ON THE EFFECT OF A TRANSVERSE MAGNETIC FIELD ON THE DISCHARGE THROUGH A GEISSLER TUBE.

By James E. Ives.

1. Introduction.

During the course of some recent investigations[1] on the so-called magnetic rays of Righi, discharges through a peculiar form of Geissler tube, it became necessary to determine the effect of a transverse magnetic field on the discharge. It was found that the current through the tube was increased, and the potential difference across the tube decreased, by the field. When the strength of the field was further increased, the discharge became periodic for a certain value of the field, and finally ceased altogether when the field, being still further increased, reached a certain value.

Not only does the magnetic field affect the current and potential of the tube, but it also changes very greatly the appearance of the positive column. As the strength of the field increases, the striæ increase in number and move down the tube towards the negative glow; at the same time the positive column becomes narrow and is pressed over to one side of the tube. When the discharge becomes periodic, the striæ coalesce and the positive column presents a continuous (unstriated) appearance to the eye. The tube then emits a high note.

Certain questions, of great interest, are raised by these phenomena. (1) Why does a certain strength of field cause the discharge to become periodic? (2) Why does a still greater strength of field cause the cischarge to cease altogether? (3) What would be the effect of the field applied to the cathode alone? (4) Applied to the anode alone?

If the Geissler tube is cylindrical in form, the magnetic field may be applied to it in two principal directions, transverse or parallel, to its length. In this investigation the field was transverse to the length of the tube.

2. Previous Investigations.

Thomson in his treatise "Conduction of Electricity through Gases,"[2] has given a general summary of the results of investigations on the action of a magnetic field on a discharge tube.

[1] Phys. Rev., 9, 353–356, 1917.

[2] Second edition, 1906, pp. 572–579.

The effect of a *transverse* field has been investigated by a number of observers. Paalzow and Neesen,[1] with a tube 11 cm. long and 1.3 cm. in diameter, having the electrodes 1.5 cm. apart, observed the effect upon the current through it. They found that a transverse field, whether applied to the whole tube, at the anode, or the cathode, always decreased the current. They give no numerical values for current or strength of field.

Melani[2] used tubes, containing air, in which the electrodes were 2, 4, 8 and 12 cm. apart. The field, current, and potential difference were measured in C.G.S. units, milliamperes and volts respectively. The transverse field was applied to the whole tube. He found that the potential across the tube, for constant field, first decreased and then increased, as the pressure increased; and, for constant pressure, increased as the field increased.

Wiedemann and Schmidt[3] placed different portions of the positive column of a tube, 12 cm. long and 2.5 cm. in diameter, between the poles of a magnet and found that a transverse field produced an increase in the electric field. The field was made just as strong as it could be without making the discharge disruptive. Sounders, of platinum wire, were sealed into the tube about 2.5 cm. apart. The current was .63 milliampere and the pressure .5 mm.

Almy[4] found that the transverse field, whether applied at the center of a tube, 20 cm. long and 3.5 cm. in diameter, at the anode, or at the cathode, produced a diminution of the potential difference between the electrodes. The diminution increased very rapidly with the pressure.

Willows[5] investigated the variation of the effect of a transverse field with pressure, and found that when the field is applied at the *cathode*, there is a pressure below which the current is increased, and above it, decreased, by its application. This "critical pressure" was found to depend on the value of the field and also on the initial current through the tube. For the same initial current, an increase of the field increases the value of the critical pressure. For the same field, if the initial current through the tube is decreased, the critical pressure is rapidly lowered. For the values of the field and current that he used, the critical pressure was about .6 mm. When any other part of the tube but the cathode was placed in the field, there was always a decrease in current. He also determined how the potential gradient varied at every point of the tube, when the field was applied, for pressures of 2.11 and .43 mm. respectively.

[1] Ann. Phys., 63, 209–219, 1897.
[2] Nuovo Cimento (4), 5, 329–356, 1897.
[3] Ann. Phys., 66, 314–340, 1898.
[4] Proc. Camb. Phil. Soc., 11, 183–190, 1901.
[5] Phil. Mag., 1, 250–260, 1901.

Riecke[1] determined the volt-ampere characteristics for different pressures and field strengths. He used a tube of peculiar shape, a sphere of 5.9 cm. radius. The electrodes were 6.5 cm. apart, placed so that when one was subjected to a transverse, the other was, at the same time, subjected to a longitudinal field. The pressures varied from .027 mm. to 5.0 mm., and field strengths of 0, 47, 144, 335 and 473 C.G.S. units were used. A serious objection to his method is that in his results it is difficult to separate the actions of the field on the two electrodes. His results show that the effect of the magnetic field increases as the pressure becomes less; at the pressure of 14.6 mm. the effect was extremely small. The characteristic for a given field strength crosses that for zero field at a critical value of the current which decreases as the pressure increases, and increases as the field strength increases. For values of the current less than this critical value the potential difference is increased, and for values greater decreased by the action of the field. He concludes that the influence of the magnetic field is made up of two parts; its action upon the anode being to increase the potential difference, and upon the cathode to decrease it.

H. A. Wilson[2] investigated the Hall effect in the positive column under the action of a transverse field. He found a well-marked effect, showing that, in the positive column, the negative ions have a much greater velocity than the positive.

