PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The Action of Magnetised Electrodes upon Electrical Discharge Phenomena in Rarefied Gases

C. E. S. Phillips

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IV. *The Action of Magnetised Electrodes upon Electrical Discharge Phenomena in Rarefied Gases.*

By C. E. S. Phillips.

Communicated by Sir William Crookes, *F.R.S.*

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In two previous communications which I have had the honour to lay before the Royal Society, reference is made to the action of a magnetic field, either constant or changing, upon the distribution of ions within a highly evacuated space.* The chief result dealt with in the first case was the formation of a luminous ring which appeared to be in rapid rotation about the lines of magnetic induction. The other note described a case in which a positively electrified body placed in a rarefied gas became diselectrified when a magnetic field was created in its neighbourhood. I now beg to submit an account of some further experiments which have been made in this matter, with a view to obtaining evidence as to the cause of both these phenomena.

The Luminous Ring.

A detailed account of the apparatus most suitable for the production of the luminous ring in rarefied gases has already been given in the first of the papers just referred to; nor has it so far been found possible to materially improve upon the method there described.

The bulb (fig. 1) having been exhausted to a pressure of about ·005 millim. of mercury (care being taken to drive off the greater part of the gases held by the electrodes), has a strong discharge passed through it for a few seconds from the secondary circuit of an induction coil.

The discharge is then stopped and the magnetisation of the soft iron electrodes, E_1E_2, by means of the external electro-magnets, M_1M_2, gives rise to a luminous ring which suddenly appears within the bulb, circumscribing the pointed ends of the magnetic electrodes, and revolving about the magnetic axis at a considerable velocity.

* 'Roy. Soc. Proc.,' vol. 64, p. 172; 'Roy. Soc. Proc.,' vol. 65, p. 320.

3.9.1901.

The conditions most favourable to the formation of a luminous ring have been found to be—

(*a*.) A sufficiently powerful electrical stimulation of the residual gas within the bulb to ensure ionisation.

(*b*.) A magnetic field of at least 2000 lines per square centimetre between the oppositely magnetised pointed pole pieces (which may be electrically insulated).

(*c*.) Exhaustion should be continued until the discharge while passing in the bulb is oscillatory.

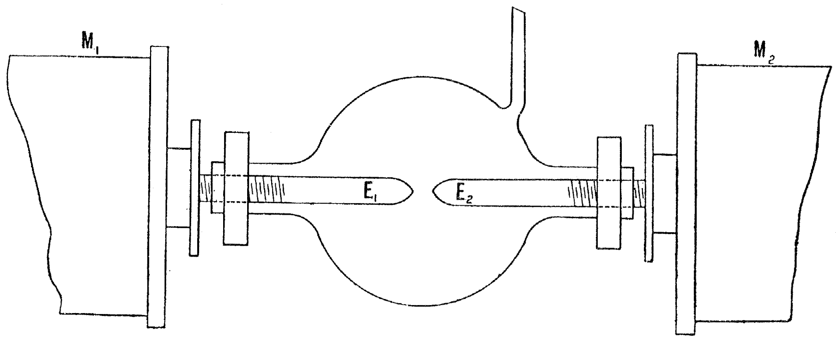

Fig. 1.

The brightness of the light emitted by the ring may be momentarily increased by—

(*a*.) Connecting the outside of the bulb (preferably at its equator) to either of the magnetic electrodes, or by merely touching it with a finger.

(*b*.) Electrifying the exterior surface of the bulb positively.

(*c*.) Electrifying the magnetic electrodes negatively.

(*d*.) Having oxygen gas in the bulb instead of air.

(*e*.) Suddenly destroying the magnetic field while the ring is faintly visible.

A ring which had once formed could be instantaneously extinguished by—

(*a*.) Electrifying the exterior of the bulb negatively.

(*b*.) Electrifying the electrodes positively.

(*c*.) Magnetising the electrodes so that like poles faced each other.

(*d*.) Destroying the magnetic field. In no instance did the ring remain visible after the current was cut off from the electro-magnets.

Satisfactory results have also been obtained when only one magnetic electrode was used, the arrangement being indicated in fig. 2.

In such cases it was generally found convenient to facilitate the oscillatory nature of the discharge within the bulb by gumming a piece of tinfoil, T, on to the outside, and connecting that with the positive knob of the induction coil or influence machine.

