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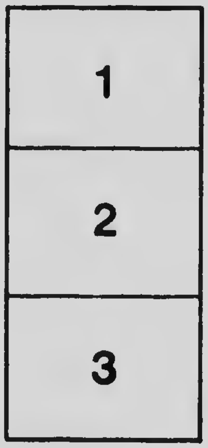

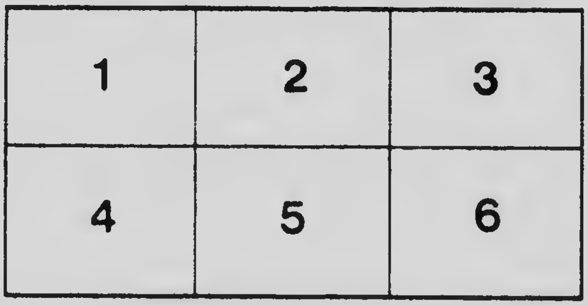

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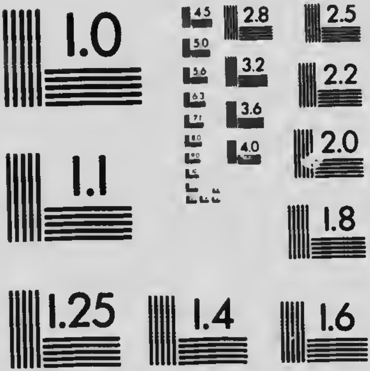

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PAPERS FROM THE PHYSICAL
LABORATORIES

No. 22: THE RADIOACTIVITY OF LEAD, BY J. C. McLENNAN

(REPRINTED FROM THE PHILOSOPHICAL MAGAZINE, DECEMBER, 1907)

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From the PHILOSOPHICAL MAGAZINE *for December* 1907.

On the Radioactivity of Lead and other Metals. By J. C. McLENNAN, *Ph.D., Professor of Physics, University of Tor[illegible]**.

I. *The Relative Activities of Different Metals.*

IN a paper in the Phil. Mag. of September 1906, Eve states that while investigating the natural ionization of air confined in vessels made of different metals, he found that 24 ions per c.c. were generated per sec. when the receivers were made of copper, zinc, iron, and tinned iron, while 96 ions per c.c. were regularly produced in air per second when the confining vessels were made of lead.

The high conductivity of air contained in lead vessels has been frequently noted by other observers; a[illegible]d from Eve's results it would appear that lead either contains some active impurity from which other metals are entirely free or else it possesses an intrinsic radiation very much strong[illegible] than that exhibited by other metals.

The view that lead contains an active impurity is supported by a description in the *Phys. Zeit.* of November 1906, of some experiments by Elster and Geitel, in which they succeeded in extracting from lead oxide small quantities of an active substance which from its characteristics they were inclined to think was Radium F. In this paper they state that they were unable to obtain any active emanation from the materials treated, and on this account they suggest that possibly the source of the Radium F can be traced to the presence of Radium D in the lead.

Since the decay period for Radium D is forty years it would follow, if the high activity of lead is due to the presence of this radium product, that very old lead should

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

exhibit an activity less intense than that which it emitted when freshly mined.

Eve does not appear to have tested many different samples of lead, but if the expl. tion offered by Elster and Geitel of the high activity of lead be correct, one should expect to find that samples of lead selected at random from different localities would exhibit widely differing degrees of activity.

Such a difference in the radioactivity of lead obtained from different sources was recently observed by the writer while making some measurements on the conductivity of air contained in metal vessels.

In these experiments the metals examined were made up into cylinders 60 cm. long and 24 cm. in diameter, and from measurements with a sensitive quadrant electrometer on the saturation current through the air which they contained, their activities were deduced.

The experiments were conducted in a room free from any artificial contamination; and in carrying them out, the cylinders were first carefully cleaned with glass paper and then thoroughly washed out with hydrochloric acid, water, ammonia, and ethyl alcohol, and finally, before making the measurements, air filtered through glass cotton-wool was blown through each of them for fifteen or twenty minutes. The results obtained with the different metals examined are contained in Table I. (p. 762).

From this table it will be seen that the values of "*q*" for aluminium and zinc are somewhat less than those found by Eve for this constant with the same metals. They are, however, in good agreement with H. L. Cooke's corrected value "*q*" = 13·6 given by Eve for air confined in a well-cleaned brass vessel.

The values found for "*q*" in the experiments with lead cylinders, as will be seen from the table, range from 23 to 160 ions per c.c. per second. The lowest value, 23, was obtained with the lead which had been in the laboratory between twenty-five and thirty years, and had probably been a very much longer time away from the mine. With the cylinder No. 4, which was made from an old drain-pipe, the value of "*q*" was found to be 78, a somewhat higher value than than obtained with No. 1. Although both of these cylinders were made of comparatively old lead, it is highly probable that No. 4, from the n e of its use, had become contaminated with some activ. substance. It may possibly too have possessed a higher activity than No. 1 when originally mined.