Stark[3] investigated the influence of a transverse field on the *cathode fall of potential*. He determined the volt-ampere characteristics for the cathode fall for constant pressures and field strengths. As is well known, the characteristics for the cathode fall are a family of parabolas, every pressure having its corresponding parabola. He found that the effect of a tranverse field was to decrease the cathode fall and to bring the curve nearer to the current axis. By plotting the cathode fall as a function of the magnetic field he obtained curves which are very similar to those obtained by myself for the case in which the field acts on the cathode region only (see Fig. 7). I have plotted the values obtained by Stark in Fig. 13. He used a wire cathode, and experimented with fields normal and parallel to the cathode. He states that the potential difference in the *positive column* is increased by the action of a transverse field because the field diminishes its cross-section. He ascribes the effect of the transverse field upon the cathode fall to (1) a decrease in the area of the glow on the surface of the cathode, and (2) to a concentration of the

[1] Ann. Phys., 4, 592–616, 1901.
[2] Proc. Camb. Phil. Soc., 11, 249–263, 391–397, 1902.
[3] Ann. Phys., 12, 31–51, 1903.

cathode rays in the neighborhood of the cathode, the electrons being constrained to move around the lines of magnetic force. He used pressures from .031 to .493 mm.; magnetic fields from zero to 340 gausses, and currents from 75 to 850 microamperes.

Interesting papers on the effect of a *longitudinal* field on current and potential difference have recently been published by Earhart[1] and Earhart and Jolliffe.[2]

The results obtained thus far on the action of a transverse field on a Geissler tube are somewhat contradictory and do not yield definite results. In some cases the field was not entirely transverse. Also no attention has been paid to the value of the *external resistance* in the circuit, which, as I have shown in my paper on the Righi Rays,[3] plays an important part in the behavior of a discharge tube.

The discharge through a Geissler tube is affected by: (1) Size and shape of the tube; (2) kind of gas used; (3) pressure of gas in tube; (4) external resistance of circuit; (5) electromotive force impressed upon circuit, and (6) external forces acting upon tube, *e. g.*, magnetic, electric or thermal. For a given tube, and a given pressure, the effect of a magnetic field may be investigated either by determining the volt-ampere characteristics of the tube for fields of different strengths, or by varying the strength of the field, keeping the external resistance and applied electromotive-force constant, and finding the variation of the current and potential of the tube with the variation of the field. In this paper, unless otherwise stated, the measurements were made at a pressure of .13 mm. of Hg. Since it was necessary to be frequently admitting air into the tube and pumping it out again, the air of the room was used, and no attempt was made to dry it. On account of leaks, and changes in the pressure of the gas due to the discharge through it, it was difficult to keep the pressure constant. This change in pressure produced a change in the zero readings for current and potential. The errors in the readings of current and potential due to this cause, were corrected by plotting a curve showing the variation of current and potential with time, everything else being kept constant. All readings of current and potential were then timed, and the proper corrections for them taken from the correction curve.

3. Apparatus.

The form of tube finally adopted is shown diagrammatically in Fig. 1. The dimensions are given on the figure in centimeters. The anode and

[1] Phys. Rev., 3, 103–114, 1914.

[2] Astrophys Jour., 46, 76–82, 1917.

[3] Loc. cit.

cathode were alike and made of aluminum wire .328 cm. in diameter. This tube will be called Tube *C*. Two others were used exactly like Tube *C*, except that in one, which we will call Tube *A*, the electrodes were made of platinum wire .046 cm. in diameter, and in the other, Tube *B*, the anode was made of this platinum wire, and the cathode of the aluminum wire of the diameter given. The distance between the elec-

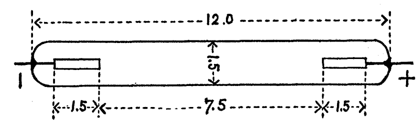


Fig. 1.

trodes in all three tubes was the same. The results obtained with Tubes *B* and *C* were of the same character. On account of the smallness of the surface of the cathode in Tube *A*, it was not found possible to get sufficiently large values of current. The high values of the potential obtained with this tube for small values of the current is shown in Fig. 11. These can be compared with those shown in Fig. 12 which were obtained with Tube *B*. The use of Tube *A* was therefore given up early in the experiments. Tube *C* was finally adopted so as to make the electrodes symmetrical and the area of the cathode fairly large. By making the electrodes symmetrical we can be sure that none of the results are due to their asymmetry.

The magnetic field was obtained by placing the tube between the poles of the electromagnet of an Einthoven galvanometer. The faces of the poles, 12.50 cm. long and 2.50 cm. wide, had a separation of 1.85 cm. The field between the poles could be varied from zero to 3,000 gausses. In actual practice, the field used was less than 400 gausses. The field, between the poles, was explored from top to bottom and from side to side and it was found that, in those parts of it occupied by the tube, it deviated from the mean value by less than 5 per cent.

The current through the tube was measured with a galvanometer or a milliammeter, and the potential difference across its electrodes with a quadrant electrometer.

The circuit of which the tube formed a part is shown in Fig. 2, where *T* is the tube; *B*, a battery of from 500 to 2,000 Planté cells; and *R*, a non-inductive resistance of graphite, water or a solution of cadmium iodide, which could be varied from a few thousand to 1,500,000 ohms. The pressure was measured with a MacLeod gauge.

4. Preliminary Theoretical Considerations.

In previous work on discharge tubes, little or no attention has been paid to the effect on the discharge of the external resistance of the circuit, R. (See Fig. 2.) It is evident, however, that the value of this resistance will play an important part in the behavior of the discharge.

