

THE
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THE DISCHARGE OF ELECTRIFIED BODIES BY THE
X-RAYS. I.

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SINCE the first article published by Roentgen announcing the discovery of the X-rays, there have been only a few points established which give further knowledge concerning their properties. Of these the discovery that X-rays discharge an electrified body is, perhaps, the most important. Some contradictions concerning this phenomenon led me to study it, in order to determine, if possible, the effect on the rate of discharge produced by a variation in the density of the air surrounding the electrified body. Before giving my own work, it will not be out of place to review briefly the articles on this subject which have already been published.

Resumé of Articles Published.—Lenard had found that the cathode rays would discharge electrified bodies, and Roentgen¹ was aware that X-rays possessed this same property at the time of the first announcement of his discovery. The first published accounts of this effect, however, were given almost simultaneously by Benoist and Hurmuzescu² under date of February 3, 1896, and by J. J. Thomson,³ on February 7.

Question of Final Charge.—Concerning the fact of discharge there has never been any question, but very contradictory results were ob-

¹ Sitz. der Wuerzb., phys.-med. Ges., March, '96.

² C. R., 122, p. 235.

³ Lond. Elec., 36, p. 491.

tained by the first experimenters as to the complete discharge of a body, and as to the charging of a body originally unelectrified. Benoist and Hurmusezcu¹ state that the discharge is complete, and that it is more rapid if it be of the negative sign. Borgman and Gerchun² state that a zinc plate loses a positive charge rapidly and then becomes negatively charged to a certain fixed value; but if charged negatively at first, the charge is dissipated far more slowly and stops at the same value as before.

Righi³ says that rays act upon non-conductors as well as conductors, and that the ultimate charge depends upon the kind of metal. Perrin⁴ states that there is no final charge greater than $\frac{1}{20}$ of a volt. Minchin⁵ states that some metals become positively charged and others negatively, when X-rays strike upon them. The order in the list which he gives agrees very closely with that in the list of metals given for contact potential differences.

Apparently, little thought was given in these experiments to the substance surrounding the metal from which the discharge took place. More attention has been given by later experimenters to this point, and more consistent results have been obtained. Murray⁶ found that when X-rays passed between zinc and tin-foil the metals took on final charges corresponding to those they would have if connected by acidulated water. Perrin,⁷ and Lord Kelvin, Beattie, and Smolan⁸ found the same thing to be true in the case of several metals. The latter are of the opinion that there is no variation in the final potential due to variation in the intensity of the rays. Murray states that the final potential does depend somewhat upon the intensity of the rays striking the plate. Righi⁹ found that the pressure of the air at which the charging effect of the rays is greatest is lower than atmospheric pressure, and higher than the corresponding air pressure for ultra-violet light.

Measurement of Discharge with a Galvanometer.—As has been stated, the later results indicate that the air through which the X-rays are passing acts like acidulated water. This idea led Min-

¹ C. R., 122, pp. 235, 779-993.

² C. R., 122, p. 378.

³ C. R., 122, pp. 376 and 601.

⁴ L'Ecl. El., 7, p. 525.

⁵ London Elec., 36, p. 736.

⁶ Proc. Roy. Soc. Lond., 59, p. 333.

⁷ C. R., 124, p. 496.

⁸ Nature, 55, p. 344.

⁹ C. R., 122, p. 878.

chin¹ to endeavor to detect, by means of a galvanometer, the presence of a current when discharge is caused by X-rays. Having found the resistance in megohms between the plates where the discharge took place, he computed the current that should flow, and though his galvanometer was abundantly sensitive, he was unable to detect any sign of such a current. However, he made the assumption in this work that the current should obey Ohm's law, and, as will be shown later, this is an incorrect assumption. Whether this would entirely invalidate Minchin's work or not, is not certain.

Perrin found quite the opposite result from that found by Minchin. He states² that when X-rays were allowed to pass between a copper and a zinc plate, a current of 7×10^{-9} ampere was produced as measured by a galvanometer. The area of each plate was 100 cm.² and there was no electromotive force except that caused by the X-rays between the copper and zinc plates.

Discharge by Roentgenized Air.—It was soon found that it was not necessary for the X-rays themselves to strike the electrified body in order that discharge should take place. It is sufficient if the body is in an atmosphere through which the X-rays have passed. Various experiments to show this were given by Villari³ and others.

Discharge in Different Gases.—The discharging effect in different gases has been studied by Roentgen, J. J. Thomson, and others. Roentgen, in the article to which reference has already been made, states that the action is somewhat slower in hydrogen than in air. Righi⁴ states that the rate of discharge varies as the density of the gas in which the discharge occurs.

Benoist and Hurmuzescu⁵ give the rates of discharge in air, CO₂, and H, and find that these rates are approximately proportional to the square roots of the densities.