The plane in which the luminous ring appeared was controlled by the position of the tinfoil during stimulation. Fig. 2 shows the appearance of the ring for two respective positions of the tinfoil patch. On no occasion did a luminous ring form when T was placed behind the point of the electrode. Sometimes, when the electrode was magnetised, a glowing gas encircled it at an inch or so from the pointed end, and this faintly luminous cloud moved rapidly forward, gaining in brightness until it circumscribed the point itself. Then it slowly faded away. It must be understood, however, that this effect was seldom seen, the ring generally appearing to suddenly encircle the extremity of the electrode, where it remained visible for some seconds unless disturbed by unequal attractions exerted upon it through alterations in the electrostatic charges residing, either upon the magnetic electrode (which was insulated) or upon the walls of the bulb. This effect was more noticeable, however, with the apparatus shown in fig. 1, for, in that case, by touching different parts of the bulb, or by slightly electrifying the electrodes by means of an influence machine, the

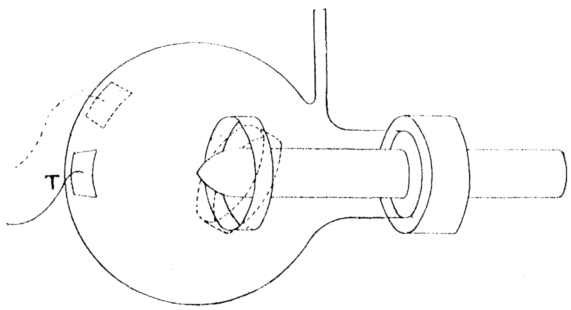

Fig. 2.

luminous ring could be moved backwards or forwards—threaded first on to one electrode and then the other—in a manner consistent with the view that it was mainly composed of a negatively electrified cloud of gaseous particles.

Intermittent Luminosity.

A stroboscopic examination of the ring proved that its luminosity was not continuous. The number of flashes of light per second also varied from time to time. The luminosity of the ring therefore appeared to depend upon an intermittent discharge occurring within the bulb.

Residual Gases.

The nature of the gas in which the ring appeared did not markedly influence its brightness or colour. It must however be pointed out that with the apparatus shown in fig. 1, the large mass of metal exposed within the bulb, made it difficult to ensure that the gases experimented with were in a pure state. The iron electrodes continued always to give off a little contaminating gas at very low pressures, even after a week's pumping. When the characteristic spectrum of the gas used was visible while the discharge passed freely (the bulb having been evacuated and filled with the gas alternately six times), observations on the appearance of the ring at still lower pressures were begun. In the case of oxygen obtained from steel cylinders, and also from potassic chlorate, the ring appeared to be somewhat whiter than in air. With hydrogen and carbon dioxide, however, no change of any kind was noticeable. Mercury vapour was present in every case. As the object of the investigation was to determine the process by which the luminous ring formed, it was not thought advisable to devote too much time to more detailed experiments upon the gases.

The Spectrum.

It was considered sufficient to ascertain whether the composition of the light emitted by the ring was similar to that of the faint blue haze visible in the bulb while the induction-coil discharge was passing. This was found to be the case over a range from about λ4365 to λ5451. Great difficulty, however, was found in distinguishing the lines owing to their feeble intensity, nor was it possible to obtain satisfactory photographs of the ring itself.

The Ring in Rotation.

The want of uniformity in the density of the glowing nebulous stream constituting the ring enabled its rotation to be plainly made out. The following experiment, however, placed the fact beyond a doubt.

A bulb, similar to that shown in fig. 3, was exhausted and a discharge passed

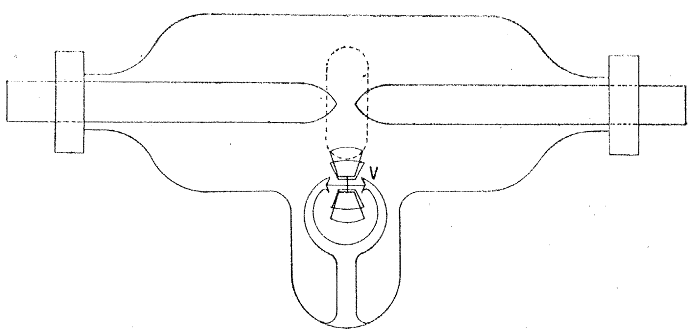

Fig. 3.

through it. It will be seen that a luminous ring forming under the influence of the magnets would, in this case, partially envelop the wings of the light mica vane, V, so that, if the ring revolve, the vane might also turn, and by the direction of its rotation show the sense in which the luminous ring itself was rotating. Under favourable circumstances it was found that whenever the luminous ring was adjusted (by touching the glass at various points) to slightly envelop the wings, as indicated by the dotted line in the figure, a very violent rotation of the vane resulted. In this way it was seen that the ring rotated in the same direction as that in which a current would momentarily be induced in a coil of wire if it were suddenly moved towards a magnetic north pole, namely clockwise, looking through the coil at the pole. It was often noticed however, that a very faintly luminous haze hung about the ring, and when that, instead of the brightest portion, enveloped the mica wings, a rotation of the vane, also very rapid, again took place, but in the opposite direction to that observed in the first case.

Distribution of Ions.

Assuming that the path of an electrified particle rapidly moving towards a magnetic field is modified thereby in accordance with laws known to hold good in the case of the mutual action of such a field and current-carrying wires, the direction of rotation of the luminous ring indicated that it consisted of negative ions streaming inwards towards the strongest part of the magnetic field.