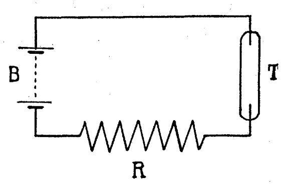


Fig. 2.

Kaufmann[1] has shown that the discharge through the tube will not be stable if

$$R < -\frac{\partial e}{\partial i},$$

where e is the potential across the tube; and i, the current through it; that is, if the discharge through the tube has a falling characteristic and its slope is greater than R.

Apart from this criterion of stability of discharge, however, the magnitude of the external resistance will affect the shape and slope of the curves showing the relation between current and strength of magnetic field, potential and field, and under certain conditions, current and potential.

In the circuit of Fig. 2, let E be the electromotive force of the battery B; then if e and V are the potentials across the tube, T, and the resistance, R, respectively, we have

$$V + e = E. \tag{1}$$

If E and R are kept constant and a small variation of e, Δe, is produced by varying the magnetic field applied to T, we shall have

$$\Delta V = -\Delta e. \tag{2}$$

But by Ohm's law

$$V = iR$$

and (2) becomes[2]

$$R\Delta i = -\Delta e$$

or

$$R = -\frac{\Delta e}{\Delta i}$$

or in the limit

$$R = -\frac{de}{di}. \tag{3}$$

Therefore, if, starting with a given current through the tube, i_0, and potential across it, e_0, we produce a variation of the current by applying some external force to the tube, keeping the applied electromotive force and external resistance of the circuit constant, we obtain a linear relation

[1] Ann. Phys., 2, 158–179, 1900.

[2] See also Stark, Elektrizität in Gasen, 1902, pp. 407–409.

between e and i which will be represented by a straight line, the *slope* of the line being numerically equal to the *external resistance* R.

Three of a family of such lines are shown in Fig. 4. These lines were obtained for Tube B, using different external resistances, R. Such a line may be called a "Line of constant E and R."

Let Fig. 3 represent such a line. Let i_0 and e_0 be the values of the current and potential before the field is applied. Then as the field is increased, let the current first decrease and then increase. The line $l'l''$ will be obtained, giving the relation between e and i produced by the increasing magnetic field. When the line stops at l'' the discharge becomes periodic. If the line $l'l''$ be continued it will intersect the axis of ordinates at P (see Fig. 3). Then OP will be equal to E, and we will have the relation

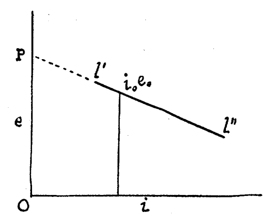


Fig. 3.

$$e = E - iR.$$

This is the equation of the straight line $l'l''$, and is equivalent to (1). This line has been called by Riecke[1] the "Verbindungslinie."

If we integrate (3) we get

$$i - i_0 = -\frac{1}{R}(e - e_0). \tag{4}$$

But e is a function of the strength of the magnetic field, H, and also of R. Therefore we may write $e = f(H, R)$, and (4) becomes

$$i - i_0 = -\frac{1}{R}(f(H, R) - e_0). \tag{5}$$

If the characteristic for the tube when no magnetic field is acting, is a rising characteristic, as it is, except for very small values of the current,[2] $f(H, R)$ will decrease as R increases, since an increase of R, if E is constant, will produce a decrease of e. Therefore $[f(H, R)]/R$ will decrease as R is increased, more rapidly than $1/R$.

Thus we see that the *variation of the current* $(i - i_0)$ will depend on the *variation of the potential* $(e - e_0)$ in the manner shown in (5). The sign of the current variation will always be opposite to that of the potential variation, and its magnitude will depend on the magnitude of the external resistance, R, decreasing as R increases. This variation of i with R for actual experimental values, is shown in Fig. 6.

Although the magnitude of the current variation when the magnetic

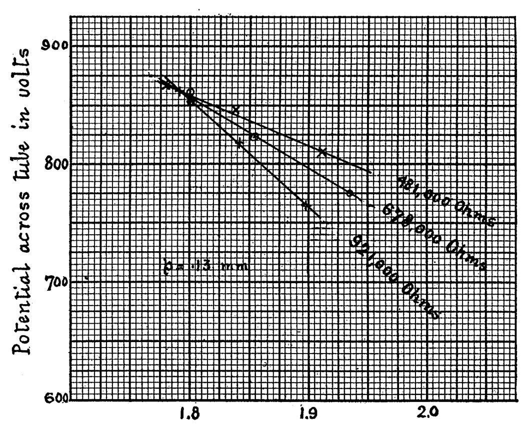
[1] Loc. cit., p. 597.

[2] See Ives, PHYS. REV., 9, p. 360, 1917, Fig. 7.

field acts on the tube depends on the magnitude of R, the volt-ampere characteristic for a tube subjected to a magnetic field of constant strength is not affected by variation in the external resistance, since a change in i, due to a change in R, will be counterbalanced by a change in e so that the point e, i, after the change in R, will lie on the same characteristic that it did before. This is a reasonable conclusion, and was found, by experiment, to be actually the case for the volt-ampere characteristic for $H = 157$ gausses, shown in Fig. 12. If, for a given pressure, the volt-ampere characteristics are drawn for several constant values of the magnetic field as in Fig. 12, the "line of constant E and R" is a straight line such as the dotted line in the figure, cutting these curves and connecting those points on them which have the same E and R.

