



## LXII. Measurements on the Earth's penetrating radiation with a wulf electrometer

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effected, indirectly, through its hydrated halogen and oxygen combinations in aqueous solutions, so would the anhydrous oxides of other members of the series  $H\ 2n$  (and of other series) be resolved into their ultimates through the medium of their silicates, acting as solutions, during the process of transmutation.

All the silicates of the series  $H\ 2n$ , and some of other series, are easily vitrified in small quantities in laboratory crucibles and appliances. Their spectra can then be examined during electrification in tubes (under suitable conditions of temperature and pressure) for the discovery of new elements and the identification of those already known.

It may be laid down as a canon of chemical science, that the members of any natural series of elements are never transformed into the members and ultimates of any other series. Thus neon is the permanent transformation ultimate of the series  $H\ 7n$ ; just as helium is the fixed ultimate of the series  $H\ 2n$ . Hence, also, helium and neon will be evolved from the vitrified silicates of calcium and barium. By the substitution of sodium and potassium for calcium and barium in their vitrified silicates, the transformation products would be neon and hydrogen, but without helium\*.

LXII. *Measurements on the Earth's Penetrating Radiation with a Wulf Electrometer.* By Prof. J. C. McLENNAN and Mr. A. R. McLEOD, *University of Toronto* †.

I. *Introduction.*

IN a paper by one of us in the *Phil. Mag.* of Sept. 1912, the results were given of a number of observations on the intensity of the earth's penetrating radiation taken, with a C. T. R. Wilson gold-leaf compensating electrometer, at a number of points on the sea and also at a number of places on land on both sides of the Atlantic. These results showed that while at a number of places in England and in Scotland and in the open at and near Toronto, the number of ions generated per c.c. per sec. in a zinc vessel containing air and hermetically sealed, was between eight and nine, the number

\* During the course of an elaborate analysis of many fine crystals of uraninite which led to the discovery of terrestrial helium, Dr. Hillebrand has shown (*Bulletin U. S. Geological Survey*, 1889-90) that this mineral, from various localities, contains from 3 to 10 per cent. of lead (Pb), the transformation ultimate of which is helium, as shown in my Tables, and is not, consequently, the ultimate of uranium (U).

† Communicated by the Authors.

generated in the same vessel on a steamer on the Atlantic was only about 6.03 ions per c.c. per sec.

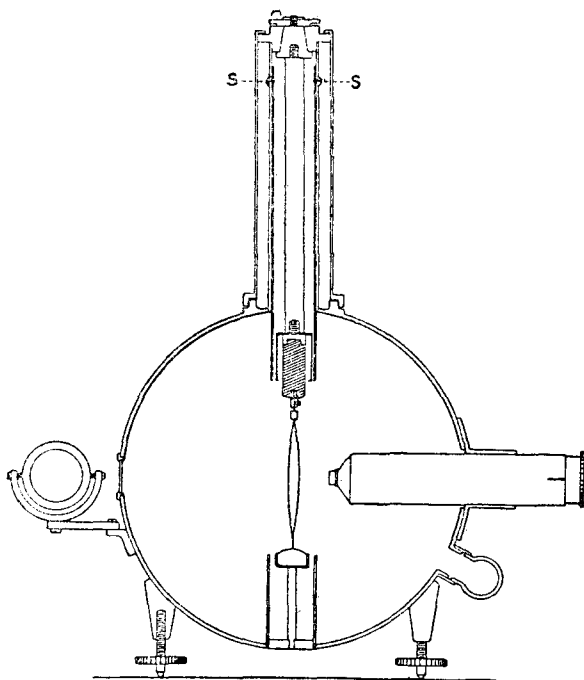
The readings on the Atlantic were taken with difficulty on account of the continued oscillation impressed upon the gold-leaf system by the swaying of the steamer. As a result these readings were not considered to have the same reliability as those taken on land at the different points of observation.

With a view to obtaining more reliable observations on the surface of the ocean a second set of readings was taken when crossing the Atlantic in September 1912, and again a third one when crossing in June of the present year. This time, however, a Wulf bifilar electrometer was used. The instrument behaved admirably, and with it readings were taken on board ship with the same ease as on land.