TABLE I.

No.	Material of cylinder. Length 60 cm. Diameter 24 cm.	Thickness of sheet in mm.	"q" Average No. of ions per c.c. generated per second.	Remarks.
1......	Lead	1·85	23	This sample was taken from a sheet of lead which had been used as a lining in a case installed in the University over twenty-eight years ago.
2......	Lead	2·25	160	Commercial English sheet lead obtained from the lead works at Toronto.
3......	Lead	1·45	37	Commercial English sheet lead selected from a different shipment from No. 2.
4......	Lead	1·85	78	This sample was obtained from a sheet rolled from an old pipe which had been used as a drain for 25 or 30 years, and was afterwards melted down.
5......	Lead	1·80	34	Rolled from a pig of lead recently received from the smelter at Trail, B.C. Canada.
6......	Lead	1·80	55	Rolled from English pig lead; Quirk and Bartons.
7......	Lead	1·80	61	Rolled from English pig lead. Cookson's.
8......	Zinc	1·62	15	Commercial sheet zinc.
9......	Aluminium ...	·41	15	Commercial sheet aluminium.

With cylinder No. 5 the value obtained for "q" was 34 ions per c.c. per second. This lead, we have reason to believe, was mined not more than two or three years ago, and under the circumstances might have been expected to show a much higher activity. Its activity, however, was practically the same as that of No. 3, which was selected at random from a commercial sheet of lead which probably had been on the market for some years.

Cylinders No. 6 and No. 7 possessed a moderate activity compared with the others of the same metal. The number of ions per c.c. generated in air per second with them being 55 and 61 respectively.

With cylinder No. 2 the greatest ionization was obtained, the value of "q" in this case being 160 ions per c.c. per second.

This cylinder was treated precisely the same as the others, but on account of its high activity special measurements were made with it in order to investigate more fully the character of the radiation which it emitted.

Measurements on the radiation from this cylinder showed it to be in great measure an easily absorbed one. When aluminium linings 0·73 mm. thick were inserted in cylinders No. 1, No. 2, and No. 3, and measurements made on their saturation currents, the values of "q" were found to be 12·0, 13·3, and 14·4 respectively. These numbers, it will be seen, are slightly lower than those found for aluminium alone, which is exactly as one would expect owing to the absorption of the penetrating rays from the earth by the lead. The value for "q" 13·3 found for No. 2 is slightly greater than that "q"=12 given by No. 1, although this lead cylinder was 2·25 mm. thick, while No. 1 was only 1·85. This would seem to indicate the existence of a penetrating type of radiation issuing from No. 2 which was absent from cylinder No. 1.

A second series of measurements was made with cylinder No. 2 to investigate the distribution of the substance which was the cause of its high activity. Readings were taken on the saturation current first with the lead cylinder entirely unscreened, then with one half of the cylindrical surface screened internally with aluminium 0·73 mm. thick, and finally with the whole of the inner cylindrical surface covered with the aluminium.

The values are given in Table II., and from them it will

Table II.

Experiment number.	Cylinder No. 2.	Ionization. (Arbitrary Scale.)	Decrease in Ionization. (Arbitrary Scale.)
1............	Completely unscreened.	54·6	
		....	22·2
2............	One-half inner cylindrical surface screened.	32·4	
		....	22·57
3........	All inner cylindrical surface screened.	9·87	

be seen that the decrease in conductivity was the same for each half of the cylindrical surface. This goes to show that the radioactive impurity in the lead was uniformly distributed over its surface. It was also very probably distributed in a uniform manner throughout the mass of the cylinder, as repeated scourings with glass-paper failed to remove it. In this connexion it is of interest to note that, during the last six months, measurements have been repeatedly made on the conductivity of air confined in this cylinder, but during that period no indication of a falling off in the intensity of the radiation from it has been observed.

II. *On the Ionization produced in Metallic Receivers by the Secondary Rays excited by the Gamma Rays from Radium.*

From the foregoing results it is abundantly evident that the high activity of lead, which has from time to time been recorded by a number of observers, cannot be ascribed to any intrinsic property of the metal, but must be connected with the existence in it, in amounts varying with different specimens, of some foreign body of considerable activity.

It is known that part of the ionization in a gas confined in metallic vessels must be due to the penetrating radiation emitted by the earth, and part to the secondary rays excited in the substance of the metallic receivers by these penetrating rays. From the results given above, part must also be due, in some cases at least, to active impurities present in the metal.