5. Experimental Results.

1. "*Lines of Constant E and R.*"—Three of these lines are shown in Fig. 4. They were obtained with tube B. When the magnetic field was



Current in milliamperes

Fig. 4.

equal to zero, the current through the tube was 1.8 milliamperes, and the potential across it in each case, about 860 volts. As the field was gradually increased, the current first decreased to about 1.78 milliamperes and then increased to about 1.93 milliamperes, when the discharge became periodic. Each straight line represents a different external resistance, and a separate series of readings of current and potential. The magnetic field was varied from zero to about 157 gausses, the whole tube being acted upon by the field.

In Table I. are given the corresponding values of magnetic field, H, in

gausses; current, i, in milliamperes; and potential difference, e, in volts, for the three values of external resistance, R, in ohms.
no field and (*b*) with field of 157 gausses. It is seen that when the field is applied the striæ increase in number, fill the whole tube, and also appear on the side of the tube behind the cathode.

5. *Field Acting on Anode Only.*—To determine the effect on the region of the anode, the magnet was moved *up* until the bottom of the magnet was 4 cm. below the upper end of the tube. The ampere-gauss and the volt-gauss curves for this case, for Tube C, are shown in Fig. 9. The

Table I.

H.	$R = 481,000$.		$R = 678,000$.		$R = 921,000$.	
	i.	e.	i.	e.	i.	e.
0	1.800	858	1.800	854	1.800	852
80	1.780	867	1.800	861	1.792	863
118	1.838	847	1.854	824	1.841	819
157	1.911	810	1.935	775	1.898	765

It is interesting to note that we have here a method of measuring the external resistance in a circuit containing a battery, a high resistance and a discharge tube. For instance, the "lines of constant E and R" were plotted for external resistances of 132,000, 681,000 and 1,380,000 ohms,

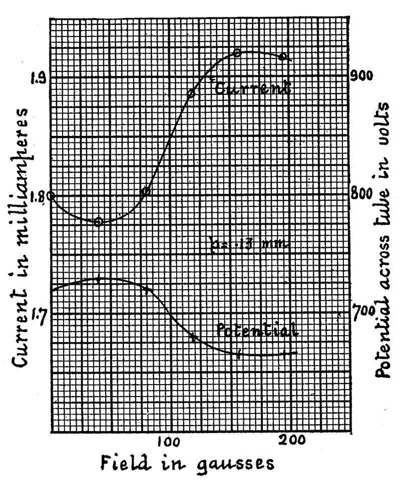


Fig. 5.

respectively. The values of these resistances as determined, in each case, by measuring the slope of the lines in volts/amperes, were 137,000, 685,000 and 1,300,000 ohms.

2. *Ampere-gauss and Volt-gauss Curves.*—The relation of the current to the field and of the potential to the field when the whole length of Tube C is subjected to an increasing uniform transverse magnetic field, and E and R are kept constant is shown in Fig. 5. It is seen that the current first decreases and then increases rapidly to a maximum value. At this maximum value the discharge becomes periodic. Readings of the milliammeter and electrometer after the discharge became periodic were not taken. The periodicity of the discharge was observed both with a rotating mirror and a telephone receiver in series with the tube. The potential across the tube varies, as we have seen that it must, in an opposite manner to the current.

3. *Effect of Magnitude of External Resistance on Shape of Ampere-gauss Curve.*—This is shown if we cause the magnetic field to act on the tube and gradually increase its strength. The current through the tube and the potential across it will vary so that they will be related to each other as shown in equations (4) and (5). The magnitude of the variation will depend on the magnitude of the external resistance, R. Three curves for the variation of the current with the field for three different values of R, 132,000, 681,000 and 1,380,000 ohms, respectively, are shown in Fig. 6. Tube B was used for these observations, and the

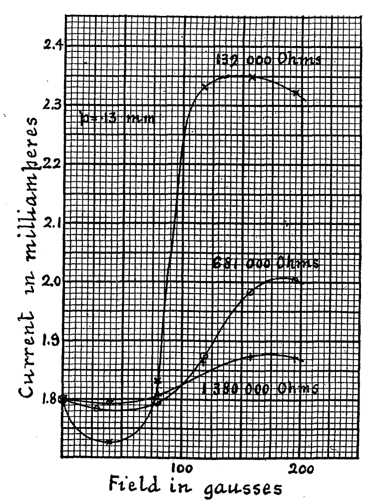


Fig. 6.

whole length of the tube was acted on by the field. It is seen that decreasing the value of the external resistance magnifies the curve. This was to be expected from equations (4) and (5).

4. *Force Acting on Cathode Only.*—To find the effect of the field on the

cathode only, Tube C being placed vertically, the anode above and the cathode below, the magnet was moved downwards until its top was only 2.8 cm. above the lower end of the tube. The curves shown in Fig. 7 were then obtained. The position of the tube with respect to the magnet

