



XLVII. Magnetic rotation of electric discharge

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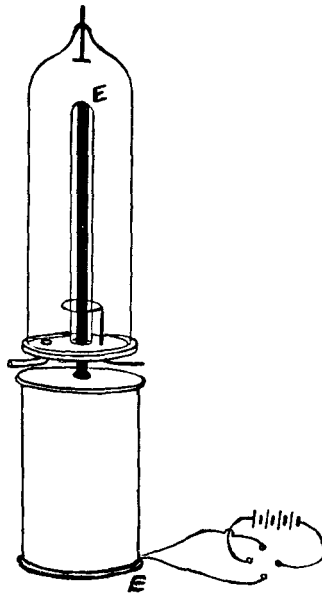
XLVII. *Magnetic Rotation of Electric Discharge.*
 By Prof. D. N. MALLIK, B.A., Sc.D., F.R.S.E.*

[Plate XXI.]

1. **T**HE present paper presents a detailed study of the properties of the electric discharge in De La Rive's apparatus.

The apparatus is of the usual form. The vacuum-tube, however, is in communication with a pump and an ordinary barometric gauge. An aluminium disk and ring of the same material form the electrodes.

Fig. 1.



The electromagnet (E, E) is, as usual, made up of a coil carrying current and a soft iron core projecting from it. The discharge (in most of the experiments) is passed from an induction-coil, the E.M.F. of which is varied by changing the number of cells in the primary circuit.

2. As the pump is worked, it is found that at a certain pressure depending on the number of cells in the primary of the induction-coil, *i. e.* the E.M.F. of the induction-coil, and

* Communicated by the Author.

the distance between the electrodes and the nature of the gas, the discharge passes, but this discharge when it becomes continuous is, as a rule (§ 18), in the form of a spray or shower consisting of infinite number of streams or "rays" all round the axis of the tube. This discharge is unaffected when the electromagnet is excited.

Figs. 2, 3 (Pl. XXI.) are photographs* of such a discharge in air. The streams seem to be reflected at the side of the vessel; their shape therefore depends partly at least on the shape and dimensions of the vessel and the electrodes. Fig. 3 shows also a few bright streaks. They were formed temporarily, one after the other, during exposure of the plate, and were the results of the confluence of a certain number of "streams."

3. As the exhaustion proceeds, more and more of the rays aggregate into a band which becomes brighter and thicker as aggregation proceeds. This band is at first unsteady owing evidently to the fact that there is a continuous change in the constituent streams. Fig. 3 shows the initial stage of this process.

4. The bright band gradually becomes steady when the constituents do not any longer change with time. It then extends from a *definite* point on the ring to the nearest point of the disk (cathode), which is partially surrounded by a glow.

In the present apparatus (in which the ring has a gap) this point in the ring is about 180° from this gap. It is apparently the point in the ring at which the electric density is greatest, and the path of the band then meets the anode at the point at which normal electric force is greatest.

Fig. 4 (Pl. XXI.) shows a fully developed "band" discharge. [The dark space in this is only apparent by contrast.]

5. The pressure at which this band attains steadiness and definite form depends on the E.M.F. of the induction-coil and also on the distance between the electrodes and the nature of the gas.

With the induction-coil I have used in these experiments, and for air, when there were three cells in the primary circuit, this state was attained somewhere about the pressure of 22 millimetres of mercury. With four cells it was about 26 millimetres, and with five cells about 30 millimetres, the distance between the electrodes being 18 cm.

6. It is when the discharge forms a band of definite shape that rotation ensues on the application of the magnetic field.

* Kindly taken for me by Mr. Hughes of the Cavendish Laboratory.

With a weak magnetic field the discharge sticks and rotates with a jerk, but gradually the rotation becomes steady as the magnetic field is intensified. As the pressure is further lowered, the "band" gradually broadens and changes in colour (fig. 5, Pl. XXI.).

7. The dark space is now well defined, increasing in size as the pressure becomes less, while the glow surrounding the disk is seen to extend, changing in form from oblate spheroid through spherical to prolate. And the rotation continues *so long as a considerable portion of the discharge passes very nearly through the same point of the ring.*

In air, the rotation at first follows the law investigated later, viz., $p\omega = \text{constant}$, where p is the pressure and ω the corresponding angular velocity (§ 22); but when the pressure is less than a certain amount, depending on E.M.F. of the induction-coil, &c. (§ 5), the angular velocity increases less rapidly than would be consistent with that law. Gradually the ring end of the discharge (ring being the anode) extends over a *finite* arc of the ring (fig. 6, Pl. XXI.). In this case there is only a twist on the application of the magnetic field. The pressure at which this occurs depends on the E.M.F. of the induction-coil &c. (§ 5), as well as on the magnetic field itself. Thus in my experiments with three cells in the primary it was about 3 millimetres; with four cells 4.5 millimetres; and with five cells 5 millimetres (fig. 6).

