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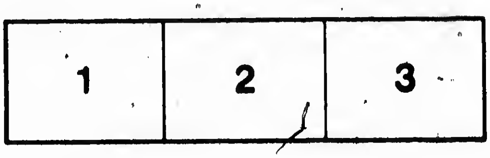

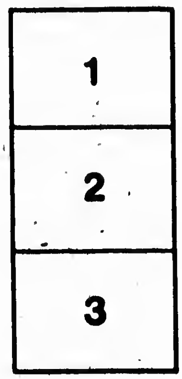

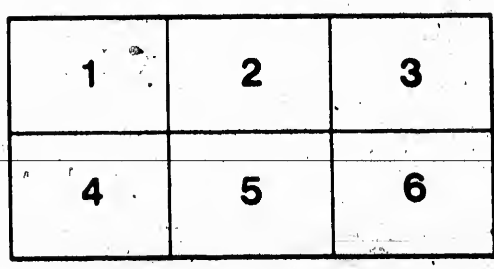

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Electric Screening in Vacuum Tubes

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1900

IX.—*Electric Screening in Vacuum Tubes.*

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Demonstrator in Physics, University of Toronto.

(Communicated by President Loudon and read May 29, 1900.)

In his work entitled "Discharge of Electricity through Gases," page 170, Professor J. J. Thomson describes an effect which he observed in a series of experiments with Faraday cylinders inserted in vacuum tubes for the protection of exploring electrodes.

In these experiments tubes similar in form to that shown in Fig. I were used. An exploring electrode *C.* was sealed into the tube and surrounded by a metal cylinder *D.* The end of this cylinder facing the bulb of the discharge tube was closed by a plate of some selected metal such as aluminium or brass. A small opening *c* served to equalize the air pressures inside and outside the cylinder, and an ebonite plug closed the lower end and acted as a support to hold the cylinder in position.

On passing an electric discharge through these tubes no unusual action was observed at high pressures; but when a pressure of about one millimetre of mercury was reached the gas within the cylinder became conducting, and electric charges given to the inclosed electrodes were gradually dissipated.

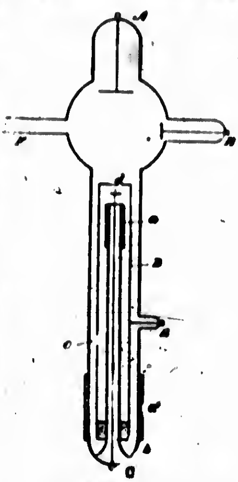

FIG. I.

With pressures low enough to allow the cathode rays to fall upon the end of the cylinder, the protected electrode gained a negative charge. With still higher exhaustions the same effect was obtained, but the rate at which the negative charge was gained rapidly increased as the pressure was lowered.

The effect was obtained when the ends of the cylinders were closed by plates ranging all the way from thin aluminium foil up to brass 1·5 mms. in thickness, but the rate at which the charge was acquired by the electrode decreased with the thickness of the plate selected.

In discussing this effect Professor Thomson brought forward the hypothesis that cathode rays were in some manner produced in the gas surrounding the electrode *C.*

It is well known that these rays impress electrical conductivity upon gases which they traverse, and it is generally agreed that they consist of very small negatively charged particles of matter. Their presence within the cylinders would therefore account for the observed conductivity, and for the negative charges gained by the electrode at low pressures.

But there are difficulties connected with the supposed production of cathode rays within the cylinders which are not easily explained. That these rays travelled from the cathode of the discharge tube through the thick brass walls to the electrode *C*, Professor Thomson considered highly improbable. He suggested, however, that possibly the effects may have been due to secondary discharges between the cylinder and the inclosed electrode; that, in fact, the ends of the cylinders, when under bombardment by the cathode rays of the discharge tube, may have become negatively charged, and acting as new cathodes may have projected streams of cathode rays against the electrode.

As an objection to this explanation it may be pointed out that when the discharge tubes were excited, the cylinders were always connected to earth by wires of small resistance. It therefore seems probable that if portions of cylinders acquired potentials sufficiently high to produce discharges of cathode rays, these discharges would also have been accompanied by electric currents of considerable intensity along the earth wires. There appears, however, to be no indication that such currents existed, and in default of further experimental evidence the hypothesis of secondary discharges seems hardly tenable.

The object of the experiments described in this paper was to investigate this point more fully and to determine, if possible, a more satisfactory explanation of the effect.

