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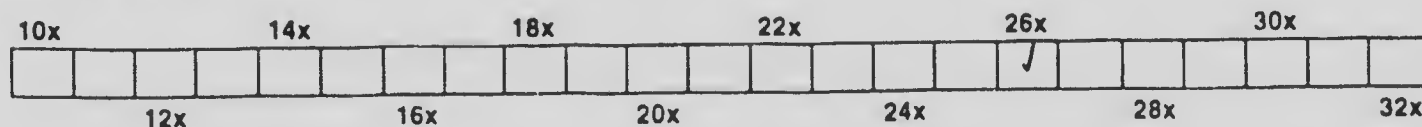
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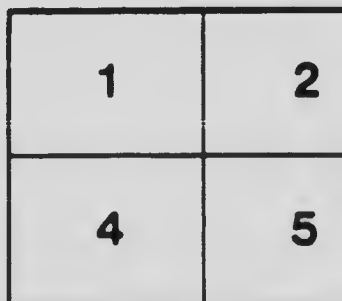
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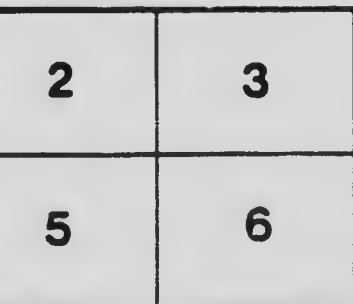
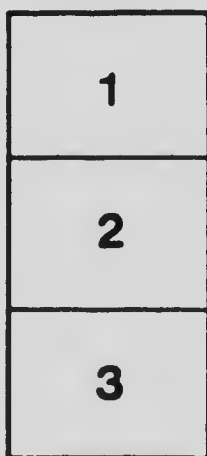
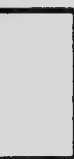
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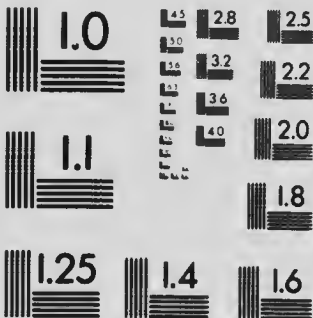
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ON THE ACTIVE DEPOSIT FROM ACTINIUM IN
UNIFORM ELECTRIC FIELDS.

By **W. T. KENNEDY, B.A.**

Communicated by Prof. J. C. McLENNAN

OTTAWA
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1909

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On the active deposit from actinium in uniform electric fields.

By W. T. KENNEDY, B.A.

Communicated by Professor J. C. McLennan, and read before the Royal Society of Canada on May 26, 1909.

INTRODUCTION.

In a number of experiments which have been carried on with the emanations and the emanation products from the radioactive substances, it has been shown by Rutherford¹ that with thorium emanation, the amount of activity imparted to a rod charged negatively was independent of the pressure until a pressure of 10 mm. was reached, and that below this pressure it decreased as the pressure in the containing vessel was lowered. At 1/10 mm. pressure it was only a small fraction of its maximum amount. Makower² has shown similar effects with the excited activity from radium emanation. Further, Rutherford³ experimenting with radium emanation, found that at atmospheric pressure the greater part of the active deposit went to the cathode, while only about 5 per cent went to the anode. From these results he has drawn the conclusion that while most of the active deposit particles of radium are positively charged, some at least must carry a negative charge in as much as they are drawn to the anode in electric fields.

More recently Russ⁴ shewed that when positively and negatively charged electrodes were placed in a vessel containing either air, sulphur dioxide, or hydrogen charged with the emanation from radium, that the relative amounts of the active deposits obtained on the two electrodes varied with the pressure at which the exposures were made. With all three gases, the active deposit on the negative electrode gradually decreased as the pressure was lowered, while that obtained on the positive electrode showed a corresponding increase, until ultimately at the lowest pressure investigated, the amounts of the active deposit obtained on the two electrodes were approximately equal.

In a second paper, Russ⁵ gives an account of a similar set of ob-

¹ Rutherford, Phil. Mag., Feb., 1900.

² Makower, Phil. Mag., Nov., 1905.

³ Rutherford, Phil. Mag., Jan., 1903.

⁴ Russ, Phil. Mag., May, 1908.