8. Finally the discharge spreads over a considerable portion of the ring, gradually becomes striatory and whitish in colour, and ultimately fills the whole tube (fig. 7, Pl. XXI.). The only effect of the magnetic field in this case is to produce an apparent lengthening of the negative column, due to the fact that the ions move in spirals on the application of the field (§ 17).

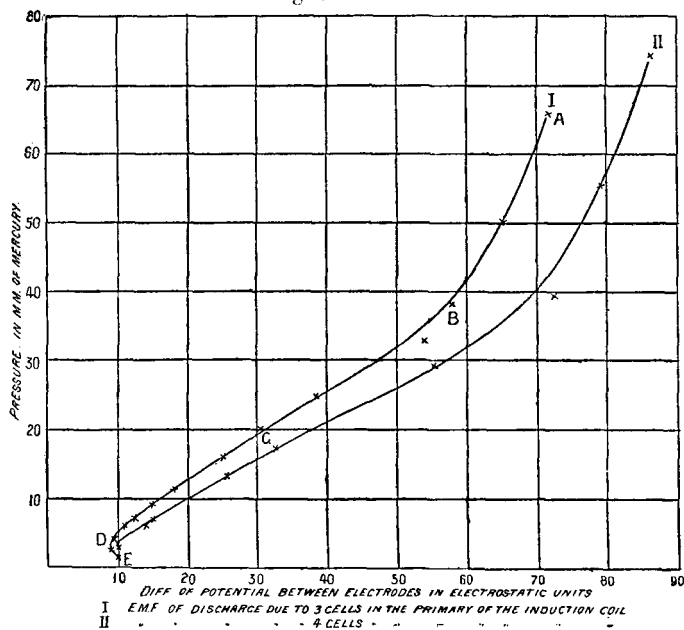
9. It will be thus seen that whenever the discharge consists of a large number of rays going in all directions there is no rotation.

10. Thus rotation is only possible if the bulk of the discharge follows a certain path. This path joins the point of maximum electric density in the anode to the cathode, and is apparently the *least path* from the cathode to this point. Moreover, this is the case when the pressure is between certain limits (depending on the E.M.F. of the induction-coil and other quantities). The "band" discharge thus behaves like a flexible wire carrying current of sufficient intensity to produce rotation under a magnetic field of suitable intensity.

11. Nearly all the salient points with regard to these

discharges in air can be derived from the curves (fig. 8, I. & II.). In these, pressures in millimetres of mercury

Fig. 8.—I. & II.



are ordinates, and the corresponding potential-differences between the electrodes in electrostatic units are abscissæ.

These curves were obtained by measuring the lengths of sparks between two brass spheres of 3 cm. diameter *in parallel* with the discharge tube and deducing the corresponding potential-difference from the table given at p. 461 of J. J. Thomson's 'Conduction of Electricity through Gases,' 2nd ed., by interpolation.

12. It will be seen that we may roughly distinguish four portions in each curve, AB, BC, CD, DE. The first portion (AB), which is very nearly straight, corresponds to the "spray" discharge. As the pressure decreases the character of the discharge changes; it forms into a band by the confluence of most of the discrete streams. This is indicated by the bend in the curve at B.

After this, the relation between pressure and potential-difference is given by a straight line BC. Throughout this stage, the discharge is in the form of a band of light which rotates according to the law $p\omega = \text{constant}$. Gradually the

curve bends away from the straight line BC, and at this point (somewhere about C) it appears that the above law ceases to hold. Ultimately it bends round, as is also *a priori* evident from the fact that at a very low pressure the resistance to the passage of discharge is very great. With the method of spark distance, it is difficult to trace this portion of the curve; I have accordingly made use of a different method (fig. 8, III., p. 536) for the purpose.

13. If we admit that pressure \times spark-length is a linear function of the corresponding potential-difference between the electrodes, the fact that AB, BC are approximately straight indicates that the average length of the path of the discharge is very nearly constant during these stages, and moreover that the path is longer for AB than for BC. That this is actually the case would be evident from an inspection of the figures 2, 3, and 4.

14. Curve I. traces the changes in the case in which there were three cells in the primary circuit of the induction-coil, and Curve II. when there were four. It is evident that the potential-difference for the same pressure is greater in the second case than in the first, and it approximates to equality as the pressure decreases.

15. Again, the pressure at which the band appears is seen to be higher in the second curve than in the first; so also the pressure at which the rotation ceases, the difference being more marked in the first case than in the second.

16. For the same strength of the magnetic field, the rotation is very much less when the ring is the cathode than when the disk is the cathode.