The extremely low value found for the ionization with the lead in cylinder No. 1, coupled with the value for "*q*" obtained with zinc and aluminium receivers, suggests the possibility that the materials out of which these vessels were made were entirely or very largely free from active impurities, and that the differences observed in the ionizations were due to differences in the intensities of the secondary radiations from the different metals. It is known that the secondary radiation increases with the atomic weight of the metal composing the radiating surface, and it seemed to the writer possible that the difference in the values of "*q*" found for lead and aluminium, namely 23 and 15 ions per c.c. per second, might be accounted for entirely on this ground.

With the object of investigating this point an aluminium cylinder was prepared from a thin sheet of the metal 0·41 mm. in thickness, and a series of accurate measurements made on the saturation current through the air which it contained. A small quantity of radium bromide was enclosed in a block of lead about 3 cms. in thickness, and placed at a distance of about one metre from the aluminium cylinder. The saturation current in the aluminium cylinder was again measured, and the difference between its value and that due to the natural conductivity of the air was noted, and recorded as being due to the gamma rays from the radium bromide together with the secondary rays produced by this radiation.

Each of the first eight cylinders referred to in Table I. was then used in turn as a screen between the lead block containing the radium and the testing cylinder, and the corresponding saturation current measured. The differences between these readings and that taken with the radium before the screens were inserted, were taken as a measure of the absorption of the gamma rays by the respective cylinders. From these differences, combined with the ionization produced by the gamma rays impinging directly on the testing cylinder, the absorptive power of each of the cylinders was calculated as a percentage of the intensity of the penetrating rays issuing from the lead block, and these are given in Table III. The absorption of the gamma rays by two sheets of aluminium 0·73 mm. and 1·46 mm. in thickness was also determined in the same manner, and these are recorded, together with the others, as Nos. 9 and 10 in Table III.

Table III.

Cylinder No.	Material.	Percentage in mm.	Percentage absorption by gamma rays.	No. of ions produced by natural ionization. (See Table 1.)
1	Lead	1·85	15·36	23
2	,, ...	2·25	16·29	160
3	,, ...	1·45	9·36	37
4	,, ...	1·85	11·2	78
5	,, ...	1·80	12·92	34
6	,, ...	1·80	10·12	55
7	,, ...	1·80	13·23	61
8	Zinc	1·62	4·62	15
9	Aluminium	1·43	·92	
10	,, ...	·73	·46	

A set of measurements was next made on the saturation currents in each of the first three cylinders given in Tables I. and III. These were taken (*a*) with the air under natural ionization; (*b*) with the cylinder lined with aluminium, but otherwise the same as in (*a*); (*c*) with the radium bromide in the lead block mentioned above at a distance of 1 metre from the unlined cylinders; and (*d*) with all the conditions the same as in (*b*) excepting that the cylinders were lined with the sheet aluminium.

Assuming that this lining completely absorbed the secondary radiation from the lead walls of the vessels, which is probable as the secondary rays from lead are easily absorbed, and neglecting the absorption of the gamma rays by the aluminium lining, since from the numbers given in Table III. it must necessarily have been less than one half of one per cent., it follows that the difference between the readings "*c*" and "*a*" represents the ionization produced in the unlined lead cylinder by the radium; while the difference between the readings "*d*" and "*b*" represents the ionization produced in the lined cylinder by the same cause. The excess of this first difference over the second may then be taken without appreciable error as a measure of the excess of the ionization produced by the secondary rays in the respective cylinders when unlined over that produced by the secondary rays with the lining inserted. In other words, it may be taken as proportional to the difference between the ionizing powers, in so far as the air in the cylinders is concerned, of the secondary rays excited in lead and aluminium by the penetrating rays which entered the cylinders.

Or taking I_{ls} and I_{as} as proportional to the ionizations produced in one of the cylinders by the secondary rays excited in lead and aluminium respectively by the gamma rays which entered it, we have

$$I_{ls} - I_{as} = (\text{Reading "}c\text{"} - \text{Reading "}a\text{"}) - (\text{Reading "}d\text{"} - \text{Reading "}b\text{"}). \quad \text{(i.)}$$

Further, it is known from an investigation by Eve* that the ionizing power of the secondary rays excited in aluminium by a gamma radiation is 28·6 per cent. of that possessed by the secondary rays excited in lead by the same rays.

We have then this equation

$$I_{ls} = \frac{100}{28{\cdot}6} \, . \, I_{as}. \quad \text{(ii.)}$$

Again, denoting by I_{lp} the ionization produced in the lead cylinder under examination by the gamma rays from the radium alone, we have

$$I_{lp} + I_{ls} = \text{The difference between readings "}c\text{" and "}a\text{" with this cylinder.} \quad \text{(iii.)}$$

From equations (i.), (ii.), and (iii.) it is possible then to

* Eve, Phil. Mag. Dec. 1904.

calculate I_{lp}, I_{ls}, and I_{as}, and so deduce a relation between the ionizations produced in a given lead cylinder by the gamma rays which enter it and by the secondary rays excited in the walls of the vessel by these penetrating rays.

