Electrical Conductivity in Gases Traversed by Cathode Rays

J. C. McLennan

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II. *Electrical Conductivity in Gases Traversed by Cathode Rays.*

By J. C. McLennan, *Demonstrator in Physics, University of Toronto.*

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Though it has been known that a gas becomes a conductor when traversed by cathode rays, yet the laws connecting this electrical conductivity have not hitherto been studied.

The theory has been put forward by J. J. Thomson and Rutherford* that when a gas becomes a conductor under a radiation, it does so in virtue of the production of positive and negative ions throughout its mass. This view has been established by their experiments on Röntgenised gases, and confirmed by those of Zeleny† on the same subject. The recent work of Rutherford on Uranium Radiation‡ also affords another example of such a process in the gases traversed.

The object of the experiments which are described in this paper was to investigate the nature of the conductivity in different gases when cathode rays of definite strength passed through them, and to measure the number of ions produced. With this in view, I have worked with cathode rays produced, after the method of Lenard, outside the discharge tube, as these were found to be more easily dealt with than those inside.

The investigation is described under the following subdivisions:—

1. Form of tube adopted for the production of cathode rays.
2. Ionization by cathode rays.
3. Discharging action of cathode rays.
4. Ionization not due to Röntgen rays.
5. Discussion of methods for measuring the ionizations produced in different gases.
6. Description of apparatus used.
7. Explanation of the method adopted for comparing ionizations.
8. Ionization in different gases at the same pressure.
9. Ionization in air at different pressures.

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* 'Phil. Mag.,' November, 1896, p. 393.

† 'Phil. Mag.,' July, 1898, p. 120.

‡ 'Phil. Mag.,' January, 1899, p. 109.

10. Ionization in a gas independent of its chemical composition.
11. Comparison of ionizations produced by cathode and by Röntgen rays.
12. Summary of results.

1. *Form of Tube adopted for the production of Cathode Rays.*

To produce the rays, a modified form of the tube devised by LENARD,* fig. 1, was used. The disc *a* which closed the end and carried the aluminium window formed the anode. To hold this disc in position, and to render the joint airtight, recourse was had to sealing-wax, which was allowed to set on the previously warmed glass and metal, after which the parts were made to unite by slightly melting the surfaces and pressing them together. By running round the joint with the pointed flame of a blowpipe, any air bubbles present were removed, and complete union was effected. Joints made in this way were found to hold for any time desired.

In making the aluminium window airtight, marine glue could be used, but the ordinary commercial soft wax was found to be more suitable. This was especially so when the experiments were in the tentative state and alterations were frequently necessary. The wax melted at a lower temperature than the glue, and besides being much more manageable than the latter, it was also less disagreeable to handle. A coating of it on the sealing wax also prevented cracking.

As shown in the figure, the anode was provided with a shoulder round the opening of the window. This was found very convenient when the action of the rays on the air in a partially exhausted receiver such as A was being examined. The receiver was provided with a similar but larger shoulder, and by slipping it over that on the

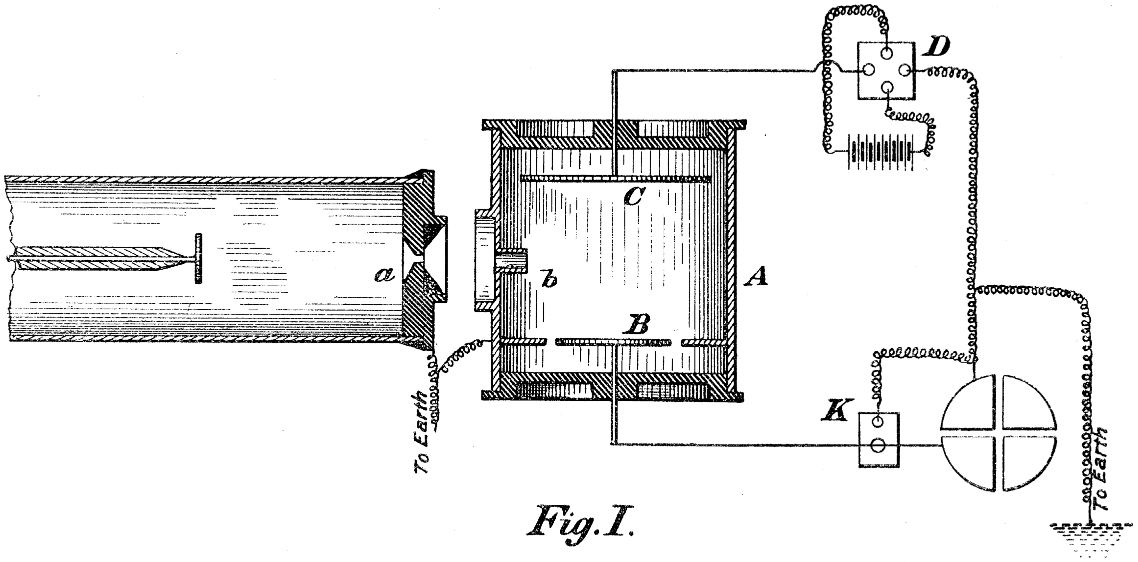

Fig. I.

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* 'Wied. Ann.,' vol. 51, p. 225 (1894).

anode and applying a coating of wax, an airtight connection could be readily made without interfering with that which secured the aluminium foil to the disc. This latter connection was effected by placing a thin coating of wax upon the brass disc and gently applying heat after the foil was laid upon it. All the space within the projecting shoulder was then covered with a thick coating of the wax, excepting the central portion of the aluminium.

In all the experiments with these tubes the anode was well earthed, as was also the positive terminal of the induction coil used to produce the discharge.

As regards the distance between the cathode and the anode, it was found best not to make it too small. Otherwise, the discharge would pass in the tube before the available maximum potential difference was reached. The velocity of the carriers has been shown by J. J. THOMSON* to vary with the potential difference between the electrodes, and as a consequence an intense radiation was more readily obtained when the distance between the anode and cathode was considerable.

In the case of tubes constructed with a short distance between the electrodes, the device adopted by McCLELLAND† of inserting an air gap in series with the tube very largely increased the intensity of the radiation.

The foil used by LENARD for the aluminium window was ·003 millim. in thickness. In practice it was exceedingly difficult to obtain such foil free from holes. Aluminium about three times as thick was, however, much better in this regard. The induction coil used in the experiments was, besides, very powerful, and, as a radiation sufficiently intense could be obtained with it, this thickness was used throughout the investigation.

2. *Ionization by Cathode Rays.*

It has been shown by LENARD‡ that air, when traversed by cathode rays, acquires the property of discharging electrified conductors against which it may be blown, and that, further, it retains this property for some time after the rays producing it have been cut off.

According to the theory of Professor THOMSON, the air, when in this state, is ionized, and the discharging action is brought about by a motion of the ions in the gas to the charged conductor. Owing to the separation of the positive and negative ions, recombination can take place but gradually, and this readily explains why the discharging power is retained by the air for some time. In order to show that these positive and negative ions are produced in a gas traversed by the rays, the apparatus shown in fig. 1 was used.

The cathode rays issuing from the aluminium window *a* passed through a narrow tube, *b*, into an earth-connected metal chamber, A. B was a disc of brass supported

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* 'Phil. Mag.,' October, 1897, p. 315.

† 'Proc. Roy. Soc.,' vol. 61, No. 373, p. 227.

‡ 'Wied. Ann.,' vol. 63, p. 253 (1897).

by an ebonite plug, and surrounded by a guard ring. A wire led from this electrode to one pair of quadrants of an electrometer, and the other pair was put to earth. Care was taken to screen off electrostatic induction by surrounding the wire and electrometer with earth-connected conductors. The second electrode, C, also supported by an ebonite plug, was connected by a commutator, D, to one of the terminals of a battery of small storage cells, the other terminal being connected to earth.

The tube, *b*, was made narrow, and penetrated a short distance into the chamber in order to confine the rays to a slender pencil, and to prevent their impinging upon the electrodes. By means of the key, K, the electrode, B, could be put to earth when necessary.

