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No. 51: ON THE DELTA RAYS EMITTED BY ZINC WHEN BOMBARDED BY ALPHA RAYS,

by Professor J. C. McLennan and C. G. Found

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On the Delta Rays Emitted by Zinc when Bombarded by Alpha Rays.

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(Read May Meeting, 1915).

I. INTRODUCTION.

In some experiments by V. E. Pound[1] and described by him in a paper, "On the secondary rays excited by alpha rays," he found that the delta radiation emitted by carbon when bombarded by the alpha rays from polonium increased very considerably when the temperature of the carbon was lowered from room temperature to the temperature of liquid air. He also showed that this increase in the delta radiation from carbon as its temperature was lowered was due to an increase in the amount of air occluded in the surface of the carbon.

Numerous observers have also found that the amount of a gas occluded in the surface of metals determines to a very considerable extent the intensity of the photo-electric effect exhibited by such metals when stimulated by ultra-violet light. Indeed, it was shown by Küstner[2] that no photo-electric effect was exhibited by zinc even with wave-lengths as short as λ = 1850 A°.U., when the metal was scraped in a vacuum after extraordinary precautions had been taken to exclude gases, particularly the active ones. Wiedmann and Hallwachs[3] have shown, too, that the removal of occluded gases from potassium by repeated distillation in a very high vacuum caused its photo-electric effect to disappear completely with light which included wave-lengths down to λ = 3,400 A°. U. The results of Küstner and Wiedmann and Hallwachs have also been confirmed by Fredenhagen.[4]

In addition, Hughes[5] has shown that the contact difference of potential between zinc or bismuth both distilled in *vacuo* and platinum is exceedingly small when the surfaces of the zinc or bismuth consist of a fresh deposit of the distilled metals. If traces of air, how-

[1] Pound. Phil. Mag. Nov. 23 and 24, 1912.
[2] Küstner. Phys. Zeit. p. 68, 1914.
[3] Wiedmann and Hallwachs. Verh. d. Deutsch. Phys. Ges. p. 107, 1914.
[4] Fredenhagen. Verh. d. Deutsch. Phys. Ges. p. 201, 1914.
[5] Hughes. Phil. Mag. Sept. 1914, p. 337.

ever, be admitted into the evacuated chamber containing the metals, a great increase takes place in the contact difference of potential between the metals.

In view of all these experiments it was thought well to investigate what the effect would be on the intensity of the delta radiation from zinc under bombardment by alpha rays when care was taken to remove as far as possible all gases from the surface of the zinc bombarded. The following paper contains an account of this investigation and from what follows it will be seen that with freshly prepared zinc surfaces the delta ray effect is exceedingly small; but that when air is permitted to be occluded in such surfaces a very great increase takes place in the magnitude of the effect.

II. Apparatus.

The apparatus used in conducting the experiments is similar to that used by Hughes[1] in his investigations on the photo-electric effect and is shown in Fig. 1. It consisted of a glass tube about 3

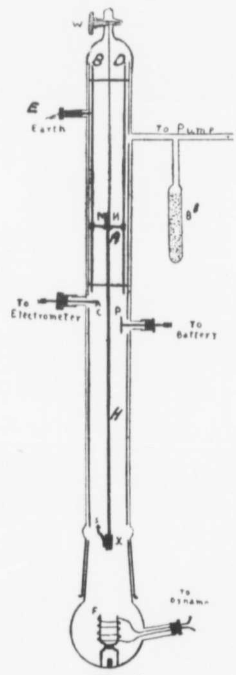

Fig. 1.

[1] Hughes. Phil. Trans. A. CCXII, p. 205, 1912.