Thomson and McClelland⁶ give the relative rates of discharge in several different gases. The data there given do not agree with the law stated by Benoist and Hurmuzescu. They conclude from their table "that the electrical conductivity of the heavier gases, when exposed to the Roentgen rays, is greater than that of the lighter gases;

¹ Lond. Elec., 38, p. 789.

² C. R., 124, p. 497.

³ Rend. Acc. Linc. 5, p. 35.

⁴ Nuovo Cim., 3, p. 177.

⁵ C. R., 122, p. 926.

⁶ Proc. Camb. Phil. Soc. 9, p. 128.

the order of the electrical conductivity does not, however, exactly correspond with the order of molecular weight. A very marked feature of the table is the high conductivity of the halogens. The high conductivity of mercury vapor is very remarkable, for this gas allows the ordinary electrical discharge to pass through only with great difficulty, whereas under the influence of the Roentgen rays it is one of the best conductors among the gases investigated."

Thomson and Rutherford¹ found that in the case of hydrogen the discharge was smaller than through air when small E.M.F.'s were used, and larger when large E.M.F.'s were used.

Discharge with Different Densities of the Gas.—The effect on the rate of discharge caused by varying the pressure of the surrounding gas has been studied by Perrin,² Villari,³ Benoist and Hurmuzescu,⁴ and Thomson and McClelland.⁵ Perrin and Villari state that the rate of discharge is proportional to the density of the surrounding gas, but no data are given by them. The others reached the conclusion that the rate of discharge varies as the square root of the density. Benoist and Hurmuzescu determined this rate by noting the time required for the leaves of an electroscope to fall from a given initial to a given final position. The potential to which the electroscope was charged is not given, but was presumably quite large.

Thomson and Rutherford studied this effect in several different gases. They used an electrometer and noted the time that it took for the potential of the charged body to fall a definite amount. The data given by them for air and coal gas agree fairly well with the law that the rate of discharge is proportional to the square root of the density; but if their data in the case of sulphuretted hydrogen, and especially in the case of sulphur dioxide, be plotted, the curves seem to show a systematic deviation from this law.

Roentgen makes the statement that the discharge was found to be much slower at quite low pressures than at atmospheric pressure. Righi⁶ states that under ordinary conditions the discharging effect of X-rays diminishes as the density of the air is diminished, while the effect due to ultra-violet light increases. The results of my own ex-

¹ Phil. Mag., 42, p. 392.

² C. R., 123, p. 878.

³ Nuovo Cim., Sept., 1896.

⁴ C. R. 122, p. 926, and 123, p. 1265.

⁵ Proc. Camb. Phil. Soc., 9, p. 128.

⁶ C. R., 122, p. 878.

periments on the effect produced by varying the density of the gas will be given elsewhere in this article.

Discharge at Different Temperatures.—Perrin states that the rate of discharge is proportional to the absolute temperature, but no data are given in support of this view. Thomson and McClelland find that as the gas is heated its conductivity reaches a maximum and then diminishes.

Discharge with Different Potential Differences.—The rate of discharge increases as the potential of the charged body increases. However, the increase does not obey Ohm's law. This effect has been studied by Thomson and Rutherford¹. For low potentials the rate of discharge is found to obey Ohm's law fairly well, but as the potential is increased the current tends to approach a limiting value.

Discharge with Different Distances between the Plates.—Thomson and Rutherford also studied the effect upon the rate of discharge caused by varying the distance between the charged body and a grounded body placed near to it. Contrary to what might have been expected, it was found that the nearer the plates were together, the less rapid the discharge. This result is also confirmed by Righi².

Discharge from Different Metals.—Benoist and Hurmuzescu³ state that the time taken for a given discharge varies with the metal from which the discharge takes place, and that the rate of discharge is inversely proportional to the transparency of the metal for X-rays.

Discharge through Solid Dielectrics.—There has been some discussion as to whether discharge takes place in the case of a solid non-conductor. J. J. Thomson's first statement was that non-conductors behave as conductors when acted upon by X-rays. This statement, however, has been questioned by other experimenters. Villari⁴ states that there is no discharge through paraffin, even when there is only a thin layer of it. A more correct statement of the case seems to be given by Thomson⁵. He states that when a charged body surrounded by paraffin is placed in the path of the X-rays, there is at first a large leakage of electricity into the paraffin, but that this action soon stops. If then the charged body be grounded while

¹ Phil. Mag., 42, p. 392.

² Rend. Acc. dei Lincei., 5, p. 342.

³ C. R., 122, p. 779.

⁴ Nuovo Cim., May, 1896.