The investigation was begun with tubes identical in construction with those used by Professor Thomson, but as these could not be taken apart to make changes in the cylinders the experiments were completed with tubes somewhat modified in form.

The experiments are described under the following subdivisions :—

1. Preliminary experiments.
2. Electrical conduction along the surface of glass.
3. Penetrating power of cathode rays.
4. Influence of bad earth connections.
5. Influence of small openings in Faraday cylinders inserted in vacuum tubes.

1. Preliminary Experiments.

In these experiments an effort was made to work under precisely the same conditions as those selected by Professor Thomson.

The form of tube used, as already mentioned, was that shown in Fig. I. The Faraday cylinder D which served as a screen for the electrode C, was kept connected to earth by means of a fine platinum wire passing through the tube at E. The plate which closed the upper end of this cylinder was made of aluminium about ·04 mms. in thickness.

As glass, even for low voltages, is not a good insulator, care was taken to prevent any leak from the electrode over its surface by melting wax on the tube at a and a'. Tests made from time to time throughout the experiments showed that this insulation sufficed to maintain any charge given to the electrode when the tube was not excited.

The tube was kept connected to a mercury pump throughout the investigation and was excited by an eight inch spark length induction coil running under a tension of eight volts. The exploring electrode was joined to a quadrant electrometer and this instrument together with the connecting wire was surrounded by an earth connected conductor in order to screen off electrostatic action.

Under these conditions, it was found that on passing a discharge through the tube the electrometer indicated no action until a pressure of about one millimetre of mercury was reached. At this pressure, with the coil joined to any two of the three terminals A, B and D, positive or negative charges given to the protected electrode gradually leaked away. At lower pressures the electrode C slowly acquired a negative charge. This charge, however, did not go on increasing when the discharge was passing, but after a time reached a limiting value and then remained stationary.

With still lower pressures the same effect was observed but the value of the limiting charge increased and was more quickly reached.

With pressures so low that cathode rays could traverse the bulb of the tube, a momentary discharge sufficed, when A acted as a cathode, to give a deflection beyond the range of the electrometer, a value which indicated a charge of at least five or six volts.

Although this statement represents in a general way the results obtained, it was exceedingly difficult to trace uniformity in the effects. It frequently happened that the electrode C, instead of receiving a negative charge, received a positive one, this being especially the case when A and B were the terminals and neither connected to earth.

If the electrode *C* were given either a positive or a negative charge it sometimes happened that no leak occurred. This result was chiefly noticeable when the terminals *D* and *A* were connected by a wire and both acted simultaneously as cathodes with *B* as the anode. Also throughout the experiments, sudden and violent deflections were frequently obtained which seemed to indicate strong inductive action accompanied by sparking within the cylinder.

With this form of tube the results were exceedingly unsatisfactory. Owing to gas being given off by the metal it was difficult to maintain the same degree of exhaustion for any length of time. The character of the discharge also seemed to be affected by the state of the electrodes, and it was consequently almost impossible to reproduce all the conditions necessary to make a proper comparison of results obtained at different times.

Besides, the Faraday cylinder *D* was not free from defects. Schuster[1] has shown that when a vigorous discharge is passed through one compartment of a vacuum tube the gas in an adjoining one is also thrown into a sensitive state. It was just possible then that, though the opening *C* served to equalise the pressures, it also afforded, by diffusion, a means of communicating to the gas inside the cylinder the conductivity impressed upon that outside by the discharge from the induction coil.

Again, in this form of tube the electrode necessarily passed through the glass and could not therefore be completely surrounded by the cylinder.

In order to overcome any disturbing influence arising from these defects, and to localise more definitely the effect investigated, a new form of tube was devised which could readily be taken apart and which did not require even a small opening in the Faraday cylinder.

2. Electrical Conduction along the Surface of Glass.

This form of tube which is shown in Fig. II, was divided into two compartments which could be separately exhausted. The metal cylinder *D* in this case formed part of a metal socket *H* into which the glass parts of the tube were fastened. Air tight joints were made by inserting rubber washers *b* between two bevelled brass ones, and then compressing the whole by a threaded brass piece which slid over the glass and could be screwed into the socket.

The upper end of the cylinder was made air tight by placing lead washers above and below the plate *d* and then screwing a brass cap

[1] Schuster, Proc. Roy. Soc., 42, p. 371, 1887.

down over them. Joints made in this way worked quite satisfactorily and besides being airtight they also afforded a means of readily taking the tube apart in order that plates of different thicknesses might be used for the end of the cylinder.

