DISCHARGE IN A MAGNETIC FIELD.

By Robert F. Earhart.

SIR J. J. THOMSON, in the "Discharge of Electricity through Gases" discusses the motion of an ion in a magnetic field.[1] Among the special cases treated is the one where the ion moves in the direction of the magnetic field. The forces are such as to cause a charged particle to travel along a helical path. In a later chapter (pp. 575–579) a résumé of experimental work on the effect of a magnetic field upon a discharge is given. Birkland[2] found that when a discharge tube was placed in a magnetic field and oriented so that the direction of the field coincided with the line joining the electrodes, the potential required to produce the discharge was lowered.

Almy in 1901[3] made a more careful and quantitative study of the case. His experiments were conducted at low pressures and he too found the action of a longitudinal field lowered the discharge potential. Among other things he noted that when the field was applied, the discharge was for the most part concentrated along limited paths and instead of the glow filling the entire tube it was concentrated into stream-like lines.

Willows[4] extended the experiments with some variations and operated with transverse fields as well.

Paalzow and Neeson[5] made some experiments with a tube in the shape of a Greek cross. There were four electrodes pointing toward the intersection of the cross arms. This was placed in a magnetic field in such a manner that the field could be made parallel or at right angles to the electric force. The electrodes consisted of pointed wires, and from their description neither the electric field nor the magnetic field was uniform. They established several interesting points, among others the fact that at some pressures a weak field facilitates the discharge while stronger fields diminish the discharge. The diminution of current strength or increase as the case may be is given in terms of scale divisions of the galvanometer employed. There is a description of the magnet used to

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[1] Second edition, pp. 111–116.

[2] Comp. Rendus, CXXVI., p. 586, 1898.

[3] Proc. Cam. Phil. Soc., XI., p. 183.

[4] Phil. Mag., VI., 1, p. 250, 1901.

[5] Wied. Ann., I., XIII., p. 207, 1897.

produce the fields but the variations produced by the magnetic field are stated only in terms of the current through the magnetizing coils. In 1901 Reicke[1] made an experiment in which he determined current-potential or characteristic curves for discharge in a magnetic field. In his experiment the discharge chamber was placed near one end of a cylindrical magnet and in a diverging field. His record shows the values of the field strength at several points along the discharge path. The longitudinal component of the magnetic field did not exceed 100 C.G.S. units at the electrode farthest removed from the magnet.

Recently there has been a renewed discussion of the effect produced by a longitudinal field both in high vacua and pressures ranging up to one or two millimeters. An article by Strutt[2] reviews some work done by C. S. E. Phillips[3] and extends his experiments along some lines. Both Phillips and Strutt noticed, among other things, that when two cylindrical iron electrodes are in high vacuo a discharge passes for a greatly reduced potential when the iron electrodes are magnetized.

In some cases the discharge potential was reduced from several thousand volts to between 350 and 400, only slightly more than the cathode fall in potential.

J. S. Townsend[4] comments on Strutt's experiment and believes the reduction in potential is due to the increase in path which electrons will have in a magnetic field of this kind. A helical motion will increase the effective path through which they move, thereby increasing the number of collisions which in turn will produce a supply of ions necessary for the maintenance of a current.

F. Horton[5] also comments on Strutt's work as well as on some results recently obtained by himself and in the main agrees with Townsend. He suggests that with strong fields ions may be diverted by the field and a critical field will be obtained when the loss from one effect balances the gain resulting from increases in collision.

The very interesting articles of More and Reiman,[6] More and Mauchley[7] and Righi[8] discuss the possible effects of a magnetic field on the discharge potential.

More and Mauchley maintain that the effect of a longitudinal field is not to produce a new type of ray but that the effect of a longitudinal

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[1] Ann. d. Phys., VI., 4, p. 592.

[2] Proc. Roy. Soc., A 89, Aug., 1913, p. 68.

[3] Roy. Soc. Proc., 189, Vol. 64, p. 172.

[4] Phil. Mag., VI., 26, Oct., 1913, p. 730.

[5] Phil. Mag., VI., 26, Nov., 1913, p. 902.

[6] Phil. Mag., Nov., 1912, p. 840.

[7] Phil. Mag., Aug., 1913, p. 252.