The next question to consider therefore was the change (if any) produced in the distribution of the electrostatic charges upon the bulb, through the action of the magnetic field, and to observe the sign of the electrification upon the ring itself. A piece of tinfoil fastened to the outer surface of the glass bulb invariably became negatively electrified when the magnetic field was suddenly created. The experiment was performed in the following order: Subsequently to the passage of a strong discharge through the bulb, the electrification on the tinfoil patch (placed at the equator of the bulb) was tested in the usual way by means of an electroscope. It was generally positive. This electrification having been neutralised by connection to earth, the current through the electro-magnets was "turned on" while the leaves of the electroscope were in contact with the patch; the tinfoil was then found to have suddenly acquired a strong negative electrification.

This result appeared to be consistent with the view that, after the stimulation of the residual gas by the induction coil discharge, there resided upon the inner surface of the bulb a layer of positively electrified gas particles which, through the action of the magnetic field, had been removed. On the other hand, such an inrush of positive ions from the inner surface of the bulb towards the denser portion of the magnetic field, did not appear to support the idea that the luminous ring was negatively electrified, nor could it account for the direction of rotation of the ring as determined by the mica vane. That the actual luminosity of the ring was mainly due, however, to the incoming radial streams of positive ions was probable from the fact that when a positively electrified body was brought into contact with the glass of the bulb, a faintly luminous ring in the interior was greatly brightened. A pause sometimes occurred between the magnetisation of the electrodes, and the appearance of a luminous ring. But in such a case positive electrification of the outer surface of the bulb immediately caused the ring to appear within. Under these circumstances the evidence that the luminosity was due to the radial streams of positive ions was also supported by the appearance of the ring as it became gradually built up of luminous arcs in the manner shown in fig. 4. The positively electrified body touched the bulb

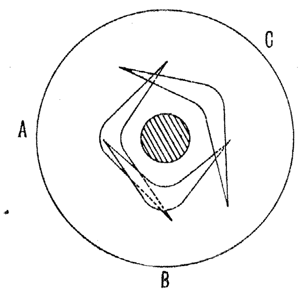

Fig. 4.

at the points A, B, and C. These luminous curves were in a few rare cases clearly visible; they revolved round the magnetic axis very slowly at first, then more rapidly for a few revolutions, blending together into a continuous ring as they moved, which widened out and soon faded completely away. On a few occasions when the electrodes were suddenly magnetised the whole of the residual gas within the bulb appeared luminous—a bluish-white glow—while at the central portion as before, the ring, slightly more luminous than the rest, could be seen rapidly revolving. An electroscope attached to the insulated magnetic electrodes showed that when a positively electrified body was brought into contact with the outer surface of the glass bulb a certain amount of positive electrification was produced upon the iron electrodes themselves. In the case of one particular bulb, on a very dry day and under correct conditions as to pressure and stimulation, the sudden magnetisation of the electrodes caused a spark to leap across a 6-mm. air gap between two wires, one connected to a tinfoil patch at the equator of the bulb, and the other in contact with either of the iron electrodes. This remarkable effect took place after all external residual electrification upon the apparatus had been removed by carefully connecting to earth each part of the bulb as well as the electrodes. By means of a tinfoil patch, fastened to the surface of the bulb at various places, some useful results were also obtained with a bulb containing only one magnetic electrode. Fig. 5 shows the distribution of charges upon the bulb at the moment the discharge through it was stopped. At a pressure scarcely low enough to give a luminous ring the action of the magnet was to increase the positive electrification around the equator, and also slightly that upon the tinfoil ring T at the end. But in this case no luminous ring appeared, nor was there evidence of the withdrawal of positive ions from the interior glass surface. At a lower pressure, however, the ring became visible, and then the sign of the electrification upon the glass at the equator reversed to negative while the tinfoil became more strongly positive, as before. The range of pressures over which the best results were obtained with bulbs nearly spherical and 6 centims. in diameter extended from 0·0120 to 0·0004 millim. of mercury, as measured by means of a

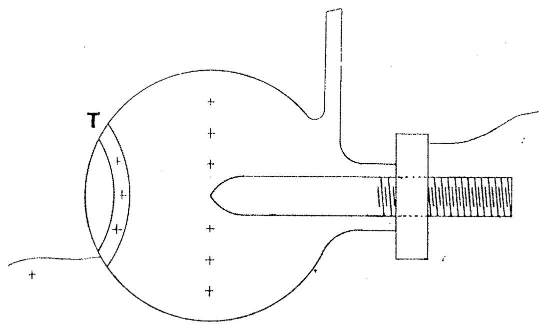

Fig. 5.