It is found that there is no essential difference in the two cases as regards the variation of electric intensity with pressure. The observed difference is therefore likely to be due to a difference in the number of ions.

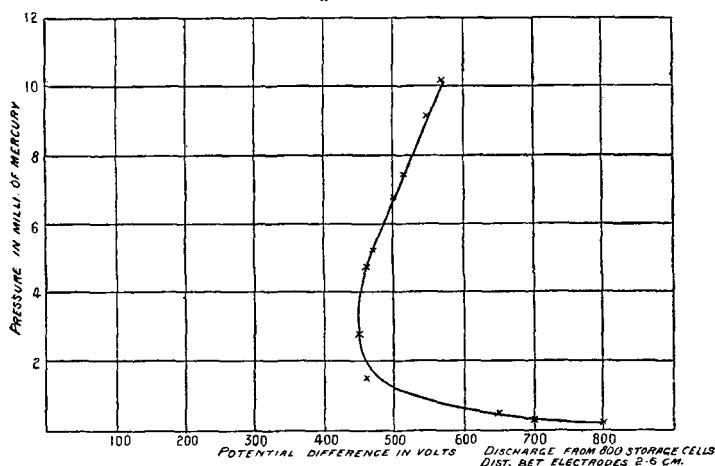
17. As the discharge from an induction-coil is intermittent, it is likely that, during the interval in which the discharge is not passing, a certain number of ions recombine. In order to find how far this affects the rotational effect, a steady discharge from 800 storage-cells was passed through a tube, the distance between whose electrodes had now to be much less (2.6 cm.) than in the previous experiments.

It is found that the discharge passes at a pressure of about 12 mm., and it is, as is to be expected, a "band" discharge which rotates as usual. As the pressure decreases the rotation ultimately ceases, the discharge spreading over the whole ring. In this state, on the application of the field a well-marked spiral is seen to mark the path of the ions,

the number of convolutions depending on the strength of the field (§ 8).

I have used the discharge from storage-cells to investigate the nature of the curve connecting the potential-difference between the electrodes and pressure when the latter is low, but as the nature of the discharge changes not merely with pressure but also with the current carried by the discharge which it is difficult to keep constant, the measurement of difference of potential between the electrodes in the case of a steady discharge is much more difficult than would appear *a priori*. The following curve (III., fig. 8), however, fairly represents the main features of the relation

Fig. 8.—III.



between pressure and difference of potential between the electrodes, for a current strength of 10 milliamperes : the difference of potential was read off on an electrostatic voltmeter.

18. It is not without interest to compare the character of the discharge in this case with that obtained for the same distance between the electrodes when an induction-coil is used. In the latter case, also, the general character of the discharge is of the same form, there being only two stages of the discharge "band" and "glow"; only the range of pressure for which the discharge is in the form of a band is much greater than with storage-cells, being due to the much higher E.M.F. of the induction-coil producing the discharge.

Experimental Determination of the Relation between Pressure and Angular Velocity, &c.

19. If a magnet-pole of strength m acts on a movable and flexible wire carrying current i , the energy of motion of such a wire is $mi\Omega$, where Ω is the solid angle subtended at the pole by the area described by the wire.

Moreover, if ϕ be the angular displacement of the wire

$$\Omega = (\cos \theta_1 - \cos \theta_2)\phi,$$

where θ_1 and θ_2 are the angles made by the bounding radii of the wire, to the pole, with the axis of the magnet.

\therefore the moment of couple acting on the wire

$$= mi(\cos \theta_1 - \cos \theta_2).$$

If, instead of a single pole, we have a distribution of magnetism and ρ is the linear density of magnetism, the moment

$$= i \int \rho dx (\cos \theta_1 - \cos \theta_2).$$

In the case of an electromagnet as in fig. 1, and a flexible wire extending between the electrodes of the discharge-tube of fig. 1, it is

$$= i\rho \int_0^l dx \left(1 + \frac{x}{\sqrt{a^2 + x^2}}\right) \\ = \frac{3}{2} im \text{ nearly,}$$

(a = the radius of the ring, being small), if m is the total magnetic strength and l the length of the iron rod above the ring.

Here ρ has been taken to be constant. This is found to be the case, both as the result of theory and experiment ("Experimental Determination of Magnetic Induction," Phil. Mag. Jan. 1908).

20. Assuming that the "band" discharge can be replaced by such a wire (and experiments justify the assumption), the equation of motion of the discharge will be of the form

$$I\omega = \frac{3}{2} mi - \int u(A_1 + A_2)rnds,$$

where I is the moment of inertia of the discharge about the axis of rotation;

ω = angular velocity;

u = velocity of an ion, due to rotation at a distance r from the axis ;

n = number of ions per unit length of the discharge, positive and negative ;

A_1, A_2 = the retardations of + and - ions respectively per unit velocity ;

ds = an element of length of discharge.

