DISCHARGE POTENTIALS ACROSS VERY SHORT DISTANCES.

By Edna Carter.

PASCHEN'S law states that the potential required to produce a discharge through a gas is a function of the product (*p.d*) of the pressure and the distance between the electrodes. Paschen[1] worked with pressures above the critical pressure and found the potential very nearly proportional to *p.d.* Carr[2] extended the measurements to lower pressures and smaller distances and found that the potential reached a minimum value and then increased with a further decrease in *p.d* and finally it was very nearly inversely proportional to this product. The work of Almy[3] and Williams[4] indicates that this would also be true even at atmospheric pressure, if the distances were made sufficiently small and the discharge could be forced to go across the shortest distance.

By means of a Chamberlain[5] compound interferometer with its massive carriage and accurate ways, it was quite easy to test these results and show that down to a distance of 0.5 wave-length of Na light the minimum spark potential of about 270 volts is still required to produce a discharge in dry air. Williams has proved that in this case the spark does not pass across the shortest distance. It was hoped that measurements could be made inside of 0.5 wave-length with this interferometer which can be made to measure distances to 1/40 of a wave-length, but it was impossible to say that the sparks which were obtained over shorter distances at lower potentials were not due to the yielding of the material under the electrostatic force so that the electrodes were first brought into contact.

Meurer[6] was unable to detect any effect of a magnetic field, transverse or longitudinal, on the potential required to start a spark discharge in air at atmospheric pressure, although such effects are obtainable at reduced pressures. It was thought that at the knee of the curve an effect might be found upon the minimum spark potential. To investigate

[1] Wied. Ann., 37, p. 79, 1889.
[2] Phil. Trans., *A*, Vol. 201, 1903.
[3] Phil. Mag. (6), Vol. 16, 1908.
[4] Phys. Rev., 31, p. 216, 1911.
[5] Phys. Rev., 23, p. 187, 1906.
[6] Ann. der Physik, 28, p. 199, 1909.

this point an electromagnet was made out of a rod of iron 1.5 cm. in diameter cast into the form of a ring about 15 cm. in diameter and wound with two layers of heavy copper wire. A gap 1.5 mm. wide was left in the ring and the iron at the gap was tapered to half its diameter. The spark gap between the iridium electrodes was introduced into this space so the magnetic field was transverse. No attempt was made to measure the strength of the magnetic field, but a current of 30 amperes through the electromagnet produced no measurable effect upon the discharge potential.

J. J. Thomson in his "Conduction of Electricity through Gases" has shown how on theoretical grounds one might expect the curve showing the relation between potential and $p.d$ to have two branches. Assuming that the curve obtained in Carr's experiments has become the hyperbola demanded by the Thomson theory for small values of $p.d$ and extrapolating for still smaller values, Madelung[7] found that the potentials obtained by experiment were very much lower than those demanded by the theory. When the pressure was reduced to about 0.07 mm. with a distance between the electrodes of 0.05 mm., the discharge took the form of a spark across the shortest distance. For this value of $p.d$ the theory requires a potential difference of about 60,000 volts. In reality it was only 9,000 volts. As the pressure was reduced in Madelung's experiments, the potential did not increase proportionally but seemed to reach a limiting value which was very nearly proportional to the spark length. This limiting value of the potential gradient he sets at 400,000 volts pro cm. He extends his curves showing the relation between potential and spark length to the origin.

Perhaps we ought not to expect Paschen's law to hold for these low pressures on account of the probable lack of uniformity in the distribution of the gas. It seemed of interest however to know what happens at distances equal to a few wave-lengths of Na light and also to find out if there is a limiting value of the potential gradient when every effort is made to rid the electrodes of gas. It was also hoped that some light would be thrown on the questions concerning electrical contact and the expulsion of electrons by metals.

An arrangement was attached to a Chamberlain interferometer in such a way that by means of a separate screw and a flexible copper disk two iridium electrodes, about 1 mm. in diameter, the one pointed and the other flat, could be brought together and separated inside the vacuum. With the aid of an additional iridium contact outside the tube, the distance apart of the electrodes could be measured in wave-lengths with as much

[7] Phys. Zeits., Feb., 1907.

accuracy as has been warranted so far by the results. The electrodes were contained in a glass tube about 2 cm. long and 2 cm. in diameter. The discharge could be observed in a low power microscope. The necessary voltages were obtained from a 1,600-volt battery of small accumulators and a high potential machine capable of furnishing any voltage up to 4,000. A Braun electrometer was used to measure the potential difference. A graphite resistance of 10^7 ohms was contained in the circuit and there was a cadmium iodide resistance permanently connected to the machine. The vacuum was secured by means of a Gaede mercury pump and cocoanut charcoal cooled in liquid air. One cannot claim for this anything higher than 0.0001 mm. The state of the vacuum was judged by the discharge through an attached Plücker tube with large capillary. With the best vacuum conditions no visible discharge was produced in this tube by an induction coil capable of furnishing 60,000 volts.