MacLeod gauge. The sign of the electrification upon the luminous ring itself was then found to be invariably negative by means of the following experiment:—

A ring of platinum wire stood within the bulb (fig. 1). It was supported by a thin metallic stalk, which terminated in a small exterior loop, and was placed so as to occupy the position in which under suitable conditions a luminous ring might have been expected to appear. The diameter of the platinum ring was approximately that of the luminous ring when at its best. A discharge was then started and stopped and the electrodes magnetised, with the result that two luminous rings appeared within the bulb, one on each side of the platinum circle and very close to it. On slightly electrifying the platinum circle negatively both these rings flew apart, each threading itself on one of the electrodes. On the other hand, when the circle was positively electrified both rings moved towards each other, and filled the space bounded by the wire with a brightly luminous whitish-blue glow. The luminous ring has, in this way, been shown to invariably be negatively electrified. Recourse was then had to a set of experiments dealing in more detail with the existence of the radial incoming streams of positively electrified gas particles previously referred to.

Diselectrification Effects.

In the first place a new apparatus was constructed, in which the soft iron rods E_1 E_2, were sheathed in a glass tube (fig. 6), which was continuous throughout and melted at the ends on to the short necks projecting from the bulb. The glass tube carried, wrapped round its central portion, a piece of aluminium foil, 2·5 cm. wide, and connected by means of a fine wire to an external terminal loop T_2. Concentrically with this thin aluminium cylinder stood a larger, though much narrower band A of stouter aluminium foil, supported upon a metallic stalk which terminated in an external platinum loop T_1.

The iron electrodes, E_1 E_2, in this case no longer used as such, but merely as prolongations of the electro-magnet cores, were screwed towards each other through the brass framework W W, adjusted to have their pointed ends 2 mm. apart, and arranged centrally within the glass tube and aluminium cylinder just described.

The results obtained at the correct gas pressure with this apparatus were as follows:—A was positively electrified while the gold leaves of an electroscope were connected with it. T_2 was joined to the case of the electroscope. When E_1 and E_2 were oppositely magnetised the leaves collapsed, showing A to have lost its charge. On the other hand, when A was negatively electrified no appreciable change occurred

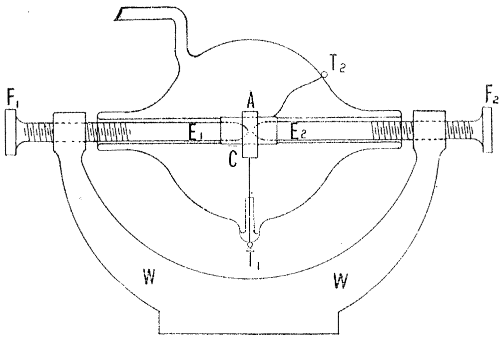

Fig. 6.

in the amount of the charge upon it, through the action of the magnetic field. Neither was there diselectrification of A, even if it were charged positively when the magnets had similar poles at the pointed ends.

[I find that Professor E. WARBURG has already drawn attention to this effect, and in 1896 published some results, with which my own observations are in complete agreement. (See 'Sitzungsber d. k. pr. Akad. d. Wissensch. zu Berlin,' p. 223, 1896, and 'Annalen der Physik,' N. F., 62, p. 385).]—*July* 1, 1901.

The aluminium cylinder C was next positively electrified, and the connection with the electroscope transferred from A to C. In this experiment A was connected to the case of the electroscope, and no change occurred in the electrification of the cylinder either on creating or destroying the magnetic field. The leaves of a second electroscope were then connected to A, as in the first case, while the other electroscope remained attached to C. A was then positively electrified, while C was temporarily to earth. On the magnets being excited the leaves attached to A collapsed, while those in connection with C slightly diverged—positively electrified; thus confirming the idea that an incoming radial stream of positive ions does, under these conditions, exist. Luminosity generally accompanied these effects. With C negatively electrified while A was temporarily connected to earth no change occurred in the electrification of C when the magnets were excited. Now, if the motion of charged particles either towards or away from the denser portion of the magnetic field and at right angles to the magnetic axis is directly facilitated by either a constant or changing magnetic field, it is reasonable to suppose that the incoming radial streams of positive ions would have their equivalent in outgoing (that is, from the centre of the bulb towards the equator) streams of negative ions. But such was not found to be the case, as this last experiment showed. Acting upon a suggestion kindly made by Lord KELVIN, this point was still further investigated by means of the following experiment:—Two plane pieces of metal were fixed into the bulb as symmetrically as possible, one on each side of the 2-mm. air gap between the pointed ends of the magnetic electrodes. There was no glass covering over these electrodes, the bulb used being similar to that shown in fig. 1. These metal planes were 1·5 centims. long, ·5 centim. wide, and 1 millim. thick, and were placed parallel to one another with a space of 2 millims. between them. The question to be tested was whether the previous diselectrification effects were in any way due to want of symmetry. But with this apparatus all the results previously obtained were easily repeated. The two metallic planes were then replaced by a finely pointed wire, which projected into the bulb, and this when charged positively became diselectrified when the magnet was excited.

