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XXXV. *Action of a Magnetic Field on the Discharge through a Gas.* By R. S. WILLOWS, M.A., D.Sc.*

WHEN a discharge which is passing through a gas under reduced pressure is acted on by a magnetic field, it is known, both from theory and experiment, that if the field is parallel to the discharge it causes it to pass more easily, while if the field is transverse the opposite is the case. I have shown †, however, that below certain pressures which vary with the conditions of the experiment, a transverse field increases the current in the tube and diminishes the difference of potential at the terminals, provided it be applied near the cathode. At other points of the discharge a decrease in current is always produced by the field.

Birkeland has shown ‡ that with the lines of force parallel to the tube, supposed cylindrical, at pressures below $\cdot 012$ mm., the potential-difference is made to diminish by the magnetic field, at first slowly as the intensity is increased, until a certain critical intensity is reached, when a large, abrupt diminution is obtained.

Almy § has studied these two effects, and has come to the conclusion that they are both due to the same cause. He concludes that the action of the magnet is simply to concentrate the discharge so that it passes through the gas by a sort of brush or arc rather than in the usual manner, and that this brings about an increase in the conductivity.

Further study of these effects was my object in starting the experiments described in the following paper.

When the negative glow is the part of the discharge acted on by a transverse field, an increase in potential at the terminals always takes place; but it has not been determined previously whether the results depend on whether the magnet acts at the surface of the cathode or at any other point in the dark space.

In the earlier paper I was fortunate enough to be able to use a large accumulator battery to produce the discharge, and so both voltage at the terminals and current through the tube could be measured. In the present case a coil, driven by a mechanical interrupter, was used, and the voltage only was measured by means of a multicellular voltmeter. Where the range of the voltmeter was not great enough, the tube was shunted by a liquid high resistance, and a fraction of the total voltage taken or the whole measured in steps. An electro-magnet with pole-pieces formed so as to give a very local

* Communicated by the Physical Society: read January 27, 1905.

† *Phil. Mag.* [6] i. p. 250 (1901).

‡ *Comptes Rendus*, cxxvi. p. 586 (1898).

§ *Proc. Camb. Phil. Soc.* xi. p. 183 (1901).

field was used, and the strength of the field at different distances from the line joining the poles, and for different currents, was found by means of a flat coil and ballistic galvanometer.

A long cylindrical tube of 25 mms. diameter, provided with disk electrodes, was pumped down until the Crookes dark space was 3 cms. long, and the transverse field applied successively at the cathode and at distances of 1, 2, 3, and 4 cms. away from it in the direction of the anode. The observations showed that when equal decreases in potential were produced, the field at the cathode surface was practically the same for all positions of the magnet. We may therefore conclude that it is at, or near, the surface of the cathode that the action arises. The field shortened the dark space from 3 cms. to about 2 mms.

If Almy's explanation is the correct one, the critical pressure, above which the field causes an increase and below which a decrease in the terminal voltage, might be expected to be more or less irregular and ill-defined. In any case, it was thought worth while to study this pressure more carefully with different transverse fields, and an observation of interest resulted. Starting from a pressure of 3-4 mms., the volts at the terminals were measured with the magnet off and on at the cathode. As the pressure is continually lowered, the magnet being off, it is, of course, known that the voltage decreases, reaches a minimum, and then rapidly rises. The value of the critical pressure corresponding to minimum volts depends on the diameter of the tube, the nature of the gas, and perhaps also on the current. The last point I could not investigate with a coil. It was found that *above this critical pressure the field caused an increase in the voltage at the terminals, while below it caused a decrease.* At pressures much above 5 mms. very little effect was noticed. This result was confirmed by experiments on tubes with lengths varying from 50 cms. to 10 cms., diameters from 25 mms. to 3 mms., and with disk or wire electrodes. By using hydrogen, carbon dioxide, and air in these tubes, the critical pressure could be shifted from .3 mm. to about 1 mm. and the observation still held, although with hydrogen the results were not so regular as with the other gases.

This critical pressure is much more sharply marked in narrow tubes. The series of observations given below will serve as an example of the results obtained. They were taken with a tube 3 mms. in diameter, 10 cms. long, filled with air, and a field of about 600 lines per sq. cm. A fraction only of the voltage is given.

VOLTS.

