ON THE FALL OF POTENTIAL AT THE SURFACE
OF A METAL WHEN EXPOSED TO THE DIS-
CHARGING ACTION OF THE X-RAYS.

By C. D. CHILD.

§1. If one causes an electric current to flow through the air from a point to a metallic screen placed opposite to it, it is found that the potential gradient determined by a Thomson water dropper increases noticeably in the neighborhood of the screen. This fact was brought to the attention of the present writer by Professor Warburg

Fig. 1.

and it was suggested that an investigation be made in order to determine if a similar effect took place in the case of discharge produced by X-rays.

§2. The arrangement of the apparatus used is shown in Fig. 1. *A* is a lead box containing the induction coil and the X-ray tube. The rays pass through an opening 5 cm. in diameter. The distance from this opening to the tube is 5 cm. *a* and *b* are two charged plates, the difference of potential between them being kept

constant by means of a battery. The water flows through a tube ending in as fine a point as possible at ϵ . The water in the beaker is connected to one pair of quadrants of a Thomson quadrant electrometer. The other two quadrants are connected to a point on the battery used having nearly the same potential as ϵ . In this way a sensitive electrometer could be used without having too large deflections. The plates first used were aluminium 15 cm. in dia-

Fig. 2.

meter. The distance between them was 6 cm. The distance from the center of the plates to the tube was 35 cm. The difference of potential between the plates was 120 volts, the potential of a being +60 and that of b -60. All other bodies in the vicinity of the plates were kept at zero potential. It ought also to be stated that the potential between the plates was not always the same, even when all the conditions were kept as nearly constant as possible. This variation was due, no doubt, to the irregular action of the tube. However, the variation in several sets of observations was not more than two or three volts.

§3. The intensity of the rays was such that when the plates

were 2 cm. apart, the difference of potential between them 120 volts, and their average distance from the tube 25 cm., the current produced was 1.3×10^{-8} ampere. This was determined by measuring the rise in potential of the plate *b*, when it was in multiple with a capacity of 1 microfarad, the X-rays passing between the plates for 30 sec.

The fall in potential when no X-rays were passing was practically uniform, and it may be indicated by the straight line *cd* in Fig. 2. Table I. gives the potential in volts between the plates before and during the time the X-rays were passing between them, also the difference between these two sets of values.

Fig. 3.

TABLE I.

Distance from Plate <i>b</i> to <i>e</i> .	Potential Without X-rays.	Potential with X-rays.	Difference in Potential.
.5 cm.	-50	-16.	34.
1 "	-40	-10.	30.
2 "	-20	- 1.5	18.5
3 "	0	5.5	5.5
4 "	+ 20	11.	- 9.
5 "	+ 40	19.	-21.
5.5 "	+ 50	25.5	-24.5

Fig. 2 shows this relation graphically.

It will be seen that in general *the curve has the same form as that found when electricity passes through a rarefied gas*. The similarity is the greater inasmuch as the fall at the negative plate is greater than that at the positive.

§4. It was not possible to arrange the apparatus so that the potential of the surrounding bodies had no effect in the experiment. But this effect, though considerable, did not change the essential character of the results, as is shown by the following observations. These show the difference between the normal potential and that observed when X-rays are passing, first with a at zero potential and b at -120 volts and then with a at $+120$ volts and b at zero potential.

Fig. 4.

TABLE II.

Distance from Plate b to c .	Difference in Potential when a was zero.	Difference in Potential when b was zero.
.5 cm.	52	19.6
1 "	47.5	15.
2 "	32.7	2.
3 "	21.	-12.5
4 "	7.	-26.
5 "	-7.	-40.
5.5 "	-10.	-45.

Figs. 3 and 4 show these relations graphically.

§ 5. The fall of potential at the plate was then studied under various conditions. The difference of potential between the plates was first varied. The distance ab was 6 cm. and eb 1 cm. The intensity of the rays was kept as nearly constant as possible. The difference between the normal potential at e and that observed when X-rays were passing is given in Table III. The plates were charged equally and oppositely, the surrounding bodies being at zero potential.

Fig. 5.

TABLE III.

Difference of Potential between a and b .	Change in Potential at e .
16 volts.	3.
30 "	6.25
60 "	13.3
90 "	21.6
120 "	30.
240 "	60.

Fig. 5 shows this relation graphically.

§ 6. In the next experiment the distance between a and b was

varied. The ratio $eb:ab$ was constant and equal to $\frac{1}{4}$, so that the potential at e when no X-rays were passing was always the same. The difference of potential between the plates was 120 volts. The intensity of the rays was kept as nearly constant as possible.