On returning to the arrangement shown in fig. 6, it was found, as a general rule, that the higher the potential to which the body A was charged, the greater for a constant pressure became the strength of the magnetic field necessary to produce diselectrification—more especially was this noticeable at very low pressures. The relationship is shown by the continuous curve in fig. 7, where the abscissæ represent the degree to which A was electrified, and the ordinates are proportional to the strength of the magnetic field sufficient to produce diselectrification. On the other hand, when A in each experiment was charged to the same potential the magnetic strength sufficient to produce diselectrification varied with the pressure of the residual gas in the manner indicated by the dotted line in the same figure.

The results graphically shown by these curves were obtained in the following manner:—A was connected with the quadrants of a Kelvin electrostatic voltmeter, while a fine wire from T_2 was securely screwed to the case of the instrument. The current supplied to the electro-magnets passed through a variable resistance, and also an ammeter which could be read to two places of decimals. It was generally found to be an advantage to introduce a small condenser between T_1 and T_2 in order to steady the needle of the voltmeter. The current through the electro-magnets was always increased very slowly, and the exact moment at which diselectrification occurred could easily be determined by the sound of the sharp snap which was heard when A suddenly lost its charge.

The regularity of the readings of the ammeter for a constant gas pressure within the bulb may be seen from the following examples, where P represents the potential in volts to which A was charged, and C the strength of the current in amperes through the electro-magnets, just sufficient to produce diselectrification (pressure was ·006 millim.).

Each reading was repeated four times.

P = 1200.
C = 3·00, 3·20, 3·20, 3·15.

. . . .

P = 2200.
C = 4·40, 4·50, 4·50, 4·80.

. . . .

P = 2600.
C = 5·10, 5·12, 5·10, 5·10.

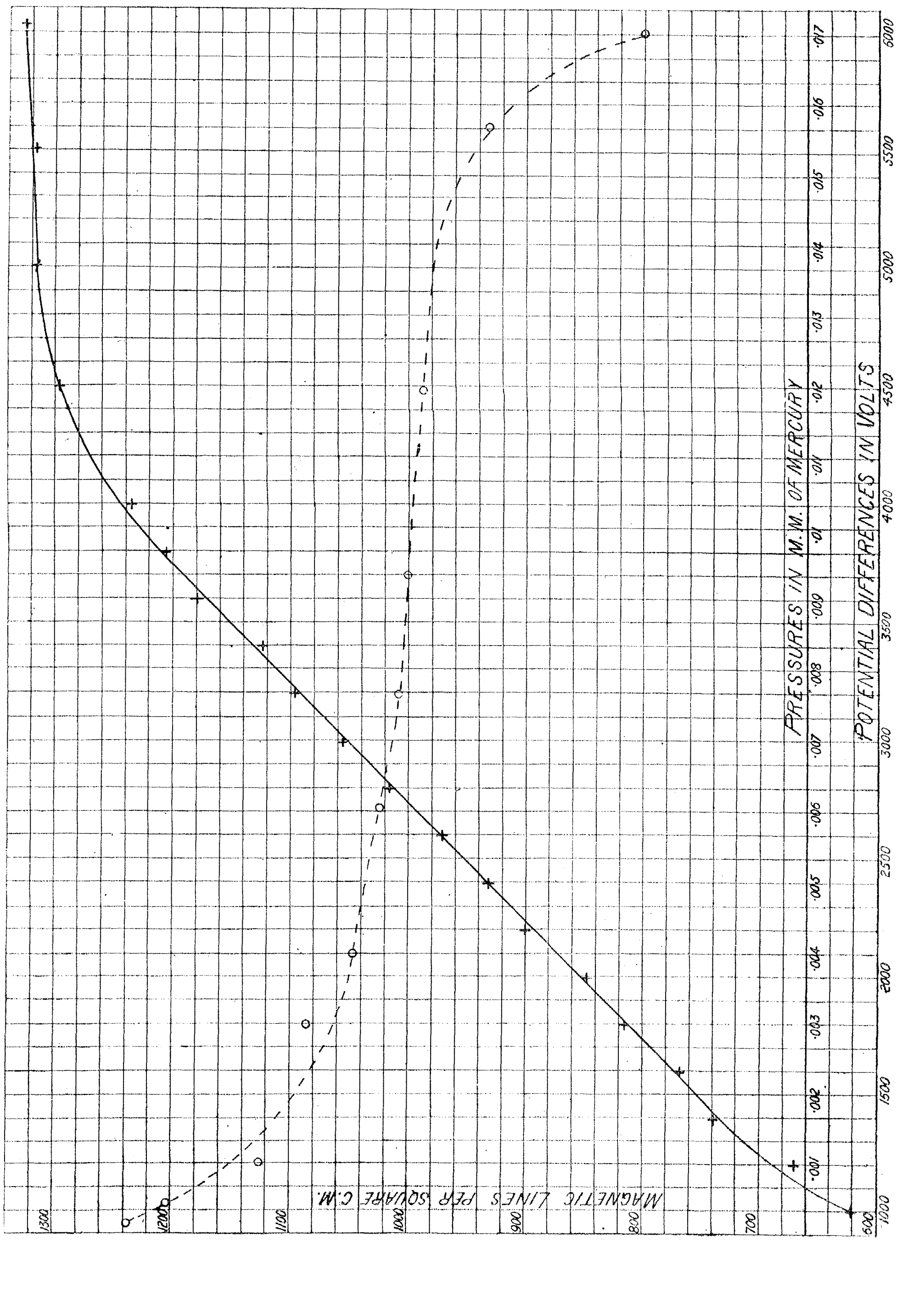

Fig. 7.