When the tube was first evacuated, bluish white sparks passed rather easily and very irregularly. They resembled the explosions of occluded gases which one sees on the electrodes in any discharge tube. As the vacuum was maintained a longer time and the discharge passed through at intervals, these irregular sparks became less frequent. The discharge almost invariably began with a faint glow on one or both electrodes, which grew brighter as the electrodes were made to approach each other; and often after long continued maintenance of the vacuum the two glows simply melted together without any sudden intense lighting up of the field and disappeared at contact. When the graphite resistance was removed, the glow appeared as usual and just before contact very brilliant sparks of the same color were seen. These were surely due to the metal vapor. On one or two occasions yellowish sparks distinctly different from the white ones were observed. These may have been due to impurities in the metal or to the presence of some other gas. The phenomena were very irregular, but the distance at which the glow first appeared and a galvanometer gave the first indication of a current was fairly well defined and was approximately proportional to the voltage used.

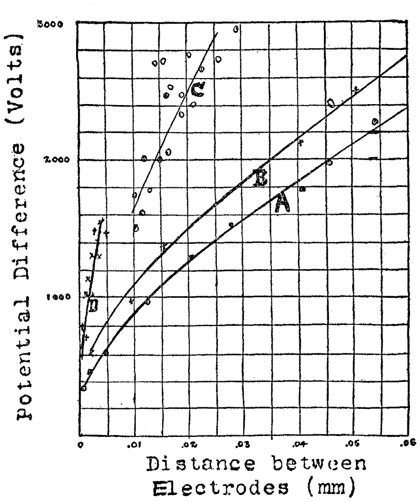

Fig. 1.

The curves represent the relation of the voltage to the distance between the electrodes when the glow first appeared. Curve *A* was obtained soon after the tube was evacuated and curve *B* a day later. The values in the neighborhood of *C* were obtained with the high potential machine after various means had been used to remove the gas from the electrodes. The values about the curve *D* were obtained with the battery after using what seemed to be the most effective method of removing the gas. Enough air was introduced so that a glow discharge was produced across the gap by an induction coil. After allowing this discharge to pass for several minutes the tube was quickly evacuated again. Taking out the graphite resistance and allowing a series of brilliant sparks to pass across, while the high vacuum was maintained, seemed to increase also for a time the potential gradient necessary to start the discharge. Later the electrodes were inserted in a quartz tube about 20 cm. long and 0.5 cm. in diameter where by means of an electric furnace they could be heated for hours to a bright red heat with the evacuation going on at the same time. The heating did not seem to have so much effect as the earlier methods and the phenomena in this smaller tube were more irregular, the discharge having a tendency to start at points back on the copper wires to which the iridium electrodes were soldered. Keeping away the mercury vapor by inserting a tube constantly surrounded by liquid CO_2 in acetone produced no noticeable effect.

The results show a minimum discharge potential in the neighborhood of 300 volts. Curve *A* corresponds rather closely to the potential gradient set by Madelung as the limiting value. Curve *C* gives a potential of 10^6 volts pro cm. and curve *D* 3.10^6 volts pro cm. Since the results are so irregular and seem to depend upon the condition of the electrodes rather than the exact state of the surrounding vacuum and since the value of the potential gradient seems to be increased by any means which would drive gas out of the electrodes, it is very probable that the discharge takes place in a gas of considerably greater density than is indicated by the state of the vacuum. This gas may permeate the electrodes but it also seems to cling fast to their surfaces. The presence of this gas may make impossible a complete confirmation of the Thomson interpretation of Paschen's law for small values of *p.d*, but another approximation may be made by using tungsten electrodes which can be more readily and more nearly completely freed from gas.

These investigations were carried out in the physical laboratory of the University at Wurzburg. My sincerest thanks are due Professor Wien and the other members of the department for their stimulating interest and helpful advice.

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