cms in diameter and about 60 cms in length. This tube carried at its upper end a tap windlass W and at its lower end it was provided with a ground joint for fitting it into the glass heating chamber shown in the diagram. The tube was lined with a thin walled brass tube, which was kept joined to earth through a connection at E. B and D were two guiding rods of brass attached to the inner lining brass tube and M N was a strip of brass which was supported by a cord from the windlass W and had loops on its ends about the guiding rods B and D. An insulated brass rod H was rigidly attached to M N through the intermediary of a short cylinder of amber A. It carried at its lower end a small plate of zinc X with a projecting piece S which came into contact with the cup C when the rod H was raised by the windlass. A slender brass rod connected the cup C to a sensitive electrometer. P was a circular plate of copper 2 cms in diameter with a deposit of polonium on its anterior face. As shown in the figure it could be connected as desired to either terminal of a battery of small storage cells. The tube B′ was filled with coconut charcoal which was used for the purpose of improving the vacuum made with a Gaede rotary mercury pump. F was a small fused quartz furnace tube and was provided with platinum heating coils as shown. It was held in an upright position by means of a short glass rod sealed into the base of the heating chamber. When making zinc deposits on the surface of the zinc plate X the apparatus was first of all evacuated as highly as possible with the Gaede pump in conjunction with the coconut charcoal cooled with liquid air. Metallic zinc placed in F was brought to the boiling point with the heating coils and the rod H was lowered so that the zinc plate X was directly above the opening in F and immersed in the issuing vapour. With this arrangement the zinc plate could be readily coated with a fresh surface when desired. In studying the delta radiation from this plate the rod H was raised with the windlass W until the projection S was in electrical contact with the cup C. Under these conditions the zinc plate X was directly in front of the polonium coated plate P and was subjected to bombardment by the alpha rays which were emitted by the latter.

It should also be mentioned that when in operation the tube was set up with that portion about P in the field and between the poles of an electromagnet.

III. Experiments.

Experiment I. In commencing the investigation two experiments were carried out similar to those described by Logeman[1] in his paper on the emission of electrons from metals bombarded by alpha

[1] Logeman. Proc. Roy. Soc. Series A, Vol. 78, Sept. 6, 1907.

rays. In the first experiment, a heating jacket was placed about the tube containing the charcoal so as to drive the air out of the latter and the apparatus was exhausted as highly as possible with a Gaede rotary mercury pump. After this was done the heating jacket was removed from B′ and when the latter had dropped to room temperature it was surrounded with a Dewar flask and cooled with liquid air. When this was done a McLeod gauge attached to the apparatus showed that the pressure in the vessel had been reduced to considerably below ·001 mm of mercury. The zinc disc X, whose surface had been carefully scraped before it was inserted in the apparatus, was raised until contact was made between S and C. The polonium plate P was then charged to various positive potentials by means of the storage battery and the corresponding currents between P and X were measured with the Dolazaleck quadrant electrometer joined to C. The capacity of the quadrants and the attached electrical system was found to be 140 e.s.u.

The values of the applied potentials and the currents they produced are given in Table I, and a curve representing them is given in Fig. 2.

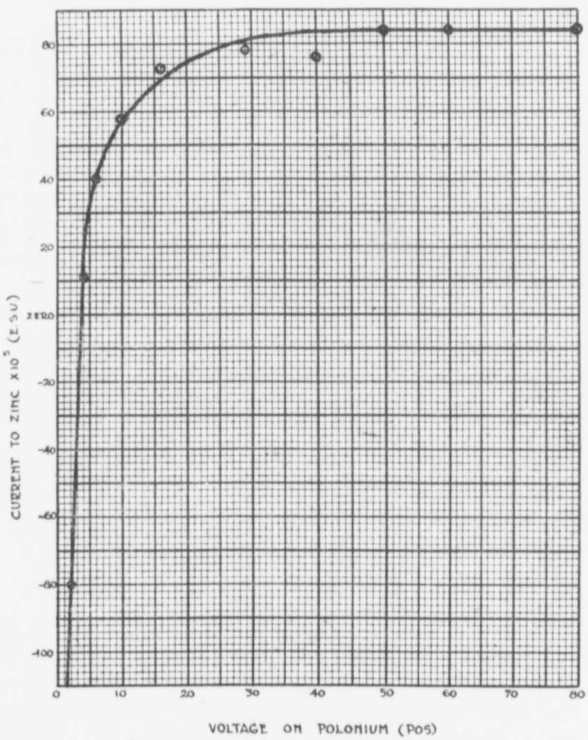

Fig. 2.

TABLE I.

Sensibility of Electrometer, S, = 220 mm. per volt.
Capacity of Electrometer, C, = 140 e.s.u.
D = deflection in mm. scale divisions per minute.
The current, i, = C. D/300. S. 60 e.s.u.