## II. *Apparatus and theory of Instrument.*

The form of the instrument used is shown in fig. 1. It

Fig. 1.



consists of a cylindrical receiver of zinc provided with plane sides which had a capacity of about two litres. The electrical

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system consisted of two conducting fused-quartz fibres attached at their upper ends to an insulating support and at their lower ends to a cross fibre also of fused quartz under tension. This cross fibre was attached to an insulating support as shown in the figure. The instrument was provided with a metal tube *ss*, which could be slid down over the electrical system. The use of this sliding tube was to limit the volume from which ions could be drawn to the fibres to as low a value as possible. With the tube raised the effective volume as given by the makers was 2021.1 c.c., but with it lowered the effective volume was only 31.5 c.c.

The fibres were illuminated by light thrown into the instrument by a mirror through a window, and the readings were taken with a microscope provided with a scale. The air in the receiver was kept dry with a small quantity of sodium carried in a small receptacle attached to the body of the instrument. The electrical system in practice was charged by means of a Zamboni pile through the intermediary of an insulated metallic sound which passed through the case, and which could be turned when desired so as to come into contact with a metal piece which connected the fibres to their upper insulating support. All the openings into the receiver, with the exception of the covering tube *A*, were either closed by soldered contacts or by fluted joints provided with leather washers. The lower end of the covering tube *A* had a ground conical surface, and when in position was held hermetically connected to the body of the instrument with a shoulder piece provided with a thread. The instrument was provided with a covering tube for the microscope and a cover plate for the window. Both of these could be screwed tightly against leather washers.

When all the openings into the receiver were carefully closed the instrument was both water-tight and air-tight.

The electrical system was calibrated in the ordinary way, and by means of a calibration curve the readings were transcribed from changes in deflexions into potential falls.

The capacity of the electrical system was 1.04 cm.

The theory of the instrument is as follows:—

Let  $Q$  be the loss of charge observed in one second and  $A$  the part of  $Q$  due to the leak over the insulating supports.

Let  $V$  be the effective volume with the tube *ss* up, and  $V_1$  its effective volume with the tube down.

Then  $Q = A + BV$  where  $B$  is a constant,

and  $Q_1 = A + BV_1$ ,

or

$$A = \frac{VQ_1 - V_1Q}{V - V_1},$$

$$= Q_1 - \frac{V_1}{V}Q$$

if  $\frac{V_1}{V}$  is a small quantity.

The charge on the ions generated per cubic centimetre per sec. is then given by

$$B = \frac{Q - Q_1}{V - V_1}.$$

Let now  $\Delta v$  be the loss in voltage per hour with the tube *ss* up, and  $\Delta v_1$  with it down.

Then if  $C$  is the capacity of the system

$$Q = \frac{C\Delta v}{300 \times 3600}, \text{ i. e. } = \frac{1.04\Delta v}{300 \times 3600}$$

in the present case, and

$$Q_1 = \frac{1.04\Delta v_1}{300 \times 3600}.$$

From this it follows that  $B$  is given by

$$B = \frac{1.04(\Delta v - \Delta v_1)}{300 \times 3600(V - V_1)}.$$

Finally, the number of ions generated per sec. per c.c. if saturation voltages are used is given by  $N = \frac{B}{e}$ , where  $e$  is the charge on an ion in electrostatic units, *i. e.*

$$N = \frac{1.04(\Delta v - \Delta v_1)}{300 \times 3600(V - V_1)e},$$

or, if  $V$  be taken as 2021.1 c.c.,  $V_1$  as 31.5 c.c., and  $e = 4.75 \times 10^{-10}$ ,

$$N = \frac{1.04(\Delta v - \Delta v_1)}{300 \times 3600 \cdot (2021.1 - 31.5) \times 4.75 \times 10^{-10}},$$