With such an apparatus, and no field initially between the electrodes, it was found on exciting the discharge tube and breaking the earth connection, K, that the electrometer gained a small negative charge, which did not go on increasing, but soon attained a limiting value.

On the assumption that the cathode rays produce positive and negative ions throughout the gas, the explanation of this is obvious. The cathode rays carried a negative charge into the gas, and set up a field which caused the negative ions to move to the walls of the chamber and to the electrode, B. The charge which the latter soon gained, however, set up a field of its own, and a state of equilibrium was reached when the conduction to the electrode was just equal to that proceeding from it. If, instead of there being no field initially between the electrodes, C was joined to the positive terminal of the battery, then the electrode, B, gained a positive charge when the tube was excited, and the rate at which its potential rose depended upon the capacity joined to B and the electrometer.

With C joined to the negative terminal of the battery, a similar charging took place, except that in this case the charge accumulated was a negative one.

This reversal in the sign of the charge collected may be shown with a field of a few volts a centimetre, and clearly points to the existence of positive and negative ions in the gas. Since the cathode rays themselves carry a negative charge, the presence of these carriers alone in the chamber would account for the negative charge obtained with a negative field. With a positive field, however, these carriers would be attracted to the electrode C, and it seems impossible to explain how the electrode B, under these circumstances, could receive a positive charge unless ions were produced by the rays.

3. *Discharging Action of Cathode Rays.*

In connection with the experiments of LENARD,[*] already referred to, cathode rays were allowed to fall upon a charged conductor surrounded with air at atmospheric pressure. This conductor consisted of a wire attached to a gold-leaf electroscope,

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[*] 'Wied. Ann.,' vol. 63, p. 253.

and was placed within a zinc box in which was a small opening covered with a film of aluminium, thin enough to allow the rays to pass through. The end of this wire was placed in front of the window and close to it, with the electroscope clear of the direct path of the rays. The box itself was connected to earth and set in position, with its window opposite that of the discharge tube.

Using this apparatus, LENARD found that positive and negative charges alike were completely dissipated by a single discharge through the tube when the aluminium windows were at any distance up to 4 centims. apart. At greater distances than this a similar but only partial discharging of both kinds of electricity occurred when the same amount of rays was used.

This loss of charge was no doubt brought about by means of the ionization in the air surrounding the conductor. The known behaviour of an ionized gas, however, would have led one to expect a somewhat different result, especially in regard to the effect obtained with short distances between the windows. When an insulated metal conductor is placed in air ionized by Röntgen rays, ZELENY* has shown that, owing to the greater velocity with which the negative ions diffuse, this conductor takes up a small negative charge, while the gas itself is left with a positive one. If then the ionizations in the two cases are of the same nature, one would have expected that in LENARD's experiments the wire and electroscope would not, under any circumstances, have been finally discharged completely, but would have been left with at least a small negative charge. When, further, it is remembered that the impinging cathode rays themselves carried a negative charge to the wire, this fact affords an additional reason for expecting such a result.

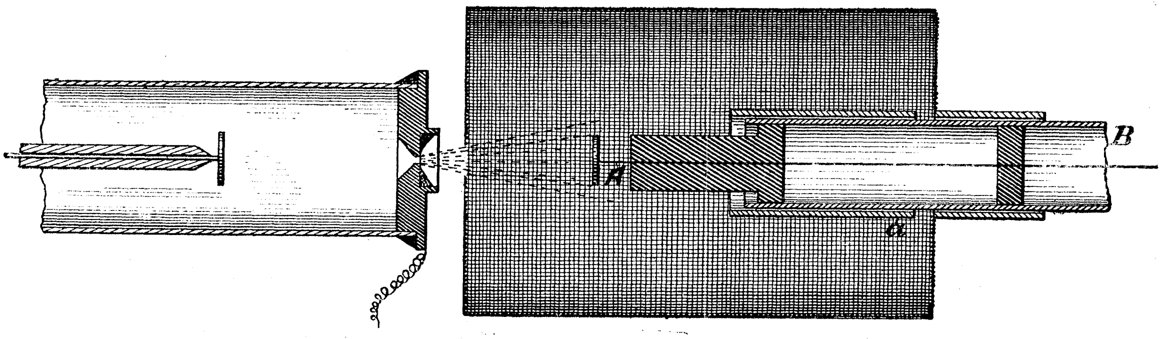

Fig. II.

Now the gold-leaf electroscope, as used by LENARD (EXNER's type), was not sensitive to small differences of potential, and it was consequently not a suitable instrument for the detection and measurement of effects of this kind. As the explanation of his results seemed, then, to be connected with this lack of sensibility in the measuring instrument, his experiments were repeated, and a quadrant electrometer was used in place of the electroscope.

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* 'Phil. Mag.,' July, 1898, p. 134.

The arrangement was that shown in fig. 2. A copper wire, terminated by a disc, A, of the same metal, was insulated by ebonite from an earth-connected copper tube B, through which it passed to the electrometer. To this tube there was fastened, as shown in the figure, a large, finely-meshed copper gauze which completely protected the disc from electrostatic induction. The tube B also carried a short concentric cylinder a, made of copper, which could be slid out when desired so as to surround the projecting end of the wire and the disc.

On placing this apparatus in front of the aluminium window so that the cathode rays fell on the disc, it was found that, although the rays caused a discharging of positive and of negative electricity, still in no case observed was a negative charge on the disc and wire ever completely dissipated.

Negative charges fell, however, to limiting values, represented in some cases by potentials of the order of ·25 volt, and then remained stationary. In the case of initial positive charges the discharging was not only complete but the disc also gained this limiting negative charge. A similar charging action was observed when there was no initial charge on the disc.

Here the disc was subjected to two influences, namely, the cathode rays carrying a negative charge to it and the ionized gas about it acting as a conductor and tending to discharge it. This limiting charge can, then, just as in the case already cited, be looked upon as representing a state of equilibrium in which the convection to the disc was just equal to the conduction away from it.

As the electric field produced by a given charge on the disc would vary with the distance between it and neighbouring conductors at a different potential, the conduction from the wire could consequently be increased or decreased according as an earth-connected conductor was brought close to the disc or removed farther from it. If then a means were devised of altering in this way the conduction without altering the intensity of the rays impinging on the disc, the value of this limiting charge could be subjected to definite variations.

The sliding cylinder a afforded a simple means of accomplishing this result. If when the tube was excited a stationary state was reached, with this cylinder shoved well back, and it was then brought forward over the wire and disc, the limiting negative charge at once dropped and assumed a steady but smaller value. In order to restore the charge to its original value it sufficed merely to slide the cylinder back to its former position.

Another simple verification of this view was afforded by the use of a blast of air. If when the rays were impinging on the disc a blast of air was directed towards it and at right angles to the rays, the limiting charge at once increased to another limiting value, and when the blast stopped it again dropped to its original amount.

As the velocity of the cathode rays has been estimated by J. J. THOMSON* to be of the order of 10^{10} centims. per second, it is clear that any ordinary blast could produce

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* 'Phil. Mag.,' October, 1897, p. 315.

very little effect on the motion of these carriers. On the other hand, the velocity of the ions in Röntgenised air has been found by RUTHERFORD* to be about 1·6 centims. per second, under a field of a volt a centimetre, and consequently of the order of that of the blast. In the experiment described, the effect of the blast, therefore, was to decrease the conduction away from the electrode by removing the ionized gas; and as no change was made in the intensity of the rays impinging on the disc, this consequently produced an increase in the residual charge. This increase, however, did not go on indefinitely, but ceased when the field it set up was sufficient to neutralise the effect of the blast; hence the second stationary value for the charge.

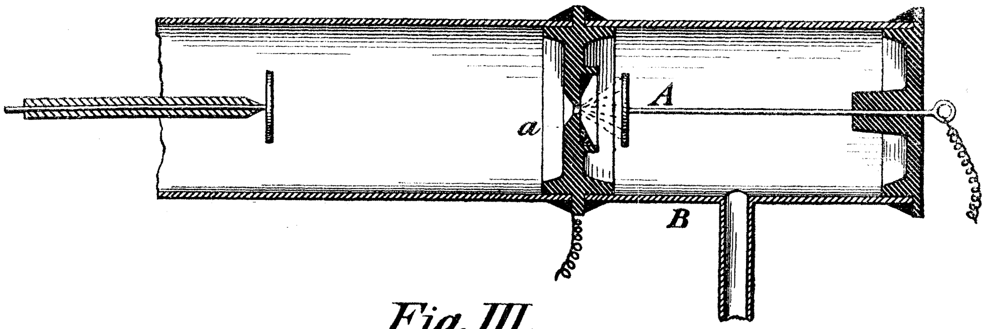

Fig. III.