⁵ Russ, Phil. Mag., June, 1908.

servations made with the emanation from actinium. In these experiments, positively and negatively charged electrodes were again exposed in a vessel filled with air and containing a quantity of actinium. In this case as the pressure of the air was lowered the amount of the active deposit obtained on the negative electrode gradually increased, passed through a maximum value at a certain critical pressure, and ultimately fell away again at the lowest pressure investigated.

On the other hand in these experiments Russ found that the active deposit obtained on the positive electrode steadily decreased as the pressure of the air was lowered.

Russ also describes a series of experiments in which exposures were made in air when the distance between the actinium and the electrodes was gradually increased. The results which he gives show that, with the air at 760 mm., the amount of the deposit obtained on the cathode steadily decreased as the salt was placed at distances varying from 2 to 50 mm. from the electrodes. Under similar circumstances the amount obtained on the anode at first increased as the salt was removed, and finally after passing through a maximum value, fell away again at the longer distances. With the air at 2 mm. pressure, however, the amount obtained on the cathode steadily increased as the distance of the salt from the electrode was varied from 2 to 42 mms., but the active deposit obtained on the anode with the same variation of distances, gradually decreased.

In discussing his results Russ points out that Debiere had found that the amount of emanation obtained at atmospheric pressure from a uniform layer of actinium fell to half value in going .55 cms. from the layer and that consequently one would expect to find a decrease in the activity of the electrodes as the salt was removed, and possibly, too, a continuance in the ratio of the activities of the deposits obtained on the two exposed terminals. The results given by him, however, show that this was far from being the case.

In the various experiments referred to above on the active deposits from radium, thorium, and actinium, the different investigators—with the exception of Debiere—do not appear to have taken any precaution to study the behaviour of the active deposits with uniform electric fields, and, as it was thought that some points which are more or less obscure in connection with these active deposits might be cleared up if they were studied in this manner, it was decided to apply this method to the investigation of the active deposits from actinium, which on account of the short life of its emanation is peculiarly suitable for the study of these active deposit products.

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II. APPARATUS.

The apparatus consisted of a metallic cylinder about 5.5 cms. in diameter which was supported horizontally in an air-tight chamber. Into this cylinder (as shown in Fig. 1) there were fitted two electrodes provided with guard plates. The salt was carried in a small tray which could move freely up and down in a vertical tube (1.5 cms. in diameter) which led into the cylinder. The tray could be clamped in position at any desired distance from the electrodes, and the latter, which were capable of easy motion, could readily be placed in the exposing cylinder at any selected distance apart. The air-tight chamber was also provided with tubes for the admission and removal of the different gases used, and through its base, wires suitably secured were led for the purpose of charging the electrodes. The electrodes, which were circular, were 2.5 cms. in diameter and the guard-plates which surrounded them were each .5 cms. in width.

III. MEASUREMENTS.

In the various experiments which are to be described later, the sample of actinium used was obtained from the Chininfabrik, Braunschweig. In making the exposures the electrodes were exposed in every case to the action of the emanation for two hours before being removed from the exposing vessel for measurement. The activities of the electrodes were tested by an ordinary alpha ray gold leaf electroscope, and all the values which are quoted in the paper represent the activities of the electrodes 10 minutes after the exposures ceased. In making the measurements of the activities of the two electrodes, observations were continued for a period of forty or fifty minutes. From these observations, of which Fig. X is illustrative, the rates of decay of the deposits on both anode and cathode were found to be the same, and to be approximately about 39 minutes. In making all the exposures the electrodes were charged to a potential of approximately 250 volts.

IV. ACTIVE DEPOSITS AND DISTANCE BETWEEN THE ELECTRODES.

In commencing the study of the active deposits from actinium, a set of measurements was made on the active deposits obtained on the two electrodes when the salt was placed in the vertical tube at a constant distance from the cylinder and the electrodes were gradually separated. In a particular set of observations the plates were placed vertically 1 mm. apart, and the salt was brought as close to them as the construction of the apparatus would permit. With this arrangement, the salt which was always covered with a layer of thin filter paper, was at a distance of 11 mm. from the lower edge of the plate electrode.