⁵ Nature, 54, p. 302.

the X-rays are turned off, upon turning them on again there is a large discharge of electricity out of the paraffin. This electricity may be held by the paraffin a long time, if it is not acted upon by the X-rays. Lord Kelvin, Beattie, and Smolin¹ came to the conclusion that paraffin and glass are not rendered sensibly conducting by the X-rays. Burke² came to the same conclusion. Righi³ states that solid and liquid non-conductors do not become conductors; in petroleum and vaseline the discharge soon stopped, but in sulphuric ether it was very much increased. In the latter part of this article an experiment is described bearing upon this point.

Electrification of the Air.—Lord Kelvin, Beattie, and Smolan⁴ state that the air under the action of the X-rays, and in the neighborhood of a charged body, becomes electrified. Rutherford⁵ also found this to be true. He states that the amount of electrification is proportional to the conductivity of the gas and to the absorption of the rays by the gas; the amount of electrification does not depend upon the amount of dust in the air, nor is it affected materially by the metal from which the discharge takes place. It is greatly affected, however, by the kind of gas through which the discharge occurs. There appears to be some conflict regarding the character of the charge given to the air. The first writers state that it is always negative. Rutherford states that the charge in the air is always opposite in sign to that of the metal from which the discharge takes place. It is difficult to see why either of these statements should always be true, and it would seem that more experimental data upon this point are needed.

Law of Inverse Squares.—It has been found by Thomson and McClelland, and by others, that the rate of discharge varies inversely as the square of the distance from the tube giving off the rays.

Allied Phenomena.—Several phenomena are known which are more or less allied with the discharging effect of X-rays. Villari⁶ states that gases which are in this Roentgenized condition have either a greater thermal capacity or a greater thermal conductivity. This he says is shown by heating a platinum wire to red heat by a current. When the X-rays are turned upon the wire, it becomes perceptibly

¹ Nature, 55, pp. 472, 498.

² Lond. Elec., 37, p. 374.

³ Rend. Acc. Linc., 5, p. 342.

⁴ Nature, 55, p. 199.

⁵ Phil. Mag., 43, p. 241.

⁶ C. R., 123, p. 398.

cooler. Upon trying this experiment in a crude manner myself, I was unable to detect any such effect.

Villari¹ also states that Roentgenized air is in a condition opposite to that which is produced when ozone is formed ; that the two neutralize each other in their effects ; and that on sending Roentgenized air through an ozonizing apparatus, its peculiar properties are destroyed.

Attention has also been called to the fact that gases may be given the ability to discharge electrified bodies by other means than the X-rays. Thus Villari² states that the air acquires this property when sparks pass through it, and Garbasso³ states that discharge takes place when the products of combustion strike a charged body. A discussion of these phenomena will be found in Wiedemann's *Electricität* IV., p. 870.

Righi⁴ states that the discharge takes place along lines of force.

Frankland⁵ thinks that if ionization occurs, there should be a change in the rotatory power in the case of optically active substances. He did not, however, find such to be the case.

Discharge by Becquerel Rays.—Becquerel⁶ has found that the invisible rays emitted by uranium have the same power of discharging electrified bodies. He finds that the effect is in every way similar to the discharge produced by X-rays. Among other things he finds that the rate of discharge is proportional to the square root of the density of the surrounding gas.

Discharge by X-rays Compared with that by Ultra-violet Light.—To compare the discharging effect of X-rays with that of ultra-violet light is, of course, one of the first things to suggest itself, but the differences in the two effects are of such a radical character that it seems scarcely worth while to go into detailed comparison.⁷ The ultra-violet light discharges negative electricity only, while the X-rays act alike on positive and on negative. Ultra-violet light produces no effect except when it shines on the body to be discharged. In the case of the X-rays, however, it is only necessary that the air through which the rays have passed should strike the charged body.

¹ C. R., 124, p. 558, and elsewhere.

⁴ C. R., 123, p. 399.

² C. R., 123, p. 598.

⁵ Nature, 53, p. 356.

³ Nuovo Cim., 4, p. 24.

⁶ C. R., 124, p. 483.

⁷ See article by Merritt on "The Influence of Light upon the Discharge of Electrified Bodies." Science, 4, pp. 853 and 890.

With ultra-violet light the kind of metal and the character of the surface have a great effect upon the rate of discharge; with X-rays these have almost no effect.

With the ultra-violet light there is a disintegration of the surface from which the discharge takes place. This phenomenon has not been shown to accompany discharge by means of the X-rays. I am not aware, however, that any attempt had been made to find an effect due to X-rays similar to that observed by Righi, showing that a charged plate is driven away from ultra-violet light, or to that of Lenard and Wolf, showing the roughening of a surface from which discharge takes place.

Experiments have been made showing that an effect is produced on the formation of fog, when steam is ready to condense, both by the ultra-violet light and by the X-rays; but there would appear to be a radical difference between the effects in the two cases. Lenard and Wolf find that the ultra-violet light has no effect upon the formation of fog, unless the action takes place in the neighborhood of a charged body so that there may be dust particles driven off from it. Wilson¹ and Richardz² do not mention the necessity of a charged body when performing the similar experiment with X-rays, but think that the action is due to some effect upon the gas itself.

