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UNIVERSITY OF TORONTO STUDIES

PAPERS FROM THE PHYSICAL LABORATORIES

No. 41: THE INTENSITY OF THE EARTH'S PENETRATING RADIATION AT DIFFERENT ALTITUDES AND A SECONDARY RADIATION EXCITED BY IT, BY J. C. McLENNAN AND E. N. MACALLUM.

(REPRINTED FROM TRANSACTIONS OF THE ROYAL SOCIETY OF CANADA, 3RD SERIES, VOL. V.

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The Intensity of the Earth's Penetrating Radiation at Different Altitudes and a Secondary Radiation Excited by it.

By PROF. J. C. MCLENNAN and MR. E. N. MACALLUM, B.A.

(Read May 16, 1911.)

I.—PENETRATING RADIATION AT DIFFERENT ALTITUDES.

In a paper in the Phil. Mag. Jan. 1911, page 37, Dr. A. S. Eve on certain assumptions calculates the probable effect of altitude on the intensity of the γ rays from radium C present in the earth and obtains the values given in Table I. below for the ionization due to this radiation at points at different heights above the ground.

In his calculations he made no correction for a decrease in the density of the air with increase in altitude, but pointed out that this would tend to augment the lower figures given in the table. He also stated in the paper that the number of ions made per cubic centimetre per second should perhaps be doubled if the effect of thorium in the earth were added to that of radium.

From the numbers given in the table it is clear that if the penetrating radiation present at the surface of the earth is entirely of terrestrial origin, it should be possible to detect a diminution in the intensity of this radiation even at moderate distances above the earth's surface.

TABLE I.

Height in Metres.	Penetrating Radiation.	
	Ratio.	Ions per cm.³ per sec.
0	1·00	·80
1	·98	·78
10	·83	·67
100	·36	·29
1,000	·001	·008

The only numbers which directly lend confirmation to Eve's conclusions appear to be given in a paper by Wulf (Le Radium June 1910, and Phys. Zeit. 15 Sept. 1910), who found "q" = 6 for the number of ions made per cc. per second by the penetrating radiation at the surface of the earth in Paris, and "q" = 3·5 at a height of 300 metres on the Eiffel Tower.

In addition to these results some observations made by Gockel*—who noted a moderate decrease in the saturation current of an electroscope which he carried in a balloon ascent of some 4 kilometres—seem to be the only ones which throw any light on the question of a diminution in the intensity of the penetrating radiation with the altitude.

In order to see if such a diminution as that indicated by Eve's numbers was observable at Toronto, a series of measurements was made at different points both on the ground and on buildings at different heights above the ground.

The intensity of the penetrating radiation at different places was obtained by measuring with a C. T. R. Wilson electrometer†, carrying a compensating electrical condenser, the saturation current through a mass of air confined in an hermetically sealed zinc receiver of about 30 litres capacity. The zinc of which the receiver was constructed was of the ordinary commercial variety and was not selected with any idea of being specially free from radioactive impurities.

As V. E. Pound‡ has shown that 7 mms. of aluminium are required to completely absorb all the different types of β radiation emitted by a sample of radium in equilibrium, it follows that the walls of the receiver used in these measurements were not sufficiently thick to exclude all radiations of the β type which might accompany and be possibly caused by the penetrating radiation.

From observations made at Toronto at different points in the month of March last, selected sets of consecutive readings are given in Table II.

From the table it will be seen that the value obtained for "q" in a room in the physical laboratory was about the same as that obtained in the open space on the University lawn, viz., slightly over 15 ions per c.c. per second. The measurements made on the ice on Toronto Bay, however, gave a much lower value "q" = 9·3 than those made on the lawn and confirmed the observations made by one of us and Mr. C. S. Wright§ in 1907 and 1908 when there was found an exceptionally low value for "q" over the water of Lake Ontario.

The observations made in a room in the basement of the City Hall it will be seen gave a mean for "q" of 16·1, while those made at the

* Gockel, Phys. Zeit, 11, p. 280, 1910.

† Pr[illegible] f Roy. Soc. of Canada, p. 85, 1908, and, Phil. Mag., Feb. 1909, p. 310.

‡ [illegible] of Roy. Soc. of Canada, p. 53, 1908, and Phil. Mag. 1909, Jan. p. 126.

§ Loc. cit.

TABLE II.

"q" = the number of ions made in the receiver per cubic centimetre per second.