Observations were made at atmospheric pressure on the active deposits obtained on both electrodes for distances 1, 2, 3, 4, 5, 6 and 8 mms., and the results are all recorded in Table I. A curve illustrating them is shown in Fig. II. From these results it will be seen that as the electrodes were separated the activity obtained on both plates steadily decreased. With distances apart greater than 3 mms. no measurable activity was obtained on the anode, but with the greater distances, viz., 8 mms., the active deposit obtained on the cathode was still about one half that obtained on the same terminal for a separation of only 1 mm.

TABLE I

Separation of Electrodes	Activity on the Cathode	Activity on the Anode
1 mm.	17.0	.15
2 mm.	13.7	.1
3 mm.	11.5	.0
4 mm.	10.3	.0
5 mm.	9.0	.0
6 mm.	8.7	.0
8 mm.	8.6	.0

V. ACTIVE DEPOSITS AND DISTANCE OF SALTS FROM THE ELECTRODES.

Measurements were also made on the active deposits obtained on the electrodes at pressures of 760, 120, 25 and 5 mms. of mercury, when the distance between the electrodes was maintained at 2 mms., and the salt placed at a series of distances from the electrodes varying from 1.1 cms. to 5 cms. These results are recorded in Table II, and curves illustrating them are drawn in Figs. III, IV, V and VI. From the numbers given and from the form of the curves it will be seen that for all pressures the activity obtained on both electrodes steadily decreased as the distance between the salt and the electrodes was increased. This result, it will be seen, is somewhat different from that obtained by Russ with his apparatus, for, as stated above, he found at certain pressures that the active deposits slightly increased as the salt was removed, attained maximum values at certain distances and finally fell away as the salt was still further removed.

TABLE II

Pressure	Distance of Salt from Electrodes	Activity on the Cathode	Activity on the Anode
Atmospheric	1.0 cms.	39.5	.8
"	1.3 "	26.5	.3
"	2.0 "	8.5	.1
"	3.0 "	2.75	.0
"	4.0 "	1.0	.0
"	5.0 "	.5	.0
120 mm.	1.1 cms.	73.0	5.5
"	2.0 "	36.8	3.2
"	3.5 "	16.5	1.7
"	4.0 "	6.3	.7
25 mm.	1.1 cms.	63.5	27.0
"	2.0 "	41.0	17.5
"	3.5 "	25.3	11.8
"	5.0 "	15.7	6.7
5 mm.	1.1 cms.	32.3	29.5
"	2.0 "	27.0	23.7
"	3.5 "	17.7	16.0
"	5.0 "	13.5	11.3

ACTIVITY OF DEPOSITS IN AIR DEPENDENT UPON PRESSURE.

The next variation made in the experiments was to keep the electrodes at a constant distance apart, 2 mms., and the salt at a fixed distance 11 mms. from them, while the pressure of the air was gradually lowered and the activity of the deposits corresponding to different pressures was measured. The range of pressures investigated was from 750 mms. to .5 mms. of mercury. Table III gives the results for air, and Figs. VII, VIII, and IX, were drawn from them and illustrate the manner in which the deposits occurred at the various pressures. The curves for both electrodes, it will be seen, follow similar laws. The

activities on both electrodes steadily rose as the pressure fell, both passed through maximum values and both fell away again and approached equality at the lowest pressure.

The maximum activity for the cathode was obtained at a pressure of 80 mms., while that on the anode was not obtained until a pressure of 17 mms. was reached. The maximum cathodic deposit, it will be seen, too, was only about 2.75 times that obtained on the anode.

TABLE III

Pressure	Activity on the Cathode	Activity on the Anode
.5 mm.	11.7	11.3
1.0 "	14.5	14.0
2.0 "	18.5	17.0
7.5 "	37.5	29.0
12.0 "	49.0	33.0
25.0 "	62.5	28.5
42.0 "	82.3	17.7
72.0 "	92.0	10.0
92.0 "	91.0	7.5
120.0 "	76.0	5.5
135.0 "	73.0	5.0
162.0 "	68.0	4.0
192.0 "	66.5	3.0
320.0 "	43.0	1.15
500.0 "	31.0	.70
750.0 "	20.5	.45

From time to time decay curves were drawn for the active deposits obtained on the two electrodes, and it was always found that these deposits decreased in activity to half value in about 39 minutes, irrespective of the electrode upon which the deposit was obtained. This fact, combined with the similarity of form in the activity curves for the two electrodes, goes to show that with both electrodes the deposit always consisted of the same transmutation product and that the difference in the amounts obtained on the two terminals must be traceable to differences

in the charge acquired by the deposit particles in their passage, by diffusion or otherwise, through the air. The phenomenon of recoil recently noted by Otto Hahn¹ must also have been an important factor in contributing to the deposit on both electrodes.