The results are given in Table IV. and are shown graphically in Fig. 6.

TABLE IV.

Distance ab .	Change in Potential at e .
2 cm.	4.7
4 "	10.8
6 "	16.1
8 "	18.7
12 "	21.6

Fig. 6.

§ 7. Finally the difference between the plates and the difference of potential were kept constant, and the intensity of the rays was varied. The distance ab was 6 cm. and eb 1 cm. The difference of potential was 120 volts. The intensity of the rays was varied by placing pieces of tin foil between the tube and the plates. The in-

tensity was determined by measuring the amount of discharge that it would produce between two pieces of tin foil placed perpendicular to the rays, the distance between the pieces being 2 cm., and the difference of potential 120 volts.¹ The original intensity was taken as unity.

TABLE V.

Intensity of Rays.	Change in Potential at e .
1.	30.
.39	21.6
.1	11.6
.04	4.2

Fig. 7 shows this relation graphically.

Fig. 7.

§8. When plates of other metals were used, the fall of potential

¹There is, of course, the possibility that the rate of discharge is not proportional to the intensity of the X-rays, yet it is highly probable that it is. It has been shown by photographic measurements that the intensity of the rays varies practically inversely as the square of the distance from the tube. Thomson and McClland have shown that the discharging power of the rays also varies inversely as the square of the distance, and this law was roughly tested and found to hold for the same pieces of tin foil that had been used to measure the intensity of the rays.

at the surface of the plates was found to be smaller, but when an opaque obstacle was so placed that the rays nearly filled the space between the plates without touching the plates themselves, no variation in the fall of potential with different metals could be detected. In other words, any variation in the fall of potential produced by varying the metal, depended on the fact that some of the rays struck the metal.

In order to study the effect of different metals to better advantage, the plates were, therefore, placed perpendicular to the rays. It was found, however, that the curve *cd* in Fig. 2 was entirely distorted, due to the fact that the conductivity of the gas near the tube was greater than that further from it. It was also impossible to use any metal on the side next the tube, other than aluminium or tin foil, because of the greater absorption by any others that were to be had.

First, however, an attempt was made to determine whether the fall of potential diminished or increased when the rays struck the plates normally instead of being parallel to them. The potential was found 1 cm. from the negative plate, first, when the negative plate was nearest the tube, and second, when it was farthest from it. By taking the average of these two measurements any effect due to the greater conductivity of the gas nearer the tube was largely eliminated. The change in potential 1 cm. from the negative plate was 14.1 volts, when the plate was nearest the tube, and 26.5 volts, when it was farthest from it. The average change in potential was 20.3 volts.

Of course, in both these cases there was a sheet of aluminium between the point where the potential was noted and the tube. When the plate was parallel to the rays and the rays passed through a piece of aluminium of the same thickness as the plate in the former case, the change in potential 1 cm. from the negative plate was 28.3 volts. The mean distance of the plates from the tube in both cases was 35 cm. It would thus seem that the fall of potential at the plates was diminished by allowing the X-rays to strike the plates normally. This fact was still more apparent when other metals were used.

In comparing the different metals the plate nearest the tube,

which we will call a , was always tin foil, and the plate b , the one farthest from the tube, was varied. All the plates were 15 c. in diameter. c is a point 1 cm. from b . The other conditions were the same as they were in the first experiment. The following results were obtained with the different metals.

TABLE VI.

Metal at b .	Change in Potential at c when b is	
	Positive.	Negative.
Platinum	- 9	14
Lead	-11	17
Steel	-15	21
Zinc	-15	22
Copper	-15	22
Iron	-16	22
Tin foil	-16	23
German Silver	-15.5	23.5
Brass	-16	24.5
Aluminium	-17.5	26.5

The fall of potential depended to a very small extent upon the surface of metal, rust or dirt affecting the result slightly.

§ 9. We should expect the current between the plates to be least in the case of metals which show the greatest fall of potential at the surface. The rate of discharge with different metals has been investigated by Benoist and Hurmulescu,¹ but it seemed well to find the rate of discharge with the same metals that had been used in the previous experiments. The rate of discharge was determined by connecting an electrometer to the plate b for a short length of time, while a discharge was passing, and noting the deflection of the electrometer.

It has been already found that when the rays passed between the plates without touching them the fall of potential was independent of the kind of metal used. Similarly it was found that under the same conditions the rate of discharge between the plates was independent of the metal used.

