THE PENETRATING RADIATION IN THE ATMOSPHERE AT HOBART.

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(With 6 Text Figures.)

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GENERAL.

If a gas be enclosed in a thick-walled vessel and protected from all external disurbances a few of its atoms are still found to be ionised during every second. It can be shown that this residual ionisation cannot be due to the heat energy of the gas itself (1), the atoms must therefore be broken up by a radiation coming from without. This external radiation must arise in the walls of the vessel itself, or penetrate them. If the former is the case we may say with fair certainty that it is due to radio-active matter in the walls, and if the latter it must be a radiation of extremely great penetrating power, as shielding the vessel with several feet of water has little effect on the ionisation. The residual ionisation is now known to be due to both these causes, and they may be distinguished from one another experimentally. The origin of at any rate a part of the radiation is still in doubt, and measurements made at different parts of the earth's surface may be expected to provide evidence indicating what factors are concerned.

Recent experiments by various workers have given curiously contradictory indications as to the nature of the penetrating radiation, leaving the matter in a condition most stimulating for further research.

Millikan (2) and others (3, 4, 5) have shown that the radiation increases in intensity with the height above sea level at which the measurement is made, and, further, that it varies with meteorological conditions (6). This would seem to show decisively that it is an external radiation, and that it probably arises in the upper atmosphere.

But at a depth of six metres under water it shows little or no trace of absorption (7). Also Downey (8) and Fruth (9) have shown that in a sphere of radius 12 inches at a pressure of approximately 47 atmospheres the ionisation no longer increases with pressure, but remains constant. These facts suggest that there is no penetrating radiation coming from without, but that everything is due to the walls of the vessel containing the gas. Experiments such as those of Millikan necessitate some other explanation, however. The most hopeful appears to be that an extremely penetrating external radiation of the γ type ejects high-speed electrons from the walls of the vessel, which in turn produce the observed ionisation.

If this explanation is the correct one we are brought to the interesting conclusion that the penetrating radiation is very different from any other γ radiation of which we know. In the first place the great range of the ejected electrons shows that its frequency must be greater than at any rate most of the γ rays from radium B and C. This suggestion is borne out by its great penetrating power. Secondly, if it were of ordinary γ ray type a rough calculation shows that at 47 atmospheres as many high-speed electrons should be ejected from the gas as from the walls of the vessel, and consequently the ionisation should still increase with pressure. Perhaps it is best to attempt to explain Downey's and Fruth's results by supposing a change in the molecular constitution of gases at this pressure. Certain of Fruth's results appear to lend colour to this view.

Recent experiments show clearly that the intensity of the penetrating radiation varies with time. There is certainly a daily variation and probably a seasonal variation as well (10). The maximum intensity of the penetrating radiation does not occur at different places at the same local time.

In view of the fact that there are indications that the atmospheric potential gradient exhibits a diurnal variation whose maximum occurs at different places at the same Greenwich time and not at the same local time, considerable interest attaches to the problem of determining the time at which the maximum intensity of the penetrating radiation occurs at different places on the earth's surface.

OBJECTS OF RESEARCH AND GENERAL EXPERIMENTAL METHOD.

The present paper describes the results of a set of measurements made to determine the intensity of the penetrating radiation in Hobart, and to investigate its diurnal variation.

The investigation was commenced under the direction of one of us by Mr. R. W. Crabtree earlier in this year, but before the construction of the apparatus was complete he left to take up the position of Demonstrator in Natural Philosophy in the University of Melbourne.

It is hoped later to investigate the variation of the intensity of the radiation with altitude, and to make further experiments on its variation with time.

The method used is similar to one employed by Dr. K. M. Downey (10), but our apparatus is less refined. The ionisation is produced in a cast-iron sphere, A., fig. 1, 20 cms. in internal diameter, with walls 1½ cms. thick. An electrode consisting of a small sphere, C., of 3.5 cms. diameter, soldered to the end of a stout wire, is held inside the

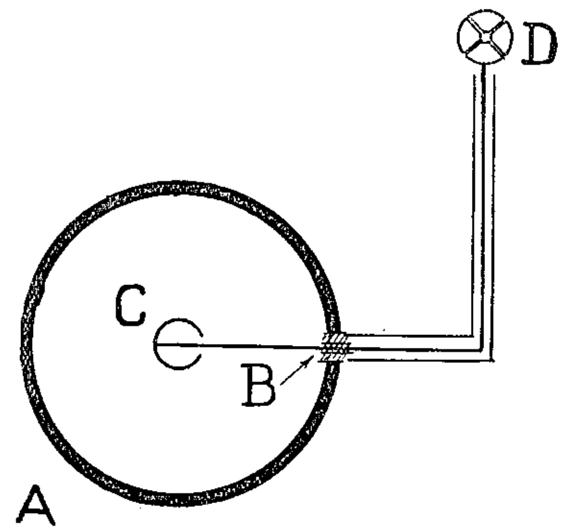

Figure I

sphere by a sulphur plug B. This serves to collect the ions produced within A. by the penetrating radiation and other causes. The rate of production of ions so collected is measured by the motion of the needle of a Compton quadrant electrometer D.

