



# LIII. On the emission of negative electricity by radium and thorium emanations

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deduced will serve our purpose equally well. We can for instance assume that the class of types of well-ordered series which can be formed from the terms of a limited class is itself a limited class\*. We can then prove that there is no greatest cardinal without making any assumption as to the exponential function.

I may point out that the proofs which I have given of Schröder and Bernstein's theorem, and of the propositions that

$$\mathfrak{a} + \mathfrak{a} = \mathfrak{a}, \quad \aleph_0 \mathfrak{a} = \mathfrak{a} \quad \text{and} \quad \mathfrak{a}^2 = \mathfrak{a}$$

do not depend for their validity on the assumptions which I have made. Those propositions are true for all aggregates, and for all cardinal numbers which exist. But we cannot determine what cardinal numbers do exist without the aid of some assumptions.

From the proposition that  $\mathfrak{a}^2 = \mathfrak{a}$  we can infer that the logical sum of an aggregate of mutually similar aggregates is an aggregate; but we cannot from this alone infer that the logical sum is an aggregate in the particular case where the cardinals of the component aggregates form in order of magnitude a series with no last term, unless we know independently that there is a cardinal greater than any of those cardinals. It is this latter case of the proposition which I have actually made use of in proving that the class of cardinals is unlimited. In my later paper I have expressly treated this proposition as an axiom.

Burdwan, 17th May, 1905.

LIIL. *On the Emission of Negative Electricity by Radium and Thorium Emanations.* By Miss J. M. W. SLATER, B.Sc.; Bathurst Student, Newnham College, Cambridge†.

IN a recent communication made to the Cambridge Philosophical Society‡, Prof. J. J. Thomson has described some experiments which show the existence of a new type of rays in connexion with certain active substances. These are negative rays of the same nature as cathode rays; they differ from the ordinary  $\beta$  ray in moving much less rapidly, so that their ability to penetrate aluminium foil and other media is no greater than that of the positive  $\alpha$  particles. This accounts for their not having been detected by the ordinary methods of testing for  $\beta$  rays. Prof. Thomson

\* This axiom is really assumed in Cantor's argument.

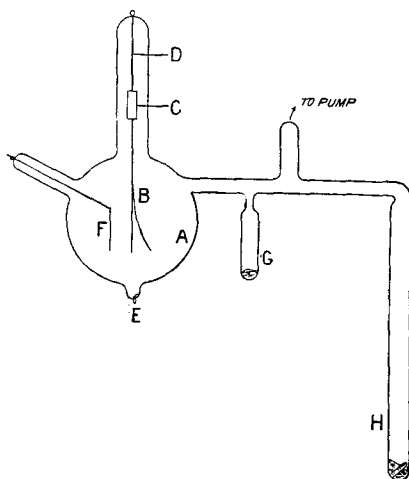
† Communicated by Prof. J. J. Thomson, F.R.S.

‡ Proc. Camb. Phil. Soc. vol. xiii. part 1.

has shown that both polonium and radium give out quantities of these rays; at distances from the active matter exceeding a few millimetres they are found to have entirely neutralized the charge on the  $\alpha$  particle. Prof. Thomson suggests that these rays may also be emitted by the emanations of radium and thorium (though they have been shown to give out no rapidly-moving  $\beta$  rays); and that if this is the case, it may offer an explanation of the deposition of excited activity on the negative electrode. The experiments described in this paper were undertaken in order to decide this point.

The method of experimenting and the apparatus employed were essentially the same as those used by Prof. Thomson (fig. 1).

Fig. 1.



The inner surface of the bulb A (7 cm. in diameter) was silvered over, and kept connected through the terminal E to earth. B is a gold-leaf electroscope, mounted on a quartz rod C, and charged by contact with the wire F, which is then earthed. The wire D throughout each observation was kept at the potential to which B was initially charged, thus acting as a guard-ring. In the side-tube G was placed a small quantity of impure radium bromide; H contained hard charcoal, and could be immersed in liquid air, in order to get as good a vacuum as possible.