Since it has not been found possible to polarize X-rays, no phenomenon has been observed with them similar to the effect observed when using ultra-violet light. However, Heydweiler³ states that he found the X-rays more effective in discharging an electrified body when the incidence was nearly grazing. If this should prove to be true it would be an important similarity between the two classes of phenomena.

It has been found that a strong magnetic field has a great influence on the amount of discharge caused by the ultra-violet light. I am not aware that any experiments have been undertaken for the purpose of showing a similar effect in the case of the X-rays.

It has been found that if polarized light is used, the greatest discharge takes place when the plane of polarization is such that

¹ Roy. Soc. Lond., 59, p. 276.

³ Chem. Zeitung, 53, p. 521.

² Wied. Ann., 59, p. 594.

there is the greatest absorption at the charged surface ; and in general the discharging effect is greatest when there is the most absorption at the surface. But in the case of the X-rays the rate of discharge seems to depend more on the absorption of the rays by the gas surrounding the body, than upon the absorption by the substance from which the discharge takes place. Rutherford¹ states that there is a very great difference in the conductivity of different gases, and that this conductivity is proportional to the absorption of the rays. It would not appear from his experiments that the character of the metal affected the rate of discharge. However, Benoist and Hurmuzescu² find that the amount of discharge depends somewhat on the character of the metal used, and they state that the metals which discharge best are those which absorb the X-rays most. If this is confirmed by further experiment it will show that the action of the ultra-violet light is more similar to that of the X-rays in this respect than would now appear.

According to Stoletow the rate of discharge becomes smaller, in the case of ultra-violet light, as the distance between the plates is made greater. According to Thomson and Rutherford the rate of discharge in the case of the X-rays, under the same circumstances, becomes larger.

There are, however, a few points of similarity in the two effects : In both the discharge does not increase as rapidly as the potential of the charged body, when the latter is varied. It would appear that currents may be produced by X-rays similar to the photo-electric currents of Stoletow. If the metals be arranged according to their tendency to acquire a positive or negative charge, the order in the two cases will be approximately the same, and will correspond to a series for contact difference of potential. It has been found by Cave,³ Borgman and Gerchun,⁴ Sella and Majorana,⁵ Swyngedauw,⁶ and Guggenheimer⁷ that the effect on the sparking distance is nearly the same in the two cases. The effect due to changing the density of the gas will be considered in connection with my own work.

¹ Phil. Mag., 43, p. 241.

² C. R., 122, p. 779.

³ Lond. Elec., Feb. 21, '96.

⁴ C. R., 122, p. 378.

⁵ Rend. Acc. Linc., 5, pp. 323 and 389.

⁶ C. R., 122, p. 374.

⁷ C. R., 124, p. 259.

Theory.—Most experimenters are agreed that the effect is due to the fact that the gas becomes a conductor under the influence of the rays. The most probable explanation seems to be that given by J. J. Thomson, that the gas is in some way dissociated. This would explain all the phenomena much better than any other theory which has at yet been proposed. This theory will be discussed more in detail in the latter part of this article.

Experimental Work.

Description of Apparatus Used.—My own work has been devoted chiefly to the study of the relation between the rate of discharge and the density of the surrounding gas. The apparatus used in the present work is shown in the accompanying diagram. The zinc plate, *A*, was connected to two quadrants of the electrometer, *E*, and placed inside a zinc box, *B*, from which it was insulated.

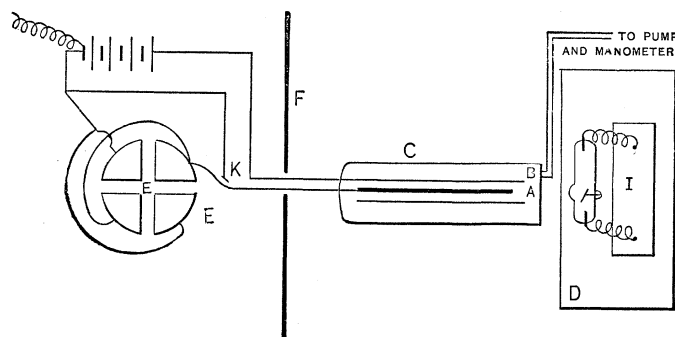


Fig. 1.

Both the plate and the box were carefully cleaned. One end of the box was partially open so that the X-rays could strike the plate at grazing incidence. The box and the plate were placed within a bell jar, *C*, the rays entering at the end of the jar. Over this end a thin piece of board was sealed. This had been soaked in paraffin and was found to be sufficiently air-tight. It possessed the advantage of being almost entirely transparent to X-rays, much more so than aluminum. It could be removed from the jar and the metal removed or its condition changed. The bell jar was connected to an air pump and to a manometer.