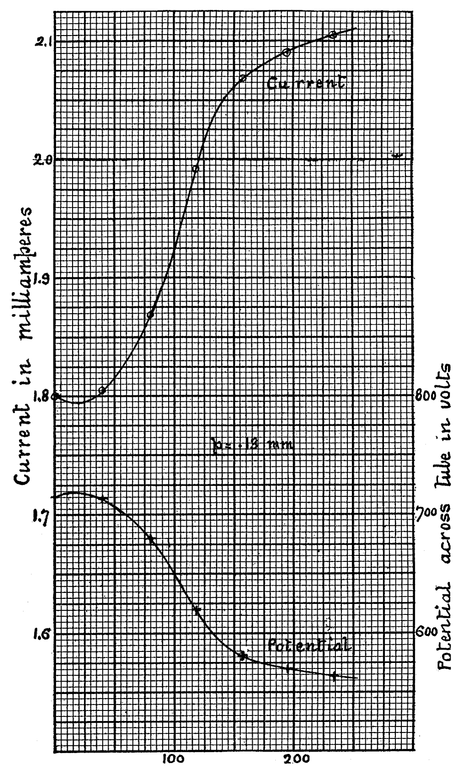


Fig. 7.
Field in gausses.

is shown in Fig. 8a, except that in this figure Tube B is shown in place, instead of Tube C. It will be noted that the curves are of the same form as those shown in Fig. 5, for the whole length of the tube exposed to the field, but that the current and potential variations are more than twice as great. To determine if the shape of these curves was affected to any extent by the stray field above the poles of the magnet, the magnet was still further lowered until its top was on a level with the lower end of the tube. A fresh series of measurements were made for the tube in this position. The results obtained were, within the accuracy of the experiment, like those of Fig. 7. The true values of the field above the poles of the magnet in this case were determined experimentally and these values used in plotting the curves. In Fig. 8 are shown representations of the appearance of the discharge through Tube B, (a) with position of the tube with respect to the magnet is shown in Fig. 10a, except that in this figure Tube B is shown in place instead of Tube C. It will be observed that the curves are entirely different from those for the cathode and are straight lines, showing that when the field acts on the region of the anode the current decreases as the field increases and, that the decrease of the current is directly proportional to the strength of the field. In Fig. 10 is shown the appearance of the discharge, through Tube B (a) with no field and (b) with the field of 241 gausses.

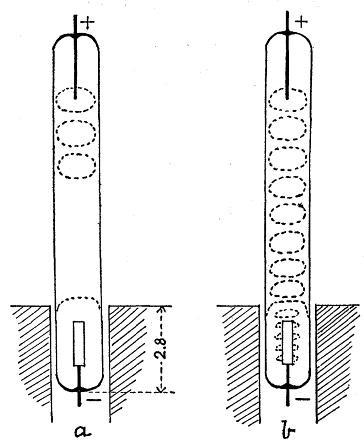


Fig. 8.

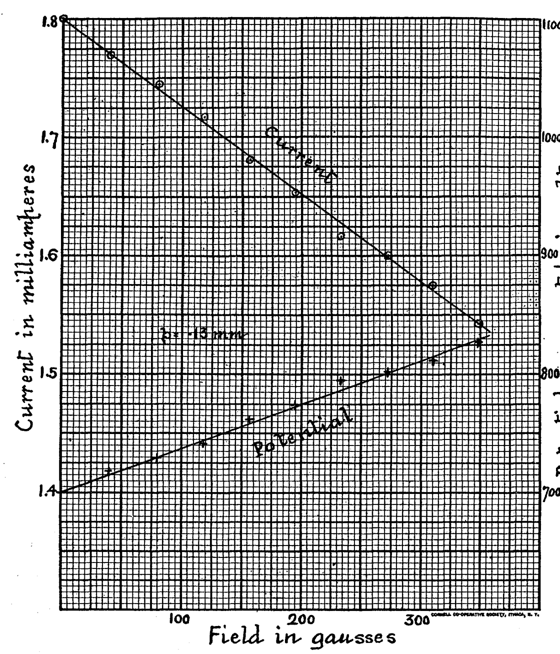


Fig. 9.

6. *Volt-ampere Characteristics for Magnetic Fields of Different Strengths.* —Preliminary experiments to determine the volt-ampere characteristics

for zero field and a field of 41 gausses were made with Tube A. The results are shown in Fig. 11. The field was applied to the whole length of the tube. They are very similar to those obtained by Riecke and show that the characteristics for fields greater than zero cross the characteristic for zero field; for the smaller values of the current, they lie above the characteristic for zero field and for larger values, below it.

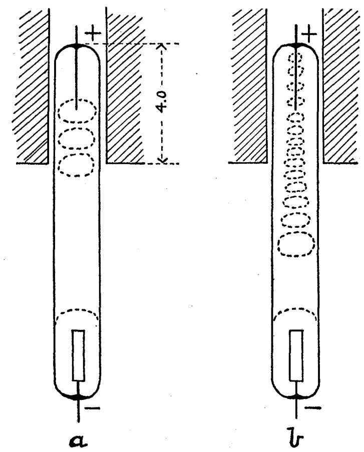


Fig. 10.

The volt-ampere characteristics found for Tube B, for zero field and for fields of 40, 118 and 157 gausses, respectively, are shown in Fig. 12. They were obtained by first determining the characteristic for zero field, and then finding the increase, or decrease, of the current and potential, when a

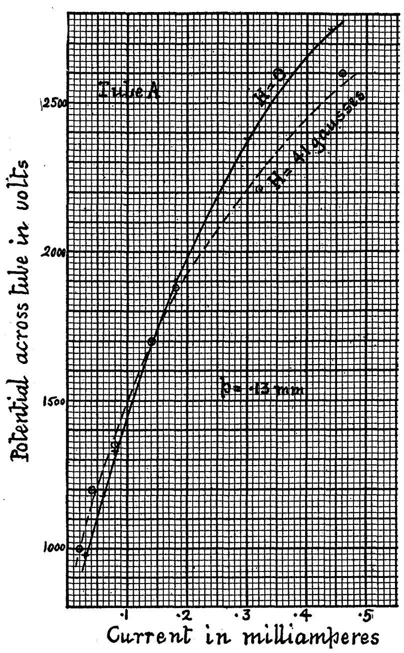


Fig. 11.

given field was applied, for a number of points on it. They are of the same general form as those given by Riecke.[1] The dotted line, shown in Fig. 12, is a line of constant E and R.