The Physical Laboratory.	The lawn, University. Campus.	The ice on Toronto Bay. Depth of water 5 metres. Distance from shore = 400 metres.	Basement of City Hall. Engineer's room.	City Hall Clock Tower. 64 metres high.
15·2	15·1	9·3	16·5	11·9
15·3	15·2	9·2	15·9	12·2
15·5	15·0	8·9	15·2	11·6
14·9	15·2	9·0	15·7	12·7
15·1	15·1	9·8	16·3	11·8
15·5	15·2	9·0	16·6	12·4
14·6		9·8	16·9	12·2
14·9		9·4	15·7	11·8
15·2		9·8	15·5	12·1
15·8		9·1	16·4	12·4
Mean = 15·2	Mean = 15·[illegible]	Mean = 9·3	Mean = 16·1	Mean = 12·1

top of the clock tower on the building 64 metres from the ground, gave a mean of only 12·1 ions per c.c. per second.

From the evidence adduced by C. S. Wright* it would appear that the ice and water in Toronto Bay cut off practically all the penetrating radiation from the ground beneath. Assuming this to be so we obtain from the numbers given in Table II. the value 5·8 for the number of ions made per c.c. per second in the air in the receiver by the penetrating radiation present at the lawn as well as by the secondary rays produced by this radiation at the metallic walls of the receiver and probably, too, at the surface of the ground.

The table shows also, with the same assumption, that 2·8 represents the value for "q" arising from the penetrating radiation present at the top of the City Hall tower and from the secondary rays excited by it. These numbers shew that the effect of the penetrating radiation and its accompanying secondary radiation in ionizing the air in the receiver at the top of the tower was only about 48 per cent. of the effect produced by similar radiations on the University lawn. This diminution in intensity for an altitude of 64 metres is practically the same (as Table I. shews) as that calculated by Eve for a diminution of the earth's penetrating radiation.

* Wright, Phil. Mag. Feb. 1909, p. 310.

It must be remembered, however, in this connection that probably the walls of the tower itself were not without influence. The clock tower was a sand-stone structure with a square cross section of about 50 square metres area and while the building proper of the City Hall was about 40 metres high, the tower extended up as a column to over 24 metres above the roof of the building. The clock room in which the measurements were made was provided with four glass windows serving as dials for the clock, each with a diameter of about 5 metres. The room itself had an attic space above it and this again was covered with a tile roof. It is presumable that the walls of the clock room emitted penetrating rays and also absorbed to a certain extent those coming from the outside. However, the ionization observed in the basement of the City Hall was only 1 ion per c.c. per second greater than that obtained on the University lawn. Consequently the amount contributed by the tower and walls of the clock room was probably not greater than 1 ion per c.c. per second. The absorption by the glass windows, too, would not be very considerable and so one may perhaps without sensible error set off the one effect against the other and conclude that the readings obtained represent fairly well the relative intensities of the penetrating radiation at the surface of the earth at Toronto, and at a point 64 metres above it.

II.—Secondary Rays Produced by the Earth's Penetrating Radiation.

In the discussion which has preceded, it has been assumed that 5·8 ions per c.c. per second represents the ionization produced in air confined in a zinc receiver by the penetrating radiation present at the surface of the earth at Toronto and by other radiations which it may give rise to or be accompanied by.

This value is somewhat higher than that obtained by Wright* in 1908 at Toronto whose numbers shew a difference of only 3·8 ions per c.c. per second between the readings taken on the ice of Toronto Bay, and those taken on the University lawn. It must be remembered, however, that in his experiments the lawn was covered with a layer of ice and snow to a depth of 20 centimetres while in the present measurements the ground was bare. This difference in the condition of the ground might easily account for the difference in the results. Further support for this explanation is found in the fact that in the present investigation the readings obtained in the physical laboratory were practically the same as those obtained on the bare lawn while in Wright's

* Proc. Roy. Soc. No. A. 577, p. 175, 1911.

observations the readings in the laboratory were 1·7 ions per cc. per second higher than those obtained on the lawn, when covered with ice and snow.

The conclusion that 5·8 ions per c.c. per second is approximately a measure of the normal intensity of the earth's penetrating radiation is also supported by some readings recently made (near Cape Town) by Simpson and Wright,* who are at present attached to the Scott Antarctic Expedition. In the course of some observations made by them with an apparatus similar to that used by us, they found a difference of 6 ions per c.c. per second, between the readings taken inland some 200 miles at Matjesfontain and those taken on the "Terra Nova" on the open sea.

A further point of interest which they noted in connection with their observations is that the readings which they obtained on the "Terra Nova" due to the penetrating radiation immediately on leaving land gave a mean about 3 ions per c.c. per second higher than those they obtained some time later when the vessel was well out to sea. This increase they ascribed to the presence of radioactive matter which came from the atmosphere over the land and was deposited on the surface of the vessel when lying in port.