Voltage on Polonium.	Deflection in mm. per min.	Current $\times 10^5$ e.s.u.
0 Volts	− 35 mm.	− 127
+ 2 "	− 22 "	− 80
+ 4 "	+ 3 "	+ 11
+ 6 "	11 "	+ 40
+ 10 "	16 "	+ 58
+ 16 "	20 "	+ 73
+ 22 "	20 "	+ 73
+ 28 "	21·5 mm.	+ 78
+ 40 "	21 mm.	+ 76
+ 50 "	23 "	+ 84
+ 60 "	23 "	+ 84
+ 80 "	23 "	+ 84

From the numbers in the table and from the curve in Fig. 2 it will be seen that although the terminal P was always either at zero or at a positive potential relative to X, the current was initially negative and remained so until a potential of about 4 volts was reached, when it passed through zero and became positive, gradually increasing to a maximum with an applied positive potential of about 40 volts.

In this experiment it will be noted that the current between P and X consisted of: (1) a very small positive current in the residual gas due to ionisation; (2) a positive current consisting of the stream of alpha particles emitted by the polonium; (3) A positive current consisting of a stream of recoil atoms from the polonium; (4) A positive current due to electrons passing from X to P arising from the bombardment of X by the alpha particles and (5) a negative current due to electrons passing from P to X which accompanied the alpha particles and had their origin either in the polonium or in the copper surfaces on which the polonium was deposited. With zero or low positive voltages the stream of electrons mentioned in (5) it will be seen, completely masked the other four constituents of the current. As the positive applied voltages, however, were increased, this stream of electrons was more and more prevented from leaving the electrode

P and, finally, when a potential of 40 volts was reached, none escaped from P at all and the current became constant and consisted of the first four constituents mentioned above. This result was exactly in accordance with what Logeman had previously observed and it showed that the apparatus was working satisfactorily.

Experiment II. In the second experiment the polonium-coated disc, P, was kept joined to the positive terminal of the battery at a steady potential of 80 volts. This ensured that no electrons escaped from P.

The electromagnet was then excited with currents of different intensities and readings were taken on the corresponding currents through the chamber to the zinc plate X. The results in one of the experiments of this type are given in Table II and are represented graphically in Fig. 3.

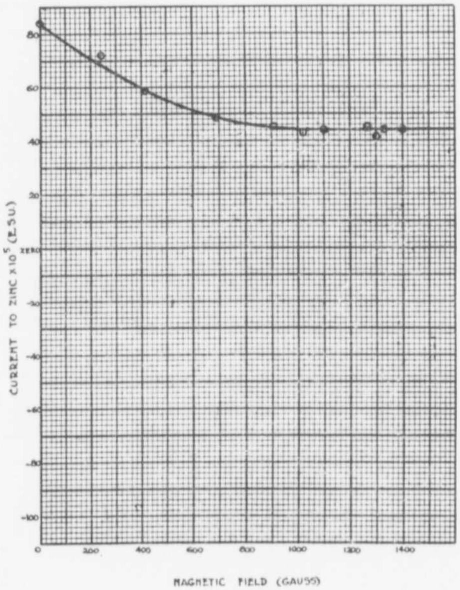

Fig. 3.

TABLE II.

Voltage on polonium plate = 80 volts, positive.

Current through the coils of the electromagnet.	Value of the magneticfield.	Electrometer deflection per min.	Current $\times 10^5$ e.s.u.
zero	zero	23·0	84
·5 amps	240 gauss	22·3	72
1·0 "	410 "	18·0	58·3
1·7 "	690 "	15·0	49
2·5 "	905 "	14·0	45
3·0 "	1,020 "	13·2	43
3·3 "	1,100 "	13·5	44
3·7 "	1,190 "	11·5	37
4·4 "	1,275 "	14·0	45
4·7 "	1,300 "	12·7	41
5·0 "	1,330 "	13·7	44
6·0 "	1,400 "	13·7	44

From these it will be seen that the current gradually fell off as the field was increased and ultimately reached a steady state with a field of approximately 1,000 gauss.

From the known properties of the ionisation currents of the alpha rays and of recoil atoms, it is clear that a field of this intensity was not sufficient to modify to any appreciable extent the current carried by them to X and it follows therefore that the decrease in the current observed was due to the action of the magnetic field in curling the electrons emitted by the zinc plate under bombardment by the alpha rays back again into that plate. This experiment, therefore, showed that a field of 1,000 gauss was sufficient, when the applied potential difference was 80 volts, to entirely cut off the stream of electrons. The problem before us, then, was to apply the procedure just described to the investigation of the intensity of the electronic stream from the zinc plate X when the surface of this plate was made to undergo various modifications.