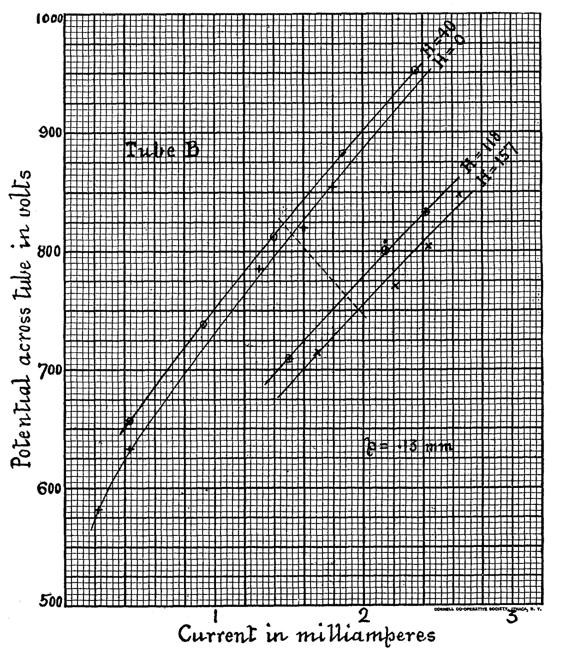


Fig. 12.

6. Discussion of Results.

It will be seen from Figs. 5, 7 and 9, that, to a first approximation, the effect of the field acting upon the whole tube is the *sum* of the effects obtained when acting upon the cathode and anode regions separately.[2] It will also be seen that the action of the field upon the cathode region is, in the main, to greatly increase the current, whilst its effect upon the anode region is always to decrease it. The curves given are only three out of a great many obtained which all show the same general character. The curves for the cathode region all show a slight decrease for small fields and then a very large increase for greater fields, reaching a maximum value at which the discharge becomes unstable. The curves for the anode region are all straight lines. For the curves of Figs. 5, 7 and 9 the external resistance was of graphite and had a value of 481,000 ohms. In Fig. 7, for field acting on cathode region only, the decrease in current for small values of the field was very carefully investigated. I was

[1] Loc. cit.

[2] See Stark, Elektrizität in Gasen, 1902, pp. 408, 409.

rather skeptical of its existence, but very careful measurements showed that there was a small decrease for small values of the field. It was also found to exist when the magnet was moved down so that its top was on a level with the lower end of the tube. It is probably due to the influence of the weak field outside the poles of the magnet on the Faraday dark space or on the lower end of the positive column.

Stark,[1] in the paper referred to above, has given curves showing the effect of a transverse magnetic field on the cathode fall. It is to be noted that Stark's investigation deals with the cathode fall alone and not with the fall between the cathode and anode. In his paper he plots the relation between the cathode fall and the magnetic field, but not between current and field. The curve given in Fig. 11 of his paper, for a pressure of .163 mm., agrees very closely in form with the volt-gauss curve I have given in my Fig. 7 except that his curve does not show a small increase of potential for small fields. If we plot the values of the current given by him, we get a curve very similar to my current curve of Fig. 7. A plot of Stark's values both for current and potential is given in Fig. 13. The fact that Stark's values do not show a decrease of

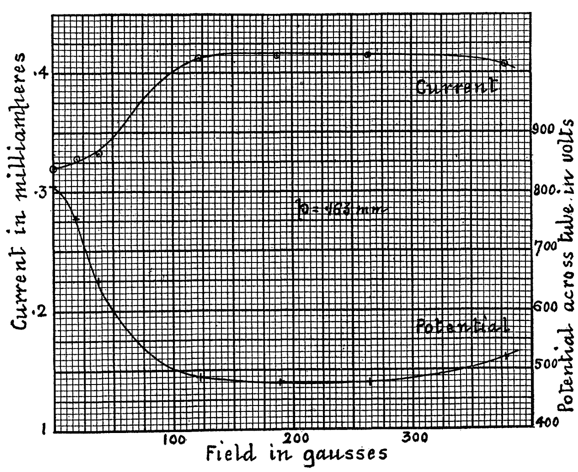


Fig. 13.

the current for small values of the field tends to support the theory that in my results this decrease was due to the action of the weak external field on the Faraday dark space, or on the lower end of the positive column.

Aside from the small decrease of the current for small fields, Fig. 7 reminds one, for a considerable part of its length, of the curves given by

[1] Loc. cit., pp. 43–45.