Again, if

S = electric intensity along the line of discharge,

e = charge on an ion,

K_1, K_2 = the velocities of + and - ions under unit electric intensity ;

then K_1S, K_2S will be the velocities of the ions along the line of discharge.

$$\therefore Se = K_1SA_1; \quad \therefore A_1 = \frac{e}{K_1}.$$

Similarly,

$$A_2 = \frac{e}{K_2}$$

\therefore the equation of motion becomes

$$\begin{aligned} I\omega &= \frac{3}{2}mi - \omega ne \left(\frac{1}{K_1} + \frac{1}{K_2} \right) \int r^2 ds \\ &= \frac{3}{2}mi - \mu\omega, \quad \text{say.} \end{aligned}$$

This gives

$$\omega = \frac{3}{2} \frac{mi}{\mu} \left(1 - e^{-\frac{\mu}{I} t} \right).$$

\therefore when the steady state is reached,

$$\omega = \frac{\frac{3}{2}mi}{en \left(\frac{1}{K_1} + \frac{1}{K_2} \right) \int r^2 ds}.$$

Moreover,

$$Se(K_1 + K_2)n = i;$$

$$\therefore \frac{\omega}{\frac{3}{2}m} = \frac{K_1K_2S}{\int r^2 ds}.$$

21. Experiments * were made to obtain the law connecting

* Similar experiments with a different apparatus have also been made by Prof. H. A. Wilson and Mr. Martyn (Phil. Trans. June 1907).

pressure (p), ω , m , and V (the E.M.F. of the induction-coil) in air in the first instance. It should be noted that this law pertains entirely to the portion AB of the curves, fig. 8.

Experiment I.—Current in the electromagnetic circuit constant ($=2.2$ amperes). E.M.F. of the induction-coil $3E$, where E is the E.M.F. due to one cell in the primary circuit.

p (in millimetres of mercury).	T (in seconds).	$\frac{P}{T}$
16.5	1.97	8.4
14.5	1.55	9.3
11.76	1.25	9.3
9.4	1	9.4
Mean		<u>9.1</u>

Experiment II.— $C=2.2$ amperes. $V=4E$.

p .	T .	$\frac{P}{T}$
18.85	1.67	11.1
15	1.27	11.3
13.5	1.15	11.8
12	1.07	11.2
10.97	.98	11.1
Mean		<u>11.4</u>

Experiment III.— $C=2.2$. $V=5E$.

p .	T .	$\frac{P}{T}$
23	1.605	14.37
19	1.26	15.8
15	.99	15.1
12	.72	16.6
10	.63	15.8
8	.515	15.5
Mean		<u>15.5</u>

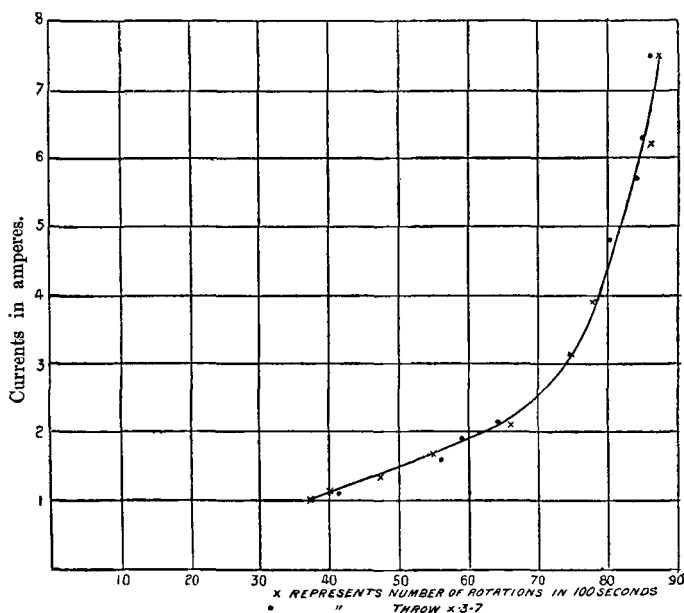
Combining all these results, we see that

V.	$\frac{p}{T}$	$\frac{p}{TV}$
3 E	9.1	3
4 E	11.4	2.8
5 E	15.5	3.1

22. And we conclude that $p\omega = \lambda V$, where λ is independent of p , ω , V , but depends on m and the nature of the gas. It also depends on the spark-length.

23. It was *a priori* evident that ω varies as m . In order to verify this and obtain the value of m , in the particular case in which the current in the electromagnet circuit was 2.2 amperes, the following method was adopted :—

Fig. 9.