[8] Phil. Mag., Nov., 1913, p. 848.

field upon the production of the so-called magnetic rays is to reduce the cathode fall in potential so that a moderate potential will effect a discharge. These possess peculiarities which lead Righi to designate them magnetocathodic rays but More and his colleagues evidently regard them as cathode rays with some features accentuated and these peculiarities are brought out by a delicate adjustment of pressure, potential and a magnetic field but that the latter is not essential.

The article by More and Reiman suggested to the author the desirability of finding out the effect of a magnetic field on a discharge when the conditions were simplified to a greater extent than in some of the previous work. The author has no criticism of previous experiments but wishes to point out that the conditions in many of them were not reduced to the most simple terms. An effort was here made to produce a discharge between plane parallel electrodes having the electric and magnetic field parallel and uniform. The measurements made consisted of the potential required to maintain a steady current whose magnitude was measured while the magnetic field was varied from 0 to 10,000 C.G.S. units. Furthermore, these were obtained under different pressure conditions and for several gases. Fig. 1 indicates the arrangement of the discharge chamber in its relation to the two fields. The discharge chamber *D* was a glass tube 14 mm. long and 12 mm. diameter. This was closed at the ends by the electrodes *A* and *B* which were brass plates 8 cm. in diameter. The chamber *D* was placed in the region where the field would be most uniform. The electrodes were backed with fiber 1/32 inch thick and mounted on the faces of the magnet poles *MM* by means of fiber collars *FF*. The tapered pole pieces were 5.08 cm. across the face. An exploring coil showed that the magnetic field in the central region between the

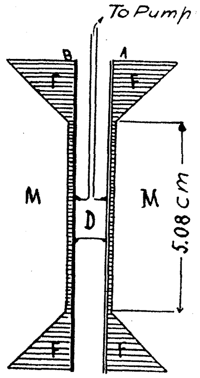

Fig. 1.

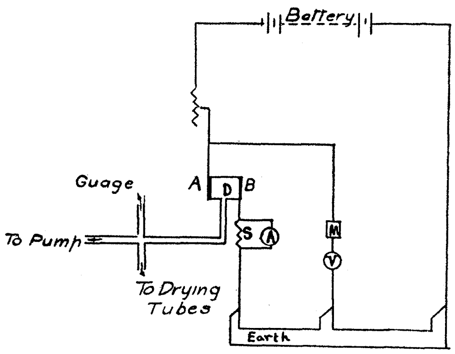

Fig. 2.

poles was uniform. Fields of 10,000 C.G.S. units were obtainable with this gap.

Fig. 2 indicates the electrical arrangement. One terminal of a battery of 400 storage cells was earthed while the other was connected to the electrode *A* of the discharge chamber through a high variable resistance. The second electrode of the chamber was earthed through a low resistance which formed a shunt, *S*, for a D'Arsonval galvanometer, *A'*. This served to measure the current passing through the discharge chamber. A Weston voltmeter, *V*, with a multiplier, *M*, measured the P.D. between *A* and the earth. The discharge chamber was connected with pump, McLeod gauge and drying apparatus through a small glass tube. Confining the discharge to the central portion of rather large electrodes and in the central portion of the magnetic field approximates rather closely the end desired, viz., to secure uniform and parallel fields. The glass walls enabled changes in the appearance of the discharge to be readily noted.

The motion of the ions under the pressures used, is no doubt a complicated one. In developing the theory of the path which ions follow, it is assumed that saturation is not attained; but in the luminous discharge saturation is attained. It is customary to regard intense ionization as a condition for luminosity. Hence while the magnetic and electrical fields may be applied in the most simple way the results of collisions will no doubt make the motion of the ions a very complicated one.

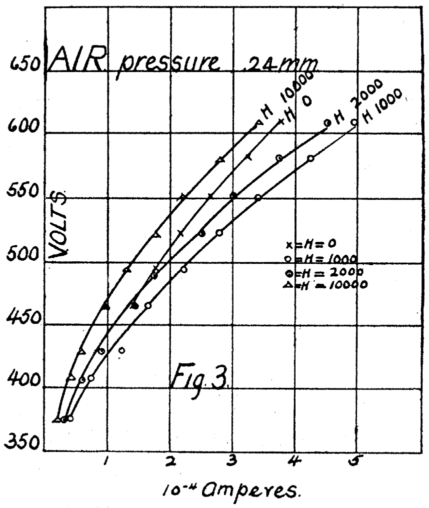

Fig. 3.