Townsend[1] in his Theory of Ionization by Collision of Negative Ions, for increase of current due to increase of length of path. I think we may assume that the ascending part of the current curve, from the point where it cuts a line parallel to the axis of abscissas to its point of inflexion, is due to an increase in the length of the path travelled by the electrons under the action of the magnetic field. As pointed out by Stark,[2] a transverse magnetic field will increase the ionization in two ways, (1) by increasing the length of the path, and (2) by concentrating it, by holding the electrons in the neighborhood of the cathode. Both of these causes would act like an increased length of path. In the upper part of the curve, from the point of inflexion to the point where it becomes horizontal and the discharge becomes unstable, besides the action increasing the length of path of the electrons, another action of the field enters in. After the field reaches a certain strength, a retarding effect of the field begins to appear due to its taking the electrons prisoners and causing them to revolve continually around the lines of force or else to travel along them to the walls of the tube. If this is so, the current through the tube should first increase, with increasing field, after a while reach a maximum value and then begin to decline in value. The curve shown in Fig. 7 indicates that the current is approaching such a maximum when it becomes unstable. This maximum is shown by Stark's values in Fig. 13.

The linear decrease of the current when the *anode region* is exposed to a transverse magnetic field, may perhaps be explained by the fact that the length of the positive column is increased by the action of the field. This increase of length is shown in Fig. 10*b*. It is seen there that the effect of the field is to press the positive column away from the observer, at the same time causing its upper end to move along the wire forming the anode towards the upper end of the tube. If the potential difference across the electrodes increases as the length of the positive column increases, its change of length, in this case, might produce the change of potential shown in Fig. 9. Another cause for the reduced current, under the action of the field, may be the decreased cross-section of the positive column. Also it is possible that the transverse magnetic field deflects some of the negative carriers so that they do not reach the anode, and that the number deflected is proportional to the strength of the field.

The fact that the effect of the transverse magnetic field is different, according as it is applied at the anode or cathode, raises the question "Are the negative carriers of the same nature in the cathode glow, as in

[1] Electricity in Gases, 1915, pp. 266, 267.

[2] Ann. Phys., 12, p. 34, 1903.

the positive column?" Skinner[1] has come to the conclusion, from his own experiments on electrode polarization and those of Chrisler on anode absorption, that in general the negative carriers in the positive column are atoms and "that the electrons must become largely attached to the atoms after leaving the negative glow." H. A. Wilson[2] in his experiments on the Hall effect found that the difference between the velocities of the negative and positive ions was large in the striæ and small in the dark places between them. He suggests that electrons are produced largely in the striæ and that by the time they get into the dark spaces they have become attached to "molecules."

In my experiments on the so-called Magnetic Rays of Righi,[3] I found that the Righi effects were not produced if the transverse magnetic field acted only on the positive column. To get them it must act on the negative glow. That is, the negative carriers in the positive glow do not follow the lines of the magnetic force as they do in the negative glow. This result apparently shows that in the positive glow the negative ions, if of the same nature as those in the negative glow, do not move with as great a velocity, since Thomson has shown that for the ions to follow the lines of magnetic force the product of their velocity and the strength of the magnetic field must be large.[4]

Wellisch[5] from his researches on air ionized by polonium comes to the conclusion that in air the negative carriers are both ions and electrons, and that at a pressure of .15 mm. the ions form more than 50 per cent. of them. He also concludes that the ions have a definite mass which does not vary with the pressure.

Fulcher[6] and Gehrcke and Seeliger[7] have shown that the color of the light emitted from a glow discharge depends upon the velocity of the electrons; the bluish light being produced by the fast-moving, and the reddish by the slow-moving electrons. So that it is possible that all the light in the Geissler discharge, both of the positive glow and of the negative glow may be produced by electrons.

The weight of the evidence, at the present time, seems to be in favor of the view that the ionization in the positive column is produced by electrons, and that the difference in the behavior of the positive glow and the negative glow under the action of a magnetic field is due to the lower velocity of the electrons in the positive glow.

[1] Phys. Rev., 9, 314, 1917.

[2] Loc. cit.

[3] Phys. Rev., 9, 354, 1917.

[4] See Thomson, Conduction of Electricity through Gases, second edition. 1906, p. 105.

[5] Am. Jour. Sci., 39, 583–599, 1915.

[6] Astro. Phys. Jour., 34, 388, 1911; 37, 60–71, 1913.

[7] Verh. Deutsch, Phys. Gesell., 10, 335, 1912.

When the whole length of the tube, shown in Fig. 1, is subjected to a transverse magnetic field and a current of 1.8 milliamperes passes through it, the negative and positive glows behave very differently. The negative glow, or at least that portion of it bounding the Crookes dark space, is not sensibly changed in position by the strongest field that can be applied, whereas the positive glow is extraordinarily modified. The number of striæ is increased from 3 to 17; each stria is reduced to a fraction of its former length, is much reduced in width and is flattened against one side of the tube, and the striated positive column extends from the anode right up to the negative glow.[1] The positive column acts like a flexible metallic conductor.

In the experiments described in this paper the positive column was always striated, there being usually three striations present for zero magnetic field. At the pressure used, .13 mm. Hg, the condition of striation is a condition of stable discharge, *i. e.*, the discharge is only continuous when the column is striated. As the field is increased from zero, the discharge stays continuous until it reaches a value of about 300 gausses, when it becomes periodic. If the field is still further increased, a value is reached where no discharge at all passes. This action of the field in stopping the discharge periodically does not depend on lowering or raising the potential difference across the tube, since, when the field is applied at the cathode, the discharge ceases when the potential is *lowered* to about 560 volts, and when applied at the anode, ceases when the potential is *raised* to about 830 volts. The peculiar behavior of the positive column being the same in both cases, the striæ being increased in number, shortened in length and pressed against the side of the tube, suggests that the instability of the discharge when the field reaches a certain strength may have something to do with the decrease in the cross-section of the positive column or with the properties of the striæ.