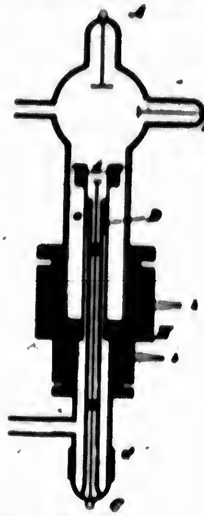

Fig. II.

As before, the electrode *C* was insulated by melting sealing wax on the glass at *a* and *a'*, and the cylinder was kept connected to earth through the socket *H*.

Experiments were first made by exhausting the upper chamber, while the lower one was kept at atmospheric pressure. The disc *d* was taken from aluminium ·04 mms. in thickness, and the coil was kept running during the exhaustion.

Various selections of the terminals *A*, *B* and *H* were made, but in no case, even with the lowest pressure obtainable, did the electrometer attached to the electrode *C* give the slightest evidence of any electric action.

The two compartments of the tube were then united, as shown in Fig. III, and provided with the taps *E* and *F*.

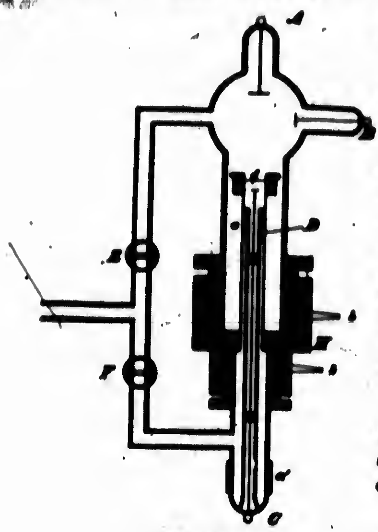

Fig. III.

On then re-exhausting the upper chamber and keeping the tap *F* closed, no action was observed until a pressure somewhat lower than a millimetre of mercury was reached. At this point the electrometer began to gain a negative charge, and the action became more intense as the exhaustion proceeded. It was very strongly marked when *A* and *H* were the terminals, and was measurable, though feeble, when *A* and *B* were the discharging electrodes.

The effect appeared to be slightly greater when *H* was the cathode and *A* the anode, than when the opposite arrangement was made.

As the air in the lower chamber was at atmospheric pressure during the experiment, and as no such action was exhibited when the two compartments were not united, the result pointed to the existence of an electric conduction along the surface of the glass joining the two parts of the tube.

In order to test this the electrometer was simply connected to the wax a' instead of to the electrode C. On then exciting the tube the same charging action was obtained.

It was therefore clear that, although the sealing wax was a good insulator for small voltages such as those used in testing the insulation of the electrode C when no discharge was passing in the tube, it was not sufficient to cut off conduction along the glass when the tube was excited by the induction coil.

To overcome this difficulty part of the glass tube E, F, was removed, and replaced by one of brass held in position by sealing wax. With this tube joined to earth the experiments just described were repeated, and not the slightest trace of any electric action was observed in connection with the electrode C.

The effect of reducing the pressure in the lower as well as in the upper chamber was then investigated. The two taps E and F were kept open and both chambers exhausted together until any desired pressure was reached. The tap F was then closed and the exhaustion in the upper chamber completed.

In this way a wide range of pressures was examined and in no case did the electrometer give any indication that the electrode C either gained or lost a charge when the tube was excited. In all these tests the tap F was kept closed when the discharge was passing in the tube in order to prevent any possible conduction in the gas from one chamber to the other. This was found to be especially necessary at very low pressure when A and H were selected as the discharging electrodes. Otherwise the well known phenomenon illustrated by Hittorf's experiments occurred, the discharge preferring to take the longer path round by the tube E, F, rather than the short one across the bulb of the tube from the cylinder D to the disc A.

In all the experiments with this form of tube hitherto described the end of the cylinder D consisted of a disc of aluminium d ·04 millimetres thick. This disc was now replaced by one only ·004 millimetres in thickness and both chambers were as highly exhausted as possible. The tap F was then closed and the tube excited. Different methods of connecting the coil to the tube were tried but in every case the cylinder again effectively screened the electrode C, and no charging was observed. Charges given independently to the electrode C were also maintained without loss during the passage of the discharge in the upper chamber.