Another means of increasing this limiting charge was afforded by the removal of the air surrounding the electrode. To show this the gauze cap was removed from the apparatus in fig. 2, and the metal tube surrounding the wire was brought forward and sealed to the anode of the discharge tube. The arrangement is shown in fig. 3.

With this apparatus it was found that, as the exhaustion proceeded in the chamber B, the negative charge received by the electrode A gradually increased, until finally, at a very high vacuum, a momentary discharge of the rays was sufficient to raise its potential beyond the range of the electrometer. This result, therefore, confirms the explanation already given of the discharging action of the rays. In a recent paper by LENARD† this charging action of the cathode rays in a high vacuum was described, but its connection with the ionized air surrounding the electrode was not brought out. From the experiments just described it is clear that, while this action is directly due to the fact that the cathode rays carry a negative charge, the extent of the effect obtained in all cases depends to a very great degree upon the opposing influence exerted by the ionized air surrounding the electrode upon which the rays fall.

4. *Ionization not due to Röntgen Rays.*

It has been thought by some that the ionization produced by cathode rays was due to Röntgen rays, which might possibly be sent out from the window at the same time. The results of experiment are, however, entirely opposed to this view.

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* 'Phil. Mag.,' November, 1897, p. 436.

† 'Wied. Ann.,' vol. 63, p. 253.

In order to investigate the point an apparatus similar to that shown in fig. 3 was adopted. Different thicknesses of aluminium foil were in turn used for the window, and the air in the chamber B was kept at a pressure low enough to absorb but little of any radiation coming from the window, and yet sufficiently high to afford considerable conductivity when ionized.

With different thicknesses of the foil down to ·04 millim., it was found that the electrode A did not gain any charge when the tube was excited. Further, if in these cases a charge, either positive or negative, was given independently to the electrode, this charge was maintained when the discharge passed in the tube, and no leak occurred. But when the window was made of foil ·008 millim. in thickness, the effect obtained was such as that already described in the last paragraph. Under these conditions the electrode A, if carrying initially a positive or a negative charge, finally assumed a stationary state, in which it carried a definite negative charge whose value, as has already been pointed out, depended upon the pressure of the air in the chamber B. As, then, no leak from the electrode occurred when the aluminium was ·04 millim. in thickness, it seems justifiable to conclude that if any Röntgen rays were present under these circumstances they were of an extremely weak character. If Röntgen rays of even very moderate intensity had entered the chamber, a leak would have taken place which could have been observed. In practice the aluminium foil used in my experiments was about ·008 millim. in thickness, and with this foil intense ionization was observed. From the known character of Röntgen rays, it was quite impossible for this great ionization to be produced by rays which could be absorbed by a layer of aluminium ·032 millim.—the difference in thickness of the two windows.

Again, an ordinary focus tube illustrates very well the fact that the Röntgen rays produced issue in a large measure from the face of the anticathode, upon which the cathode rays fall, while the radiation appearing to come from the opposite face is always very weak. The theory now generally accepted is that the Röntgen rays are electromagnetic pulses sent through the ether when the moving electrified particles which constitute the cathode rays are suddenly stopped. If then the Röntgen radiation sent out in the direction of propagation of the cathode rays, when these carriers were stopped by foil ·04 millim. in thickness, was at most but very feeble, it appears highly improbable that a strong radiation of this kind could be produced by those carriers that passed through the thinner foil without being stopped.

The conductivity produced in a gas by cathode rays is, moreover, far in excess of that excited by even the strongest Röntgen rays. In order to make a direct comparison, measurements were taken of the ionizations produced in the same chamber by both radiations, and the following illustration gives an indication of their respective efficiencies. By using the apparatus shown in fig. 1, it was found that, under the action of cathode rays with a saturating intensity of field, a capacity of

750 electrostatic units attached to the electrode B gained in 15 seconds a charge represented by 300 divisions on an arbitrary scale. A Röntgen ray focus tube giving out very strong rays was then used in place of that for producing the cathode rays, and was excited by an induction coil capable of giving a 50-centims. spark. Under these circumstances, with the same field, which was also in this case a saturating one, a capacity of 150 electrostatic units was charged in one minute to an amount represented by 20 on the same scale. This case, which is an extreme one, shows that the ionization by cathode rays was about 300 times that due to an intense Röntgen radiation. In the present investigation these latter rays, even if they did accompany the cathode rays, must have been very feeble, and could therefore only exert an ionizing influence which may be left out of consideration.

The known action of a magnetic field naturally suggested itself as a means of sifting out the cathode from any accompanying Röntgen rays. The intensity of the cathode rays, however, soon falls off owing to their rapid absorption by the air, and on this account it was necessary to place the chamber in which the ionization was measured close up to the discharge tube. Under these conditions it was found impossible to deflect the rays outside the tube without also deflecting those inside. This difficulty consequently rendered the test indecisive, and the method had to be abandoned.

5. *Discussion of Methods for Measuring the Ionizations produced in Different Gases.*

In the construction of Röntgen-ray bulbs, the disengagement of gas from the electrodes and the inside of the glass is facilitated by the application of heat to the tube. In the case of Lenard tubes, however, the joints are made of wax, and the final stage of exhaustion cannot be hastened by adopting this device. In practice a tube was kept attached to the mercury pump, and exhausted while the discharge was passing through it. After some hours of this procedure the coil was stopped, and the exhaustion was continued until only some traces of air were being taken over. On then exciting the tube, the vacuum was found to be sufficiently high for the cathode rays produced to penetrate the aluminium window. After running the coil for a short time, a small quantity of gas accumulated in the tube, and the pressure rose so high that the rays ceased to be propagated outside. After this air had been removed the vacuum again became good, and the original intensity of the rays was restored. As the ionizing power of the rays was very great, charges sufficiently large to be accurately measured were easily accumulated by exciting the tube only for short periods. By following this course quite satisfactory results were obtained and much loss of time was avoided.

On account of this running down of the discharge tube, it was impossible, in comparing the ionizations in two different gases, to use an apparatus with a single chamber, such as that shown in fig. 1. In order to obtain accurate results, it was necessary either to have a constant source of rays, or else to be able to ascertain the relative intensities of the rays used with the different gases.

One method which suggested itself was the use in series of two chambers, such as that shown in fig. 1. By inserting a thin aluminium membrane between them a different gas could be put in each chamber, and a single pencil of rays could be used to produce the ionization in both chambers. With this arrangement it was thought that the ionization obtained in the first chamber might perhaps bear a constant ratio to that produced in the second. But this relation was not found to hold, and further, as the cathode rays are rapidly absorbed, the amount of ionization obtained in the first chamber was so very much greater than that in the second, that even if the ratio had been fairly constant the method would not have been at all satisfactory.

This led to a trial of two receivers in parallel. Although the cathode rays on issuing from the window diverge very greatly, mechanical difficulties made it impracticable to receive part of the issuing rays in each chamber, and so recourse was had to the use of two windows. With a single large disc as cathode, a stream of rays was received in each of the chambers. The ratio of their intensities, however, as measured by the ionizations they produced, did not remain constant but varied quite irregularly. The explanation of this is probably found in a paper by A. A. C. SWINTON,* where he points out that the carriers are shot off in a hollow cone from the cathode, and that the dimensions of such a cone of rays vary with the degree of exhaustion in the tube. Besides, the aluminium windows were opposite to eccentric points on the cathode, and the ratio of the intensities of the two pencils was in this way greatly influenced by slight variations in the directions of the rays within the tube. A cathode formed of two small discs was then tried, and the results obtained were very satisfactory. The ratio of the discharges from the windows was in this case quite constant, and it was therefore possible to make measurements with confidence. The main difficulty of the investigation was in this way overcome, and the method was applied to obtain among other things a knowledge of—1, the absorption of the rays; 2, the ionizations produced by them in air at different pressures; and 3, the relative ionizations in different gases.