Magnet off.	Magnet on.	Magnet off.	Magnet on.
290	305	218	200
262	272	248	218
252	260	268	235
208	198	270	242
190	197	285	265
184	191	295	275
186	187 (?)	305	285
195	190		

The pressure was gradually reduced from the beginning to the end of the series, the minimum voltage is 184–186; before this is arrived at the magnet causes an increase, after it is passed a decrease in the volts, but it never causes the voltage to fall below 186. The field therefore does not reduce the absolute minimum voltage causing the discharge. This is worthy of note, as Carr* has shown that the minimum sparking potential is a constant for the gas, and there is doubtless a close connexion between the minimum sparking potential and the minimum voltage required to maintain the discharge.

With tubes much shorter than 10 cms., the pressure had to be lower than the minimum voltage pressure before the magnet caused a decrease. This is no doubt due to the fact that the field could never be sufficiently localized to act at the cathode only, and where it acts at other points of the discharge it brings about a rise in voltage.

It would appear, therefore, from my experiments, that the transverse magnetic effect is closely connected with other features of the discharge, and hence is probably not due to a concentration of the luminous portion into a brush or arc.

I tried next the effect of a longitudinal field on several of the tubes, but, down to a pressure .01 mm., a certain decrease in the terminal voltage was never obtained. The iron core of the magnet employed to produce the field was of greater diameter than the largest cathode used; the field had a maximum value of 900, it was therefore more intense than that used by Almy or Birkeland. I am unable to account for the discrepancy between my results and those of these physicists.

One tube was about 2 cms. long, so that the longitudinal field could act along the whole length of the discharge. Still no effect could be found, but if the same field was applied transversely at the cathode it produced a fall of 30 per cent., and this although it was not specially concentrated. The

* Phil. Trans. cci. p. 403 (1903).

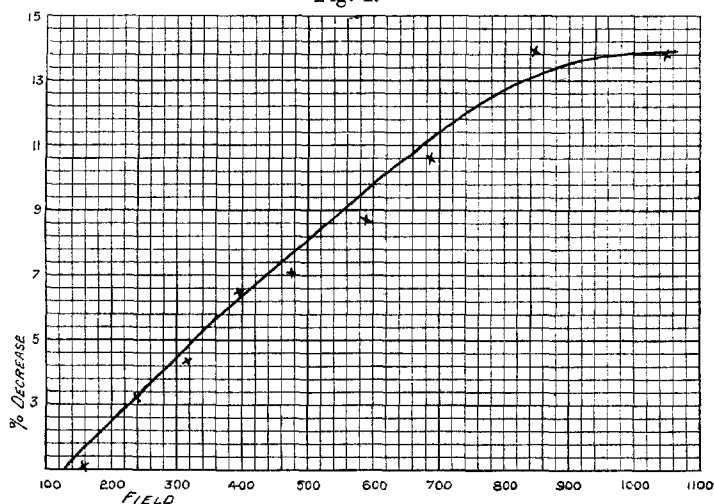
transverse and longitudinal effects are therefore of a different nature.

The dependence of the fall in voltage on the strength of the field when the pressure in the tube is kept constant, can be seen from the following series of readings. The gas-pressure was $\cdot 052$ mm.

Field.	Per cent. decrease in volts caused by field.
159	1.1
238	3.2
318	4.3
398	6.5
477	7.1
589	8.7
685	10.6
844	13.9
1050	13.8

These numbers are shown graphically in fig. 1. The effect reaches a limiting value in this case ; in others it reached a maximum, and then slightly decreased as the field continually increased ; this usually took place in the wider tubes.

Fig. 1.

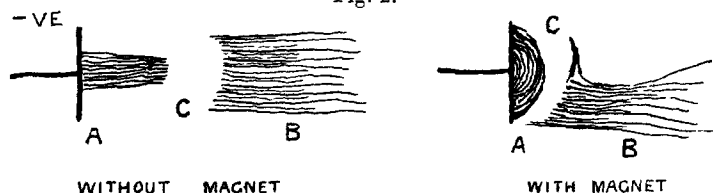


The fall in volts does not increase indefinitely as the pressure is decreased. In all the cases tried, it appeared either to reach a limiting value or much more generally to fall off, and in some cases, at the lowest pressures reached,

·002 mm., a rise in volts was brought about by the field. The results, however, at the lowest pressures were very irregular, and it may be that Almy's supposition as to the concentration of the discharge may have some weight here.

When the transverse field is applied, the Crookes dark space is greatly shortened on that side of the tube to which the discharge is deflected, very little alteration in its length is seen on the other side. The glow at the surface of the cathode (called by German writers the first negative layer) is also affected. The figures adjoining (fig. 2) show this.

Fig. 2.