Fig. 3 indicates the effect of applying a magnetic field at a pressure less than the critical pressure. The line designated $H = 0$ gives the current and potential values for zero current in the field coils. The core of the magnet was of very soft iron and the current was reversed with diminishing values until the circuit was broken. However, there is probably some residual magnetism and the field was not strictly zero. It will be noted that with fields up to 1,000 units the discharge current for any potential is increased. In fact at this pressure a potential which will not produce a discharge under the action of the electric field alone

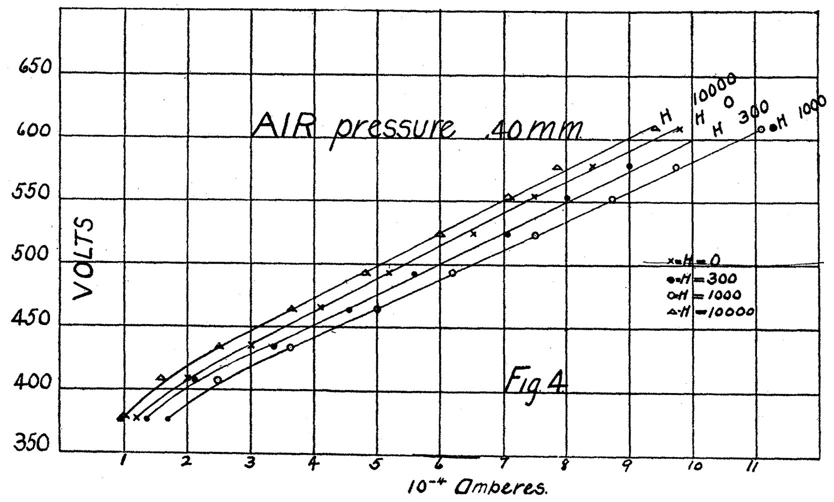

Fig. 4.

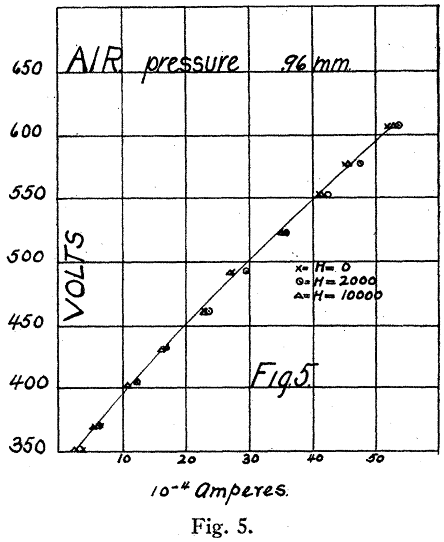

Fig. 5.

will, upon applying a magnetic field, cause the discharge to pass. Reversing the polarity of either electric or magnetic field does not modify the current. I noted, as Almy had previously noted, that when the field was applied, the appearance of the discharge changed. Instead of a soft glow filling the tube a series of blue stream-like filaments appeared along the axis of the tube and while the glow did not disappear it was visibly affected by the magnetic field. The current for a given potential increased with field strengths up to 1,400 units; beyond that the current

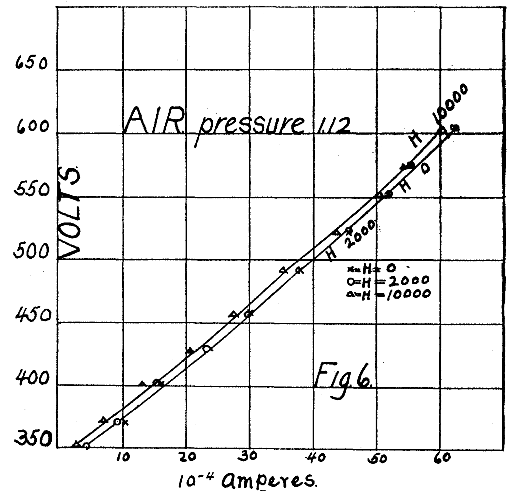

Fig. 6.