Experiment IV.— ω was determined for different values of the current in the coil of the electromagnet, and the results were represented by a curve, in which the ordinates represented current (in amperes), and abscissæ number of revolutions in 100 seconds (fig. 9).

Experiment V.—In the next place a small coil ($\frac{1}{4}$ inch thick) containing 36 turns of wire, in circuit with a ballistic galvanometer and an earth inductor (in series) was placed in the same relative position to the soft iron rod, as the ring of the discharge-tube (which was removed for the purpose) and the throws (d) of the galvanometer corresponding to different currents were noted. Then, if μ = strength of pole of an elementary magnet of length dx , $\mu dx = Idv$, where I is the intensity of magnetization ;

$$\begin{aligned} \text{or} \quad \mu &= Ids \\ &= \frac{B}{4\pi} ds, \end{aligned}$$

$$\text{or} \quad m = \frac{1}{4\pi} \times \text{total magnetic induction.}$$

Hence, $\frac{4\pi m \times 36}{P} = \frac{d}{d'}$, where P is the magnetic induction through the earth inductor, and d' the corresponding throw, when the earth inductor is rotated through 180° , about a horizontal axis. Therefore m evidently varies as d . Now when these throws were plotted, as abscissæ on a suitable scale, currents in amperes being ordinates as in Experiment IV., it is seen the curve so obtained virtually coincides with the curve obtained in Experiment IV. This proves that $\omega \propto m$.

In particular, when the current in the magnetizing coil is 2.2 amperes, m is given by

$$\frac{4\pi m \times 36}{8.6 \times 10^4} = \frac{17.2}{7.5}, \text{ since } P \text{ was known to be } 8.6 \times 10^4 ;$$

and we have ultimately

$$K_1 K_2 S p = \frac{\lambda V}{\frac{3}{2}^m} \cdot \int r^2 ds,$$

where

$$\lambda V = 2\pi \times 9.1 \text{ when } V = 3E,$$

and

$$m = \frac{17.2}{7.5} \times 8.6 \times 10^4.$$

In order to determine $\int r^2 ds$ and $\int ds$, the band discharge

was photographed and the quantities calculated from measurement.

p .	V.	$\int r^2 ds.$	$\int ds.$
14.5	5E	38.16	19.97
17	4E	36.92	19.85
30	5E	37.12	19.92
Mean		<u>37.4</u>	<u>19.91</u>

24. Therefore, finally, we have

$$K_1 K_2 V' p = 3.28 \times 19.91,$$

where V' is the potential-difference corresponding to S at the pressure p .

25. It is not without interest to note that Prof. Wilson and Mr. Martyn's result can be written

$$p V' K_1 K_2 = 23.4 \times 3.1.$$

26. If we take V' equal to the actual potential-difference between the electrodes, we have the following values of $K_1 K_2$ for different values of p .

p	V' in volts.	S in volts per cm.	$K_1 K_2$.
3	1158	58.2	1.878×10^6
5	2130	107	6.159×10^5
10	4560	229	1.438×10^5

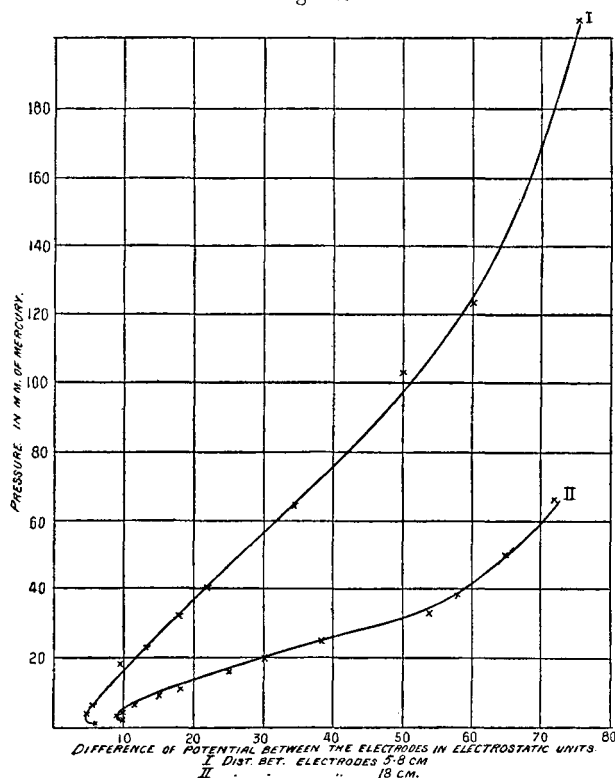
27. These results may obviously depend on the special conditions of the experiments, such as the distance between the electrodes besides the E.M.F. used for producing the discharge. I proceeded accordingly to investigate the effects of these quantities.