Before leaving this experiment it may be pointed out that the results obtained go to show that approximately three electrons were emitted by the bombarded zinc plate for every alpha particle which struck it.

From the table it will be seen that the current under the electric field combined with the maximum magnetic field was approximately 44 x 10^{-5} e.s.u. This current consisted of (1) alpha particles; (2) recoil atoms and (3) the ionisation current. As the gas pressure in the apparatus was exceedingly low the ionisation current must have been negligible. Taking it to be so the current must have been carried by the alpha particles and the recoil atoms. If, now, we assume that as many alpha particles were shot back into the polonium plate as were projected forward from it, it follows that the number of recoil atoms taking part in the current was very closely equal to the number of alpha particles which contributed to it. Taking the charge on the alpha particle to be 2e, and that on the recoil atom to be e, we have then, since the current carried by the electrons emitted by the zinc plate must have been 40×10^{-5} e.s.u., the number of alpha particles striking X given by $44 \times 10^{-5}/3e$. Since the number of electrons emitted by the zinc plate was $40 \times 10^{-5}/e$ it follows that 2·73 electrons were emitted by the zinc plate per alpha particle which struck it.

Experiment III. The next experiment which was performed served to illustrate the fatigue of the delta ray effect. In this case the apparatus was continuously evacuated for two days after the measurements made in Experiments I. and II were taken. At the end of this time readings were taken by applying various positive potentials up to 80 volts and when this was reached the magnetic field was turned on and readings were taken with fields up to 1,400 gauss. These are all recorded in Table III and are shown graphically in Fig. 4 together with the results of Experiments I. and II. From the results it will be seen that while the maximum current under 80 volts was 84×10^{-5} e.s.u. at the beginning of the experiment it was only 63×10^{-5} e.s.u. after two days evacuation. With an applied potential difference of 80 volts and a magnetic field of 1,400 gauss, however, the readings obtained on the two occasions were practically the same. This showed that the current carried by the alpha particles and the recoil atoms remained the same for the two days but that in the interval the electronic current from the zinc plate under bombardment by the alpha rays had dropped from 40×10^{-5} e.s.u. to 18×10^{-5} e.s.u.

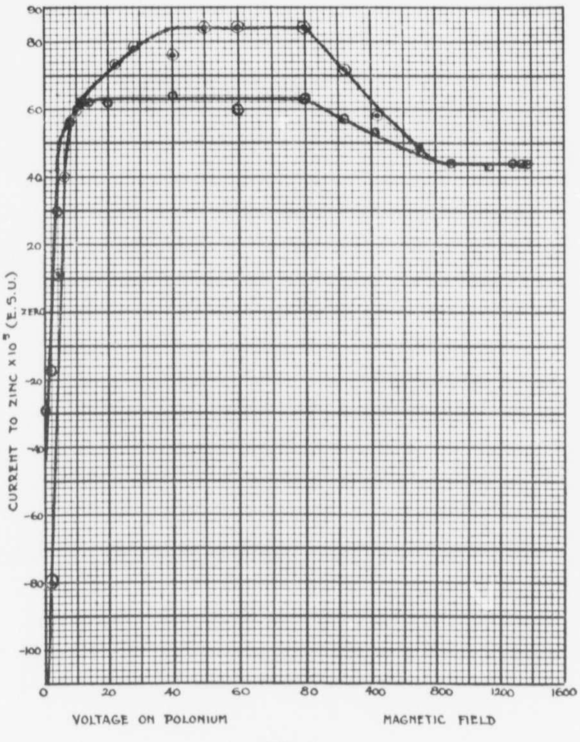
90
80
60
40
20
ZERO
-20
-40
-60
-80
-100
CURRENT TO ZINC x 10⁵ (E.S.U.)
0
20
40
60
80
400
800
1200
1600
VOLTAGE ON POLONIUM
MAGNETIC FIELD

Fig. 4.