The apparatus was exhausted to the best vacuum obtainable on the pump, and then sealed off and set up with the tube H in liquid air. The gold-leaf was then charged, and its rate of

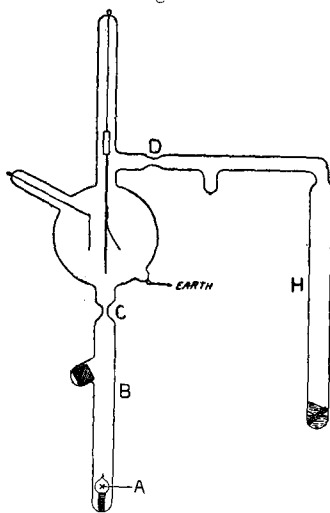
collapse observed through a window in the silver lining of the bulb, by means of a microscope with micrometer eyepiece. The potential used was generally  $\pm 200$  volts. The average rate of leak when the leaf was positively charged was 6 scale-divisions per hour, the negative leak being only 1.7. It is evident that with the arrangement above described, a large proportion of the radium emanation would distil over into the side-tube H, and have very little effect on the leak in the bulb. To prevent this the liquid air was removed, and the observations repeated. The average + leak was now 47 divisions per hour, the - leak 7.3. Any ionization leak due to air remaining in the bulb would equally tend to discharge both positive and negative electricity, so that this large difference shows clearly that there must be a very considerable emission of slow cathode rays from the radium products in the bulb. It was shown that the effect was not due to the direct action of  $\beta$  rays from the excited activity in the tube G by placing a thick lead screen between this tube and the testing bulb; the leak was not appreciably altered.

These experiments gave no indication as to whether the emission of the negative rays was due to the emanation or to the excited activity, since throughout the experiment both substances must have been present. To test this point, a rather different arrangement was used. (Fig. 2.)

The radium was placed in a small tube (A) ending in a very thin bulb drawn out to a fine point; this was exhausted on the pump and sealed up. It was then placed in a wide tube (B) with a short side branch holding a lump of soft iron; this tube was sealed onto the bottom of the testing bulb, and the whole exhausted as before. The direct effect of the radium in this position was found to be negligible, the leak, both + and -, being too small to be measured.

By means of an electromagnet, the iron was now moved from its place, and made to fall on the little tube containing the radium; the thin bulb was broken, and the accumulated

Fig. 2.



emanation was able to diffuse into the testing-vessel. The effect on the leak is shown by the following observations, the zero of time being taken as the moment at which the radium tube was broken.

I. Leaf charged +200 volts.      II. Leaf charged -200 volts.

Time in minutes.	Position of Leaf on Scale.	Time in minutes.	Scale-readings.
3	95.0	19	82.9
5	93.6	24	82.7
7	92.7	29	82.5
9	91.0	34	82.2
11	89.6	39	82.8
13	87.9	44	82.4
15	86.5		
Leak per hour, 42.5 scale-div.		Leak per hour, 1.9 div.	

III. Leaf charged +200 volts.

Time in minutes.	Scale-readings.
48	84.1
52	81.2
56	76.9
60	74.7
65	71.0
Leak per hour, 46 div.	

At  $1\frac{1}{2}$  hours after the breaking of the bulb, the positive leak reached its maximum value of 52 divisions per hour, and then fell off, the leak after  $4\frac{1}{2}$  hours being 39. This was evidently due to the gradual diffusion of the emanation into the branch tubes, and away from the gold-leaf.

The charcoal tube H was now put into liquid air, and an immediate reduction of the positive leak was observed. Measuring time from the moment at which the tube was placed in the liquid air, the readings obtained were as follows:—

Time in minutes.	Scale-readings.
5	70.6
7	70.0
10	68.8
15	68.4
21	67.5
25	67.1
30	66.3
35	65.8
Leak per hour, 9.6 div.	

From these observations it is evident that the greater part of the leak observed was directly due to the presence of the emanation, since for the first 5 or 10 minutes after breaking the radium tube, the amount of excited activity in the bulb must be very small, and the maximum amount would not be produced for several hours. The change caused by cooling the side-tube in liquid air would also occur much less rapidly if the leak observed were mainly due to rays from the excited activity on the walls of the vessel. That very little of the initial leak was due to the presence of ionized gases in the bulb, is shown by the very low value obtained when the gold-leaf was charged negatively; so that the change caused by the liquid air cannot be due merely to an improvement of the vacuum, but must be owing to the condensation of a large proportion of the emanation in the tube H.