28. In order to examine the effect of the distance between the electrodes on the discharge, the potential-difference between the electrodes for different pressures was determined as in art. 11, for the case in which the discharge between the electrodes was 5.8 cm. (fig. 10). The curve for this case and that in which the distance was 18 cm. are plotted together (fig. 10) for purposes of comparison.

It will be seen that the first bend in the curve associated with a change in the character of the discharge occurs at

higher pressure when the distance between the electrodes is less and is, moreover, less marked. In fact when the distance

Fig. 10.



is small (2.5 or 3 cm.) there is no such bend, the first stage in which the discharge is showery being absent (§ 18).

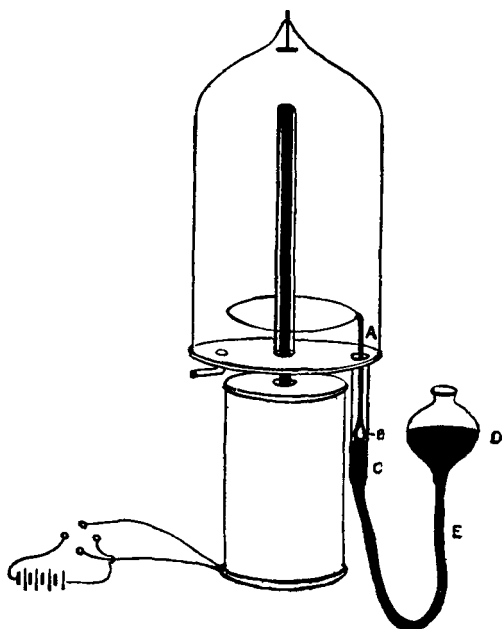
29. In order to determine the effect of the distance between the electrodes on rotation, the apparatus (fig. 11, p. 544) was used.

The ring electrode is joined to a stiff copper wire (A), passing through and moving with a glass float B, which slides in the tube C. Mercury fills a portion of C, the flask D and the indiarubber tube E. The ring can be raised or lowered by the adjustment of the level of mercury in C.

30. In this way experiments were made at different pressures and different distances between the electrodes. The

results are given in the following table and are also exhibited in the curve (fig. 12, p. 545). In these I have taken the amount of induced magnetism proportional to the length of

Fig. 11.

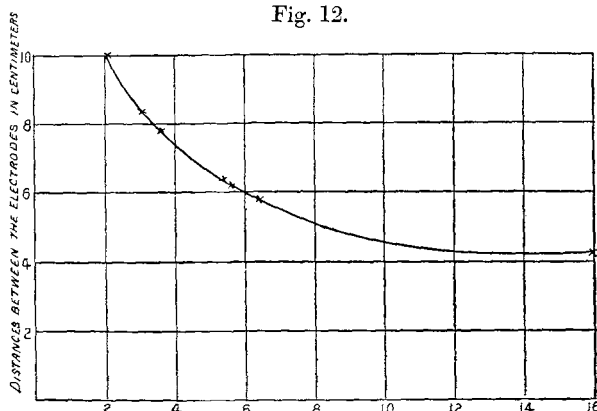


the iron core of the electromagnet above the ring, in accordance with results already established ("Experimental determination of magnetic induction in an elongated spheroid.")

Distance between electrodes (l).	$\frac{p}{T_m}$ proportional to	$\frac{pl^2}{T_m}$ proportional to
10	2.1	210
8.35	3	209
7.8	3.6	219
6.4	5.4	237.5
6.3	5.8	230.2
5.8	6.4	215.2
4.2	16	281

i. e., $\frac{p}{T_m}$ varies inversely as the square of the length of the discharge, as a rough approximation.

Fig. 12.



$\frac{p}{Tm}$, where p is in millimetres of mercury, T in seconds, and m taken equal to the length of the rod above the ring.

31. But since we have

$$\frac{2\pi}{Tm} = \frac{\omega}{m} = \frac{\frac{3}{2}K_1K_2S}{\int r^2 ds},$$

we have, corresponding to any pressure, $\frac{K_1K_2S}{\int r^2 ds}$ varying as $\frac{1}{(\int ds)^2}$ roughly or K_1K_2V' very nearly, independent of the distance between the electrodes. That is, K_1K_2 is practically independent of this distance except in so far as V' depends on this distance.

32. I have also examined the behaviour of different gases and vapours, when the discharge is passed through them at different pressures.

In all the following experiments, the distance between the electrodes was 4.5 cm., the number of storage-cells in the primary of the induction-coil = 3, and the current in the electromagnet circuit 3.4 amperes.

(For purposes of comparison, the results for air obtained with the same apparatus are given below.)