It is obvious, however, that the above observations can only refer to a particular bulb and a certain set of conditions. The principal difficulty lay in determining the conditions. Readings taken at the beginning of the week could not be accurately repeated at the end of it, although the curves plotted from such records were in the main parallel. Those shown in fig. 7 were obtained with oxygen as the residual gas within the bulb, and are typical of the results obtained with a particular bulb, irrespective of whether the residual gas was air, hydrogen, carbonic dioxide, or oxygen; the only difference in all the various cases being a shifting, parallel to itself of the complete curve.

Reference has already been made to the interval which occasionally elapsed between the excitation of the magnet and the appearance of a luminous ring within the bulb. A similar pause was noticed in connection with experiments upon the diselectrification effects. It should also be pointed out that the sign of the electrification of the bulb, both in the case of the luminous-ring experiments and those relating to diselectrification, was invariably negative through the action of the magnetic field. Moreover it has already been seen that luminous flashes usually accompanied diselectrification. The question as to the origin of the luminous ring appeared therefore to be intimately involved in any explanation that might be found to account for the diselectrification phenomenon, and it became important to see finally whether conditions favourable to the one but unfavourable to the other could be found to exist simultaneously.

A general survey of the results up to this stage pointed to a concentration of negative ions at the centre of the bulb, and a series of independent experiments were then carried out in order to ascertain what was the distribution of charged gas within the bulb at the moment the induction coil discharge ceased to pass through it. For instance, the action of the magnetic field upon the residual gas particles was examined not only subsequently but also during the passage of the discharge. A screw thread was cut upon each electrode, so that by its means the uniform green fluorescence of the glass might appear as a luminous spiral and show, by widening out or twisting, the paths of the electrified particles shot off from the metal. The action of the magnetic field upon jets of gas* which, at the lowest pressures and even after continued exhaustion, were found to be given off from metal exposed within the bulb, was also examined. The results of these experiments are embodied in fig. 8, which shows the probable distribution of the electrified gas to be such that the central portion of the bulb was fairly uniformly filled with negative ions, while a layer of positively electrified gas resided upon the interior surface of the glass: the former being indicated by the small dots and the latter by the larger circles. The diagram represents the state of affairs at the moment an oscillatory discharge had passed through the bulb, and I desire to call attention to the accumulation of negative ions at either end.

With the object of ascertaining whether these clouds of negative ions were affected

* 'Electrician,' vol. 41, p. 425; 'B. A. Report,' 1900, p. 639.

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by the sudden production of a magnetic field at the centre of the bulb, the following experiment was then arranged:—The apparatus shown in fig. 9 was intended to answer two purposes. In the first place, it would test whether the negative ions tended to concentrate and be drawn from the ends of the bulb in towards the central portion, and also, if that action were prevented, whether the ball A would lose a positive charge when the magnets were excited.

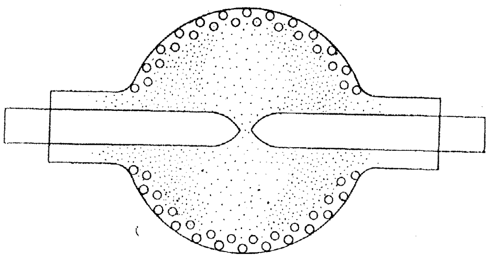

Fig. 8.

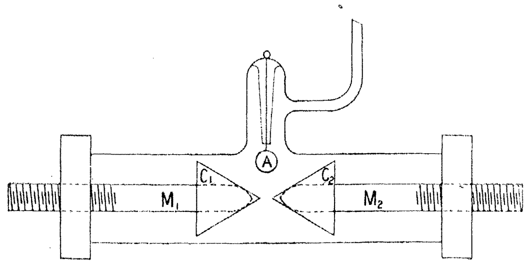

Fig. 9.