In most of the experiments the induction coil was operated by a magnetic interrupter. The coil, *I*, was placed within a metal box, *D*, which had an opening for the rays to pass through. This opening was covered with wire gauze to screen off electrostatic induction.

Care was taken to avoid ordinary electrical leakage. The electrometer and its connections were protected from the action of the X-rays by the sheet of lead, *F*, and they were also protected from the action of the air through which the rays had passed. The zinc plate which was used with most of the experiments had an area of 40 cm.² The sides of the box were 2 cm. from the plate.

The tube used was a Bowdoin tube and had previously had much use. It appeared to be more constant in its action than other tubes tried.

Method of Taking Observations.—The method first employed was to ground the plate for an instant, and after insulating it to allow the rays to act for a given length of time, usually six seconds, between the plate and the box, the box being kept charged to a given potential. It was found that ordinary electrical leakage could best be avoided in this way; the result was the same, of course, as discharging the plate to the box, and will be spoken of as such in what follows.

Several observations were made in each case and the average taken. The difference of potential between the plate and the box did not, of course, remain the same through the discharge; but by taking an average between the initial and the final difference of potential, a fairly satisfactory result could be obtained. The work is not capable of sufficient accuracy to warrant any more elaborate correction, for it is very difficult to keep the action of a Roentgen tube perfectly constant.

Discharge with Different Densities of Gas.—It has already been stated that the relation between the rate of discharge and the density of the surrounding gas has been found to be different under different circumstances. The potential at which the discharge took place had the greatest effect upon this relation. If a curve be plotted with pressures of gas as abscissæ, and rates of discharge as ordinates, the curve will be found to take different forms as the potential is varied. The accompanying tables gives data showing the rates of discharge

TABLE I.

Initial Difference of Potential in Volts.		6	11	20	35
25 mm.	Fall of Potential in Scale Readings.	1.3	1.2	1.6	1.7
		1.5	1.3	1.8	1.8
		1.7	1.4	1.3	1.6
		1.8	1.5	1.6	1.7
	Average Fall. Average Fall in Volts.	1.6 .8	1.4 .7	1.6 .8	1.7 .85
75 mm.	Fall of Potential in Scale Readings.	3.2	3.1	3.2	3.2
		3.1	3.4	3.4	3.1
		2.8	3.4	2.6	3.5
		2.7	3.1	2.9	3.3
	Average Fall. Average Fall in Volts.	3. 1.4	3.2 1.47	3. 1.4	3.4 1.55
150 mm.	Fall of Potential in Scale Readings.	3.1	4.	4.	5.
		3.1	4.1	4.8	4.5
		3.3	3.9	4.4	5.1
		3.7	4.2	3.8	4.7
	Average Fall. Average Fall in Volts.	3.3 1.5	4. 1.8	4.3 1.95	4.8 2.15
250 mm.	Fall of Potential in Scale Readings.	3.7	4.8	6.	6.5
		3.9	5.2	4.8	6.
		3.9	4.6	5.6	6.
		3.5	4.3	5.2	6.2
	Average Fall. Average Fall in Volts.	3.6 1.65	4.8 2.15	5.4 2.4	6.2 2.77
500 mm.	Fall of Potential in Scale Readings.	2.6	4.2	6.2	7.5
		3.1	4.1	5.5	8.
		2.8	3.8	6.	7.8
		2.8	4.3	5.	8.
	Average Fall. Average Fall in Volts.	2.8 1.3	4.1 1.87	5.9 2.65	7.8 3.3
760 mm.	Fall of Potential in Scale Readings.	2.6	3.8	6.3	8.5
		2.6	3.4	6.4	10.
		2.8	3.9	6.8	9.8
		2.8	4.	6.2	9.4
	Average Fall. Average Fall in Volts.	2.6 1.2	3.9 1.8	6.4 2.8	9.4 3.88

at different potentials and at different pressures, and from this table curves are plotted in Fig. 2 for initial potentials of 6, 11, 20, and

35 volts. There was a condenser having a capacity of .002 microfarads in multiple with the plate at this time. The data are given in full in order that some idea may be had of the accuracy attained.