<i>Air.</i>		
$\frac{p}{\text{(in millimetres of mercury)}}$	$\frac{T}{\text{(in seconds)}}$	$\frac{p}{T}$
58	1.41	41.1
49	1.14	43.3
39.4	.95	41.1
34	.86	40
Mean		<u>41.35</u>

At lower pressures $\frac{p}{T}$ decreases as p decreases. Thus

p .	T.	$\frac{p}{T}$.
26.5	8	33
19	7	27

Nitrous oxide (N_2O).

The discharge passes at a higher pressure than in air.

The rotation begins above a pressure of 10.4 cm.; the relation between pressure and the corresponding period of rotation is similar to that in air.

p .	T.	$\frac{p}{T}$.
62	2.4	25.8
39	1.6	24.4
33.6	1.37	24.5
23.58	1	23.5
14.82	.6	24.7
Mean		<u>24.6</u>

Since in air $\frac{p}{T} = 41.5$,

$\frac{p}{T}$ varies inversely as the density, very nearly.

The curve connecting pressure and potential-difference between the electrodes is of the same type as that for air, being situated further from the p -axis than the latter.

Carbonic acid (CO_2).

The discharge passes at a very high pressure, the band discharge appearing at a pressure above that of 15 cm.

$p\omega$ is not constant, but increases with pressure as is shown below.

p (in millimetres of mercury).	T (in seconds).	$\frac{p}{T}$.
125.5	1.8	70
102	1.7	60
75	1.4	53.5
42	1.07	40
32	.84	38
23.5	.7	33.5
15	.55	27.3

The relation between p and T is represented by curve I. (fig. 13).

Fig. 13.

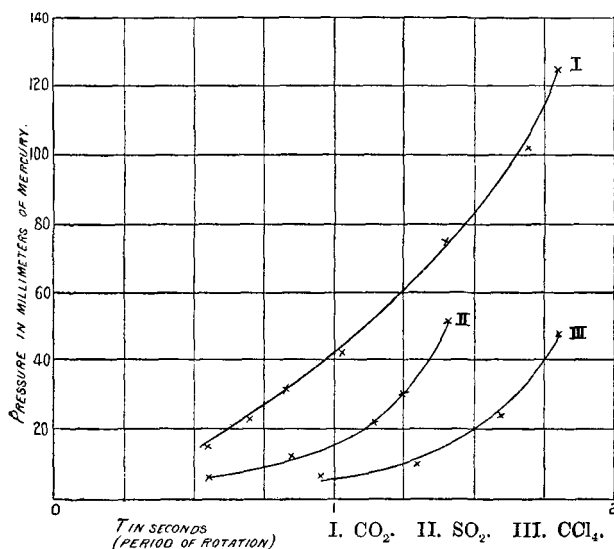
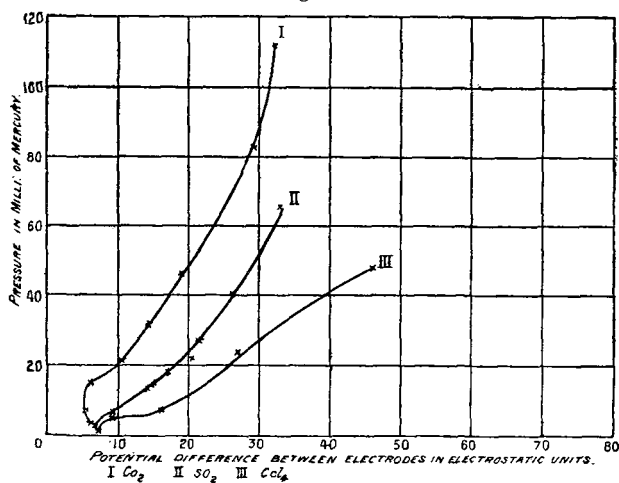


Fig. 14.



The relation between p and potential-difference between the electrodes is represented in curve I. (fig. 14).

In order to get rid as far as possible of the effect of decomposition on the passage of the discharge, the gas was pumped out and fresh gas introduced several times during the experiments.

Carbon tetrachloride (CCl₄).

The "band" discharge appears at about 48 millimetres and the rotation continues up to a pressure of 6.9 millimetres.

The following results indicate the variations of the period of rotation T and pressure :

p .	T .	$\frac{p}{T}$.
6.9	.95	7.2
10	1.3	7.7
24	1.6	15
48	1.8	26.6

It was found to be a rather inconvenient gas to work with ; accordingly, sufficient number of determinations could not be obtained.

The curves of p , T , and $\frac{p}{T}$ and the potential-difference are given in figs. 13 and 14.

Sulphur dioxide (SO₂).

Rotation was observable between the pressures 46 mm. and 3 mm.

$\frac{p}{T}$ increases with pressure.

p .	T .	$\frac{p}{T}$.
46	1.45	31.7
30	1.25	24
21	1.19	17.6
13	.84	15.5

The curve connecting p and T , and that connecting p and potential-difference are given in figs. 13 and 14.