But when the plates were perpendicular to the rays, the rate of discharge depended very largely upon the kind of metal. In the following experiments the distance between the plates was 1 cm., and the difference of potential was 120 volts. The plate a was

¹C. R. 122, 779.

always of tin foil and changed positively. The average of a number of different observations is given.

TABLE VII.

Metal.	Deflection of Electrometer.
Platinum	16.6
Lead	15.8
Steel	13.9
Zinc	13.1
Copper	12.4
Tin foil	12.1
Iron	11.8
German Silver	11.8
Brass	11.6
Aluminium	9.8

It will be noted that, with the exception of tin foil, the order of the metals in this list is the same as that in Table VI., so that it is evident that in general *there is the largest rate of discharge from those metals which have the least fall of potential at the surface.*

The ratio between the current when the plate *b* was platinum and that when it was aluminium is seen in the above case to be 1.7. This was found to vary as the difference of potential was varied, as is shown in the following table. The distance between the plates and the intensity of the rays were the same as before.

TABLE VIII.

Difference of Potential.	Deflection of Electrometer with <i>b</i>		Ratio of the Deflections.
	Aluminium.	Platinum.	
8 volts.	5.3	6.7	1.26
18 "	7.5	13.3	1.77
30 "	8.4	15.	1.78
60 "	8.8	16.	1.82
120 "	10.	17.	1.70

It appears that it makes little difference what kind of metal is used when the difference of potential is small, but that the saturation current is reached sooner in the case of aluminium, so that when the potential is large, the rate of discharge depends largely on the kind of metal.

Next, the distance between the plates was varied, the plates being moved so that the average distance of the plates from the tube was constant. The difference of potential between the plates was 120 volts.

TABLE IX.

Distance Between the Plates.	Deflection of Electrometer with δ		Ratio of the De- flections.
	Aluminium.	Platinum.	
.5 cm.	8.5	15.2	1.79
1 "	9.3	16.6	1.79
2 "	10.2	18.	1.76
4 "	11.2	18.	1.61
8 "	10.5	15.4	1.46

It appears that the ratio between the rates of discharge in the two cases becomes slightly greater as the distance between the plates is decreased.

We thus see that, under certain circumstances, the rate of discharge produced by the X-rays depends largely upon the nature of the metal used, while, under other circumstances, the nature of the metal has little effect on the rate of discharge, and that when the rays do not touch the plate, it seems to have no effect. This fact, no doubt, accounts for the contradictory conclusions to which different observers have come regarding the variation of the rate of discharge with different metals.

§ 10. Benoist and Hurmulescu made the statement that the metals which absorb X-rays most, discharge electricity when under the action of X-rays most freely. It has not been possible to determine the absorbing powers of the metals used, nor have data been found for more than a few of the metals, but it is well known that in general the denser metals absorb X-rays most. It is, therefore, evident that in general the foregoing experiments substantiate the statement of Benoist and Hurmulescu, and they also show that there is the least fall of potential at the surface of the plates which absorb X-rays most. The fact that this fall of potential and the variation in the rate of discharge with different metals depends upon the striking of the metals by the rays, accord well with this view.

§ 11. These experiments show, therefore, first, *that there is a large fall of potential at the surface of the metal when discharge is caused by X-rays*; second, *that this fall of potential is diminished by allowing the X-rays to strike the plate*, and third, *that it is diminished to the greatest extent in the case of metals which absorb X-rays most*.

It is of interest to compare these results with those found by Elster and Geitel¹ in the case of discharge of electrified bodies by

¹ Wied. Ann., 61, 445.

ultra-violet light. It was apparent from their experiments that the absorption by the metal of the light plays an important part in the discharge of the electricity, while the experiments here described show that the absorption by the metal of the X-rays likewise plays an important part.

It is evident that the preceding experiments throw doubt upon any determination of the velocity of the ions which is based upon the assumption that the fall of potential between the plates is uniform. It is possible to make a determination of this velocity by an investigation of the length of time that discharge continues after the X-rays cease, and, in fact, the velocity thus determined was found to be much greater than that found by Rutherford.¹ However, it has not yet been possible for the writer to attain the desired accuracy in this determination, and it, therefore, seemed better to postpone the publication of any results until the work could be done more accurately.

In conclusion, I wish to express my thanks to Professor Warburg and also to Dr. Kaufmann for their kind aid and assistance.

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¹ Phil. Mag., Oct., '97.