Now it is known from Lenard's[1] experiments that when cathode rays impinge upon one face of an aluminium disc ·004 millimetres in thickness a pencil of similar rays issues from the opposite face of the disc. In the experiments just cited one would then have expected at low pressures, especially when A was the negative terminal, that some indication would have been given by the electrometer of the presence of Lenard rays within the cylinder.

But the lowest pressures attainable with this form of tube only permitted the cathode dark space to extend about one half the distance across the bulb from the disc *A* to the end of the cylinder. The cathode rays could, therefore, not reach the disc *d*; no cathode rays could then be produced within the cylinder, and, as a consequence, no electrical conductivity be impressed upon the gas surrounding the exploring electro

While this form of tube was thus of great service in locating the cause of the effect observed by Professor Thomson it was not suitable for the production of the lowest pressures on account of the large amount of metal which it contained.

A third form of tube was then devised in order to examine the screening action of Faraday cylinders at very low pressures.

3. Penetrating Power of Cathode Rays.

In this tube, Fig. IV., the electric screening was partly brought about by the use of mercury. The tube itself consisted of two parts, which were united by a carefully ground joint, and the cylinder *D* was made from a steel tube held in position by fitting tightly to a plug of ebonite *b*. This plug also fitted tightly to a central glass tube, and was pierced, as shown in the figure, by a small hole which permitted the pressures inside and outside the cylinder to be equalized when the mercury was lowered.

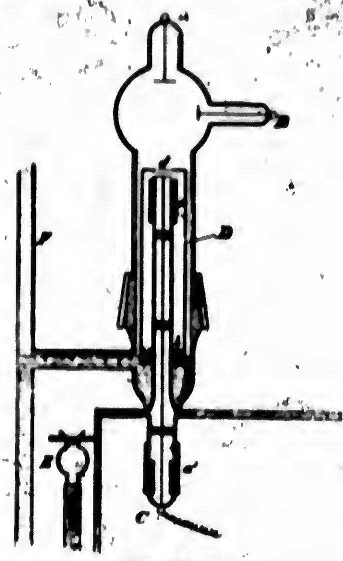

Fig. IV.

[1] Lenard Wied., Ann., p. 51, 225, 1894.

The upper end of the cylinder was again made air-tight in the manner already described and was closed by a thin disc of aluminium. A platinum wire attached to the cylinder made electrical connection with the mercury and an iron wire dipping into the mercury in the receiver E connected the whole to earth.

As before, the electrode C was carefully insulated by melting sealing wax on the tube at a and a^1. To prevent conduction along the surface of the glass the part of the tube below the bulb was tightly bound with tin foil connected to earth.

The highest vacua could be obtained with this tube and the use of the ground joint gave easy access to the interior without causing any derangement of the apparatus.

When ready for use, the tube was placed in position with its lower end extending into the earth-connected metal box that contained the electrometer. The air was then exhausted through the tube F until any desired pressure was reached and the mercury raised until it made contact with the steel cylinder.

By this arrangement the Faraday cylinder consisted of the steel tube D, the mercury, and the metal box containing the electrometer, the whole practically constituting a single earth connected metallic conductor.

In the first experiments with this tube aluminium ·04 millimetres was used for the plate d. The air was then exhausted until the cathode dark space extended completely across the bulb of the tube and its walls were covered with a green phosphorescence.

With these conditions A, B and D, were in turn selected as the negative terminal of the tube, but in no case was there obtained any evidence of electrical action within the cylinder. Charges, either positive or negative, given independently to the exploring electrode were maintained without loss when the tube was excited.

The aluminium plate d was then replaced by one ·004 millimetres in thickness and the tube re-exhausted.

With B or D now acting as a cathode there was again no indication of electrical action within the cylinder, even with the lowest pressures obtainable. But, when A was taken as the negative terminal, it was found that just as soon as the walls of the tube in the neighbourhood of d began to phosphoresce, the electrode C slowly acquired a negative charge. With still lower pressures this charging became more rapid until finally with very high exhaustions a momentary discharge in the tube sufficed to charge the electrode beyond the range of the electrometer.

This effect clearly pointed to the existence of cathode rays within the cylinder.

To verify this conclusion the induction coil was suddenly reversed while the electrode C was gaining its charge. This action at once stopped the effect and the electrometer needle came to rest and remained stationary. On again reversing the coil the charging immediately recommenced.