The averages of a great many measurements made in this way with the cylinders Nos. 1, 2, and 3 are given in

TABLE IV.

Cylinder No.	Natural ionization (Arbitrary Scale). Reading "*a*."	Natural ionization (Arbitrary Scale). Reading "*b*."	Combined ionizations in unlined lead cylinder (Arbitrary Scale). Reading "*c*."	Combined ionizations in aluminium-lined lead cylinder (Arbitrary Scale). Reading "*d*."
1	7·7	4·02	97·75	53·52
2	53·94	4·48	142·44	48·87
3	12	4·67	113	57·97

Table IV.; and in Table V. the numbers corresponding to the reduced values of these observations are recorded.

TABLE V.

Column 1. Cylinder No.	Column 2. Ionization due to gamma rays from radium and secondary rays excited in lead by these rays. $I_{lp}+I_{ls}$. (Arbitrary Scale.)	Column 3. Ionization due to gamma rays from radium and secondary rays excited in aluminium by these rays. $I_{lp}+I_{as}$. (Arbitrary Scale.)	Column 4. Ratio $\frac{I_{ls}}{I_{lp}}$ (calculated)	Column 5. Ratio $\frac{I_{as}}{I_{lp}}$ (calculated)	Column 6. Value of ionization in unlined lead cylinder due to penetrating rays from radium $= I_{lp}$ (calculated).	Column 7. Value of I_{lp} corrected for absorption (calculated).
1	90·05	49·5	1·74	·49	33·05	39·0
					$\left(\frac{100}{84\cdot64} \times 33\cdot05\right) = 39\cdot0$	
2	88·50	44·39	2·31	·66	26·7	32·0
3	101·00	53·3	1·95	·56	34·2	38·0
		Mean	... 2·00	·57	31·32	36·3

Applying equations (i.), (ii.), and (iii.) to the measurements with cylinder No. 1, as an example of the manner in which the reductions were made, we have

$$I_{lp} + I_{ls} = 90{\cdot}05 \quad \ldots\ldots \quad \text{(iv.)}$$

$$I_{lp} + I_{as} = 49{\cdot}5 \quad \ldots\ldots \quad \text{(v.)}$$

and

$$I_{ls} = \frac{100}{28{\cdot}6} I_{as}. \quad \ldots\ldots \quad \text{(vi.)}$$

From which we have

$$I_{lp} = 33{\cdot}05$$
$$I_{ls} = 57{\cdot}00$$
$$I_{as} = 16{\cdot}3,$$

or

$$I_{ls} = 1{\cdot}735\, I_{lp},$$

and

$$I_{as} = {\cdot}493\, I_{lp}.$$

Similar calculations were made on the readings obtained with cylinders Nos. 2 and 3, and the results of the three are recorded in columns 4 and 5 of Table V. From these it will be seen that the ionization produced in the air in a lead cylinder by the gamma rays from radium is only one-half that produced in it by the secondary rays excited in the lead walls by these same rays. On the other hand, with gamma rays of the same intensity entering an aluminium cylinder of the same size as the lead one, the results show that the ionization produced by the penetrating gamma rays is approximately twice that produced by the secondary rays excited by these gamma rays.

It will also be seen from the numbers given in the above table, that we have sufficient data to calculate the ionization produced by the radium in a cylinder of any material of the same dimensions as those used in this investigation, provided it was placed in the standard position indicated above.

For example, Colum 6 of Table V. gives the reduced readings corresponding to the gamma rays alone which entered the respective cylinders. From Table III. the absorption powers of these cylinders are known in percentages; and by means of these numbers values can be calculated for the ionization which would be produced in the same volume of free air by the gamma rays from the radium. Column 7 of Table V. contains the values of I_{lp} corrected in this way, and the mean of the results is 36·3. This number, it will be seen, represents the ionization which would be produced by the gamma rays from the radium, used in these experiments in a cylinder of any metal 60 cms. high, and 24 cms. in diameter, situated in relation to this radium exactly as the cylinders were in the experiments described above on the supposition that no absorption of the rays took place on traversing the walls of the vessel.

If absorption did occur, and the absorption constant for the cylinder was known, the value 36·3 could be modified accordingly, and the ionization produced by the gamma rays alone within the cylinder be deduced.

Suppose, for example, that the cylinder was an aluminium one 0·73 mm. in thickness, the absorption from Table III. could be neglected, and 36·3 would represent the ionization produced by the gamma rays in the air which it enclosed. From the results given in Column 5, Table V. the corresponding ionization due to the secondary radiation excited in the aluminium by the gamma rays would amount to 57 per cent. of 36·3 or 20·7, so that the total ionization within the aluminium cylinder due to the gamma rays from the radium and to the secondary rays which they excited, could be represented by (36·3 + 20·7) or 57 would be the estimated reading.