6. *Description of Apparatus used.*

A diagram of the apparatus is shown in fig. 4, and the way in which the connections were made is exhibited in fig. 5. The exciting tube was slightly over 3 centims. in diameter. The two discs of the cathode were each about a centimetre in diameter, and they were placed with their centres directly in front of the aluminium windows. That portion of the apparatus in which the ionizations were

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* 'Proc. Roy. Soc.,' vol. 61, p. 79 (1897).

measured consisted of two chambers, A and B, each made of brass and similar in form to that shown in fig. 1. The two electrodes C and D were held in position by ebonite plugs, which closed the ends of the receivers and at the same time served as insulators.

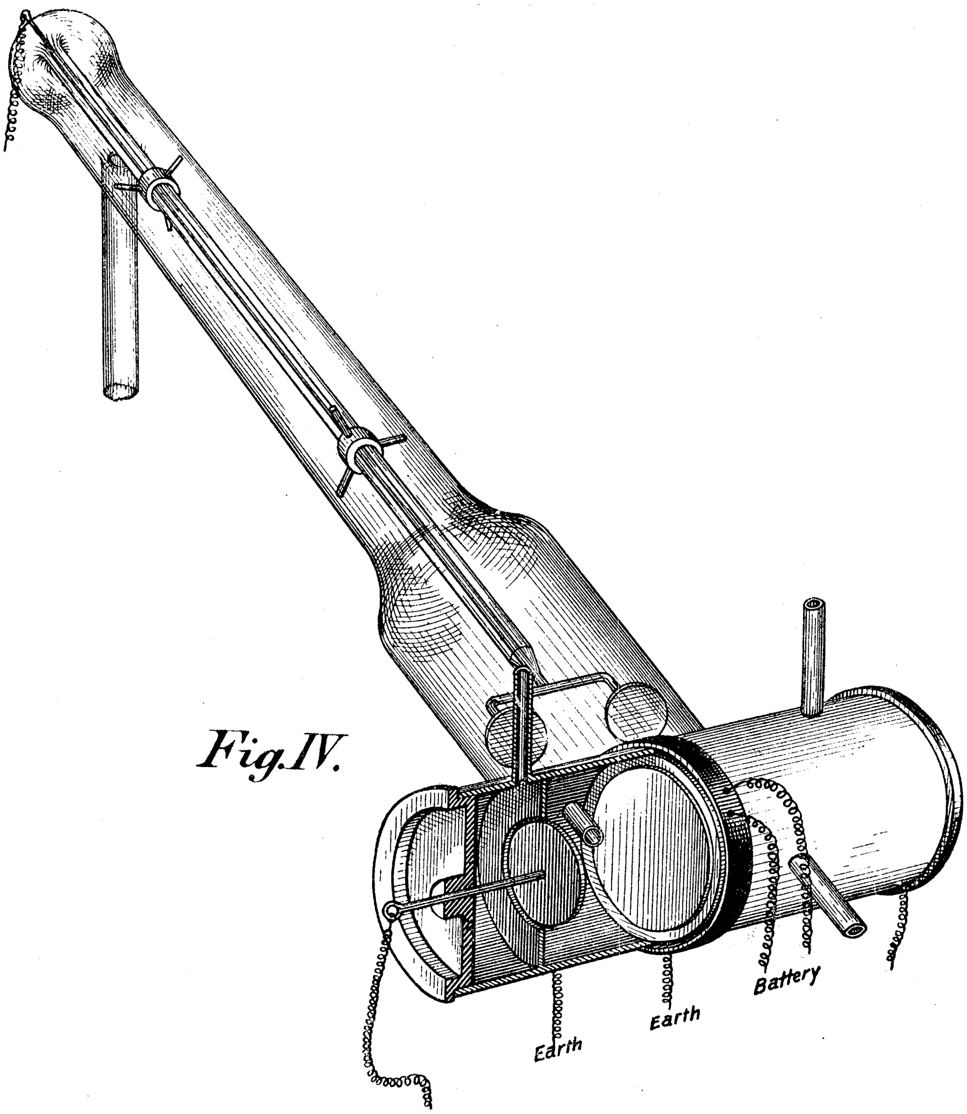

Fig. IV.

In each experiment the receivers themselves were well earthed, and also, initially, the electrodes C and D. As the electrostatic induction was very intense in the neighbourhood of the discharge tube, it was found necessary to take special precautions in regard to the earth connections. Wires of but very small resistance were used, and these were led to water mains and all the joints carefully soldered.

The two chambers were separated by a disc of ebonite, and to its faces were attached thin brass plates, *a* and *b*. By means of wires passing out through the ebonite to the battery of storage cells E, these plates could be charged to any desired potential, high or low. As the electrodes and the walls of the receiver were earthed, this afforded a means of setting up in each chamber a field which could be readily modified. The fields themselves, moreover, were quite distinct, each disc serving as a screen to cut off any action arising from the other.

Each of the chambers was provided with a projecting shoulder, which slid over a corresponding one on the anode surrounding the window opposite. By coating these joints with wax the chambers were then not only made airtight, but also were entirely separated from each other.

In the apparatus used, the diameter of the chambers A and B was about 3 centims., and the distance between each of the electrodes and its corresponding plate *a* or *b* about 1·6 centims. The diameter of the narrow cylinders which admitted the rays to the chambers was 3 millims., and the distance between the aluminium windows and points corresponding to the centres of the electric fields was about 2 centims.

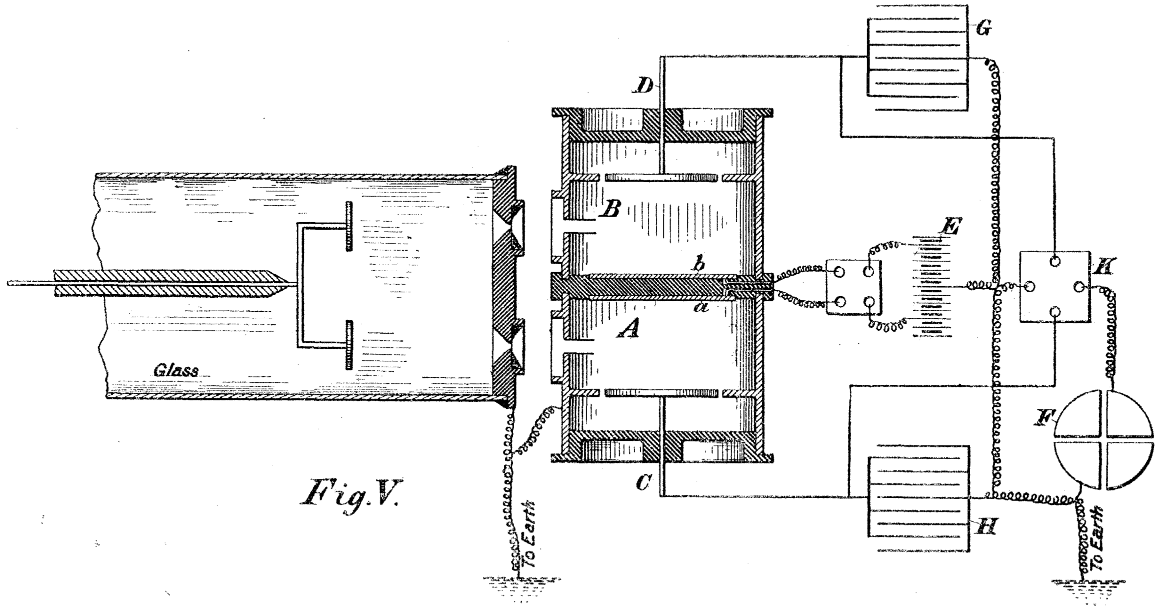

Fig. V.

Each of the electrodes was connected to an air condenser, whose capacity was about 600 electrostatic units. These condensers, G and H, were each made of two sets of parallel plates separated by small ebonite supports. The plates were made by coating both sides of a sheet of glass by a single sheet of tinfoil. In this way plates tolerably plane were obtained, and yet difficulties arising from electric absorption were avoided, the glass merely serving as a support for the foil plates.