or

$$N = 1.02(\Delta v - \Delta v_1),$$

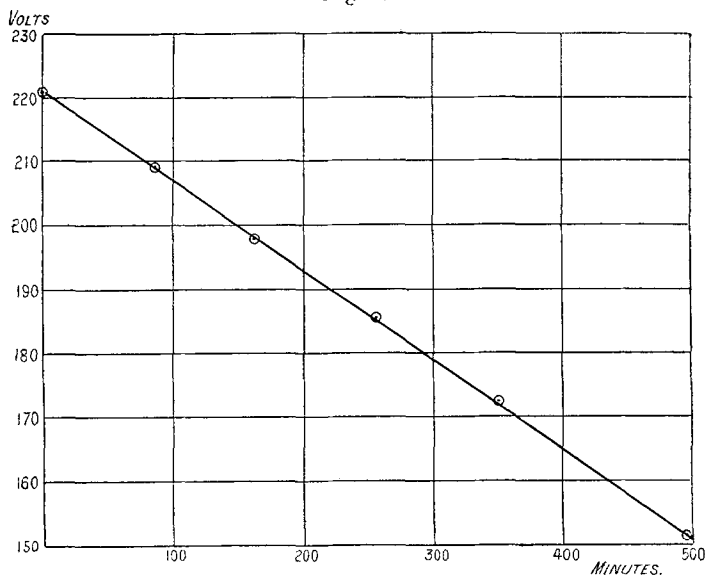
*i. e.* the number of ions generated in the receiver per cubic centimetre per sec. is equal to 1.02 times the difference in the drops in voltage per hour observed with the tube *ss* up and down.

A set of readings taken with instrument at Cambridge, England, is given in Table I., and a curve representing them

TABLE I.

Time in minutes.	Potential of electrical system.
0	221 volts.
86	209
164	197.9
257	185.5
351	172.1
442	159.5
495	151.3

Fig. 2.



is shown in fig. 2. These serve to exhibit the constancy of the ionization produced by the penetrating rays at the point of observation for a period of time extending over eight hours.

### III. Measurements on the Atlantic Ocean.

The readings taken on the two voyages referred to above are given in Table II.

TABLE II.

Measurements on the ionization in a closed vessel taken on a steamer on the Atlantic Ocean with a Wulf electrometer.

VOYAGE NO. I. ON SS. 'HESPERIAN.'		
Sept. 14, 1912.....	Firth of Clyde .....	4.4 ions per c.c. per sec.
15, „ .....	On the Ocean .....	4.2
16, „ .....	„ „ .....	4.5
17, „ .....	„ „ .....	4.1
18, „ .....	„ „ .....	4.3
19, „ .....	„ „ .....	4.3
20, „ .....	Off Belle Isle .....	4.1
21, „ .....	Off Romouski.....	4.0
22, „ .....	River St. Lawrence, near Quebec.....	4.5
		Mean = 4.3 ions per c.c. per sec.
VOYAGE NO. II. ON SS. 'MEGANTIC.'		
June 24, 1913.....	River St. Lawrence .....	5.57 ions per c.c. per sec.
25, „ .....	River and Gulf of St. Lawrence.....	5.26
26, „ .....	Gulf of St. Lawrence and Atlantic .....	5.07
27, „ .....	Atlantic Ocean .....	4.64
28, „ .....	„ „ .....	4.80
29, „ .....	„ „ .....	4.41
30, „ .....	„ „ .....	4.20
July 1, „ .....	Off North Coast of Ireland and Irish Sea .....	4.44
		Mean of last three readings = 4.35 ions per c.c. per sec.

The readings taken on the first voyage, it will be seen, are quite regular and uniformly low. Their average was 4.3 ions per c.c. per sec. The lowest reading, 4.0 ions per c.c. per sec., was that taken on Sept. 21, the day on which the steamer was passing from the Gulf into the River St. Lawrence.

The readings taken on the second voyage it will be seen started at 5.57 ions per c.c. per sec. and finally dropped to about 4.35, which is the mean of the readings taken on the last three days. The high initial readings were probably due to radio-active deposits which settled on the ship when in port at Montreal, but it is interesting in this connexion to note that no important drop was observed in the ionization when the steamer left port in the first voyage. If the prevailing winds at Glasgow were south-west ones it might afford an explanation, in part at least, of this result.

It is interesting also to note that the final readings on the ss. 'Megantic' were practically the same as those taken during the voyage of the 'Hesperian.' This would go to show that the contribution to the ionization by radiation from the materials and contents of the steamer was practically the same for both ships. Further, as Simpson and Wright\* had previously obtained 4.1 ions per c.c. per sec. for the ionization in a closed zinc vessel on a small skiff on the Atlantic, this would go to show that the amount contributed to the ionization by radiation from the ship was inconsiderable.