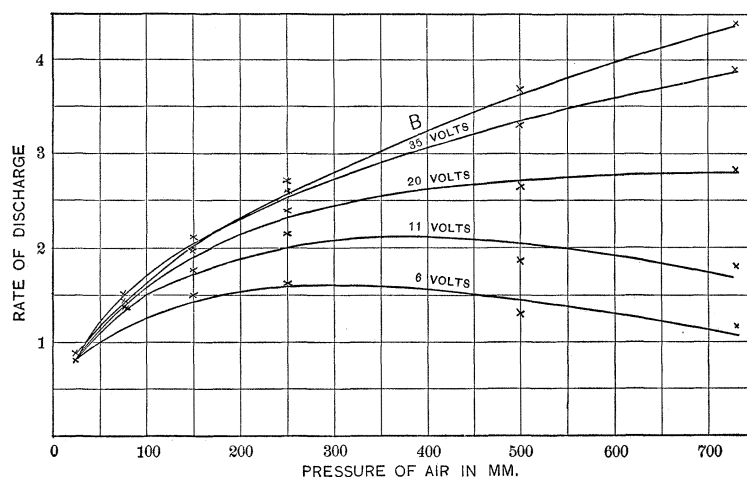


Fig. 2.

To find whether there was any leakage other than that to be studied, the rays were screened off from the plate by a thick piece of lead, and the tube was allowed to act for the same time as before. In this set of experiments such leakage was negligible.

Observations were also taken at a pressure of 12 mm. The values found were such as would be expected from the curves, but the rate of discharge was so small that the irregular leakage was appreciable as compared with that to be studied, and the data have therefore not been included in the table.

The difference in the essential character of the curves can be seen by comparing the curve for 35 volts with that for 6 volts. The former obeys fairly well the law given by Benoist and Hurmuzescu that the rate of discharge is proportional to the square root of the density. This agreement is shown by plotting from their data the curve marked B. The curves taken for higher potentials are practically the same as that given for 35 volts, but approach somewhat nearer to that given by Benoist and Hurmuzescu.

The curve for 6 volts obeys an entirely different law, and in fact it has a maximum at about 200 mm. The divergence from previous results in the case of this curve was so great that it seemed possible that there might be some error, at least as far as the maximum at 200 mm. was concerned.

Variation in method.—The results were therefore tested by a somewhat different method. The plate from which the discharge took place was connected to a given potential through a very high resistance. When the X-rays were allowed to strike the plate continuously, its potential would drop to a certain definite value. If V_1 was the potential of the point to which the high resistance was connected, V_2 that of the discharging plate and r the resistance, the current would be $\frac{V_1 - V_2}{r}$. V_1 and V_2 can be observed, and r is a constant which need not be known for comparative results. If one wishes to study the effect of other changes while V_2 is kept constant, V_1 may be varied so as to bring V_2 always to the same value. Two wires having cotton insulation were wound around each other, and there was sufficient leakage through the insulation to furnish the desired current. This resistance was measured by observing the rate at which it discharged a condenser of known capacity. It was found to be about 5,000 megohms.

In some respects this method would be preferable to the one used; but it is necessary that the tube should be in action several minutes before the discharging plate reaches a steady potential, and it was not found possible to keep the action of the tube constant for the time necessary to take several determinations. The data thus obtained were therefore less reliable than those which have been given. However, the method was of great value in verifying the conclusion reached by the first method. The curves found in the two cases were practically the same.

It is altogether possible that others have failed to find the results here described on account of using less intense rays. An aluminum window would be quite fatal, as far as getting any point of maximum discharge is concerned, unless a very efficient tube were used.

This method of performing the experiment has a bearing on the

conclusion of Minchin, that there is no current in the case of discharge by X-rays which can be detected by means of a galvanometer.¹ Although no galvanometer was used in this experiment, it is difficult to see how there could be a fall of potential through a high resistance, nor why the fall of potential in this method should be proportional to the rate of discharge as found in the other method, if there is no current.

It is known that a metal tends to assume a final potential different from zero when X-rays strike upon it. It was thought that this effect might be complicating the phenomena being studied, but care was taken that the plate from which the discharge took place was surrounded by a grounded metal of the same kind. Under these circumstances the potential of the plate when it was disconnected from any source of electricity, and the rays were allowed to strike upon it continuously, differed but very little from zero, and any error due to this effect was entirely negligible.

Discharge with Different Potential Differences.—It is evident that another set of curves could be plotted, showing the relation, at different densities of the gas, between the rate of discharge and the potential. Thomson and Rutherford have studied the relation be-

TABLE II.

Initial Difference of Potential in Volts.		60	40	25	15	10	5	
75 mm.	Average Dif. of Pot.	56.6	37.3	22.4	12.6	7.9	3.6	
	Fall in Pot. in Volts.	3.9	3.4	3.65	3.65	3.4	2.05	
150 mm.	Average Dif. of Pot.	56.	36.5	21.7	12.1	7.5	3.7	
	Fall in Pot. in Volts.	5.	4.9	5.2	4.6	4.2	1.95	
400 mm.	Average Dif. of Pot.	55.6	36.	21.7	12.	8.	3.7	
	Fall in Pot. in Volts.	5.95	6.05	5.20	4.75	3.2	1.85	
760 mm.	Average Dif. of Pot.	54.2	35.	21.	12.5	8.1	3.9	
	Fall in Pot. in Volts.	8.6	8.1	6.45	3.9	2.85	1.55	
Initial Difference of Potential in Volts.		25	15	10	8	6	4	2
25 mm.	Average Dif. of Pot.	22.8	13.	8.1	6.1	4.4	2.7	1.2
	Fall in Pot. in Volts.	3.	2.8	2.9	3.	2.5	2.	1.2

¹ Lond. Elec., 38, p. 789.

tween the potential and the current produced by the discharge at atmospheric pressure, and have shown that the current does not obey Ohm's law. As high potentials are reached, the current does not increase in a manner proportional to the increase in potential.