This effect may possibly account for a difference between some numbers recently published by Pacini† in connection with his observations near the naval station at Livorno in Italy, and those obtained at Toronto and Cape Town. In his measurements he found a difference of only 2·4 ions per c.c. per second between the readings taken on the land near the shore and those taken on a launch on the sea some 300 metres from the shore.

The effect due to active deposits on the launch would naturally depend to some extent on the size of the latter, but upon the basis of Wright's observations one may perhaps legitimately attribute 3 ions per c.c. per second to such active deposits. This would make the ionization due to the radiation from the land at Livorno equal to 5·4 ions, per c.c. per second, and so make the readings at Toronto, Livorno and Matjesfontain practically the same.

It would seem then that 5·8 ions per c.c. per second, may be taken as representing approximately the ionization produced under normal conditions by the earth's radiation in air confined at atmospheric pressure in a zinc receiver.

Since Eve has shewn that 1·6 ions per c.c. per second is all that can be estimated as being produced directly by the penetrating rays

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* Proc. Roy. Soc. No. A. 577, p. 175, 1911.

† Annali dell' Ufficio Centrale Meteor. e. Geod. Italiano, Vol. XXXII, 1910, pt. 1.

coming from known radioactive substances in the soil, it follows, therefore, that about 4·2 ions per c.c. per second must be accounted for by the presence of other types of radiation.

From the observations made by a number of investigators, it is clear that one of these types is the secondary radiation produced at the walls of the zinc receiver by the penetrating rays themselves. A second type which it was thought might possibly be present and contribute to the ionization in the receiver was a secondary radiation produced at the surface of the ground by the penetrating rays coming from the soil. Some observations were taken which seem to establish the existence of this type.

The measurements which led to this conclusion were made by taking readings on the ionization of the air in the zinc receiver as it was gradually brought up to a high and extensive brick wall forming part of a brick building which bounded the University lawn on one of its sides. These readings are recorded in Table III. and are represented by a curve in Fig. 1.

TABLE III.

Observation Station.	"q" No. of ions per c.c. per second.
At the centre of the lawn........................	15·1
13·7 metres from the wall........................	15·4
12·2 " " " "	15·45
10·7 " " " "	16·4
7·7 " " " "	16·7
4·6 " " " "	16·7
·3 " " " "	16·5

From the numbers given in the table it will be seen that the ionization began to increase when the receiver was about 14 or 15 metres from the wall. At the centre of the lawn the reading was 15·1 while at 13·7 metres from the wall it was 15·4. At a distance of 10·7 metres the reading was 16·4 ions per c.c. per second, and at 7·7 metres it was 16·7. From there on to the wall the readings remained practically steady. As it had been shewn previously that at any one place readings could be taken with the apparatus which did not shew a variation greater than 3 per cent., it is clear from the numbers given above that the wall emitted a radiation whose range extended out in the air from the wall to a distance of between 14 and 15 metres. The absorbing power of this amount of air is roughly equivalent to between 6·5 and 7 millimetres of aluminium, and this thickness it has been pointed out is practically