A peculiar property of the Geissler tube discharge has been observed by Reiger.[2] He found that such a discharge may be continuous in one part of the tube, and discontinuous in another part, at one and the same time. I observed the same thing while performing the experiments described in this paper when the whole length of the tube was subjected to the magnetic field, and the field was of about the strength which made the discharge periodic. The striated positive column extended from the anode to the cathode glow, was pressed against the side of the tube, and had 16 or 17 striæ. As the field was increased the striæ at the middle

[1] See Ives, PHYS. REV., 9, pp. 350, 351, 1917.

[2] Sitzber. d. Phys. Med. Soc. in Erlangen, 37, 1–130, 1905.

of the tube disappeared first. Using a rotating mirror, it could be seen that the discharge in this part of the positive column was discontinuous, while it was continuous throughout the rest of the tube. Since the mean current must be the same through every cross-section of the tube, this condition, apparently, can only exist if a certain portion of the tube acts as a condenser, periodically storing up a charge, and then discharging it slowly through the rest of the tube, which acts as a high resistance.[1] The phenomenon was particularly striking and significant when the field acted on the anode region only and the striæ differed in width and length as shown in Fig. 10*b*. In this case, it was observed that the discharge became discontinuous only in the narrow part of the column where the field was strong and the striæ narrow and close together. The striations at the lower end of the column, near the cathode, remained intact until the discharge ceased altogether.

I have already stated that, when the magnetic field, applied at the cathode, was gradually increased, new striæ appeared at the anode and those already in existence moved down towards the cathode so that the distance between the negative glow and the first stria gradually decreased. This behavior of the striæ under the action of the field, may, I think, be explained in this way: Stark's results and my own show that the effect of the field is to lower the cathode fall of potential. This decrease of the cathode fall will produce a decrease in the free positive charge in the Crookes dark space, and this in turn will increase the strength of the field in the Faraday dark space, so that the first stria will move a certain distance towards the cathode.

A possible explanation of the action of a magnetic field in making the discharge periodic is suggested by the remarkable results obtained by Thomson[2] for the striations when the discharge is produced by a Wehnelt cathode. He found that in this case the electric field in the dark spaces between the striations actually became *negative*, so that the ions traversing a dark space and moving against the force, must have had a sufficient initial velocity to carry them across the space. Now, very little is known about the effect of a transverse magnetic field on the difference of potential across the ends of a positive column,[3] or upon the electric field in this column. However, Willows'[4] results show a very decided lowering of the electric field in the positive column under the action of a magnetic field. Suppose, now, that in the experiments described in my present paper, when the magnetic field is gradually made stronger and

[1] For such a discharge, see Fulcher, Astrophys. Journ., 33, p. 56, 1910.

[2] Phil. Mag., 18, 441–451, 1909.

[3] See Ives, loc. cit., p.355, Table II.

[4] Loc. cit., p. 258, Fig. 7.

stronger the maxima and minima of the electric field, corresponding to the bright and dark parts of the striations, still persist, but that the minima decrease in value until the undulating curve representing the electric field cuts the x axis. We would then have a curve similar to that given by Thomson, in Fig. 1 of his paper. If the depression of the curve still further continued as the magnetic field was further increased, a value of the magnetic field would be reached where the negative field in the dark spaces would become so strong that the ions could no longer get across them, and the discharge in that part of the tube would be interrupted. Such an action would, it appears to me, suffice to produce the effects observed. Whether there is such a distribution of the electric field in the present case can only be determined by a series of measurements of its strength in the positive column as the magnetic field is gradually increased.

7. Summary.

1. In a discharge tube, 1.5 cm. in diameter, with the electrodes 7.5 cm. apart, containing air at a pressure of .13 mm. and carrying a current of 1.8 milliamperes, the effect of a transverse magnetic field upon the discharge, when acting on the cathode region only, is to increase the current through the tube; when acting on the anode region only, to decrease it; and when acting on the whole tube, to increase it.

2. The ampere-gauss curve for the field acting on the cathode region only is a modified exponential curve of the form obtained by Townsend for increasing length of path.

3. The ampere-gauss curve for the field acting on the anode region only is a descending straight line.

4. The ampere-gauss curve for the field acting on the whole tube is, to a first approximation, the sum of the curves for field acting on cathode region only and for field acting on anode region only.

5. When a magnetic field acts on a tube, the external variables of its circuit being kept constant, the potential across the tube and the current through it vary oppositely, one decreasing when the other increases according to the law

$$e = E - iR,$$

where e is the potential across the tube; i, the current through it; E, the impressed electromotive force and R the external resistance of the circuit. If the potential is plotted as a function of the current, we get a straight line, whose slope is equal to R, passing through the point E on the axis of ordinates. Such a line may be called a "Line of constant E and R."

6. The amplitude of the ampere-gauss or the volt-gauss curve is affected by the value of the external resistance, R, of the circuit; the amplitude of the ampere-gauss curve being decreased by increasing R, and that of the volt-gauss curve, increased.

7. The volt-ampere characteristics of the tube were determined for magnetic fields of different strengths. The characteristic for a magnetic field of a given strength crosses the characteristic for zero field at a certain critical value of the current, which differs for different values of the field. For values of the current less than the critical value, the current is increased by the field, for values greater, decreased.

Clark University,
Worcester, Mass.,
February 18, 1918.