In an actual experiment with an aluminium cylinder of the dimensions given above, and situated approximately in the position indicated, the reading 62 was obtained as the mean of a number of observations. This difference between the experimental and the calculated values for the ionization is not more than 8 per cent.; and it is not surprising when it is remembered that no special precautions were taken to place the aluminium cylinder exactly in the position occupied by the lead cylinders with which the measurements were made upon which the present calculations are based. It is possible that the aluminium cylinder may have been as much as a centimetre out from the position it was supposed to occupy during the measurements. From the agreement presented by these measurements, it seems warrantable to conclude that the relation which has been established between the relative amounts of ionization produced by primary and secondary radiations within a mass of air confined in lead or aluminium cylindrical vessels with the dimensions described above, is a reliable one.

III. *On the Character of the Radiation from different Metals.*

From the foregoing discussion it is evident that with the cylinders examined, a definite proportion existed between the ionization produced by the gamma rays and that produced by the secondary rays which they excited. With lead cylinders the amount contributed by the secondary rays was, as we have seen, twice that arising from the passage of the gamma rays. But with aluminium cylinders the relation was almost exactly the inverse of the preceding, the ionization due to the primary rays being nearly twice that due to the corresponding secondary radiation.

It will be remembered, too, that the radium from which the gamma rays were obtained was surrounded by a block of lead 3 cm. in thickness, so that the radiation which issued from it must have been of a very penetrating nature, and therefore similar in its characteristics to the penetrating radiation which has its source in the earth, and contributes to the natural ionization observed in air or other gases confined in metallic vessels.

It seems fair to conclude then, that in natural or spontaneous ionization in air confined in metallic vessels a proportion should hold between the ionization due to the primary and that due to the secondary rays, similar to the one which was found to hold experimentally with the gamma rays from radium, and the secondary rays emitted by them.

Assuming this relation to hold, it is possible to establish a connexion between the conductivity of air confined in a vessel of one metal with that of air enclosed by a second of the same dimensions but of different material, provided neither metal contains any radioactive impurities.

With this relation established it is possible then to check the results obtained experimentally in particular cases, and by so doing arrive in a measure at a knowledge of the relative importance of the different factors which determine the ionization.

In Section I. of this paper it has been shown that with the lead cylinder No. 1 there was generated on the average 23 ions per c.c. per second. Assuming that no part of this was due to any impurity in the metal, it follows from the numbers given in Table V. that one-third of this number was due to the penetrating radiation which entered the cylinder, that is 7·67 of the 23 ions were generated by the penetrating radiation which traversed the air in the vessel. Allowing for the absorption by the cylinder of 15·36 per cent. of the penetrating radiation, it follows that 9·06 ions were generated per c.c. per second in free air by the penetrating radiation from the earth. Turning now to the aluminium cylinder No. 10, it is fair to assume, since its absorption of the gamma rays has been shown to be negligible, that 9·06 may be taken, without sensible error, to be the number of ions generated per c.c. per second by the penetrating radiation which entered it. The number produced per c.c. per second by the induced secondary radiation would then, according to Table V., be 57 per cent. of this number, that is 5·16, and therefore 14·22 would be the total number generated per c.c. per second by the combined radiations. In the same manner it can be shown, by taking Eve's value of 53·7 per cent. as representing the amount of secondary radiation excited in a zinc radiating surface compared with that obtained with a lead one, that 17·88 is the number of ions which should be generated by the penetrating radiation from the earth, and by the secondary rays excited by these in each cubic centimetre of air enclosed in the zinc cylinder No. 8.

TABLE VI.

Column 1.	Column 2.	Column 3.	Column 4.	Column 5.	Column 6.
Cylinder No.	Metal.	Percentage of penetrating rays absorbed. Per cent.	Total No. of ions generated per c.c. per second (observed).	Total No. of ions generated per c.c. per sec. by penetrating rays from earth and excited secondary rays. (Calculated on basis of no active impurity in No. 1.)	Difference in "q" representing active impurities in substance of cylinder.
1	Lead	15·36	23	23	
2	"	16·29	160	22·77	137·23
3	"	9·36	37	24·63	12·37
4	"	11·2	78	24·15	53·85
5	"	12·92	34	23·67	10·33
6	"	10·12	55	24·42	30·58
7	"	13·23	61	23·58	37·42
8	Zinc	4·62	15	17·88	
9	Aluminium	·23	15	14·22	·78

Calculations similar to the above have been made on the number of ions which, on the basis laid down, should be generated per c.c. per second in the air enclosed by each of the lead cylinders, Nos. 2–7, and the deduced values are all recorded in Column 5 of Table VI. With cylinder No. 9 the calculated value and that found experimentally present a good agreement; but with cylinder No. 8 the calculated is slightly greater than the observed value, and may be due to our making too high an estimate of the ionization produced by the secondary rays from the zinc walls. Eve states in his paper that he found the secondary radiation came not only from the surface of the different radiators, but from a considerable depth as well; and since the zinc used in these experiments was only 1·62 mm. in thickness, it was probably not so thick as the plates used by him. A smaller value should then be assigned to the ionization produced by the secondary radiation from the zinc walls; and if this were done, the calculated and the observed values for zinc would come into better agreement.