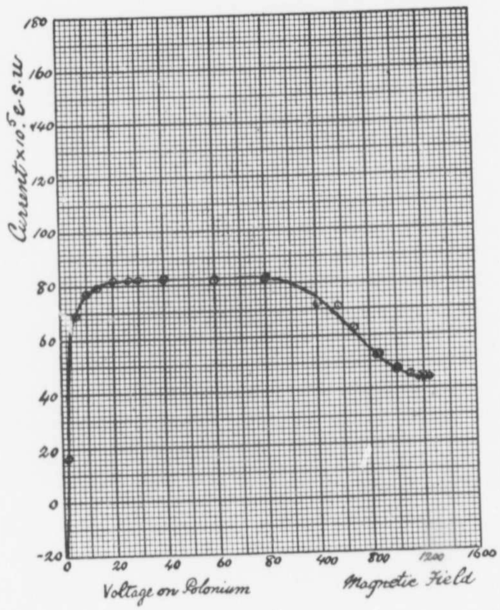
Current × 10⁻⁵ e.s.u
180
160
140
120
100
80
60
40
20
0
-20
0
20
40
60
80
400
800
1200
1600
Voltage on Polonium
Magnetic Field

Fig. 5.

TABLE III.

Voltage on Polonium.	Current through coils.	Magnetic Field.	Deflection per min.	Current × 10^5 e.s.u.
zero	zero	zero	− 10 mm.	− 29·5
2 volts	"	"	− 6	− 17·0
4	"	"	11	30
8	"	"	19	56
14	"	"	21	62
20	"	"	21	62
40	"	"	21·7	64
60	"	"	20·5	60
80	"	"	21·2	62·6
80	·8 amps	240 gauss	19·5	57·6
80	1·0 "	410 "	17·8	53
80	1·7 "	690 "	16·5	49
80	2·5 "	905 "	14·8	44
80	3·5 "	1,140 "	14·5	43
80	4·4 "	1,275 "	15	44
80	5·0 "	1,330 "	15	44
80	5·7 "	1,390 "	15	44

This result made it evident that the electronic stream from the zinc plate was determined to a considerable extent by the amount of air occluded in its surface. For it is clear that under the continuous evacuation for two days there must have been a gradual diminution in the amount of air occluded in the metal and as everything else in the experiment remained the same this diminution must have been the cause of the decrease in the stream of delta radiation.

Experiment IV. In this experiment a freshly cleaned plate of zinc was attached to the rod H at X and the apparatus was left full of air at atmospheric pressure for 6 days. It was then exhausted as highly as possible with the Gaede pump and the coconut charcoal surrounded with liquid air.

Readings were first taken with positive potentials applied to P up to 80 volts and then keeping the potential of P at 80 volts positive readings were taken with increasing magnetic fields up to 1,245 gauss. These readings are given in Table IV and the curve representing them is shown in Fig. 5.

TABLE IV.

Zinc surface first scraped clean and then exposed to air at atmospheric pressure for six days.

Voltage on Polonium	Current through Coils.	Magnetic Field	Deflection per min.	Current $\times 10^5$ e.s.u.
zero	zero	zero	– 8 mm.	–25
+ 2 volts.	"	"	5	16
6 "	"	"	22	69
10 "	"	"	24·5	77
14 "	"	"	25	79
20 "	"	"	26	82
26 "	"	"	26	82
30 "	"	"	26	82
40 "	"	"	26	82
60 "	"	"	26	82
80 "	"	"	26	82
80 "	·5 amps	240 Gauss	23	72
80 "	·95 "	405 "	23	72
80 "	1·3 "	570 "	22·5	71
80 "	1·65 "	680 "	20	63
80 "	2·3 "	860 "	17	53
80 "	2·8 "	995 "	15	47
80 "	3·3 "	1,100 "	14·5	45·6
80 "	3·6 "	1,160 "	14	44
80 "	3·9 "	1,205 "	14	44
80 "	4·2 "	1,245 "	14	44

From these it will be seen that the maximum current obtained without any magnetic field was 82 x 10^{-5} e.s.u. but that with the magnetic field applied the current fell to 44 x 10^{-5} e.s.u. and this current as was pointed out before, consisted of (1) the residual ionisation current (2) the stream of alpha particles from P and (3) the stream of recoil atoms from the same source.

After the set of readings had been taken the liquid air was taken from about the charcoal which was then allowed to rise to room temperature. The heating jacket was then placed round it and its temperature gently raised so as to drive off as much of the occluded air as possible. While this was being done the Gaede pump was kept constantly in action. Meanwhile the rod H was lowered with the windlass W until the plate X was directly over the furnace F and about 2 cms above it. When the pressure had been reduced to below ·001 mm of mercury a current of 10 amperes was passed through the platinum wire of the furnace for 15 minutes. This sufficed to vapourize the zinc in the furnace and to deposit a good coating on the surface of the zinc plate X.