The measurements were made with a quadrant electrometer F, and the tube was excited by a 50-centims. spark-length induction coil, whose positive terminal, together with the anode of the tube, was kept to earth. This coil was provided with an Apps interruptor, and besides being very powerful was also very efficient. It required a potential of only eight volts to excite it, and with the interruptor working slowly, this was sufficient to produce sparks of the maximum length in air at normal pressure. In practice, the interruptions were made at the rate of 20 to 25 per second.

7. *Explanation of the Method adopted for Comparing Ionizations.*

It is well known that, in conduction in Röntgenised gases, and in gases acted upon by uranium radiation, the current of electricity obtained does not increase in proportion to the electromotive force applied. The current, after reaching a certain critical value, becomes practically stationary, and increases but very little when very large increases are made in the electromotive forces. This maximum, or saturation current, was also found to characterise the conductivity produced by the passage of cathode rays through a gas. With Röntgen or uranium radiation, a field of 400 or 500 volts a centimetre has been found to give saturation in most simple gases; but with cathode rays it was necessary to apply fields of much stronger intensity.

As already stated, the distance between either of the electrodes C and D, fig. 5, and the dividing partition was about 1·6 centims. In order to ascertain the saturating electromotive force, the plate *b* was kept at a very high potential, while that of *a* was gradually increased from zero. At each stage the ratio of the currents obtained in the two chambers was noted, and it was not until a potential of about 900 volts was applied to *a* that an approximation to the saturation current was obtained in the chamber A. With a potential difference of 1200 volts the increase in the current was small, and an increase only slightly larger was obtained with a potential of 1600 volts, or 1000 volts a centimetre. This small increment in the current very probably arose from the influence of the field itself. It may be that in certain parts of the receiver the rays, acting in conjunction with the applied difference of potential, had not quite sufficient intensity to produce dissociation. An increase in the field under these circumstances would produce greater ionization, and consequently a larger current would be obtained. As this field of 1000 volts a centimetre practically produced saturation currents in both chambers, it was used throughout in measuring the ionizations. Sparking was prevented by using in the charging circuit liquid resistances, such as xylol.

An explanation of the saturation current is that the number of ions used up by the current in a given time is exactly equal to the number produced by the rays in the same time, or in other words, the ions are removed so rapidly by the applied field that recombination is practically eliminated. The saturation current is then a direct measure of the ionization produced, and in order to compare the ionizations in any two gases, it suffices to measure their saturation currents. In this investigation the saturating electromotive force was applied to the plates *a* and *b*, the discharge tube was then excited, and the currents obtained were used to charge up the condensers G and H The discharge having been stopped, the potentials of the two condensers were then successively determined.

As the effective capacity of the electrometer was the same fraction of that of each of the two equal condensers, the deflection readings were direct measures of the charges obtained. The charging of both condensers proceeded for the same time, and consequently the electrometer deflections were also direct measures of the saturation currents, and therefore of the ionizations in the two chambers.

The method possessed the advantage of being independent of the time of charging and of the strengths of the rays coming from the two windows, provided only that the ratio of their intensities remained constant. In using the electrometer the needle was kept at a high potential, and one pair of quadrants always connected to earth. Though with this arrangement slow losses from the needle occurred, yet the short interval required for the two readings made the gradual change in the effective capacity of the electrometer inappreciable.

In practice, the electrometer was initially connected to one of the condensers, and the tube allowed to run until a suitable deflection was obtained. After noting this reading, the electrometer, having been put to earth, was then connected to the other condenser and the second reading taken. In this way the ratio of the ionizations in the two chambers was obtained.

From the experiments described in Section 2, it is clear that the signs of the charges obtained in the condensers depended on the signs of the charges given to *a* and *b* by the battery. In case these plates were positively charged, the charges collected were positive, and were due entirely to ionization. With a negative field, however, the negative charges obtained included not only negative ions produced by the rays, but also the negative carriers, constituting the rays, that were stopped in their motion by the gas. For this reason the positive field was always used, and consequently the charges obtained gave a measure of the number of ions produced in the gas by the passage of the rays.

8. *Ionization in different Gases at the Same Pressure.*

To compare the ionization in a selected gas with that in air at the same pressure, the saturating electromotive force was applied to the plates *a* and *b*, fig. 5. The two chambers A and B were first filled with air at atmospheric pressure, and a series of readings taken, the mean of which gave the ratio of the saturation currents in the two chambers. The air was then removed from A, and the gas to be tested introduced. A set of readings similarly taken gave a ratio for the saturation current obtained with the given gas in A, compared with that obtained with air in B. The combination of these results gave the ratio of the saturation current in A, when filled with the given gas, to that in the same chamber when filled with air. This ratio was, consequently, the ratio of the ionization produced in the selected gas to that produced in air at an equal pressure under the action of cathode rays entering the chamber with the same intensity in both cases.

The results obtained from this method for hydrogen, air, and carbon dioxide are given in the first column of Table I. In the second column are given the relative ionizations found by J. J. Thomson* for these same gases when ionized by Röntgen rays of constant intensity.

Table I.

Name of gas.	Column I.	Column II.
	Ionization by cathode rays.	Ionization by Röntgen rays.
Hydrogen	2·65	·33
Air	1·00	1·00
Carbon dioxide . . .	·34	1·40

These numbers, it will be seen, present a very marked difference. In the one case the ionization decreased as the density of the gas traversed increased, while in the other a law directly the reverse of this was followed.

One explanation of this difference in the results is that the character of the ionization under cathode rays may be essentially different from that produced by Röntgen rays. Apart from these numbers, however, there seems to be but little ground for this view. Strong experimental evidence now exists to support the assumption that the cathode rays consist of small particles of matter carrying negative charges of electricity. We may therefore regard the ionization they produce as being due to their impinging on the molecules of a gas, and to the consequent breaking up of the latter. On this hypothesis it is not clear that the resulting ions should differ in character from those produced under the influence of Röntgen radiation.

It appeared rather that the true explanation was to be found in the varying absorbing powers of the different gases. Lenard,† who studied these rays by the fluorescence they excited, found that the absorption of cathode rays by gases at atmospheric pressure was considerable. He was also led by his experiments to propound the law, that while different gases at the same pressure absorbed the rays to different degrees, yet their absorption depended only upon the densities of the gases, and not upon their chemical composition.

In the apparatus here used, the distance traversed by the rays after they left the discharge tube until they reached the centre of the field where the ionization was

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* 'Proc. Camb. Phil. Soc.,' vol. 10, Part I., p. 12.

† 'Wied. Ann.,' vol. 56, p. 255 (1895).

measured, was about 2 centims. From LENARD'S conclusions, it is obvious that in this distance the absorption of the rays by carbon dioxide would be greater than by air, and very much greater than by hydrogen. The effective intensities of the rays in the three gases at the same pressure would then be very different, and numbers such as those given in Column I. follow naturally under these circumstances, without assuming any difference in the character of the two ionizations.

9. *Ionization in Air at Different Pressures.*

In order to study more closely the influence of absorption, a number of experiments were carried out similar to that just described. The same apparatus was used, and the same method followed, but the ionizations, instead of being measured in different gases at the same pressure, were determined for the same gas at different pressures.

TABLE II.

Pressure.	Ionization measured.
millims.	
767	1·00
530	1·44
340	1·92
205	2·32
104	2·68
53	2·74

Between 40 and 45 millims. a sudden large increase was obtained in the ionization. This was found to be due to the action of the field itself in dissociating the gas.

The results obtained with air are shown in Table II. The pressures are expressed in heights of columns of mercury at the same temperature. The ionizations given are relative, that corresponding to atmospheric pressure being taken as unity, and each value is the average of a large number of readings.

The results are also shown graphically in fig. 6, where the abscissæ represent pressures, and the ordinates corresponding relative ionizations.

The numbers show that as the pressure decreased the ionization obtained with a saturating electromotive force steadily increased, until a pressure of about 75 millims. of mercury was reached. This result, though surprising, can be readily explained by the great absorption of the rays at atmospheric pressure.