The argument which has just been used to explain the high ionization calculated for the zinc cylinder would apply with still greater force to the secondary rays from aluminium. With this metal Eve found that the secondary radiation came from as great a depth as 3 mm.; and if this condition holds generally for aluminium, it follows that we have assigned for this metal also too high a value to the ionization produced by the secondary rays. A reduction should then be made in the calculated value for "q" of 14·22 ions per c.c. per second, and as this value is already slightly below the observed value of the number of ions generated per c.c. per second in the aluminium cylinder, this reduction would leave a correspondingly greater number of ions to be accounted for, very probably by the presence of active impurities in the substance of the receiver.

It is of special importance, however, to note the fair agreement which exists between the calculated and the observed values, in these experiments, for the ionization produced in air enclosed in cylinders of lead, zinc, and aluminium, as illustrated by the numbers given in Table VI. for Cylinders Nos. 1, 8, and 9, since it emphasizes the view that ordinary metals do not possess any intrinsic radiation, and that when any high conductivity is observed in air confined in metallic vessels, it must be due to the existence of quantities, more or less considerable, of some foreign radioactive substance in the metals.

Examples of such contamination are clearly in evidence in the results given in Table VI. for the lead cylinders Nos. 2 to 7 inclusive; and the numbers given in Column 6 give an estimate of the relative amounts of the active impurities present in the different samples of lead used in their construction.

In what has preceded in this Section the discussion has rested upon the assumption that the lead in Cylinder No. 1 contained no active impurity; and while the experimental results rather fit in with the deductions which have been made on this hypothesis, there still remains the possibility that some part of the ionization observed with this cylinder may have been due to traces of some foreign active substance.

If one could surround the cylinder with some substance which would act as a screen, and so cut off entirely the earth's penetrating rays, and consequently also the induced secondary radiation, any ionization within the cylinder would then be due to active impurities present in the metals. The difficulty, however, is in finding a suitable screen. In some experiments made in this direction by the writer * in collaboration with E. F. Burton some years ago, screens of water were used, and with them it was found possible to make a reduction as high as 37 per cent. in the ionization within a closed cylinder. About the same time H. L. Cooke †, in studying the conductivity of air enclosed in a brass vessel, was able to reduce the ionization 30 per cent. by surrounding the brass with a screen of lead. Later still Elster and Geitel ‡ observed a fall of 28 per cent. in the conductivity of the air enclosed in an aluminium cylinder on removing the apparatus from the surface of the earth to a closed space in a mine surrounded by a wall of rock salt. But in none of these experiments is there clear evidence that the penetrating radiation was entirely cut off. On the other hand, in several of the experiments which have been made with this object in view, it has been found that active impurities were present in the substances used as screens, and the screens themselves were observed to contribute a penetrating radiation which masked any falling off in the intensity of the external radiation arising from absorption.

Although many of the surface waters of the earth which have been examined, among other substances, by different experimenters, have been shown to contain minute traces of radium, it is possible that such waters as those of the great lakes of Canada might be fairly free from such an impurity, and if so might serve to screen off radiations from an ionization chamber immersed in them. Some experiments made a few years ago by the writer failed to show the existence of any measurable amount of the emanation from radium in the water of Lake Ontario; and from this result it would appear that the water of this lake would seem to afford the substance requisite to carry out an experiment such as that just indicated. The experimental difficulties, however, are considerable, and it is doubtful if they could be overcome in a

* McLennan and Burton, Phys. Rev. no. 3 (1903); Burton, Phys. Rev. no. 3 (1904).

† H. L. Cooke, Phil. Mag. [6] vi. p. 403 (1903).

‡ Elster and Geitel, *Phys. Zeit.* Nov. 1, 1905, p. 733.

manner to give satisfactory results. If this water proved to be an efficient screen, it would be interesting to see whether all ionization would disappear from the air confined in a cylinder such as No. 1 of this investigation, if it were immersed to a considerable depth in it; for on the assumption that the material used in the construction of the cylinder contained no active impurity, this is what one should expect to find.