The furnace current was then cut off and the rod H was raised as quickly as possible until contact was made with S at C. A positive potential of 80 volts was then applied to P and readings were taken with increasing magnetic fields at intervals of a few minutes for half an hour.

The magnetic field was then cut off and at the end of 55 minutes readings were again taken at intervals for half an hour with electric fields ranging from zero to 80 volts. At the end of 90 minutes a reading was taken with an applied field of 80 volts and a magnetic field of 1,200 gauss and at the end of 190 minutes a reading was again taken under the same conditions.

All these readings are recorded in Tables V and VI and curves drawn from them are shown in Figs. 6 and 7.

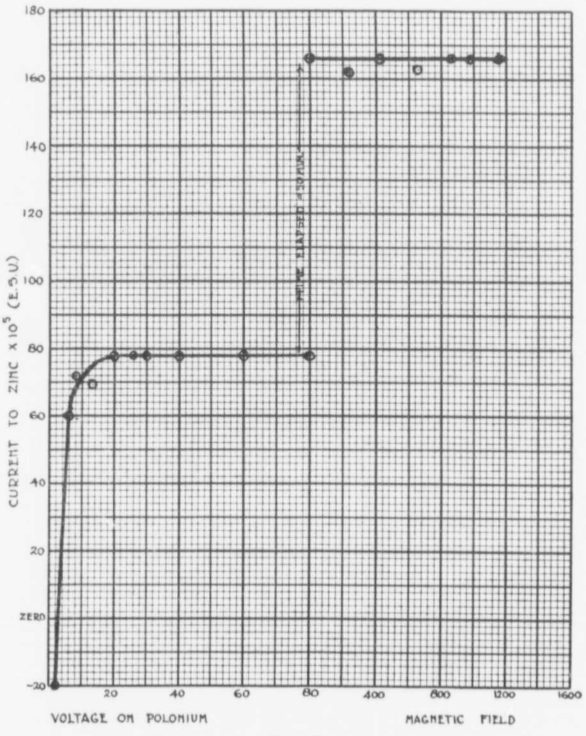

Fig. 6.

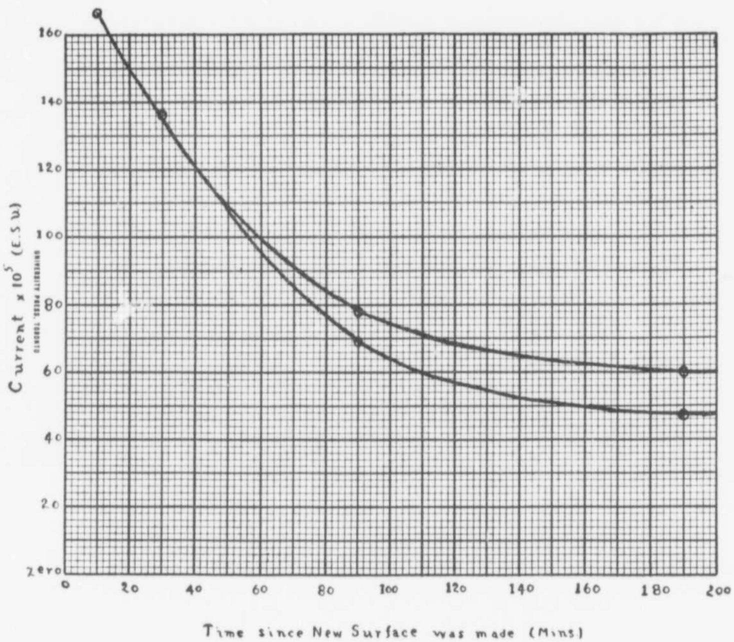
160
140
120
100
80
60
40
20
zero
Current x 10^5 (E.S.U.)
0
20
40
60
80
100
120
140
160
180
200
Time since New Surface was made (Mins)

Fig. 7.

TABLE V.

Zinc surface deposited from zinc vapour in a high vacuum.