The rays had to travel at least 1·5 centims. from the window before they reached that part of the chamber from which the saturation current was obtained. For this reason their effective intensity was very largely determined by the pressure of the gas traversed.

While a diminution in the pressure would not affect the original intensity of a pencil of rays issuing from the window, it would, owing to a decrease in the absorption, increase the ionizing power of this pencil at the centre of the receiver. In this way, although the available amount of matter to be ionized was lessened by lowering the pressure, it could happen that the resultant ionization, as measured by the saturation current, would at first exhibit increasing values. This in all probability accounts for the numbers obtained in Table II.

Now from this point of view such a condition would only hold down to a stage when the two influences produced equal effects. The ionization would then be a maximum, and would afterwards fall off with diminishing pressures. Although the numbers obtained for the saturation current do not show definitely that a maximum value was obtained for the ionization, still there are indications from them, as the curve shown on fig. 6 illustrates, that the maximum value was reached at a pressure of about 75 millims. of mercury.

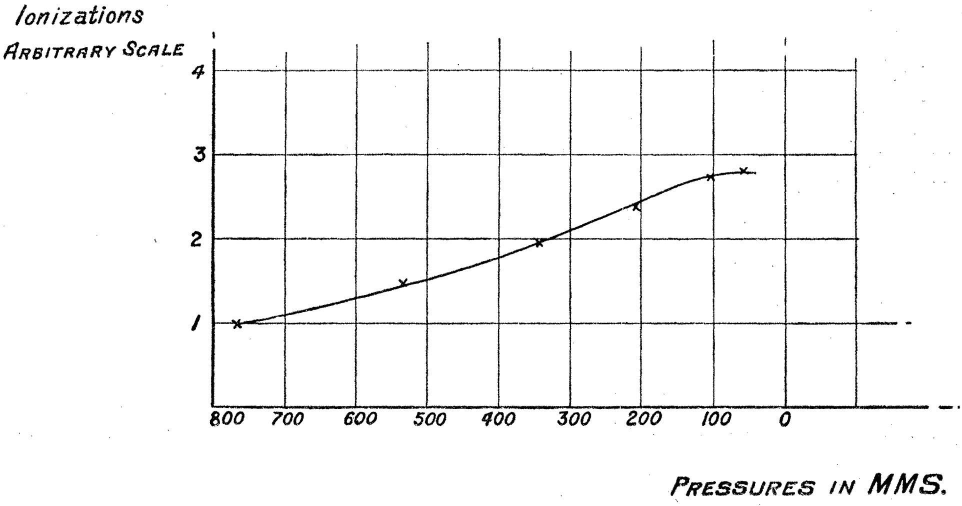

Fig. VI.

As indicated in Table II., the conditions of the experiment made it impossible to measure the ionization in air at pressures much below 50 millims. At about 40 millims. pressure a sudden large increase was obtained in the value of the saturation currrent, whch was found to be due to the influence exerted by the applied field in breaking down the gas. At these low pressures the electric intensity, which was 1000 volts a centimetre, was sufficient to dissociate the attenuated gas and to produce a discharge on its own account between the electrodes. This was shown by simply connecting the electrometer to one of the electrodes, C for example, and applying the potential difference without exciting the discharge tube. On then exhausting the chamber, the electrometer showed no leak until the critical pressure was reached, when it immediately began to charge up.

10. *Ionization in a Gas independent of its Chemical Composition.*

An important result in connection with these experiments is the agreement exhibited between the number given in Table I. for the ionization in hydrogen at atmospheric pressure and that given in Table II. for the ionization in air at a pressure of 53 millims.

Here two gases, hydrogen and air, were introduced in succession into the same measuring chamber and adjusted to the same density. Cathode rays of the same intensity were projected into this chamber in the two cases, and these rays, after traversing a certain length of the gas, reached a point where the ionization they there produced was measured. The values obtained show that under the circumstances the same number of ions was produced in both gases.

Since the rays issuing from the window were in both cases of the same intensity, it follows from LENARD's absorption law that the disposition of the rays, their actual intensities, and the quantities of them absorbed from point to point in the chamber, were precisely the same in both gases. Under these circumstances, therefore, the equal ionizations obtained in hydrogen and in air at the same density not only form a confirmation of LENARD's absorption law, but also show that where equal absorption occurs equal ionization is produced.

In the case of Röntgen radiation, RUTHERFORD[*] has made a determination of the relative absorbing powers of a number of gases. Taking I to denote the intensity of the rays on entering a particular gas, and $Ie^{-\lambda x}$ their intensity after traversing a length x, he has found that the values of the coefficient of absorption for the different gases practically represented the relative conductivities produced in these same gases by Röntgen rays. It is thus interesting to note that with cathode rays, just as with Röntgen rays, equal absorption gives equal ionization.

To test still further the accuracy of this conclusion a detailed examination was made of the ionization produced in a number of different gases. Throughout the experiments air in the chamber B, fig. 5, was taken as the standard. In some comparisons this air was kept at atmospheric pressure, while in others lower pressures were taken, the pressure selected being maintained through each complete determination. In making a comparison the chamber A was filled in turn with the two gases to be examined, and their pressures were adjusted so as to reduce them to the same density. Two ratios were in this way found for the ionizations in the chambers A and B, and as the influence of absorption was eliminated on account of the equal densities, these ratios represented the relative ionizations in the two gases under cathode rays of the same intensity.

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[*] 'Phil. Mag.,' April, 1897, p. 254.

These ratios were determined by taking the mean of a number of readings. Samples of the results obtained in five different comparisons are given in Tables III., IV., V., VI., and VII., the numbers being consecutive readings with each gas in A. They represent very well the working of the method. Although the variations were considerable, similar ones occurred in both sets of observations in each comparison, and as the number of readings taken was very large, any errors were in a great measure compensated.

TABLE III.—Oxygen and Air.

Air in both chambers at 746·7 millims.		Oxygen in A at 675·1 millims. Air in B at 746·7 millims.	
Ionization in A.	Ionization in B.	Ionization in A.	Ionization in B.
1·09	1·00	1·40	1·00
1·37	,,	1·28	,,
1·54	,,	1·39	,,
1·24	,,	1·20	,,
1·35	,,	1·54	,,
1·25	,,	1·41	,,
1·07	,,	1·20	,,
1·41	,,	1·26	,,
1·54	,,	1·41	,,
1·31	,,	1·33	,,
1·32	1·00	1·34	1·00

TABLE IV.—Nitrogen and Air.

Air in A at 734·3 millims. Air in B at 757 millims.		Nitrogen in A at 757 millims. Air in B at 757 millims.	
Ionization in A.	Ionization in B.	Ionization in A.	Ionization in B.
1·10	1·00	1·04	1·00
1·02	,,	1·12	,,
1·21	,,	1·03	,,
1·05	,,	1·34	,,
1·29	,,	1·03	,,
1·10	,,	1·06	,,
1·18	,,	1·15	,,
1·04	,,	1·12	,,
1·07	,,	1·08	,,
1·00	,,	1·06	,,
1·11	1·00	1·10	1·00

TABLE V.—Carbon Dioxide and Air.

Air in both chambers at 772·7 millims.		Carbon dioxide in A at 504·7 millims. Air in B at 772·7 millims.	
Ionization in A.	Ionization in B.	Ionization in A.	Ionization in B.
1·22	1·00	1·17	1·00
1·12	,,	1·16	,,
1·17	,,	1·23	,,
1·33	,,	1·31	,,
1·02	,,	1·37	,,
1·30	,,	1·00	,,
1·11	,,	1·21	,,
1·17	,,	1·24	,,
1·03	,,	1·31	,,
1·23	,,	1·00	,,
1·17	1·00	1·20	1·00

TABLE VI.—Hydrogen and Air.

Air in both chambers at 53·2 millims.		Hydrogen in A at 770·9 millims. Air in B at 53·2.	
Ionization in A.	Ionization in B.	Ionization in A.	Ionization in B.
1·58	1·00	1·52	1·00
1·77	,,	1·82	,,
1·64	,,	1·91	,,
1·41	,,	1·63	,,
1·62	,,	1·58	,,
1·63	,,	1·80	,,
1·79	,,	1·70	,,
1·73	,,	1·32	,,
1·85	,,	1·75	,,
1·81	,,	2·04	,,
1·68	1·00	1·71	1·00

Table VII.—Nitrous Oxide and Air.