The mean of the readings taken on the ocean with the Wulf electrometer, viz. 4.33 ions per c.c. per sec., it will be seen was 1.7 ions per c.c. per sec. less than the mean of the readings previously taken with the Wilson electrometer, and in view of the accuracy and ease with which the readings could be made with the Wulf instrument, the value 4.33 ions may be accepted as closely representing the true value of the ionization obtainable on a large ship on the sea.

#### IV. *Measurements on Land.*

At various times previous to and succeeding the two voyages, as well as at times in the intervals between them, readings were taken with the instrument at a number of points at or near Toronto and also at a number of places on the other side of the Atlantic. These are summarized in Table III., and along with them are given the readings taken at a number of places with the Wilson Compensating Gold-leaf Electrometer.

From the numbers given it will be seen that the readings with both instruments were practically the same at Midlothian, Scotland, at Cambridge, England, and at the Physical Laboratory, Toronto. This, combined with the

\* Simpson and Wright, Proc. Roy. Soc. Ser. A. vol. lxxxv. p. 175 (1911).



TABLE III.

Measurements of penetrating radiation at Stations on Land.

OBSERVATION POINT.	Values of "q" = $\left\{ \begin{array}{l} \text{the number of ions pro-} \\ \text{duced per sec. in air} \\ \text{at atmospheric pres-} \\ \text{sure by the pene-} \\ \text{trating radiation.} \end{array} \right.$	
	Wulf Electrometer.	Wilson Electrometer.
Braunschweig, Germany .....	8.1	...
Midlothian, Scotland .....	9.0	8.32
Cambridge, England, I. ....	...	9.03
II. ....	8.26	...
The "Physical" Laboratory, Toronto .....	8.62	9.08
The Meteorological Observa- tory, Toronto .....	...	8.88
The University Lawn .....	8.1	...
In a residence in Toronto made of red brick .....	9.47	...
In a deep pit in the Lorraine Shale in a brick-yard at Toronto .....	12.0 to 14.8	...
Close to walls of glacial clay deposits .....	8.84	...
On layer of sand and clay, 2.5 metres thick, above pit of shale .....	8.67	...
On surface-layer of sandy loam about 33 metres from entrance to opening in clay deposits .....	6.83	...
On the surface of Lake Ontario Eight metres under the sur- face of Lake Ontario at a point where it was twenty metres deep .....	4.93	4.46
Mean of measurements taken on the Ocean .....	4.77	...
	4.33	6.03

high value obtained for the ionization on the ocean with the Wilson electrometer, goes to show, as one might have anticipated, that it is quite impossible to take readings on ship-board with an instrument provided with a gold-leaf system with any degree of accuracy.

In the course of the observation at Toronto values between 9 and 10 ions per c.c. per sec., with a mean of 9.47, were obtained when the readings were taken in a residential building the walls of which were constructed of red brick.

As values close to 8.62 for "q" were always obtained in

the Physical Laboratory, which was constructed of stone and white brick, and as these values were uniformly lower than those obtained in the residence referred to, it was thought that possibly the higher values might be due to a measurable excess of radio-active matter contained in the bricks of the residential structure.

As the bricks for both structures were made from different deposits in the same brick-yard a series of measurements was made in the neighbourhood of these different deposits, and it was found that the surmise was correct.

In this particular brick-yard the surface-layer is a sandy loam about one metre thick ; below these there is a series of strata of glacial clays, each stratum ranging from 4 to 10 metres in thickness. Below the clay is a deposit of Lorraine shale some 250 metres in depth. This brick-yard, which has been worked for over fifty years, now consists of a great opening in the face of a hill and a huge cylindrical cavity in front of this opening and extending down into the shale. The depth of the cavity at present is about 25 metres and the length of its diameter is about the same. The sides of the opening in the face of the hill as it stands consist of a series of terraces, each of which consists of one particular deposit of clay. This system of terraces in the clays, it will be seen, provided an excellent means of investigating the radiation from each deposit in turn, and when readings were taken on each terrace it was found that these gave values for " $q$ " extending from 8 to 9 ions per c.c. per sec. with a mean value of about 8.84.

In the shale pit, however, much higher readings were obtained. These were taken at different points on the base of the pit and on a number of ledges which were accessible. The values found for " $q$ " in the shale-pit ranged from 12 to 14.8 ions per c.c. per sec., the lower values being obtained when the stations were taken at points near surfaces which were weathered, and the higher ones when the observation stations were close to places where the surface of the shale had been recently exposed.