The effect of the penetrating radiation itself is estimated by observing the change in the speed with which the electrometer charges when gas at different pressures is contained in A.

More than 19-20ths of the radiation due to radio-active matter in the walls of the sphere is completely absorbed by the gas in the sphere at atmospheric pressure, and consequently the ionisation due to it does not change sensibly with increasing pressure. On the other hand, the effect of the penetrating radiation for the relatively low pressures we have used is proportional to the pressure. The two effects can therefore be distinguished by such experiments.

EXPERIMENTAL PROCEDURE.

The earlier experiments made had for their object the determination of the average intensity of the penetrating radiation in Hobart. They will not be discussed, as the later work on the diurnal variation has superseded them. The earlier experiments were consistent with the later ones, but were not made under the same standard conditions.

Under the rather bad experimental conditions in which this work has been carried out it has not been found possible to maintain the pressure constant in the sphere (A. fig. 1.) in which the ionisation is measured. The sphere is filled with oxygen to a pressure of 50 to 60 lb. per sq. in. above atmospheric, and observations are made while it decreases owing to leakage. In these circumstances the accurate determination of the effect of the soft radiation from the walls of the sphere is of the first importance in making a determination of the variation of the penetrating radiation with time, as well as in its absolute measurement.

There is no effect due to emanation, as the gas used is oxygen from a cylinder in which it has stood for more than a month.

Ionisation due to Soft Radiation.—To determine the ionisation due to the soft radiation it is necessary to measure the total ionisation when the pressure in the sphere is as high as possible, and when it is atmospheric, while the penetrating radiation must remain sensibly constant during an experiment.

The ionisations are plotted as ordinates against the pressures as abscissæ. The slope of the straight line joining the points then gives the ionisation due to the penetrating radiation per unit increase in pressure, while the ordinate at zero pressure gives the effect due to the soft radiation. The assumption is here made that the curve connecting ionisation and pressure is a straight line for the low pressures we have used. This has been found by Downey and others, and has been roughly verified by our earlier experiments.

Fig. 2 shows two curves obtained as indicated on two different days. Ionisation is given in volts fall per second of the electrode system, and the pressure is given in atmospheres with zero at vacuo. The figures above the points give the minutes occupied by the observations. The soft radiation as deduced from the two curves is the same within the limits of experimental error. Curve B has twice the weight of A., and the resulting value of the ionisation due to the soft radiation is $.87 \times 10^{-4}$ in the arbitrary units used. Less direct methods show that this is certainly not far from the truth.

Experiment on Diurnal Variation.—The following experiment is made to determine the diurnal variation of the penetrating radiation. Oxygen is admitted to the sphere and left for an hour. The electrode system is charged, the voltage sensitivity of the electrometer measured, the electrode is isolated, and an observation made of the time taken for the system to charge 2, 3, or 4 fiftieths of a volt, according to circumstances. The electrode system is then recharged, and the observation repeated until the pressure falls to about 20 lb. per sq. in. above atmospheric, when oxygen is again admitted. From the determination of the ionisation so made the constant ionisation due to the soft radiation is subtracted and the result divided by the pressure in atmospheres measured from vacuo. This is the ionisation due to the penetrating radiation per atmosphere. The curves of Fig. 3 show this quantity plotted against time on various days.