Voltage on Polonium Volts +	Current through Coils.	Magnetic Field Gauss.	Time since surface made.	Deflection per minute.	Current × 10^5 e.s.u.
80	zero	zero	5 min.	53 mm.	166
80	·5 amps.	240	11 "	52 "	163
80	·95 "	405	15 "	53 "	166
80	1·65 "	680	18 "	52 "	163
80	2·3 "	880	23 "	53 "	166
80	2·8 "	995	28 "	53 "	166
80	3·6 "	1,160	30 "	53 "	166
zero	zero	zero	55 "	−21 "	−66
2	"	"	58 "	0 "	0
6	"	"	60 "	19 "	60
10	"	"	62 "	23 "	72
14	"	"	65 "	22 "	69
20	"	"	67 "	25 "	78
26	"	"	70 "	25 "	78
30	"	"	72 "	25 "	78
40	"	"	75 "	25 "	78
60	"	"	77 "	25 "	78
80	"	"	85 "	25 "	78

TABLE VI.

Zinc surface deposited from zinc vapour in a high vacuum.

Time since surface was made.	Electric field alone.		Electric and magnetic field.	
	Deflection per minute.	Saturation current.	Deflection per minute.	Saturation current.
10 min.	53 mm.	166 x 10^{-5} e.s.u.	53 mm.	166 x 10^{-5} e.s.u.
30 "	43 "	135 "	43 "	135 "
90 "	25 "	79 "	22 "	69 "
190 "	19 "	60 "	15 "	47 "

One point which is brought out very prominently by these readings is that for the first half hour the current between P and X, under a potential difference of 80 volts was the same whether a magnetic field, as high even as 1,160 gauss, was applied or not. From this it was manifest that during this interval there was practically no emission of electrons from the newly deposited zinc surface, under bombardment by the alpha rays. It will be noted, too, that during the interval the saturation current was about 165 x 10^{-5} e.s.u., which was about twice as great as that saturation current obtained in the previous experiment with the ordinary zinc plate without the fresh deposit. This was very probably due to the air pressure in the apparatus being somewhat higher immediately after the deposit had been than it was when the observations were made with the zinc plate in its original condition. Even with the Gaede pump in action the effect of heating the furnace and the charcoal would be to drive off considerable air from the walls of the vessel and the charcoal into the apparatus and as the volume of the apparatus was considerable it would take time to remove this air again. That this interpretation was the correct one is shown by the readings taken in the second period extending from 55 minutes after the deposit had been made up to 85 minutes after that time. These it will be seen show that with increasing positive potentials the current increased and finally reached a maximum of only 78 x 10^{-5} electrostatic units. This would indicate that during the first half hour the ionisation constituent of the current was very considerable, as it should have been on account of the higher air pressure, while at the end of 85 minutes after the deposit had been made it was much less on account of the removal of the air from the apparatus.

The numbers given in Table VI. and the curves in Fig. 7 are also of interest in this connection for they show not only that the current gradually diminished with the lapse of time owing to the diminution of the ionisation current constituent arising from the gradual reduction of the air pressure but also that there was a gradual increase in the electronic stream from the zinc plate with the lapse of time under the bombardment by the alpha rays.

From what has gone before it is evident that this development of a delta radiation from the zinc plate arose from the gradual occlusion of air into the surface of the zinc.

For, as the vapour was deposited on the zinc plate in a high vacuum the surface would not contain any air at first. It would not, however, in this state be in an equilibrium condition and a tendency towards absorption would exist. The result of this would be that so long as air was present in the apparatus, absorption would take place at least until an equilibrium was established between the air occluded in the surface and that within the apparatus. This gradual occlusion of the air by the zinc surface would therefore appear to account for and to be the cause of the gradual development of the electronic current.

IV. Summary of Results.

1. In the present investigation, it has been shown that when a plate of zinc, with a freshly scraped surface, is placed in a highly exhausted chamber and bombarded by alpha rays, there is an emission of slow moving electrons or delta rays from it at the rate of three electrons for each alpha particle impact.

2. It has also been shown that the emission of electrons from such a plate of zinc under bombardment by alpha rays diminished with the lapse of time from the moment when it was placed in the high vacuum.

3. It has also been shown that initially there is no emission of electrons under bombardment by alpha rays from a surface of zinc deposited from zinc vapour in a high vacuum; but that as time elapses, an electronic emission is gradually developed under the gradual absorption of air by the surface of the zinc deposit.

The Physical Laboratory,
University of Toronto.
May 1st, 1915.