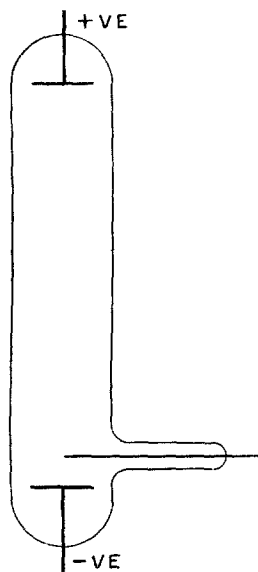
When the field is off, the first negative layer, A, covers the centre only of the cathode and is cylindrical in section; with the field on, its length is considerably less and it covers much more of the cathode area.

Since this layer is supposed to be due to ionization caused by canal-rays striking the cathode, an experiment was performed to see whether the path of these rays was altered by the field. A tube, as shown in fig. 3, with an aluminium wire projecting across the surface of the cathode was used.

The surface of the cathode behind this wire is devoid of all glow as shown by various investigators. The magnet caused no shift of this shadow, so that the fields used were not sufficient to deflect the canal-rays.

Townsend * has given a complete explanation of the fact that there exists a pressure for which the sparking potential between two fixed electrodes is a minimum. The fact that there exists a pressure for which the E.M.F. required to *maintain* the discharge is a minimum yet awaits a detailed explanation. The following observation on this point is of interest.

Fig. 3.



* Phil. Mag. Nov. 1903, p. 598.

If a curve be plotted showing the relation between terminal voltage and pressure of the gas in the discharge-tube, then, as the latter is diminished, starting from a few mms., the relation between the two is a linear one. As soon, however, as striæ appear at the cathode end of the positive column the voltage decreases less quickly than before; when the whole length of the positive column is striated, the voltage reaches its minimum value. If the pressure is further decreased, the voltage required to maintain the discharge rapidly increases. This observation was confirmed on tubes up to 50 cms. in length, of diameters ranging from 3–25 mms., and on air, carbon dioxide, and hydrogen. The last gas was irregular.

It appears, therefore, that the positive column striates because, by that means, the discharge is enabled to pass most readily. After it is completely striated, the magnetic field causes the current to pass more easily.

The field always causes more striæ to appear. Measurements were made on the longer tubes to see if it caused an alteration in the distance between the striæ when they were so far away from the cathode as to be unaffected by the field directly. The results obtained with a coil as source of current were too irregular to admit of conclusions being drawn.

That the positive column is differently affected in different gases may be inferred from the following experiment. A long tube filled with air giving striæ at a suitable pressure was used. If a current was then sent through the electro-magnet and gradually increased, from each of the original striations a smaller one emerged on the side remote from the anode; with a further increase of field, this smaller one eventually coalesced with the original stria next nearest the cathode, and this could be repeated several times by continuously increasing the field. Below is a set of observations.

Current in magnet in amperes.	Appearance of striæ.
0	Fairly clear.
1.4	Very distinct double, one small one appearing exactly midway between two large ones.
1.65	No doubling.
2.4	Clear.
2.9	Double.
5.8	Very clear.
6.6	Very double.
7.3	Not so double.

Crookes * has shown that the double striæ frequently met with in hydrogen are due to the current being carried partly by the hydrogen and partly by mercury vapour. A similar explanation would probably apply to the above results.

The appearance with hydrogen in the tube was very striking at certain pressures. When the magnet was off, the bright parts of the striæ were very narrow and pink in colour, the spaces between being hazy. On putting on the magnet the voltage was reduced, the striæ became very distinct and steady, double as in air and the interspaces much less hazy. After a few seconds each small stria retreated into the adjoining large one next nearest to the anode. After another interval of a few seconds the voltmeter became very unsteady, the positive column changed from pink to grey, the striæ assumed the form they had before the magnet was put on, and the voltage rose to its original value. If the coil was stopped and turned on again after the lapse of 15 seconds or more, the whole of the changes were reproduced; if turned on at a shorter interval, any particular stage was at once produced according to the time that had elapsed since the stoppage.

The magnet evidently causes the current to be carried entirely by one gas; this change occupies several seconds, and the tube must rest for 15 secs. in order to allow the ions of one gas to disappear so that the other may carry its share of current.

The lower the pressure the smaller the field required to produce double striæ.

I next sought to determine whether the decrease in potential brought about by the transverse field takes place at the cathode, or whether some of this might not be found in the positive column, owing to the increased number of striæ found there when the field is on. A tube as shown in fig. 4 was used.

The side electrodes B, C, were thin pointed wires fastened in with sealing-wax joints. B was always in the positive column when A was the anode; at the lower pressures C was in the Faraday dark space or the negative glow.