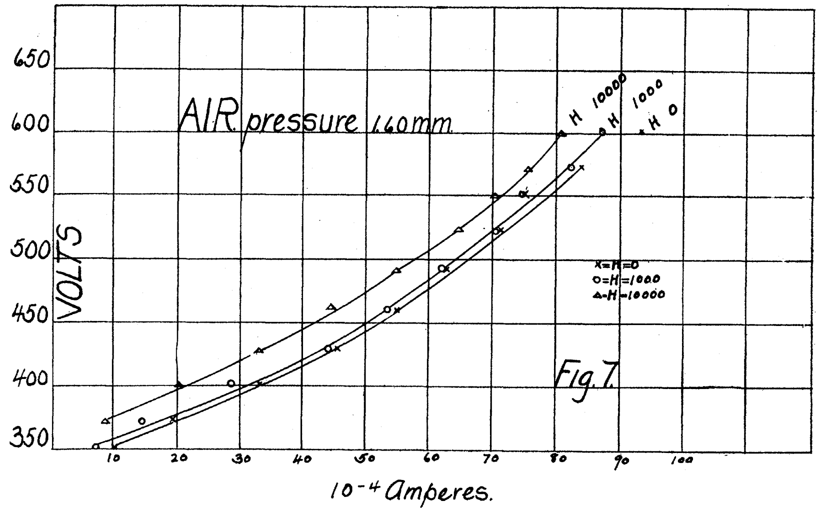

Fig. 7.

decreased. In some earlier experiments a less powerful magnet was employed with which fields of only 4,500 units could be obtained. The same effect was noted, viz., that above a critical value of the field the current became less with increase in field strength but the field was not sufficiently strong to reduce the current to the value for $H = 0$. With the larger magnet using 10,000 C.G.S. units the current value was reduced below the values for zero field.

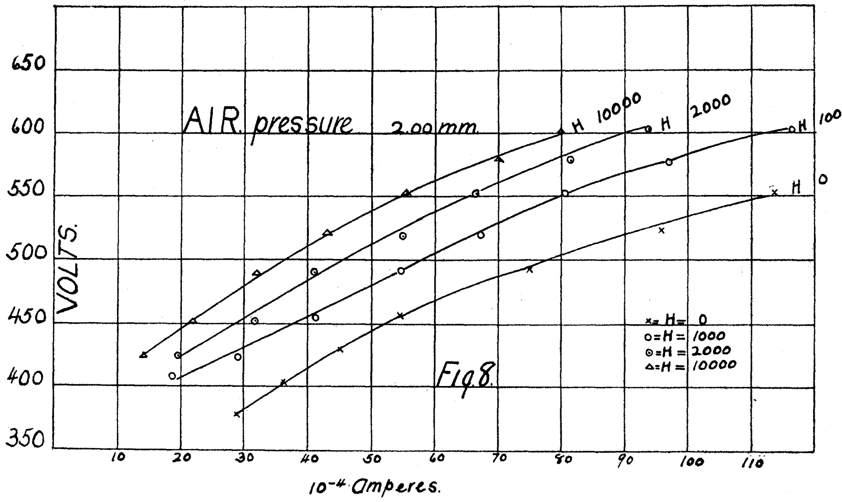

Fig. 8.

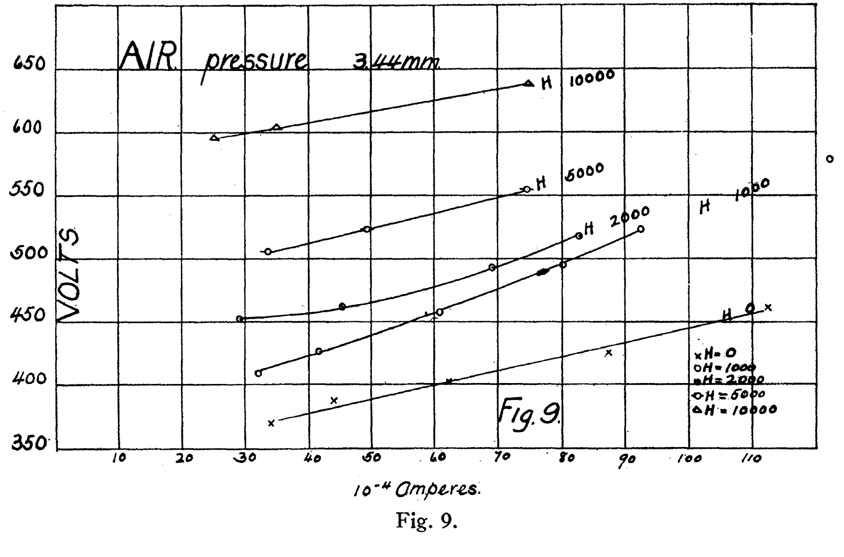

Fig. 9.