As an illustration of how definitely the comparatively strong radiation from the shale producing the high ionization was localized, a particular measurement may be cited.

The stratum immediately above the shale consisted partly of sand and partly of clay. At one particular point this layer was about 2.5 metres thick, and it extended up to the face of the opening of the pit in the shale. The reading obtained on this layer at a point about 6 metres back from the edge was only 8.67 ions per c.c. per sec., which shows

that this layer of sand and clay acted as a screen and cut off entirely the excess radiation from the shale underneath.

Another illustration of a screening effect was obtained in the reading taken on the surface of the ground back about 30 metres from the opening into the clay bank. At this station no direct radiation could reach the instrument from the shale, and the radiation from the clay deposits could only reach it after passing through the surface-layer of sandy loam, which was about one metre thick. The reading at this station was only 6.82 ions per c.c. per sec. From this low value it was evident that the sandy loam contained considerably less active matter than the clays and also that it acted as a screen to absorb the radiation coming from the clay lying below it.

It may be added, in regard to these various deposits, that it was the shale which was used in making the red-coloured bricks and the clays in making the light-coloured ones.

#### V. *On the Penetrating Radiation from the Atmosphere.*

In several previous communications by one of us \* and by C. S. Wright †, attention has been drawn to the fact that the ionization in a closed vessel is very much less over the water of Lake Ontario than it is at points on the neighbouring land. Further, in measurements made on the lake with a zinc receiver of about 27 litres capacity and a Wilson electrometer the value of "*q*" has been shown to be about 4.46 ions per c.c. per sec.

On repeating these measurements with a Wulf electrometer the mean of a number of sets of observations gave a value of 4.93 ions per c.c. per sec. for "*q*," which is slightly higher than the value previously obtained with the larger receiver. These observations were carried out on a small skiff about 2 kilometres from the shore, at a point where the water was about 20 metres deep.

In a second set of observations made at this point on the skiff the electrometer was placed for protection in a metal box of aluminium-bronze with walls a little over one centimetre thick. In these measurements the value of 4.81 ions per c.c. per sec. was obtained for "*q*".

In a third set the metal box containing the electrometer was lowered into the water to a depth of about eight metres, and in these experiments the average reading obtained was 4.77 ions per c.c. per sec. From this result it would appear

\* Phys. Rev. vol. xxvi. No. 6, p. 526 (1908).

† Phil. Mag. ser. 6, No. 17, p. 295 (1909).

that the radiation coming from the air above the lake did not contribute any more to the ionization in the electrometer than about  $\cdot 16$  ion per c.c. per sec.

In attempting to ascertain the contribution made to the ionization in a closed vessel by radiation coming from active matter in the air above the land, measurements are complicated by the effect of radiation from active matter in the soil and from active matter deposited on the surface of the ground from the atmosphere. It would seem, however, since the measurements described above were made at a point only about 2 kilometres from the shore, that the contribution made to the ionization in air in a zinc vessel by radiation from the active matter in the air over the land near Toronto cannot be very far from  $0\cdot 2$  ion per c.c. per sec.

## VI. *Residual Ionization.*

From the measurements which have been described above, it would appear that the lowest value obtainable for the ionization in a closed zinc receiver, at points near the surface of the earth where the intensity of the penetrating radiation may be considered to have a minimum value, approximates to 4 ions per c.c. per sec. This, it will be remembered, was the mean value obtained for  $q$  from the measurement made on the s.s. 'Hesperian' on Sept. 21st, 1912, and it was also practically the value found for " $q$ " by Simpson and Wright \* on a skiff on the Southern Atlantic.

To what, then, is this residual ionization due? As an attempt to answer this question the following experiments may be of interest. In these the electrometer was placed in the aluminium-bronze box used in the experiment under water on the lake, and this box was suspended in a moderate-sized tank which could be filled with water and which was situated in the attic of the Physical Laboratory at Toronto. Readings were taken of the ionization in the electrometer when the tank was empty and also when it was filled with water. With the tank empty the reading was  $8\cdot 05$  ions per c.c. per sec., and with it filled the reading was  $5\cdot 82$  ions per c.c. per sec. The dimensions of the box were  $36 \times 22 \times 18$  c. cm., and those of the mass of water surrounding it were  $121 \times 90\cdot 7 \times 83$  c. cm. This, it will be seen, gave roughly a mean of  $36\cdot 5$  cm. as the thickness of the water-screen surrounding the box.