Air in both chambers at 759 millims.		Nitrous oxide in A at 499 millims. Air in B at 759 millims.	
Ionization in A.	Ionization in B.	Ionization in A.	Ionization in B.
1·08	1·00	1·03	1·00
1·10	,,	1·21	,,
1·24	,,	1·15	,,
1·12	,,	1·07	,,
·99	,,	1·13	,,
1·08	,,	1·07	,,
1·11	,,	1·17	,,
1·23	,,	1·02	,,
1·07	,,	1·05	,,
1·12	,,	1·10	,,
1·11	1·00	1·10	1·00

Care was taken to insure the purity of the gases, and they were also well dried before being passed into the ionizing chamber.

The oxygen was prepared electrolytically, and was freed from ozone by being passed through a strong solution of potassium iodide and caustic potash.

The nitrogen was prepared by gently heating a mixture of ammonium chloride with a nearly saturated solution of sodium nitrite. The gas given off was passed through a U-tube containing strong caustic potash, and also through a second containing concentrated sulphuric acid. A Kipp apparatus was used for the preparation of carbon dioxide, which was made in the ordinary manner by allowing dilute hydrochloric acid to act on marble. In making hydrogen a Kipp apparatus was also used, dilute sulphuric acid being allowed to act on zinc. The gas was passed through a strong potassium permanganate solution, and then through a U-tube containing a strong solution of caustic potash.

The nitrous oxide was prepared by heating ammonium nitrate in a flask, and the gas was collected over water.

TABLE VIII.—Summary of Measurements.

Gases compared.		Pressures.	Ionizations.
		millims.	
Air	mean of 30 readings	746·7	1·31
Oxygen.	„ 30 „	675·1	1·32
Air	mean of 25 readings	734·3	1·11
Nitrogen	„ 25 „	757	1·09
Air	mean of 30 readings	772·7	1·20
Carbon dioxide . .	„ 30 „	505·4	1·18
Air	mean of 18 readings	53·2	1·70
Hydrogen	„ 18 „	770·9	1·79
Air	mean of 23 readings	759	1·09
Nitrous oxide . .	„ 23 „	499·3	1·10

A summary of complete sets of observations on the different gases is given in Table VIII. This statement includes the number of readings made in each case and the pressures at which these were taken. The ionizations quoted are the averages of the several sets of readings.

The close agreement exhibited by the numbers corresponding to each comparison fully bears out the conclusion deduced from the earlier experiments. It not only forms a striking corroboration of LENARD'S absorption law, but also shows that the ionization follows an analogous one, which may be stated thus:—When cathode rays of a given strength pass through a gas, the number of ions produced per second in 1 cub. centim. depends only upon the density of the gas, and is independent of its chemical composition.

The similarity in the laws of absorption and ionization, holding, as it does, with so many gases over such a wide range of pressures, is a clear indication that when cathode rays are absorbed to a certain extent, the positive and negative ions produced by these absorbed rays are of a definite amount, which bears a constant ratio to the quantity of the rays absorbed; that is to say, the absorption of a definite amount of radiant energy is always accompanied by the appearance of a fixed amount of potential energy in the form of free ions.

This granted, it follows that in order to ascertain the relative ionizations produced in any two gases by cathode rays of the same intensity, it is sufficient to determine the absorbing powers of the two gases for the same rays. In other words, the coefficients of ionization for a series of gases are fully determined when the coefficients of absorption for these same gases are known.

The existence of this general relation between absorption and ionization for both cathode and Röntgen rays is especially interesting when we remember that the two radiations are so very different in many respects.

In the one case, according to the generally-accepted view, the rays consist of small charged particles of matter moving with high velocities in space, while in the other they are supposed to consist of electromagnetic impulses propagated in the ether. With the one the dissociation is in all probability brought about by a series of impacts between the moving particles and the molecules of the gas; with the other it seems to be due to the direct action of the intense electric field forming the impulse. Again, while the absorption of cathode rays depends only upon the density of the medium traversed, the absorption of Röntgen rays, according to RUTHERFORD's results, does not seem to depend to any great extent upon the molecular weight of the gas. But while all these differences exist in the two radiations, with both of them it holds good that the same number of ions are always produced in a gas when the same amount of rays traversing it are absorbed.

11. *Comparison of Ionizations produced by Cathode and by Röntgen Rays.*

The method just described gives definite and conclusive information regarding the ionizations produced by cathode rays in gases of the same density; but where the gases are of different densities, it cannot be satisfactorily applied. As stated in Section IX., the rays, after entering the ionizing chamber, must travel some distance before reaching that part of the field from which the current is drawn. On this account, though rays entering the chamber may originally be of the same strength, still their effective intensities become at ordinary pressures quite different, when the gases traversed are not of the same density.

Also as it is impossible to define exactly the disposition of the electric field within the chamber, these effective intensities cannot be calculated with any degree of accuracy.

A difficulty arises, too, from the dispersion of the rays. As shown by LENARD, they issue from the window in a pencil whose form is greatly influenced by the density of the gas traversed. At very low pressures they pass through the aluminium window practically without deviation, but as the pressure increases, they spread out until finally they issue in all directions.

The conclusion arrived at in the last section, however, suggests a means of calculating the ionization which would be produced by rays of constant intensity in different gases at the same pressure.

LENARD,* who investigated the absorption powers of a number of gases at different

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* 'Wied. Ann.,' vol. 56, p. 258.

pressures, has shown that for any particular gas the coefficient of absorption varies directly as the pressure. In the case of air, taking I to denote the intensity of the rays issuing from the window of the discharge tube, and $Ie^{-\lambda x}$ their intensity at a distance x from the window, he found for λ the values given in Table IX.

TABLE IX.

Air pressure.	Coefficient of absorption.
millims.	
760	3·43
331	1·51
165	·661
83·7	·396
40·5	·235
19·3	·117
10·0	·0400
2·7	·0166
·78	·00416

These numbers, it will be seen, amply support LENARD's conclusion. Similar tables, given by him for a number of gases, all exhibit the same relation between the values of λ and the corresponding pressures of the gas.

Now, if the values of the coefficient of absorption are taken to represent the relative ionizations produced in a gas, at a point where the pressure is varied but the intensity of the rays kept constant, it follows from LENARD's numbers that the ionization in any particular gas would vary directly as the pressure to which it was subjected.

This result, which follows as a deduction from the preceding experiments, has also been found experimentally by PERRIN* to characterise the ionization produced by Röntgen rays. It is true that with Röntgen rays a number of experimenters have found quite different relations to hold between the ionization and the pressure; but in most cases they have vitiated their results either through omitting to use saturating electromotive forces, or through neglecting to arrange their experiments so as to eliminate the metal effect observed by PERRIN.

With uranium radiation also, RUTHERFORD† has found the ionization to be proportional to the pressure of the gas traversed.

The direct experimental verification of a law of this kind is always accompanied by a serious difficulty. The law has reference to the action of rays whose intensity is constant throughout the region ionized. With rays that are easily absorbed by gases at ordinary pressures, this condition can be realised either by the use of very thin layers of gas or by investigating the ionizations at very low pressures. Owing

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* 'Comptes Rendus,' vol. 123, p. 878.

† 'Phil. Mag.,' January, 1899, p. 136.

to mechanical difficulties, however, the former method is generally impracticable, while the action of the applied electric field in breaking down the insulation of the gas precludes the use of the latter artifice.

It is then open to measure the ionizations produced by rays traversing layers of gas of considerable thickness. But before any relation connecting ionizations and pressures can be deduced from such measurements, it is necessary to have definite information regarding the absorptive powers of the gases at different pressures, and to know exactly the form and dimensions of the region from which the ions are drawn.

Although the absorption laws for cathode rays have been fully developed by LENARD, and are quite definite and clear, it is scarcely possible to define even approximately the region in the ionizing chambers (fig. 5) from which the ions go to make up the saturation current.