The figures which follow indicate the influence of pressure change.

It may be noted (Fig. 4) that when the pressure is .40 mm. a field of 1,000 units increases the current, 2,000 units (not shown in figure) produces no further increase but rather a slight diminution. With 10,000 units the current is reduced decidedly below the value for no field. These experiments were performed before some of the recent discussions to which reference has been made occurred, but the trend of the curves indicates that for low pressures increasing the magnetic field would lower the discharge potentials and this would continue until rather strong

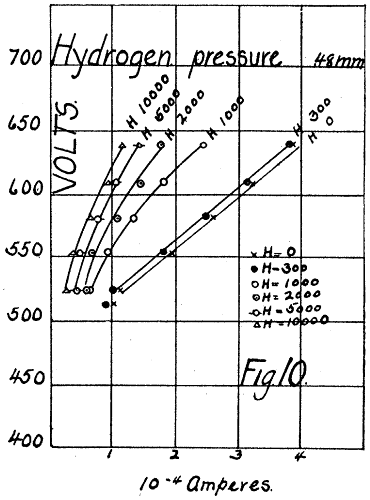

Fig. 10.

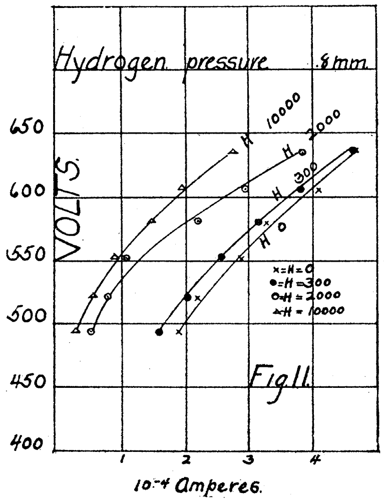

Fig. 11.

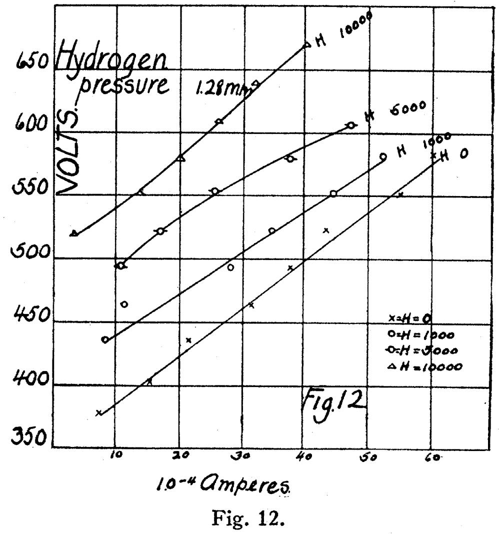

Fig. 12.

fields were produced. It would be necessary, for example, at pressures lower than .24 mm. to obtain a field of strength greater than 1,400 units before further increase in field caused a decrease in current and a very intense field to reduce the current to the value secured when *H* was 0. From my own experience in this experiment it seems that More and Mauchley are quite correct in stating that at pressures of .1 mm. the effect of the magnetic field is to reduce the effective cathode fall in potential.

At pressures of .96 mm. and 1.12 mm. (Figs. 5 and 6) the effect of the magnetic field is very small. A set of measurements made at a pressure of 1.04 mm. show variations of less than one per cent. A curve for this pressure is not shown, however. The readings taken persistently indicate that for the higher potentials the effect of the field is to increase the current slightly while for the lower potentials the current is reduced. These variations are small and would not appear in the graph on the scale chosen. It must be borne in mind that the potentials used were not greatly in excess of the cathode fall in potential and that the potential gradient between the electrodes for a portion of the distance is not the total potential difference divided by the distance separating the electrodes. It may be possible then, that a change in potential from 375 to 400 volts will double the gradient which occurs over a considerable part of the path. This pressure range is very near the critical pressure. Increasing the gas pressure above the critical pressure causes a very large increase in current under normal conditions. Attention is called to the fact that the value of the abscissæ differs in the various figures. It is