VI. ACTIVITY OF DEPOSITS OBTAINED IN CARBON DIOXIDE AT DIFFERENT PRESSURES.

In order to study how the deposits might be affected by a modification in the conditions of diffusion a set of measurements, similar to those carried out with air, was made with carbon dioxide at pressures varying from 750 mms. to 1 mm. of mercury, and the values of the active deposits obtained are recorded in Table IV. From these results,

TABLE IV

Pressure	Activity on the Cathode	Activity on the Anode
1.0 mm	15.6	14.7
8.0 "	37.5	28.5
18.0 "	60.5	29.5
30.0 "	75.5	19.6
40.0 "	79.5	16.0
73.0 "	81.6	9.0
105.0 "	72.0	7.0
123.0 "	66.5	5.8
235.0 "	46.7	3.0
480.0 "	22.0	2.2
750.0 "	11.7	7.5

the curves shown in Figs. XI and XII have been drawn. It will be seen that these curves also follow laws similar to those obtained with air, and that the deposits on the two electrodes gradually increased as the pressure was lowered. Both passed through a maximum and for still lower pressures the active deposit on both plates decreased and approached equality for the lowest pressures investigated. The maximum activity on the negative electrode was obtained at a pressure of 60 mms., while the

¹ Deut. Phys. Ges. XI Jahr No. 3

maximum active deposit on the positive terminal was not obtained until the pressure was 14 mms. The maximum active deposit on the cathode was about 2.68 times the maximum deposit on the anode, and this, it will be seen, is not very different from the ratio which was found for the maximum activities obtained in the case of air. Care was taken in the experiments with carbon dioxide and air to repeat all the observations a number of times, and the curves indicated in Figs. VII and XII were uniformly obtained for the two gases under the conditions described.

TABLE V

Pressure	Activity on the Cathode	Activity on the Anode
6 mm.	21.0	20.0
46 "	52.0	43.0
117 "	83.0	43.7
235 "	106.0	27.7
457 "	87.3	15.0
760 "	78.3	8.3

VII. ACTIVITY OF DEPOSITS OBTAINED IN HYDROGEN AT DIFFERENT PRESSURES.

Another series of measurements was made with hydrogen, under conditions similar to those already described with air and carbon dioxide, and the active deposits obtained at the various pressures are given in Table V, and a curve representing them in Fig. XIII. From these observations it will be seen again, that as the pressure was lowered, the active deposits on both electrodes steadily increased, passed through maximum values, then decreased, and on the decrease approached equality at the lowest pressures examined. In hydrogen the maximum active deposit on the cathode was obtained at about 250 mms., but the maximum active deposit on the anode was not obtained until about 80 mms. pressure was reached. The maximum active deposit on the negative electrode was about 2.3 times the maximum active deposit on the positive terminal. Repeated measurements have not been made to confirm these results, but the same precautions were taken with hydrogen as with air and carbon dioxide. It will be seen from the values given, that the ratio of the maximum activities for the two terminals in the case of hydrogen is only slightly less than corresponding ratios for air and carbon dioxide.

VIII. COMPARISON OF THE ACTIVE DEPOSITS IN AIR, CARBON DIOXIDE, AND HYDROGEN.

For purposes of comparison the active deposits obtained under the various circumstances are collected in Table VI. From this table it will be seen that the pressure at which the maximum cathode deposits were obtained for the different gases are: carbon dioxide, 60 mms.; air, 80 mms.; hydrogen, 250 mms. These pressures are approximately in the ratio 1 : 1.33 : 4.2. Now, since the coefficient of diffusion of a gas is inversely proportional to the molecular weight of a gas into which it is diffused, and since, further, the coefficient of diffusion is inversely proportional to the total pressure of the two diffusing gases, it follows, since in this case the diffusing transmutation product must be exceedingly minute, that the coefficient of diffusion for the product will be inversely proportional to the pressure of the gas into which it is passing.