Table II. gives the data showing such relationship at different densities of the gas. It seemed best not to take the same data as given before, for the readings in that case did not extend over the range of potentials best suited for showing the effect we now desire to examine. Furthermore, in the previous set, the readings for the same density of gas but with different potential were separated in time, and consequently were taken under different conditions of the tube, so that they were not strictly comparable. In this set the readings were taken consecutively. There was some leakage in this case other than that due to the discharge being studied.

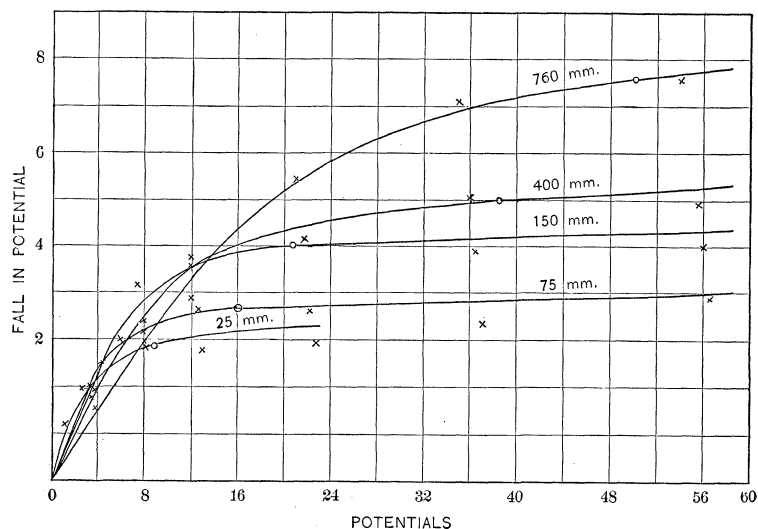


Fig. 3.

In Fig. 3, the corresponding curves are plotted. It will be seen that the limiting values of the current become smaller as the density of the gas becomes less. Points on the curves have been marked to indicate approximately the limiting currents.

These are what Thomson and Rutherford call the saturation

points. If now the densities of the gas be plotted as abscissæ, and the currents at the saturation points as ordinates, a curve will be found quite similar in form with that given in Fig. 1 for 40 volts. This is, indeed, what we should expect; for it is evident from Fig. 2 that, after the saturation point is reached, the current is independent of the potential to which the body is charged, and we would be plotting saturation currents corresponding to certain densities. But in the case of a discharge with a potential of 40 volts, saturation currents were maintained all the time. So that these currents also depended only upon the densities of the air, and the two are in fact the same curve.

Discharge with Smaller Intensity of Rays.—The effect upon the form of the curve caused by varying the intensity of the rays was next studied. The curves which have already been plotted were taken with the tube near quite the plate to be discharged. A series was also taken with the tube at some distance from the plate, and with several inches of wood placed between the two.

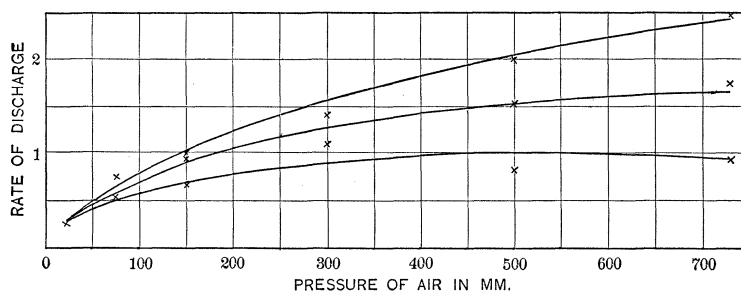


Fig. 4.

These curves are shown in Fig. 4. In none of them is there any maximum. It is thus clear that the form of the curve depends on the intensity of the rays used, and it therefore seemed unnecessary to try to find the form of the curves with any great degree of accuracy since there is no way of determining the intensity of the rays in any standard unit.