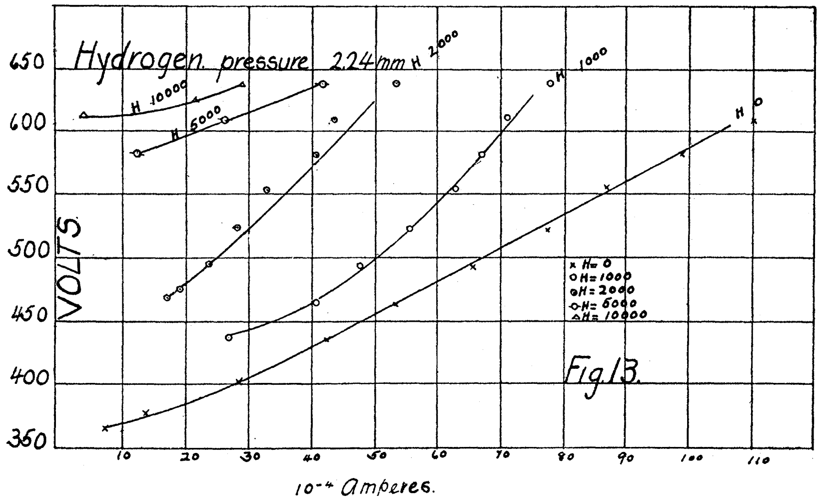

Fig. 13.

quite impossible to plot these on the same scale on account of the large changes in current produced by pressure variation. At pressures above the critical pressures the effect of the field is to greatly reduce the current.

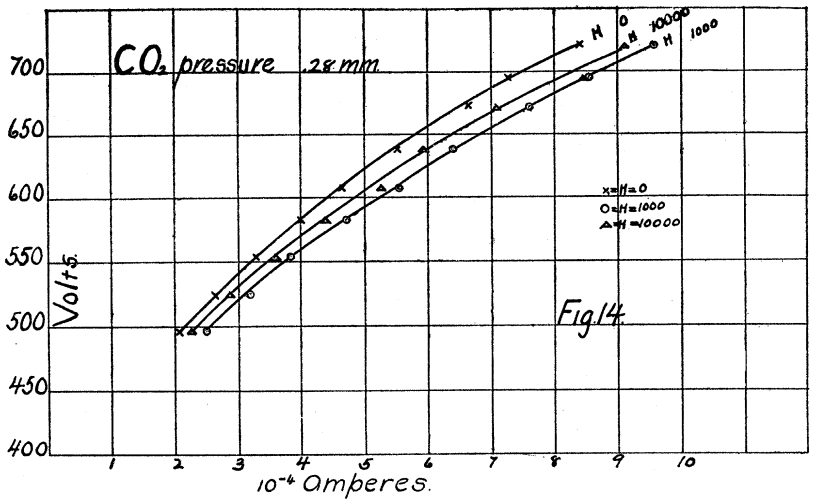

Fig. 14.

In fact at pressures of 3 mm. or more the battery was not sufficient to start the discharge in the presence of a moderate field. It was necessary

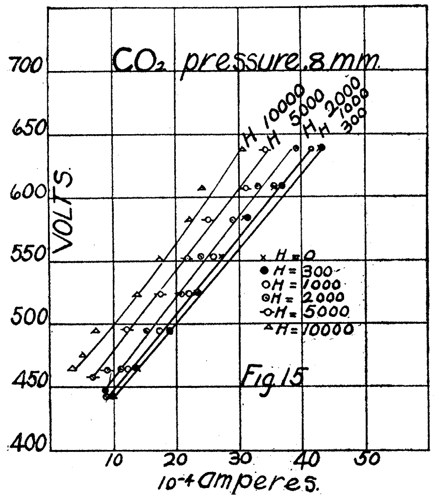

Fig. 15.

to start the discharge, then to apply the field. Unless the potential was maintained at sufficiently high value the discharge would be quenched. This is exactly the reverse of what occurs at the low pressures for in that case a discharge could be started in a magnetic field which could not be maintained when the field was withdrawn.