Two thin copper cones C_1C_2 were soldered, one upon the pointed end of each of the magnetic electrodes M_1M_2. They were fitted into the glass tube as shown, and the pressure lowered until a discharge passed between the cones with difficulty. When M_1 was connected with the negative terminal of the induction coil and M_2 to the positive, and the discharge had been started and stopped, the magnetisation of the electrodes gave rise to a luminous ring behind and close to the cone C_2. The reverse conditions produced a ring behind the cone C_1. Subsequently to an oscillatory discharge through the tube a luminous ring appeared simultaneously behind each cone immediately the magnets were excited. In all these cases the luminosity visible between the apices of the cones was slight, but it was not to be expected that all the negative ions could be prevented from concentrating at the centre of the tube by this device. A was then positively electrified, and the electrodes magnetised. It became only partially diselectrified—a very different result from that obtained in previous experiments where no cones were attached to the electrodes. This result was repeated a great many times, and, although in each case the diselectrification was enfeebled by the introduction of the cones, a further experiment was made with a view to completely preventing diselectrification of the ball A while the conditions remained suitable for the magnets to act upon the electrified gas particles as before. The cones were removed from the electrodes. An aluminium cylinder C was then slipped in before the tube was sealed up, and arranged so as to be capable of sliding along the fine wire W_1W_2 as shown in fig. 10. The ball A remained as before. As a trial experiment the pressure within the tube was lowered and A positively electrified. When the magnets were excited A was completely diselectrified. The cylinder C was then tapped into the position indicated by the dotted line and the wire W_1W_2 connected to earth. A was again positively electrified, but when the electrodes M_1M_2 were magnetised there was no diselectrification of the ball whatever. A proof that the new position of the cylinder had not disturbed the action of the magnetic field upon the electrified gas within the tube consisted in charging the cylinder itself positively and then suddenly magnetising the electrodes. When that was done the cylinder completely lost its charge in a very satisfactory manner.

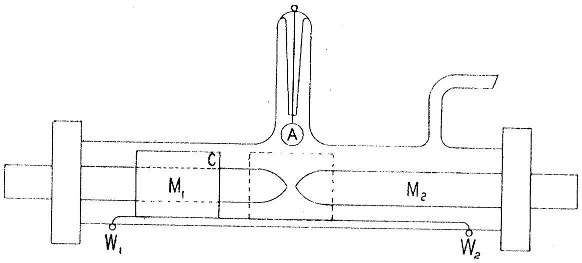

Fig. 10.

Varying Magnetic Fields.

It has long been thought that an electrified body would tend to move, through the action upon it of a rapidly varying magnetic field. The path of the body should lie along a direction at right angles to that in which the magnetic lines are moving, and also at right angles to the direction in which they spread. The conditions accompanying the appearance of the luminous rings, and also the diselectrification already described, appeared suitable for the detection of the action which a variation in strength of the magnetic field might be expected to have upon the practically weightless and very minute electrified gaseous particles freely floating about within the bulb.

It has already been pointed out that a luminous ring having become dim and almost invisible could be momentarily brightened by suddenly destroying the magnetic field. But with the apparatus shown in fig. 6 the following striking results were obtained :—The aluminium band A was positively electrified to a potential of 6000 volts. When the current supplied to the electro-magnets was very slowly increased, as much as 11 amperes was necessary to produce diselectrification of A, while on the other hand, if the current were very rapidly increased in value A lost its charge when only 6 amperes flowed through the coils.

Further than this, it was always noticed that diselectrification occurred when the magnetic field was suddenly destroyed rather than when it was created. A particular rarefaction was found for each bulb, such that the band A could be electrified, and, irrespective of the fact that the electrodes were magnetised, retain its charge. *In all such cases the effect of rapidly destroying the magnetic field was to produce diselectrification, whereas when the current supplied to the magnet coils was broken under water, and in consequence the magnetic field caused to gradually diminish in strength, no trace of diselectrification was observed.* It was therefore clear that variations in the strength of the magnetic field played an important part both in the formation of the luminous ring and also in the diselectrification process.

Conclusion.

The preceding experiments show that the principal effect of the magnets is to produce a concentration of negative ions at the strongest portion of the magnetic field, and centrally within the bulb. There is also experimental evidence to prove that this concentration of negatively electrified gas is responsible for the diselectrification of a positively electrified body placed in its neighbourhood. The experiment with the metal cones (fig. 9) and also that with the electrostatic screen (fig. 10) demonstrated that, either when the concentration of negative ions occurred between the points of the electrodes or when an earth-connected metallic screen came between the negative cloud of gaseous particles and the electrified body, no diselectrification took place. I consider that this concentration of negative ions is due to two main causes. In the first place, it is partly produced by the action of the magnetic field upon ions already in motion within the bulb. The pause of about two seconds sometimes found to occur between the excitation of the magnets and the appearance of a luminous ring or diselectrification of a positively charged body supports this view. And secondly, owing to the reaction resulting from the sudden excitation of the magnets,* the comparatively dense clouds of ions situated at the ends of the bulb (fig. 8) would, in rapidly turning about the magnetic axis, tend to move towards the pointed ends of the electrodes and so concentrate as observed. Owing to the viscosity† of the gas, however, it is not to be expected that such a rotation of the ions would be other than momentary. But that the rate of change of the magnetic lines affects the distribution of the electrified particles within the bulb is clear from the results of the experiments already given.