When discharge was passed through benzene, ammonia and ether, they decomposed so rapidly that no measurements could be obtained.

Further experiments on the subject are in progress, and I

am also engaged in working out a theory of these rotations. In the meantime, the following conclusions are justified by the results already obtained.

Conclusions.

1. The discharge in a De La Rive's tube, in general, passes through three stages, "showery," "band," and "glow."

In air, when the distance between the electrodes is small, the first stage is absent.

2. The discharge rotates under the influence of the magnetic field, only when it is in the form of a "band," over a range of pressure, depending on the nature of the gas or vapour in the tube, the E.M.F. producing the discharge, and the distance between the electrodes.

3. Gases can be divided into two groups as regards the law of rotation :

- (1) In gases such as Air, H^* , N^* , N_2O , *i. e.*, probably all elementary gases and those which do not decompose under the electric discharge, for a certain range of pressure (depending on the distance between the electrodes and E.M.F. producing the discharge)

$\frac{p}{T} = \text{constant}$, which varies inversely as the density of the gas, where T is the period of rotation at pressure p . For lower pressures, $\frac{p}{T}$ decreases as pressure decreases.

- (2) In other gases (*e. g.*, CO_2 , SO_2), which probably tend to decompose when the discharge passes through them, and probably all vapours (*e. g.*, CCl_4), $\frac{p}{T}$ increases with pressure and with the density of the gas (fig. 13).

4. In the case of the first group of gases, for pressures at which there is rotation according to the law $\frac{p}{T} = \text{constant}$, the potential-difference between the electrodes is a linear function of the pressure.

For each group the potential-difference between the electrode increases with the density of the gas.

* Prof. H. A. Wilson and Mr. Martyn have investigated the law relating to these gases.

5. For all substances, the potential-difference increases with pressure (except for very low pressures), with the E.M.F. producing the discharge, and the distance between the electrodes.

6. In air, and probably in all gases, the angular velocity of rotation is proportional to the E.M.F. producing the discharge, and increases as the spark-length decreases.

$$7. \text{ Since } \frac{\omega}{m} \propto \frac{K_1 K_2 S}{\int r^2 ds},$$

$$\frac{1}{T} \propto K_1 K_2 S ;$$

but since S increases with density and T also increases with density, $K_1 K_2$ rapidly decreases as density increases.

8. $K_1 K_2$ is independent of the distance between the electrodes (except in so far as the potential-difference in the discharge depends on it) but varies with the E.M.F. of the discharge.

I have to thank Professor J. J. Thomson for permission to work at the Cavendish Laboratory and for many valuable suggestions.

XLVIII. *Homogeneous Secondary Röntgen Radiations.* By CHARLES G. BARKLA, M.A., D.Sc., Lecturer in Advanced Electricity, and CHARLES A. SADLER, M.Sc., Demonstrator in Physics, University of Liverpool*.

THOUGH there are many phenomena of Secondary Röntgen Rays still awaiting investigation, it seems desirable in publishing the results of recent experiments—principally on the homogeneous secondary radiations—that a general survey should be made of the whole subject of “Secondary X-Rays emitted by substances subject to X-Rays,” and that a more concise statement of the experimental results and the conclusions based on these should be given. This, indeed, appears a necessity not only in order to make intelligible the results of what would otherwise appear isolated experiments of little significance, but to exhibit the observed limitations or the generality of laws

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Fig. 2.



Fig. 3.

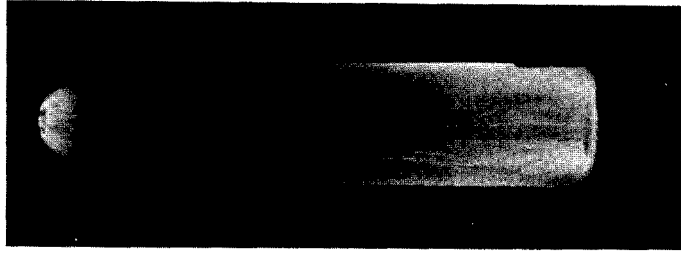


Fig. 4.

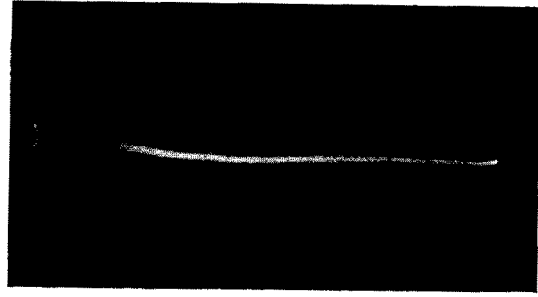


FIG. 5.



FIG. 6.



FIG. 7.