TABLE VI

Gas	Activity deposit on the Cathode	Pressure	Activity deposit on the Anode
Air	20.5	750 mms.	.45
	92.0 (maximum)	80 mms.	
		17 mms.	33.0 (maximum)
	11.7	.5 mms.	11.3
Carbon Dioxide	11.7	750 mms.	.75
	82.0 (maximum)	60 mms.	
		14 mms.	31.0 (maximum)
	15.6	1 mm.	14.7
Hydrogen	78.3	760 mms.	8.3
	108.0 (maximum)	250 mms.	
		80 mms.	46 (maximum)
	21.0	6 mms.	20

Further, since the maximum activities on the cathode for the different gases are approximately the same, i.e. 82, 93, and 108, we may look upon the results as due to the diffusion of a maximum distribution of activity in the three gases, and consequently for the critical pressures

given above, deduce an approximate estimate of the ratios of the coefficient of diffusion of the active product or products into the three gases at atmospheric pressure. These follow directly from the argument just presented and are all given in Table VII.

TABLE VII

Gas	Pressure for maximum active deposit on the cathode.	Calculated ratios of the coefficient of diffusion of the active product into the different gases at atmospheric pressure.
Carbon Dioxide.....	60	1
Air.....	80	1.3
Hydrogen.....	250	4.2

Following the same line of argument in case of the anode deposits, since the maximum effects were obtained at pressures 14 mms., 17 mms., and 80 mms., for carbon dioxide, air and hydrogen respectively, it follows that the ratios of the coefficients of diffusion of the active product concerned were as 1 : 1.21 : 5.7, i.e., the relative coefficient for air was slightly lower and that for hydrogen somewhat higher than the values deduced from the behaviour of the cathode deposits.

The ratios of the coefficients of diffusion of the active product concerned, as deduced from the cathode deposits, are practically the same as some values given in a paper by Russ¹ and this agreement goes to show that it is a diffusion phenomenon which is the paramount one in the present investigation.

The interpretation of the maximum effect obtained on each electrode with the three gases, however, presents some difficulty. One should have expected, with the active deposits in the experiments in which the salt was placed at different distances from the electrodes, that in the case of the lowest pressures a maximum value would have been obtained for a certain critical distance of the salt from the plates. But, as the curves in Figs. V and VI show, no such maximum values appeared.

IX. ACTIVE DEPOSITS IN THE ABSENCE OF ELECTRIC FIELDS.

In the experiments described up to the present the active deposits are all obtained with a potential difference of approximately 250 volts between the electrodes. With these conditions, however, it was impossible to draw any definite conclusion as to the relative quantities of charged

¹ Russ, *Phil. Mag.*, March, 1909.

and uncharged deposit particles involved in any particular measurements. With the object of throwing one light on this point an additional set of observations was made on the deposits obtained in air at different pressures with the electrodes uncharged, and at a distance of 2 mm. apart. The activities obtained on the two electrodes in these experiments were added together and the numbers representing them are given in Table VIII. For purposes of comparison the total activities obtained with air at different pressures under a field of 250 volts are also inserted in the table and curves representing both sets of values are shown in Fig. XIV. From an inspection of the two curves it will be seen that the total active deposit was practically the same with and without the field at all pressures above the critical one. At and below this pressure the deposits obtained with the electric field applied, as the figure shows, were somewhat in excess. From this experiment it would seem that the deposit particles in very great measure go to the walls of the vessel in which they are produced whether an electric field be applied or not.

TABLE VIII

Pressure	Total Deposit with field 250 volts	Total deposit, no field
9 mm.	46.1	21.6
43 mm	64.0	52.0
80 mm.	65.3	54.4
127 mm.	50.5	50.4
422 mm	23.0	24.9
755 mm	13.4	10.8

The manner in which they are carried there, however, is not evident. It is possible that a certain proportion of the deposit particles are uncharged and that these reach the walls by ordinary diffusion. Then again, these deposit particles may be electrically charged, some of them being of one sign, and some of the opposite, and diffusion again may be the chief factor in producing the deposit, or further, if the disintegration recoil phenomenon is the determining factor it is possible that, with the plates close together, the deposits are made by reason of the velocity of expulsion alone. If this latter be the explanation the sign of the charge carried by the deposit particle would not then exert any considerable influence except in the most intense fields.