Figures 10 to 13 show the results of some experiments on hydrogen. The hydrogen prepared in a Kipp apparatus was purified and dried. At the lowest pressure used, a field of 300 gauss reduced the discharge current. A very feeble field, however, would increase it slightly. At higher pressures all fields applied reduced the current. The author is skeptical about the purity of the hydrogen but prepared it in the usual manner. Carbon dioxide shows the same general results as air. At the lowest pressure .28 mm. the application of a field of 1,000 units increased the current, 2,000 units increased it still more. With 5,000 units a diminution of current occurred which was not reduced to the value obtained for $H = 0$ with the application of 10,000 units. In few cases are all of the data plotted. Measurements were made with fields of strength 0, 300, 1,000, 2,000, 5,000, 10,000 C.G.S. units. Many intermediate values are omitted in the plotted results. They have served, however, as a satisfactory check upon the other values. In so far as consistent results were obtained they were made possible by operating on a seasoned gas. In order to obtain results which can be repeated and checked several or any number of times it seems necessary to thoroughly dry the gas and to let the discharge pass through it for an hour or more. After such a period of seasoning the gas appears to attain a steady state and the quantitative results can be duplicated with an accuracy of less than one per cent. from day to day. This is not true for a fresh gas.

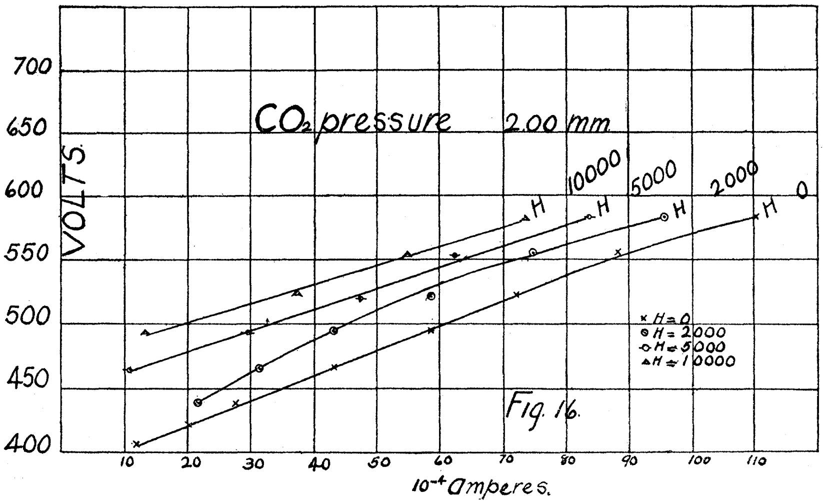

Fig. 16.

Before the discussion of Townsend and of Horton appeared the author had entertained much the same view as to the cause of the changes effected by the magnetic field. For pressures below the critical value the helical motion of the electrons will increase the effective path and ionization by impact will be increased. There is also a force tending to divert the ions from the field if their motion should have a transverse component. With the higher fields the loss due to their diversion would be greater. When the loss due to their diversion becomes greater than the rate of evolution of fresh ions the stronger fields would cause an increasing diminution. For pressures above the critical pressure there is under normal conditions a rapid ionization and the increase due to the helical motion is more than offset by the large number diverted.

The study of a large number of cases leads me to believe there is no critical pressure at which the magnetic field is ineffective at all voltages. For a particular pressure there is a field value that will produce no effect at a certain potential but for potentials slightly above this an increase in current will occur while for lower potentials a reduction of the current is obtained. Some experiments are in progress to test the questions raised. It appears that by increasing the area of the electrode, *i. e.*, using a discharge chamber of larger section, the current density would not be altered by the factor which increases the ionization, *i. e.*, the helical motion of the electrons projected from the cathode, but the factor tending to reduce the current due to the diversion of the ions would be decreased. The discussion of More and Righi on the magnitude of the fields necessary to reduce the cathode fall in potential at low pressures has caused the work so far performed to be published perhaps a little prematurely.

SUMMARY.

1. Quantitative measurements on the effect of a longitudinal magnetic field on a luminous discharge have been made in three gases above and below their critical pressures.

2. Measurements in a uniform magnetic field varying from 0 to 10,000 C.G.S. units have been made.

3. The results indicate that at pressures below the critical pressure a weak field increases the current obtained by a given potential difference while strong fields reduce it. They are shown quantitatively.

4. The lower the gas pressure the greater must be the critical value of the magnetic field to secure a reduction of the current.

5. Pressures close to the critical pressures show small effects due to magnetization but above the critical pressure the longitudinal field reduces the current.

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