Density for Maximum Discharge.—I next attempted to find the relation between the density of the gas necessary for a maximum discharge, and the potential used. In the case of ultra-violet light,

Stoletow¹ had found that if the distance between the plates is kept constant, this density varies directly as the difference of potential between the plates. I had found that when the intensity of the rays was small, the maximum point on the curve was not noticeable. The intensity of the rays was, therefore, increased, and several curves were plotted similar to those in Fig. 2, more attention being paid, however, to the variation in the maximum point. Such a set of curves is shown in Fig. 5.

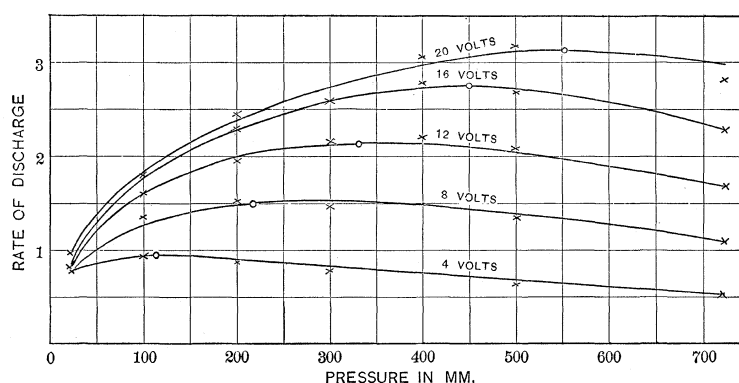


Fig. 5.

It was found that practically the same law applies in the case of X-rays, as holds when the discharge is produced by ultra-violet light; namely, that the density for a maximum discharge is proportional to the potential of the charged body. The points located by circles show where the maxima should occur in order to agree with this law.

However, it is noticeable that the conditions under which a maximum discharge occurs are quite different when it is produced by X-rays, and when produced by ultra-violet light. With X-rays the maximum was found when the pressure was 200 mm., the potential 8 volts, and the distance between the plate and the surrounding metal 2 cm.; while with ultra-violet light a maximum occurred with a pressure of 4.5 mm. when the potential was 100 volts, and the distance between the plates 8 mm.

¹ Journal de Phys., 9, p. 471.

Density for Maximum Discharge and Intensity of Rays.—An attempt was made to find the manner in which the point of maximum discharge depended upon the intensity of the rays. The data proved to be of little value in this case. For when the intensity was somewhat diminished, the rate of discharge remained practically constant throughout a wide range of pressure, and it was difficult to tell whether an apparent maximum was produced by changing the pressure of the gas or by some irregularity in the action of the tube. The difficulty was made greater because it was necessary to use low potentials, and with the intensity small, the amount of discharge was small, and trouble was caused by ordinary leakage and slight fluctuations in the potential of the charged body. However, it was apparent that as the intensity became less, the pressure for a maximum discharge became greater, although this did not increase as fast as the intensity decreased.

Discharge through a Film of Paraffin.—Various modifications in the conditions of the experiments were tried. Perrin has stated that the discharge effect can be separated into a surface effect between the metal and gas, and a volume effect through the gas. I therefore thought that by covering the surface of the metal with a thin film of paraffin it might be possible to change the relation between the rate of discharge and the density of the air. Lord Kelvin, Beattie, and Smolan¹ state that there is no discharge through paraffin, but only a condenser effect. This point was first tested. The plate from which the discharge was to take place was connected through a high resistance to a source of electricity, as in the second method. The fall in potential of the charged plate when the X-rays acted on it continuously was nearly as great as it had been before the plate was covered with paraffin. It is difficult to see how this can be explained except on the hypothesis that a discharge actually takes place through the coating of the paraffin. The pressure of the air was then varied, and the curves were found to be the same as those in Fig. 2.

The plate to be discharged was then placed in the shadow of an opaque obstacle, and the rays allowed to strike only the air surrounding the plate. The form of the curve was not different from

¹ Nature, 55, 472 and 498.

that previously obtained with rays causing the same rate of discharge. If, therefore, there is a surface effect it would appear to be small.

Discharge with Normal Incidence.—Perrin has explained the difference between the results which he found when the density of the gas was varied, and those found by Benoist and Hurmuzescu, on the ground that the experiments were not performed under the same conditions. In his experiment, the incidence was grazing, while in those of Benoist and Hurmuzescu the incidence was normal. The apparatus was therefore changed so that the incidence was normal, in order to test this point. The following table shows the fall in

Initial Potential Difference in Volts.		5	25
25 mm	Fall in Potential in Volts.	1.2	1.3
75 mm		2.1	2.7
150 mm		2.4	3.5
300 mm		2.5	4.7
500 mm		2.3	5.7
760 mm		2.2	6.2

potential for the different densities when the potential differences were 5 volts and 25 volts. This shows the same relation to exist when the incidence was normal as existed when it was grazing. The capacity in multiple with the plate was somewhat less in this case than it was when the first data were taken.

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(To be Concluded.)