In all the measurements made the cathode deposit was, except at the very lowest pressures, considerably in excess of that obtained on the

positive terminal. This goes to show that part at least of the deposit particles carry a positive charge and reach the electrode under the influence of the field.

The manner in which these particles gain their positive charge, however, is not clear.

From experiments by Logeman¹ and others it is known that a plate of copper on which polonium is deposited emits a copious stream of delta particles. These it is also known are beta particles of low velocity which are very probably ejected either from the copper or from the polonium or its transmutation product under the bombardment of the alpha particles. It is possible, too, that they may be produced by and accompany the alpha particles in the course of their expulsion from the parent atoms. Such a plate of copper as that mentioned above is known to acquire a positive charge when placed in a very high vacuum, which shows that an excess of negative electricity leaves it as a result of the action of the various radiations. It is possible then that some of the deposit particles from actinium or other active emanations may gain a positive charge under the action of the alpha radiations present in much the same way as the copper plate in the polonium experiments. This would then account for the positive charge on the particles and consequently for their removal under the field to the negative terminal.

On the other hand some experiments recently made by H. W. Schmidt² have brought out a parallelism between the amount of active deposit obtained in air under different electric fields and the intensity of the ordinary conduction current through the air under the same fields. This would seem to show that the charges are acquired by the deposit particles as a result of collision with the gaseous ions present in the same vessel.

Many of the results obtained in the present investigation go to support this view and one in particular is of special interest.

In this experiment the electrodes were 2 mm. apart, the salt was placed 1.3 mm. below the electrodes in the exposing vessel, and the exposures were made under different voltages in air at a pressure of 9 mm. The exposures were made first with the two electrodes at the same potential, and then with them at different potentials ranging in extent up to 1,150 volts.

The results of the various activity measurements are given in Table IX and curves drawn from these numbers are shown in Fig. XV.

From these results it will be seen that when the potentials of the two plates were the same the activities of both were alike, but that for all potential differences the activity of the negative terminal was greater

¹Logeman Proc. Roy. Soc. A 78, p. 212, 1907.
²Phys. Zeit. 9, pp. 184-187, March, 1908.

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than that of the positive. For potential differences from 200 to 450 volts the activities were practically independent of the potential difference applied. From 460 volts upward, however, the activities of both electrodes increased and finally at about 600 volts again became independent of the applied potential.

From Carr's results¹ it is known that 460 volts is the spark potential for a pressure of 9 mms. with the plates 2 mm. apart, consequently for all voltages above 460 the exposures were made with a current passing between the plates. This would mean that a large number of ions were present between the terminals under the circumstances during the exposure and it is interesting to note that the presence of these ions resulted in a considerable increase in the activity of the two plates. But just how this result is brought about is difficult to explain as the exact relation which exists between the number of ions present in a gas and the active deposit particles is still obscure, and it will be necessary to make additional experiments before the question can be cleared up.

TABLE IX

Pressure 9 mm.	Electrodes 2 cm apart.	Distance of salt 1.3 cm.
Voltage	Activity on negative electrode	Activity on positive electrode
0	11.0	10.6
83	12.1	10
242	14.9	10.2
467	15.5	10.3
523	15.8	11.2
545	18.6	14.2
605	17.4	13
641	35.8	25
683	19.2	13.1
794	30.7	19.2
928	30.7	25.0
955	38.7	21.6
1149	29.4	19.2

Note.—Sparking potential for pressure 9 mm. and distance 2 mm. = 460 volts Carr. Trans. Roy. Soc. Vol. 201 pp. 403-433. 1900

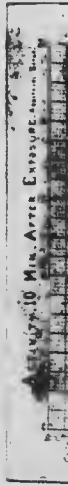
¹ Phil. Trans., Vol. 201, pp. 403-433.

One of the main questions left open in the present investigation is the cause of the decrease in activity of the electrodes in the three different gases at the low pressures.

It seems fair to conclude from the results that in the region of low pressures there was a gradual decrease both in the excess of positively charged deposit particles and also in the total number of the particles present in the space between the electrodes.