Assuming the water to contain no radioactive matter, we

\* *Loc. cit.*

may suppose the ionization in the electrometer to be given by

$$(I - x) = (I_0 - x)e^{-\mu d},$$

where  $\mu$  is the coefficient of absorption of the penetrating radiation,  $d$  the thickness of the water-screen, and  $x$  the ionization in the electrometer which is not due to the penetrating radiation. We have then

$$(5.82 - x) = (8.05 - x)e^{-36.5\mu}.$$

For soft gamma rays Rutherford \* gives the value .0558 for  $\mu$  and for harder rays the value .0472. The measurements of Hess † at Vienna on the absorption of gamma rays by air also lead to a value for  $\mu$  for water of .0413.

Applying these values we find the value of  $x$  to be as follows :—

$\mu$ .	$x$ (ions per c.c. per sec.).
.0558	5.48
.0472	5.33
.0413	5.19

In so far as these measurements go then, it would appear that 5.19 ions per c.c. per sec. is the lowest value one should have expected to get for the ionization in the zinc vessel when all the penetrating radiation was cut off.

In view, however, of the fact that 4 ions per c.c. per sec. was obtained experimentally, the above experiments can only be considered as giving a roughly approximate result.

They serve to show, however, that unless there is present at the surface of the earth a radiation of a much higher penetrating power than any yet observed, there must be a residual ionization in air confined in a zinc vessel (of about 4 ions per c.c. per sec.) when it is not traversed by any radiation from an external source.

It would seem, therefore, that this residual ionization must be due either to radiation from a minute quantity of radioactive matter still remaining in the zinc of which the receiver is made, or to a process going on in the gas which results in what may be called a spontaneous dissociation of the molecules.

If the residual effect were due to active matter in the walls of the receiver one should expect that the value obtained for " $q$ " would increase if the volume of the receiver were diminished. Since the value of 4.1 ions per c.c. per sec. was

\* Rutherford, 'Radioactive Substances and their Transformations,' p. 266.

† Hess, *Phys. Zeit.* vol. xii. p. 998 (1911).

obtained for “ $q$ ” by Simpson and Wright with a zinc receiver of about 27 litres capacity, and a value of 4 ions per c.c. per sec. by the writers with an ionization-chamber of the same metal of only 2 litres capacity, one is led to the conclusion that the experimental results obtained so far lend no support to the view that the residual ionization obtained in air confined in zinc receivers is due to a radiation emitted by the walls. It would be interesting, however, to see what resulted if receivers of still smaller capacity than two litres were used. On the other hand, it has been shown by J. J. Thomson \*, and again recently by Langevin and J. J. Rey †, that one cannot account for this residual ionization by supposing it due to collisions between the molecules, for, on this hypothesis, the increase in ionization with a rise in temperature should be enormously greater than any increase which has been observed.

The writers wish to acknowledge their indebtedness to Messrs. P. Blackman, G. S. Campbell, and E. C. Henderson for their kindness in making corroborative measurements at various times during the investigation.

The Physical Laboratory,  
The University of Toronto,  
July 1st, 1913.

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LXIII. *On a New Method of Determining the Horizontal Intensity of the Earth's Magnetic Field.* By WALTER A. JENKINS, M.Sc. (1851 Exhibitioner) ‡.

THE ordinary method for the determination of the horizontal component of the earth's magnetic field is somewhat lengthy and involves several troublesome corrections. The following method, while as accurate as the old one, possesses the very great advantage of involving no corrections.

The principle of the method is the production of a known field opposite to that of the earth's and twice its magnitude. The equality of the two fields—that due to the earth and that due to the combination of the earth's and the produced one—is determined by the equality of the times of vibration of the same magnet, when the applied field is off and on, and the applied field is determined by measuring the current producing it.

\* J. J. Thomson, ‘Conduction of Electricity through Gases,’ 2nd ed., p. 294.

† Langevin & J. J. Rey, *Le Radium*, April 1913, p. 139.

‡ Communicated by Prof. W. M. Hicks, F.R.S.