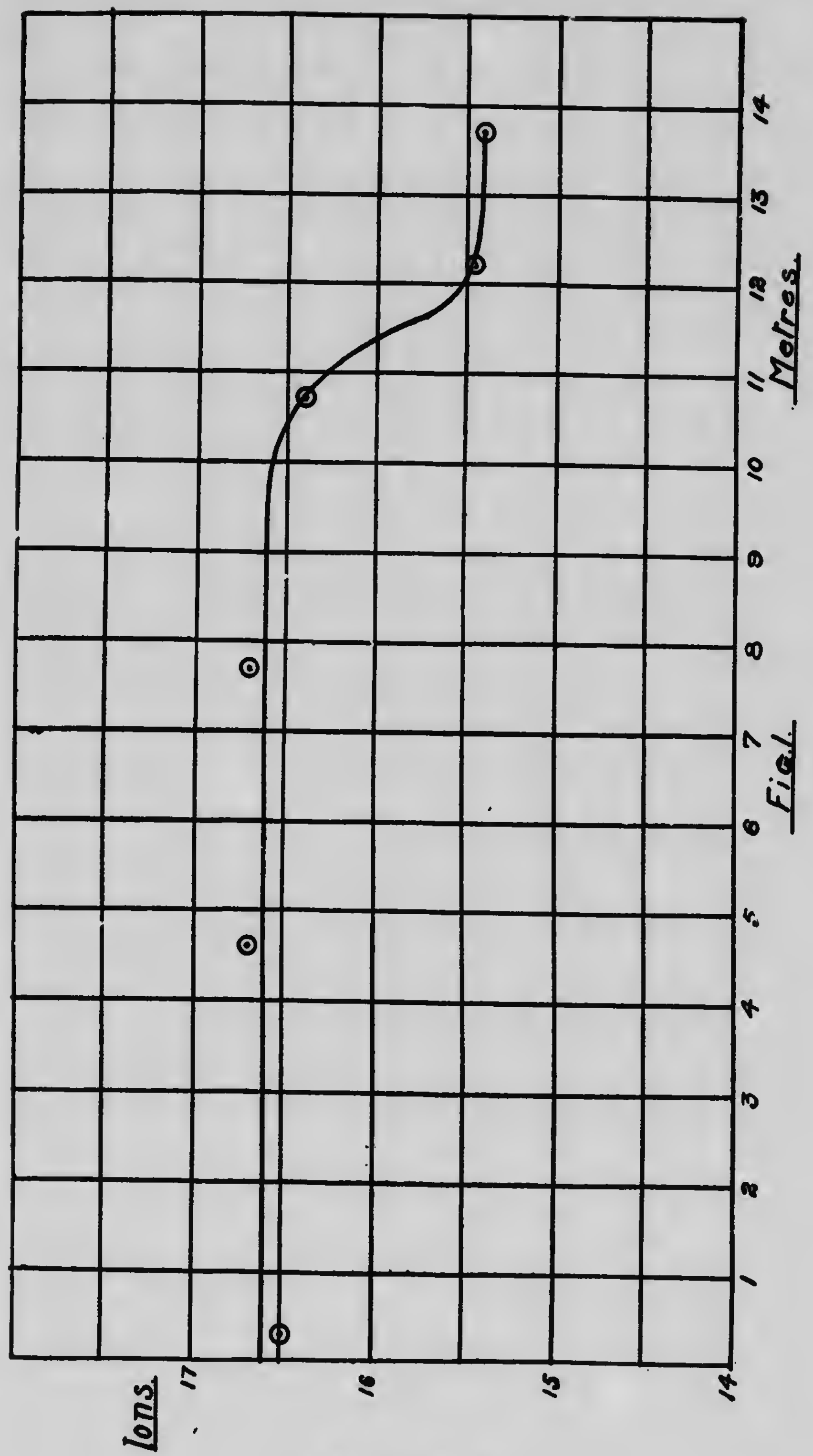

Fig. I.

what Pound* found necessary to cut off all the radiations of the β type issuing from a sample of radium in equilibrium.

It follows then that the wall emitted a radiation of the β type which produced a conductivity in the air in the zinc receiver corresponding to about 1·5 ions per c.c. per second.

From the nature of the observations it is impossible to determine whether this radiation was emitted directly by the wall or was a secondary radiation produced at the wall by the penetrating rays present at the surface of the earth. In either case it seems justifiable to conclude that a similar radiation was probably emitted by the soil of the lawn and contributed to the ionization obtained in the receiver when the observations were made there. It should be possible, however, to get more direct evidence of the existence of this β radiation from the soil by making observations at the surface of the pound in a clear space and at a point directly above in the free air about 15 metres from the ground. Such measurements should not involve great difficulty and it is hoped shortly to undertake them. Additional observations will also be made to see if a β type of radiation is emitted by walls generally of structures which are exposed to the earth's penetrating radiation.

III.—Summary of Conclusions.

1. At Toronto the ionization obtained in air confined in a thin walled zinc receiver of about 30 litres capacity on the surface of the bare ground of the University lawn is greater than that obtained in the same air on the ice in Toronto Bay by about 5·8 ions per c.c. per second.

2. Evidence has been presented which goes to shew that this same difference exists at Livorno, Italy, and near Cape Town in South Africa between readings taken on the open sea and those taken on the neighbouring land.

3. As Eve† and Simpson and Wright‡ have shewn that the penetrating radiation over the ocean from radium and thorium in the sea is negligible, it follows that 5·8 ions per c.c. per second represents the average effect of the penetrating radiation emitted by the earth and any rays of the β type which may accompany it.

4. The observations at Toronto give evidence of the existence of a radiation of the β type accompanying the penetrating radiation from the soil which produced in the air in the zinc receiver about 1·5 ions per c.c. per second.

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* Pound, Loc. cit.

† Loc. cit.

‡ Loc. cit.

5. Assuming that Eve's value of 1·6 ions per c.c. per second represents the direct effect of the penetrating radiation it follows that 2·6 ions per c.c. per second must be produced by the secondary rays emitted by the walls of the zinc receiver or by these and by other radiations which may be emitted by the soil and which have not yet been detected.

The writers wish to acknowledge their indebtedness to Mr. S. A. Kennedy for kindly assisting in making a number of the observations described in the paper.

The Physical Laboratory, University of Toronto,
May 10th, 1911.