The experiments, however, do not show whether this decrease was due to a falling off in the amount of emanation coming into the space between the electrodes, or to the emanation and deposit particles passing directly through this space into the outer chamber of the apparatus. From the fact that at the low pressures as well as the high ones the activity fell away as the distance of the salt from the electrodes was increased it would seem that the decrease mentioned above was due to a decrease in the amount of emanation entering the space between the electrodes. The matter, however, is not clear and consequently the explanation of the decrease must be deferred until the scope of the investigation can be extended.

In conclusion I desire to thank Professor McLennan for the selection of the subject, and for the very helpful suggestions he has offered from time to time during the investigation.



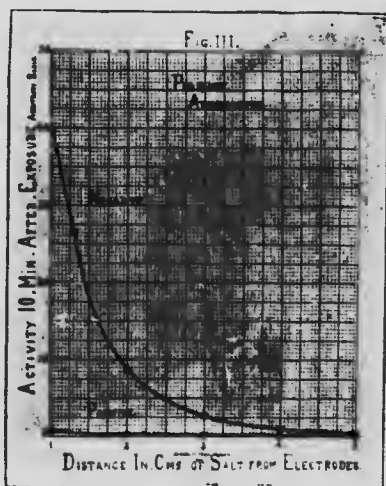
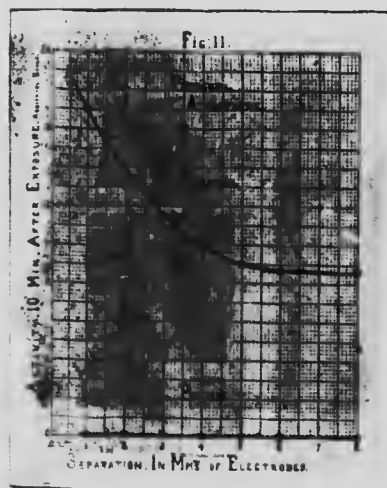
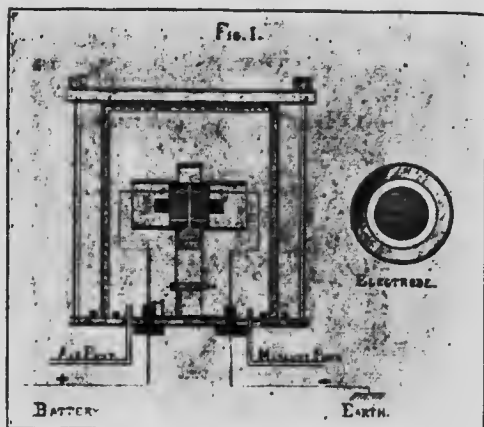




Fig. IV.

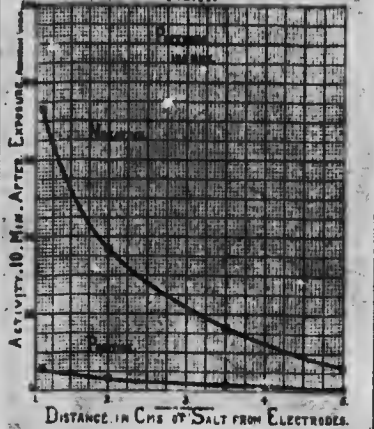


Fig. V.

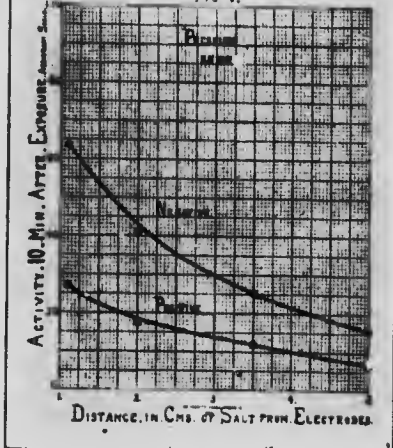


Fig. VI.

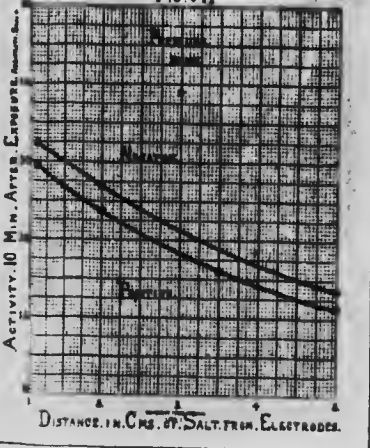


Fig. VII.