IV. *On the Rise in Conductivity of Air confined in Metallic Vessels.*

In the course of the experiments described above, it was repeatedly found when one of the cylinders was filled with fresh air filtered through cotton- and glass-wool, and afterwards sealed up, that the conductivity of the enclosed air steadily rose for a number of days, and finally reached a steady value.

This phenomenon, which has been described already by the writer and E. F. Burton in the paper cited previously, has also been observed by a number of experimenters, including Elster and Geitel*, Eve†, Wood and Campbell‡, and others, but up to the present has not received a satisfactory explanation.

During the present investigation special observations were made on this effect in connexion with air confined in the lead cylinders Nos. 1 and 2, on account of the great difference observed in the values of the conductivity impressed upon the air introduced into them.

When cylinder No. 1 was thoroughly scoured and cleaned in the manner described in the beginning of this paper, and freshly filtered air blown through it for twenty minutes, a reading of 7·7 divisions per minute, or a number within 1 or 2 per cent. of it, was regularly and repeatedly obtained throughout the period, now nearly six months, during which the observations have been carried on. If the air after being introduced into this cylinder was allowed to remain undisturbed for some time, and measurements made on its conductivity at stated intervals, it was found that the ionization steadily increased, and after a period of a week or ten days reached a value of approximately 11 divisions per minute. If when this stage was reached filtered air was blown through the cylinder for twenty minutes, it was always found that a

* Geitel, *Phys. Zeit.* ii. pp. 560–563 (1901); Elster and Geitel, *ibid.* ii. pp. 116–119 (1900).

† Eve, Phil. Mag. [6] xii. p. 189 (1906).

‡ Wood and Campbell, Phil. Mag. Feb. 1907, p. 265.

drop in the conductivity occurred to between 8 and 8·5 divisions per minute.

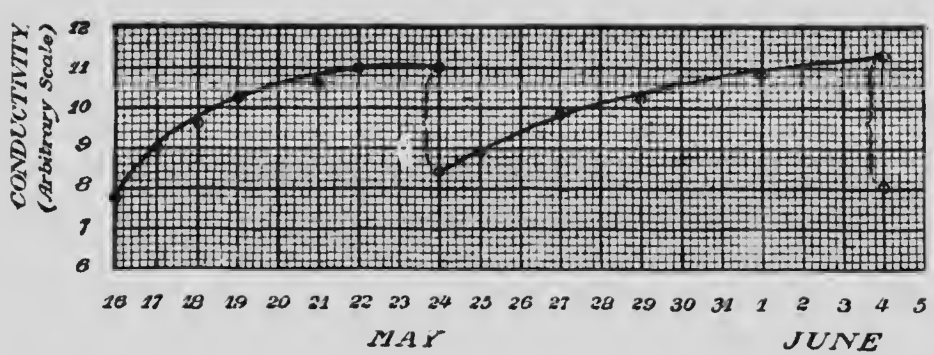
If the air was again left undisturbed in the cylinder, its conductivity rose once more and finally reached the maximum value of approximately 11 divisions per minute. In conducting these operations it was not found necessary to draw fresh air through the cylinder for more than twenty minutes in order to lower the conductivity to the minimum value.

TABLE VII.

Cylinder No. 1.

Date.		Conductivity (Arbitrary Scale).
May 16	....	7·7
17	....	9·0
18	....	9·6
19	....	10·32
21	....	10·65
22	....	11·09
24	....	11·02
Fresh air blown through cylinder for twenty minutes:		
May 24	....	8·54
25	....	8·91
27	....	9·83
29	....	10·16
June 1	....	10·79
4	....	11·3
Fresh air again blown through cylinder for twenty minutes:		
June 4	....	8·1

Fig. 1.



With cylinder No. 2 thoroughly cleaned in the manner already described, a reading of 54·5 divisions per minute with but slight variations was regularly obtained with freshly filtered air. With this cylinder, too, when the air was undisturbed in it the conductivity steadily rose, and after a time approached a maximum value. The time required for the steady state to be reached was, however, much greater than with cylinder No. 1.

A set of readings which exhibit this rise are given in Table VIII. and a curve representing them is shown in fig. 2.

Table VIII.

Lead Cylinder No. 2.

Time.		Conductivity (Arbitrary Scale).
June 5	....	54·6
7	....	58·3
9	....	61
12	....	62
15	....	63·2
17, 5 P.M.	......	64

Filtered air was now blown through cylinder for twenty minutes:

June 17, 5.30 P.M. ...	60·6
18, 1.00 P.M. ...	64·4
27, 10.30 A.M. ...	67

Filtered air again blown through for twenty minutes:

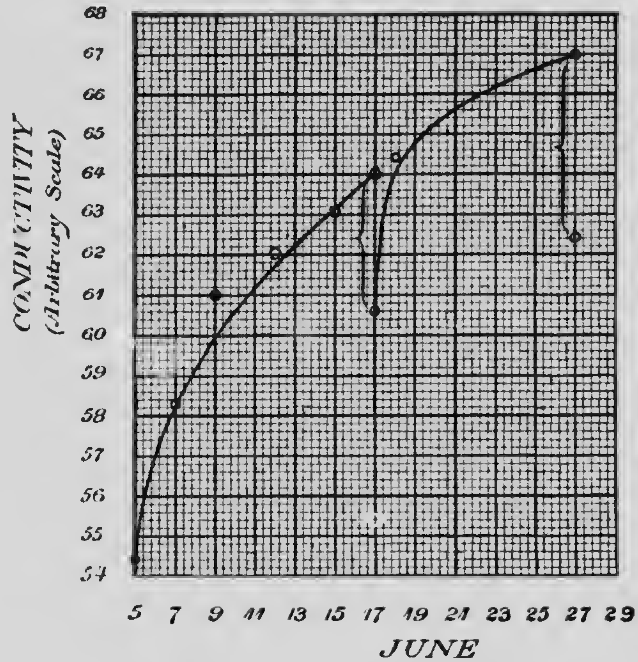
June 27, 12.30 P.M. ...	62·4

Filtered air blown through for one hour:

June 27, 3.30 P.M. ...	62·8

From this it will be seen that when fresh air was introduced into the cylinder on June 17 the reading dropped from 64 to 60·6, and again on June 27 the introduction of fresh air was followed by a drop from 67 to 62·4. Air was then drawn through the cylinder for one hour, but no further drop in the conductivity ensued. When similar observations were made on other occasions with this cylinder similar results were obtained. After a rise occurred, the introduction of fresh air was always followed by a drop in the conductivity, but the initial value of 54·5 divisions was never reached without re-cleaning and washing the inner surface of the lead.

Fig. 2.



From these observations it would appear that the rise in the conductivity of the air in both cylinders may be divided into two parts and ascribed to different causes; the one being associated with some change in the surface of the metals used in the construction of the cylinders, and the other with some substance which becomes diffused throughout the air, and can be blown out with it.

With cylinder No. 1 the part due to the first cause was very small, and in no case exceeded 10 or 12 per cent. of the minimum reading obtained the conductivity.

The second part, too, was very definite with this cylinder, and when the maximum conductivity had been reached it corresponded to a reading of between 2·5 and 3 divisions per minute.

With cylinder No. 2 both parts of the rise in conductivity were well marked. But as the numbers in Table VIII. show, both parts exhibited a steady increase during the time the conductivity was under observation, and owing to the length of time required for the maximum state to be reached, it is not possible at present to express them as definite percentages of the minimum reading obtained with this vessel.

Repeated observations on both cylinders have invariably given the results just described, and as the greatest care was taken throughout the investigation to prevent contamination of the cylinders by foreign active substances except what might be introduced along with the filtered air, it would seem clear that a process is going on in the metals, possibly a diffusion from the interior, whereby the surface becomes coated with a layer of active matter which makes an important contribution to the ionizing power of the metal.

From the observations which have been made so far, it has been impossible to decide whether the second part of the rise in the conductivity of the confined air was due, in whole or in part, to an active substance introduced with the air or to an emanation from the walls of the vessel, but as observations are still being made with the cylinders, it is possible that some additional facts may be obtained which will clear up this difficulty, and also throw light on the nature of the active impurity which has been shown to be present in varying amounts in the different samples of lead examined.

V. *Summary of Results.*

1. The conductivity of air enclosed in lead cylinders has been shown to vary widely with the samples of lead selected. The lowest conductivity observed in air enclosed by this metal corresponded to the production in the air of 23 ions per c.c. per second, and the highest to the production of 160 ions per c.c. per second.

2. These wide variations show that the high activity of lead which has been observed generally is due to the presence of active impurities in varying amounts in the lead, and not to a high intrinsic radiation from the metal.

3. Calculations made on the observations show that the differences in the conductivities of air confined in vessels of different metals, including lead, when free from active impurities, arise from and are due to differences in the secondary radiations from these metals.

4. Experiments made with the gamma rays from radium showed that of the ionization produced by these rays in air enclosed in lead receivers, two-thirds was due to the excited secondary rays and one-third to the gamma radiation itself.

With aluminium cylinders on the other hand, the measurements show that approximately two-thirds of the ionization was due to the gamma rays, and one-third to the secondary rays excited by this radiation in the metal.

5. Calculations based on observations on the conductivity of air confined in different receivers lead to the conclusion that approximately 9 ions per c.c. per second are generated in free air by the penetrating radiation from the earth.

Before concluding I wish to acknowledge my very great indebtedness to Mr. V. E. Pound, for his kindness in repeating and verifying many of the observations described in the first part of this paper.

The Physical Laboratory,
University of Toronto,
July 1, 1907.