[Professor S. P. THOMPSON‡ has already pointed out that the preliminary experiments seemed to indicate the existence of some such action taking place within the bulb.]—*July* 1, 1901.

Referring again to fig. 8, we see the distribution of ions at the moment prior to exciting the magnets. The negative ions in concentrating as explained give rise to an increase in the potential difference between the electrified gas upon the inner surface of the glass and that at the central portion of the bulb. At a gas pressure just too high to give the luminous ring, the effect of creating a magnetic field was found to be an increase in the positive electrification upon the outer surface of the bulb (fig. 5), and this is now seen to be consistent. That state of things is represented in fig. 11, where the positive ions are supposed to accumulate opposite to the

* 'Electrician,' vol. 25, p. 35.

† 'Phil. Trans.,' vol. 172, p. 387.

‡ 'Electrician,' vol. 43, 1899, p. 412.

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negative concentration until the potential is such that they suddenly flow inwards, while the superficial layers of the negatively charged gas-mass at the centre of the bulb move rapidly outward. In this manner is explained the occasional appearance of a ring of green fluorescence upon the equator of the bulb at the moment the electrodes are magnetised, and also the loss of positive electrification, not only from the walls of the bulb but from objects placed in the interior as well. The similarity

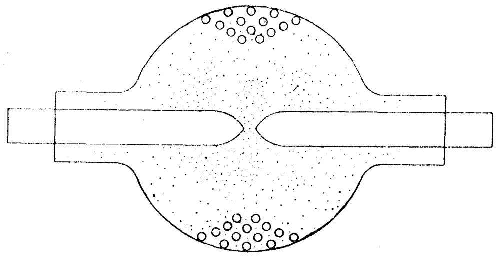

Fig. 11.

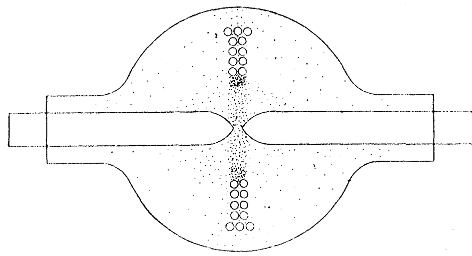

Fig. 12.

between both the diselectrification effects and the luminous ring phenomena has been also experimentally demonstrated, and it now remains to offer an explanation of the luminous ring itself. The final action of the magnetic field, the incoming streams of positive ions, and the production of the luminous ring, are represented by fig. 12. The ring is most luminous at its outer edge or surface owing to that being the boundary at which most of the incoming positive and outgoing negative ions collide.* But while the concentration of negative ions can be explained for a growing magnetic field, it is not clear why the sudden cessation of the field should also produce a concentration. The influence of the rate of change of the magnetic lines was more marked in this than in the former case. Whether Mr. WALKER's ingenious theory† of the luminous ring satisfactorily explains that result is not quite certain. I could get no direct experimental proof either one way or the other. The direction in which the luminous ring rotates has been already referred to in detail. It must now be pointed out that the sense is opposite to that in which a negative ion might be expected to move owing to the sudden growth of the magnetic field. On the other hand, it is evident that the outer surface of the ring is more positive than the surrounding negatively electrified gas particles, which would in consequence flow inwards and be deviated in a manner consistent with the observed direction of rotation of the whole. It is seen also that the positive ions felt the action of the magnetic field to a lesser degree, probably owing to their greater mass and comparative want of mobility. We have, therefore, to imagine the initial cloud of concentrated negative ions not necessarily in rotation, but that, owing to the incoming streams of positively electrified particles, the gas-mass at the centre of the bulb

* 'Proc. Roy. Institution,' vol. 9, p. 142.

† 'Electrician,' August 25, 1899, p. 634.

becomes luminious, and is then, as it were, blown upon by streams of negative ions which are attracted to the outer surface of the luminous ring, and thus cause the whole to revolve at a high velocity.

The expansion of the luminous ring is accounted for by the outward flying streams of negative ions which go forth to meet the incoming positive ones. Moreover, this view receives strong support from the experiment in which a mica vane, when partly immersed in the haze sometimes visible about the ring itself, rapidly rotated in the opposite direction to that in which it turned when the brighter portion enveloped the wings. It is also seen why the size and shape of the bulb itself exerts an influence upon the effects and why the distribution of charged gas in the interior plays so important a part. The other minor phenomena, such as the lateral movement of the ring as a whole, from one part of the bulb to another, as well as the formation of luminous rings in planes other than at right angles to the magnetic axis, may all be explained in accordance with the theory here put forth.

I desire to acknowledge thankfully the help which I have received from my assistant, Mr. CHARLES COTON, during the progress of the work, and to express my indebtedness to the managers of the Royal Institution for having kindly placed for a considerable time the exceptional resources of the Davy-Faraday Laboratory at my disposal.

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