The difference of potential between A and the other electrodes was measured with the voltmeter both when the magnet was on at D, and when it was off. A large fall in potential between A-B and A-C was always brought about by the field below the critical pressure, the percentage fall over these portions of the tube being much greater than over the whole. By far the greatest potential fall (magnet off) takes place at the cathode, so that the actual fall in volts

* Proc. Roy. Soc. lxi. p. 399 (1902).

between A-C brought about by the magnet was not sufficient to account for the whole decrease for the tube. When the magnet caused the potential between A-D to increase, it frequently effected a fall between A-B or A-C if the gas-pressure was not above about 2 mms.

The results given by this tube are, however, not altogether trustworthy, for the sealing-in of the electrodes B, C caused the magnet to influence the tube as a whole at a much lower pressure than previously; that is to say, the positive column was striated for some time before the magnet caused the

Fig. 4.

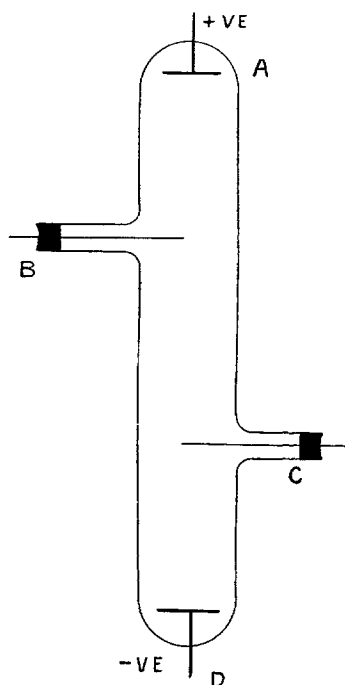
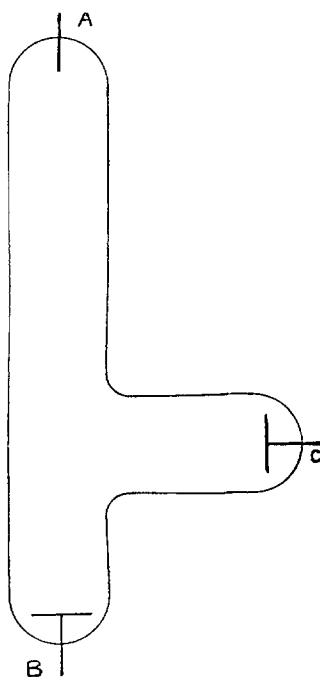


Fig. 5.



voltage to drop. This may be due to the distortion of the discharge by the wires, but it is much more likely on account of B and C acting as secondary anodes and cathodes according to which is connected with the voltmeter. It is certain that a dark space was developed round them in some instances.

A tube was next tried in which the development of the positive column could be controlled while everything else remained the same. This is shown in fig. 5.

A was a pointed aluminium wire and was always made the

anode. B, C were disks, and either could be made the cathode at will: the limbs containing them were made as nearly as possible equal. At low pressures, when B was cathode, the positive column was very short; when the glass round B gave a green fluorescence scarcely any positive column was present. Under similar conditions with C cathode the column extended to the side limb. With the field on at either cathode, the positive column extended nearly the whole length of the tube. In spite of this great difference in development, no difference could be found in the behaviour of B or C with the magnet, at a pressure when the latter brought about a large decrease in the voltage.

We may therefore conclude that the fall in potential has its chief seat near the cathode.

As to the cause of this fall, it may be suggested that the negative ions are caused to travel over greater paths in the dark space, because the magnetic field causes them to move obliquely through it. In this space, therefore, they produce more ions by collision, and the discharge being previously poor in ions at this point, as shown by numerous experiments, this causes the fall in voltage between the terminals.

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XXXVI. *Action of Radium on the Electric Spark.* By R. S. WILLOWS, M.A., D.Sc., and J. PECK, B.Sc.*

IT is well known that radioactive substances, when placed near a spark, in general cause the discharge to pass more readily by the formation of ions in the electric field. The action on a long spark is, however, different, and appears, as far as our knowledge goes at present, somewhat irregular. In some cases the discharge passes more readily, in others with greater difficulty †.

The present paper describes experiments which were undertaken with the object of studying the origin of this influence.

The spark was produced between two brass spheres of unequal diameters, one 27 mm. the other 48 mm., by means of a Wimshurst machine carrying three pairs of plates of 2 feet diameter. The radium bromide, 5 mgm., was contained in a small capsule closed with mica. The strength of the

* Communicated by the Physical Society: read January 27, 1905.

† See abstract of a paper by D. M. Sokoltzow, 'Science Abstracts,' vol. vii. p. 343 (1904), and also one by A. Stefanini & L. Magri on the same page.