An electromagnet was then placed in position with the bulb of the tube between its pole pieces. On exciting this magnet the cathode rays coming from A were deflected and again the charging ceased and the electrode C maintained its charge.

When the electromagnet was cut off the cathode rays once more impinged upon the disc d, and the charging at once began again.

These experiments then showed that the charge gained by C was due to the cathode rays produced within the cylinder by the action of the pencil impinging on the outside.

From a consideration of the results obtained with all the tubes, it thus seems evident that a closed Faraday cylinder, placed within a vacuum tube in which a discharge is passing, will completely screen off all electrical action unless made of metal thin enough to permit the passage of cathode rays through it.

4. Influence of Bad Earth Connections.

In the experiments described in Section III, special care was taken with the earth connections. These were made by soldering an iron wire to a water main and then inserting the end of the wire in the mercury in the vessel E.

To test the influence of bad earth connections the cylinder was first capped at d with a thick disc to cut off the cathode rays, and then a wet string or a column of xylol was placed in the earth circuit between the iron wire and the mercury.

Under these conditions the passage of the discharge in the tube was almost invariably accompanied by marked induction effects.

With very high exhaustions for example, A and B being the terminals and neither connected to earth, there was no inductive action when the connection was made by the iron wire or the wet string, but when the column of xylol was inserted in circuit the electrometer showed a strong positive induction. This action, however, was not accompanied by any permanent charging as the insertion of the iron wire in the mercury was sufficient to at once bring the electrometer needle to rest in its initial position.

Again, with the cathode *A* well earthed, *B* being the other terminal, a large negative charge was induced when the earth connection to the cylinder was made through the wet string; but when *B* was put to earth instead of *A* only a feeble inductive action was obtained. With *A* as anode and *B* cathode and the wet string inserted as part of the earth circuit there was a large positive induction if B was put to earth and but little when *A* was earthed. In both these cases the action was much more intense when the column of xylol replaced the wet string.

At higher pressures such as one millimetre of mercury the action again varied with the conditions of the experiment. When *A* and *B* were the electrodes and neither connected to earth a small positive induction was observed when the column of xylol was inserted, but none when the connection was made by means of the wet string. On the other hand when one of these electrodes was well earthed there was a very strong positive induction such as that obtained at much lower pressures.

The experiments in this direction were not carried further, as the presence of this inductive action was sufficient to show the importance of having good earth connections in investigations of this class.

From these results it appears highly probable that the sudden deflections obtained in the experiments described in section I may be traced to this cause, as in that case the earth connections were simply made by means of a platinum wire placed in contact with the cylinder.

5. Influence of Small Openings in the Faraday Cylinders Inserted in Vacuum Tubes.

While electric conduction along the surface of the glass appeared to explain the effects described in section I, it was also thought possible that the effects might be due in a measure to the presence of the small opening *c* in the cylinder *D*, Fig. I.

A similar opening existed in the cylinder of the tube shown in Fig. IV, but, as in this case the hole could be readily closed by simply raising the mercury, this form of tube was well adapted to investigate the influence of such openings.

To investigate this point a series of experiments were made with the mercury lowered. The disc *d* was made of metal thick enough to cut off the cathode rays, and a discharge was passed through the tube at pressures both high and low, each of the electrodes *A*, *B* and *D* being in turn selected as the cathode.

As a result of the tests no evidence was obtained of the presence of electrical charges within the cylinder except in one case.

This occurred only at very low pressures when A acted as cathode and D as anode. The electrode C then slowly gained a very slight negative charge. Its amount, however, was not at all comparable with the charges obtained in the experiments previously described, and would be fully accounted for by a slight diffusion of negative ions through the opening in the ebonite plug.

6. Summary of Results.

1. In passing a discharge through a vacuum tube, especially at low pressures, an electric conduction takes place along the surface of the glass which, unless specially guarded against, is apt to interfere with the study of true effects within the tube.

2. In the use of Faraday cylinders in vacuum tubes good earth connections are very essential.

3. Even very small openings in such cylinders exercise a disturbing influence.

4. Cathode rays, when allowed to fall upon Faraday cylinders, do not impress electrical conductivity upon the gas within unless the cylinders are made of metal thin enough to permit the rays to pass through.

The experiments were conducted in the Cavendish Laboratory and my thanks are due to Professor Thomson who proposed the investigation and offered many valuable suggestions throughout its progress.