On this account a direct verification of the proportionality law is not possible; but, as already pointed out, the results of the experiments described in Section X. strongly support the conclusion that, in the case of a gas subjected to increasing pressure, the ionizations produced by rays of constant intensity bear the same ratio to each other as the coefficients of absorption corresponding to these pressures.

If, then, the ionization in a gas varies with the pressure, it follows at once that if rays of the same intensity were allowed to traverse thin layers of different gases at a constant pressure, the ionizations produced would be directly proportional to the densities of these gases.

Take, for example, carbon dioxide and air. It has been shown that the ionization produced in carbon dioxide at a pressure of 504·7 millims. of mercury is the same as that produced in air at 772·7 millims. by rays of the same intensity.

According to the proportion law the ionization produced by these same rays in CO_2 at 772·7 would then be just 1·53 times that obtained at the lower pressure; that is, with rays of the same intensity the ionizations in carbon dioxide and in air would be to each other as 1·53 to 1 when these gases were subjected to the same pressure.

A similar conclusion may be deduced from a consideration of the other gases examined. Hence, on this view, the relative ionizations produced by rays of constant intensity in a series of gases subjected to the same pressure would be expressed by the numbers which under these circumstances give their relative densities.

These numbers are given for the gases examined in Column I., Table X., while in Column II. are given the values found by J. J. THOMSON* for the relative ionizations produced by Röntgen rays of constant intensity in the same gases.

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* 'Proc. Camb. Phil. Soc.,' vol. 10, Part I., p. 12.

TABLE X.

Gases examined.	Column I.	Column II.
	Densities (shown above to be proportional to ionization by cathode rays), air = 1.	Ionization by Röntgen rays. Ionization of air taken as unity.
Air	1·00	1·00
Oxygen	1·106	1·1
Nitrogen	·97	·89
Carbon dioxide	1·53	1·4
Hydrogen	·069	·33
Nitrous oxide	1·52	1·47

The numbers, with the exception of those for hydrogen, present an agreement which is very striking, and show that although the two forms of radiation are so very different, still the products of their action upon the gases cited are practically the same.

While the difference in the numbers for hydrogen is very large, there seems to be some doubt as to the proper value to be assigned to the conductivity produced by Röntgen rays in this gas. The conductivities under Röntgen rays in the gases named have been measured by a number of experimenters, and while their values for the other gases differ but little, a very wide divergence exists in their numbers for hydrogen. RUTHERFORD* gives the value ·5, while PERRIN† has obtained the number ·026 by a method entirely different from that of any of the others.

Though we have been thus led to conclude that the density of a gas should determine its conductivity under cathode rays, strong evidence exists against adopting any such general conclusion regarding the conductivity produced by Röntgen rays, notwithstanding the general agreement indicated above for the gases cited.

With such gases as HCl, Cl_2, SO_2, and H_2S, J. J. THOMSON, RUTHERFORD, and PERRIN have found the conductivities given in Table XI.

From an examination of these values and a comparison with those of Table X., it is evident that it is quite impossible to deduce any such relation between the densities of the gases and their conductivities under this radiation.

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* 'Phil. Mag.,' April, 1897, p. 254

† 'Thèse présentée à la Faculté des Sciences de Paris,' 1897, p. 46.

TABLE XI.—Conductivity under Röntgen Rays.

Gas.	Density.	Measured by		
		J. J. THOMSON.	RUTHERFORD.	PERRIN.
HCl	1·25	8·9	11	8
SO_2	2·23	6·4	4	6
Cl_2	2·45	17·4	18	—
H_2S	1·19	6·0	6	—

Although the laws of ionization and absorption for cathode rays are clearly defined by these results, it is difficult to apply them in practice to the direct calculation of the relative ionizations in any particular experiment.

Take, for example, the case of a pencil of parallel rays, 1 sq. centim. in cross section, traversing air at a pressure p.

Let q = the rate at which ions are produced in 1 cub. centim. of air at unit pressure by cathode rays of unit intensity

and λ_0 = the coefficient of absorption of air for unit pressure.

Consider then the ionization between two planes distant x and $x + dx$, from the source of the rays.

If I denotes the original intensity of the rays, $\mathrm{I} \, . \, e^{-p\lambda_0 x}$ will represent their intensity at a distance x, and $p \, . \, q \, . \, \mathrm{I} \, . \, e^{-p\lambda_0 x} dx$ will then represent the total number of ions produced between these two planes in one second.

Imagine now a saturating electric field applied at right angles to the rays and confined between the limits r and $r + d$.

The value of the total saturation current obtained with this field would then be represented by $\int_r^{r+d} p \, . \, q \, . \, \mathrm{I} \, . \, e^{-p\lambda_0 x} dx$,

or
$$i = \frac{\mathrm{I}q}{\lambda_0} \, . \, e^{-\lambda r} (1 - e^{-\lambda d}) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1),$$

where $p\lambda_0$ is replaced by the quantity λ, whose values for different pressures are given in Table IX.

If the air traversed be now subjected to diminishing pressures, the saturation current will assume different values and will reach a maximum when

$$\frac{di}{d\lambda} = 0 \, ,$$

i.e.,
$$(r + d) \, e^{-\lambda d} - r = 0 \, ,$$

or
$$e^{\lambda d} = \frac{r + d}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

An experiment somewhat analogous to this is described in Section IX. The apparatus used is shown in figs. 4 and 5. The diameters of the electrodes C and D were each about 1 centim. and, as already stated, the distance between the window and the centre of each of the chambers was about 2 centims.

By applying the equation (2) to this experiment, and taking $r = 1{\cdot}5$ centims. and $d = 1$ centim., it follows that the saturation current would be a maximum when

$$e^{\lambda} = 1{\cdot}66 \ldots$$

or

$$\lambda = {\cdot}5.$$

From LENARD'S values, Table IX., it will be seen that this value corresponds approximately to a pressure of about 120 millims. of mercury. The observed results, however, Table II. and fig. 6, indicate a maximum of about 75 centims. Further, the calculated values of the current from equation (1) exhibit a more rapid rise than that actually observed.

But the difference in the results is not surprising. The field within the receiver was far from uniform, being disturbed by the proximity of the walls of the chamber. The presence of the narrow tube through which the rays were conducted into the receiver also produced irregularities. On this account it was impossible to define, even approximately, the region from which the saturation current was drawn. Moreover, the actual paths of the rays, as LENARD has pointed out, are largely influenced by the pressure of the gas traversed. Even at best, then, the calculated results can scarcely be regarded as more than a rough approximation.

12. *Summary of Results.*

1. The conductivity impressed upon a gas by cathode rays is similar to that produced by Röntgen and uranium rays, and can be fully explained on the hypothesis that positive and negative ions are produced by the radiation throughout the volume of the gas traversed.

2. When cathode rays are allowed to fall upon insulated metallic conductors surrounded by air at atmospheric pressure,

(*a.*) such conductors if initially uncharged gain a small limiting negative charge,
(*b.*) positive charges are completely dissipated,
(*c.*) negative charges drop to a small limiting value,
(*d.*) the loss of charge is due to the action of the ionized air surrounding the conductor, and the value of the limiting negative charge is determined by the extent of the conduction in this air.

3. The ionization produced in a gas by rays coming from the aluminium window in a Lenard discharge tube is due to cathode rays and not to Röntgen rays.

4. Lenard's results obtained by fluoroscopic methods on the absorption of cathode rays are confirmed by a study of the ionization these rays produce in gases.

5. When cathode rays of a given strength are passed through a gas, the number of ions produced in 1 cub. centim. depends only upon the density of the gas, and is independent of its chemical composition.

6. With rays of constant intensity the ionization in any particular gas varies directly with the pressure to which it is subjected.

7. The relative ionizations produced by cathode rays of constant intensity in air, oxygen, nitrogen, carbon dioxide, hydrogen, and nitrous oxide, at the same pressure, are expressed by the numbers which represent their densities.

8. With cathode rays, just as with Röntgen rays, the number of ions produced in a gas bears a definite ratio to the amount of the radiant energy absorbed.

I gladly avail myself of this opportunity to record my grateful sense of the never failing encouragement and assistance received from Professor J. J. Thomson.