamp a current will flow from the negative side of the filament to an electrode within the lamp. This was found by Fleming to amount to several milliampères in many cases. Fleming also found that a very small current flows from the positive terminal. There seemed at first sight some discrepancy between the much greater negative discharge from carbon in the lamp and the greater readiness of the positive discharge to pass from the carbon in air at normal pressures. But these observations show that the differences in behavior are due to the varying conditions of the gas about the carbon and to the temperature.

It has been suggested that the discharge in the lamp was carried by particles of carbon. This would scarcely seem to be a complete explanation. We have reason for supposing that the particles of carbon diminish rather than increase the amount of discharge from carbon in gases at atmospheric pressures, and the same no doubt is true here. The explanation offered by Merritt and Stewart³ seems the more probable one.

Discharge in Hydrogen.—Observations were also made with hot carbon in hydrogen gas. The data taken are given in Table IV. The potential difference was 25 volts.

The positive discharge first shows itself as in the corresponding case with platinum, and the discharge with both platinum and carbon is much larger in hydrogen than in the enclosed tube with air or with a mixture of nitrogen and CO₂ as the case may be. With carbon in this mixture the space became smoky, but in hydrogen it remained clear. Neither platinum nor carbon disintegrate in hydrogen as in other gases. But in other respects the two cases are not the same. With the platinum there was no evidence that the positive discharge passed through a maximum, while here there is plain

¹ Proc. Roy. Soc., 1885, 219.

² Phil. Mag. (5), 42, 52.

³ Science, 15, 427.

evidence of such action. With the platinum the negative discharge began soon after the positive, but with carbon it took nearly twice

TABLE IV.

Current Through Carbon.	Positive Discharge.	Negative Discharge.
5.5	2.5×10^{-9}	
6	11	
7	15	
8	12.5	
9	11	5.8×10^{-9}
10	9	11
11	9.5	9.5
12	7.5	7

as much current to produce the negative discharge as to produce the positive. Moreover, with the platinum the negative discharge becomes very much larger than the positive, while here the negative scarcely exceeds the positive.

These last two phenomena are somewhat surprising, since under all the other conditions which have been tried the ratio of the negative discharge to the positive was larger with the carbon than with the platinum, while here it is smaller. I have at present no explanation for this fact.

Let us see if any conclusions can be drawn from the work thus far described. The work was undertaken to determine, if possible, two questions: first, are particles of carbon given off which diminish the velocity of the ions? and second, do these particles diminish the velocity of the negative ions more than that of the positive? In regard to the first question there can be no doubt. The particles certainly retard the velocity. At the higher temperatures where more particles are driven off the rate of discharge becomes smaller. When the carbon is enclosed in a tube, it becomes very much smaller and in this case the discharge is greater when the carbon is first heated than it is after a few seconds when the particles have become more numerous in the tube.

But when we come to the second question the evidence is not so clear. The positive discharge is able in every case to pass from the carbon at lower temperatures than the negative. This indicates that there is greater attraction between the carbon and the negative

electricity than between the carbon and the positive. From this we should expect the particles to load the negative ions to a greater extent than the positive.

On the other hand in the air and within the tube with the gases at atmospheric pressure the negative discharge is greater than the positive. This would indicate a greater velocity on the part of the negative ions. In a vacuum the negative discharge becomes very much larger than the positive. This last, however, is probably due to a secondary ionization produced by the collisions between the ions and the molecules. It may be that when the carbon is in a gas at normal pressure there is still a slight tendency for the particles to collect on the negative ions to a greater extent than on the positive, but that this tendency is not sufficient to overcome the greater velocity which the negative ions ordinarily have. Moreover, it must be remembered that when the carbon is in the air many of the particles will be oxidized and that when it is enclosed in a tube it is not surrounded by air but by a mixture of nitrogen and CO_2 .

Of these various facts none would seem to cast more light on the subject than the fact that it requires a higher temperature to cause the negative electricity to escape than to cause the positive to do so. From this we should expect the negative ions to be loaded more than the positive. Evidently we can not make any definite statement as yet concerning this matter, but it is equally evident that there is no reason for denying the possibility of a greater loading of the negative ions under certain conditions, if such a supposition is needed to explain the phenomena of the electric arc.

We may now take a further step and offer an explanation of the more rapid motion of the positive ions in the arc by assuming that the negative ions are there loaded with particles of carbon. The temperature of the arc must be very near to the boiling point of the carbon. There must be some parts of the arc that are cooler than others. If then the carbon is vaporized in some parts it must be condensed in others and it is reasonable to suppose that these particles should become charged negatively, just as the particles of platinum from the vapor of platinum formed in the arc under water become thus charged. That is the arc consists of hot vapors and

of carbon particles in the colloidal state which carry negative charges. This is in harmony with all known facts and furnishes an explanation upon which further experiment may throw more light.

Summary.—When a carbon pencil is heated the positive discharge occurs first. This is true whether the carbon is heated in air at normal pressures, in a vacuum, or in hydrogen. In air it requires only a slight increase in temperature to produce the negative discharge. At higher temperatures the negative discharge is the greater. Both positive and negative pass through maxima as the temperature is raised.

Within an enclosed tube the discharge is very much smaller than in open air.

In a vacuum the negative discharge becomes many times greater than the positive at higher temperatures. The rates of discharge do not here pass through maxima.

In hydrogen at higher temperatures the positive and negative discharge have nearly the same value. The discharge is here much higher than in air. Both discharges pass through maxima.

In general the discharge from hot carbon behaves in a similar way to that from hot platinum. The velocity of the ions is diminished because of the presence of particles driven off from the carbon. The smaller velocity of the negative ions in the electric arc is quite probably due to the loading of the negative ions with these particles.

Since writing the above my attention has been called to the work by Stenger on the arc in a vacuum, and its relation to the data given above in Table III. It appeared from that table that at higher temperatures the negative ions move more rapidly than the positive. Even if we suppose the negative discharge is largely due to secondary ionization, it would still be necessary to suppose a greater velocity of the negative ions in order to produce this effect. Of course the conditions in the arc are quite different from those which we have been studying, and yet it is not unreasonable to expect that the negative ions will also have the greater velocity in the arc when in a vacuum and consequently a greater fall of potential at the negative carbon.

As far as I know no one has investigated this point, but Stenger¹

¹ Wied. Ann., 25, 31.

has observed the intensity of light at the ends of the arc when in a vacuum. He found much trouble in maintaining the vacuum after the arc was started, but he was at length able to obtain one of 1 or 2 mm. of mercury pressure. He then found the intensity of light at the two carbons to be about the same. Now the intensity of light is probably greater where the fall of potential is greater, so that in the case examined by Stenger the fall of potential at the two carbons were probably the same.

I have myself endeavored to measure the fall of potential in the arc when it was in as high a vacuum as possible, but have not been altogether successful. Besides the difficulties of obtaining a high vacuum there was the added one of placing the exploring carbon at the desired point in the arc. I was not able to do this with any apparatus which gave even as high a vacuum as that obtained by Stenger. As a result the data obtained were very irregular, so that no more could be said than that the falls of potential at the ends were much more nearly equal when the arc was in a vacuum of 2 or 3 mm. pressure than in air at normal pressures. But even with this we see that there are reasons for believing that the change which we would expect would really occur, if we could secure a vacuum sufficiently high.

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