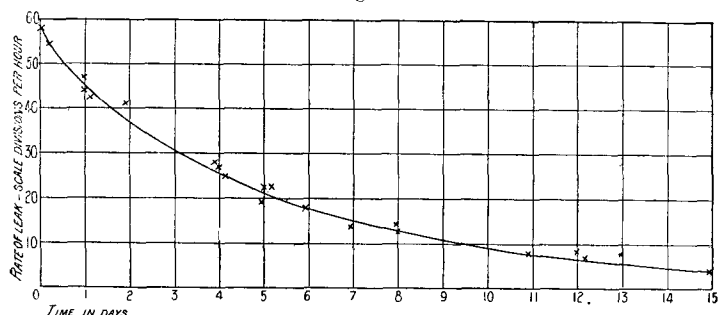
The effect was further investigated by sealing off the tube B at the point C (fig. 2), and observing the rate at which the leak subsequently decreased. This proved to be unexpectedly high, as after two days the rate of leak had fallen to less than half its original value. From this time onwards the rate of decrease was less, having about the normal value for radium emanation, viz. half in 4 days. The rapid fall at first observed may possibly have been due to absorption of the emanation by the charcoal in the side-tube, after the radium was sealed off; moreover, the earlier readings were not very consistent among themselves, so that it was thought desirable to repeat the whole series of experiments under slightly different conditions.

The radium was sealed up in a little tube which was broken as before, and the initial rapid rise in the leak to a maximum, followed by a smaller fall, was confirmed. Then the side-tube H, after being kept for some time in liquid air so as to

get as good a vacuum as possible in the apparatus, was sealed off at D, in order to prevent any variation in the amount of emanation in the bulb owing to diffusion, and absorption by the charcoal. The apparatus was then left for some days, during which the positive leak gradually increased as the emanation in the bulb accumulated. The negative leak also increased slightly, and this was probably in part an ionization leak, due to the evolution of small quantities of gas from the radium; the maximum reading obtained for the negative leak was, however, 7.5, the maximum positive leak being 65, so that the greater part of the latter must still be ascribed to the slowly-moving negative rays given off by the emanation.

The radium tube was then sealed off, and the rate of diminution of the positive leak was measured over a considerable time. No such rapid fall was observed as had been previously obtained; but the rate of leak fell off approximately according to an exponential law, going to half value in four days (fig. 3).

Fig. 3.



It is thus evident that the radium emanation gives off a quantity of slowly-moving negative rays, along with the  $\alpha$  particle, during its change to the excited activity.

The action of thorium was similarly examined. A small bulb half full of thorium hydroxide was sealed onto the bottom of the testing vessel, the apparatus exhausted, and the leak determined as before. The mean values obtained were, with a positive charge 11.5 divisions per hour, with a negative charge 2.1 divisions per hour. Here again, therefore, the same slowly-moving negative rays are evidently present.

Later on, the experiment was repeated with a larger quantity  
*Phil. Mag. S. 6. Vol. 10. No. 58. Oct. 1905.* 2 K

of thorium, so as to increase the effect; and the side-tube, after having been kept some time in liquid air, was sealed off, in order to avoid the irregularities which it had been found to introduce. Immediately before removing the side-tube, the positive leak was 17·2 divisions per hour, the negative 6·0. The liquid-air tube was then sealed off, and the rate of leak at once measured. Starting the observations four minutes after removing the tube, the successive results obtained were—positive leak, 88·5 per hour; negative leak, 33·4 per hour; positive leak, 90 per hour. This large and rapid rise shows clearly that a great part of the effect observed must be directly due to the emanation, which begins to accumulate in the bulb as soon as the cooled side-tube is removed. Owing to its rapid rate of decay (half value in about 1 minute), it only requires a few minutes for the maximum amount to collect.

The bulb containing the thorium was next sealed off, and the positive leak from 6 minutes to 16 minutes afterwards was found to be at the rate of 25·8 divisions per hour. In this space of time the amount of emanation in the testing vessel would have already become almost negligible, and this residual leak was no doubt due to rays given off by the excited activity on the walls. It fell off slowly, at a rate which was approximately that of thorium-excited activity.

From the above experiments, it is evident that in the case of thorium as well as that of radium the emanation gives off a quantity of slow negative rays in changing to the excited activity. In air at the ordinary pressure these rays would be rapidly absorbed; but at the pressures used in these experiments they reach the electroscope and discharge it. The magnitude of the positive leak obtained (compared with the negative) makes it extremely probable that the amount of negative electricity given out by the emanation is considerably greater than the positive electricity emitted in the form of  $\alpha$  rays. If this is the case, the residue from which the excited activity is derived must be formed with a positive charge, and its appearance on the negative electrode in an electric field is explained.

In conclusion I have only to express my best thanks to Prof. J. J. Thomson, to whose kind interest and advice during the course of the above experiments, which were carried out at the Cavendish Laboratory, I am greatly indebted.