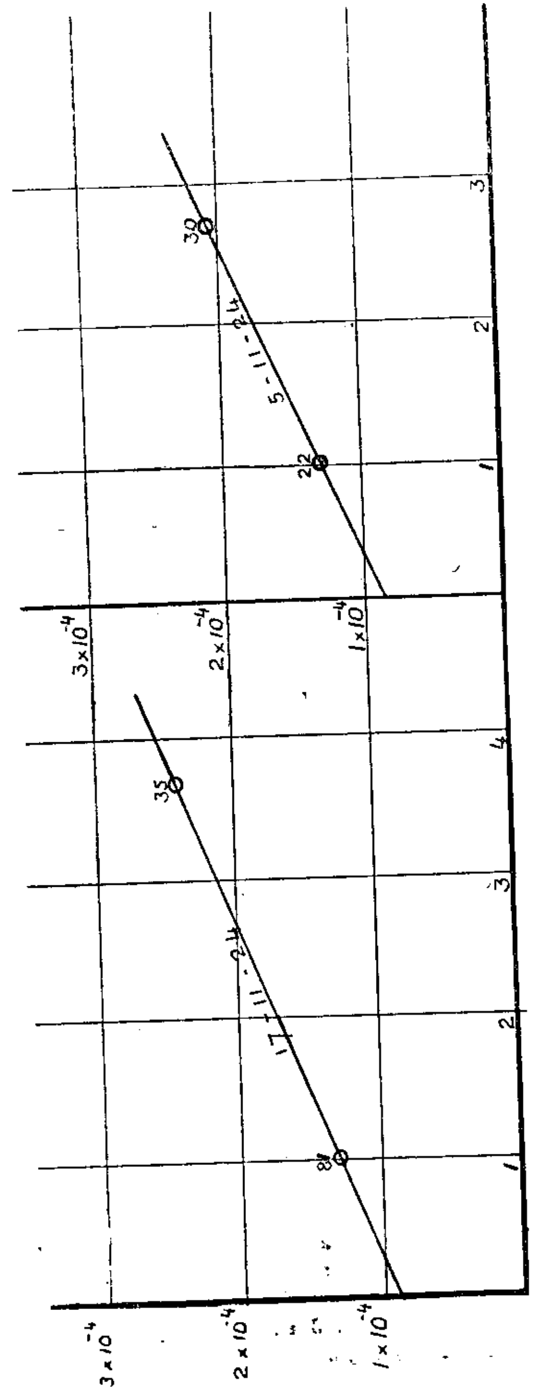

Figure II

Saturation and Insulation Leakage.—It was found that 120 volts between the sphere and the electrode gave a field amply strong enough to saturate the gas at the pressures used, and 160 volts were used in the experiments. The electrode system was insulated by sulphur and quartz, and everywhere surrounded by earthed conductors and guard-rings. When measuring the current the precaution was always taken of allowing the electrode to charge to as high a potential on one side of earth as it fell from on the other side of earth, and in this way any leakage across the insulation was eliminated. As a matter of fact, such leakage was found to be absolutely negligible.

RESULTS.

Fig. 3 shows typical curves obtained, as explained in the last section, in which the ionisation produced by the penetrating radiation alone per atmosphere of pressure is plotted against time. A and B run consecutively, and represent an experiment lasting twenty-eight hours. The blanks mark the times at which oxygen was re-admitted to the sphere, and the subsequent hour intervals that were found to be needed before conditions had once more become steady. C. fig. 3 is another similar curve, comprising ten hours' observations, and showing a different type of variation.

Absolute Value of the Ionisation Produced by the Penetrating Radiation.—It will be seen from the curves that the effect is subject to large fluctuations. The lowest value we observed for any length of time was about $1\frac{1}{3}$ ions per c.c. per second averaged over two hours. The highest value observed was about $3\frac{1}{2}$ ions per c.c. per second averaged over five hours.

To convert the arbitrary ordinates of the curves of Figs. 2 and 3 into pairs of ions per c.c. per second produced by the penetrating radiation in oxygen at atmospheric pressure they must be multiplied by 6.8×10^4. Thus the average value for the twenty-four hours beginning at noon on 13.11.24 was about 3 ions per c.c. per second.

It was found difficult to obtain consistent experimental values for the capacity of the apparatus; however, the mean of those obtained experimentally by the best methods used was fairly close to that calculated. It is perhaps pos-

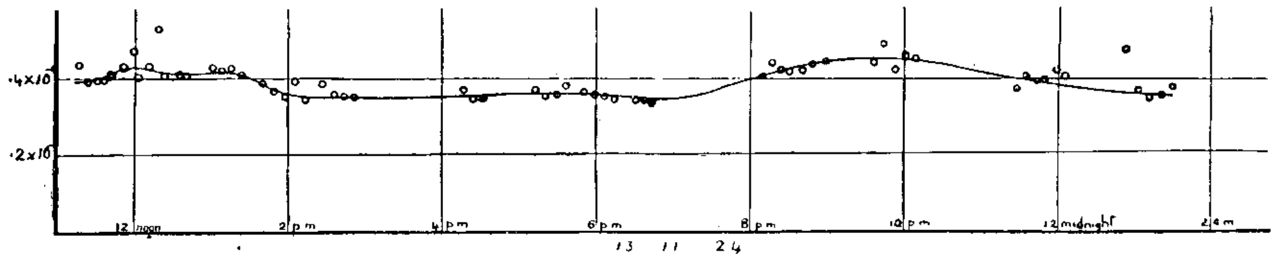

Figure III A

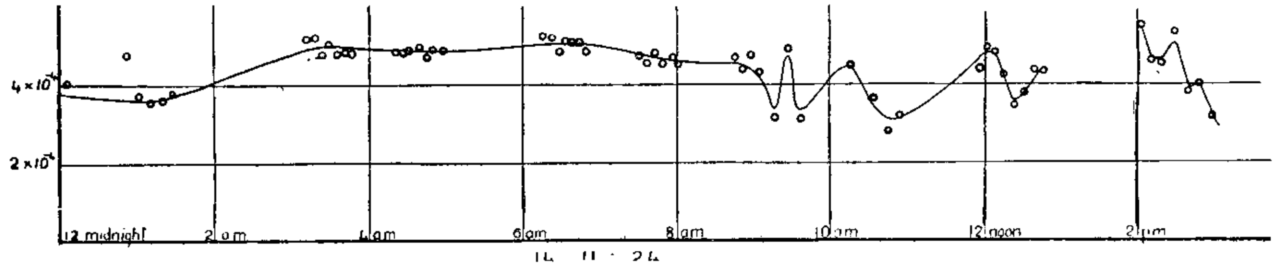

Figure III B

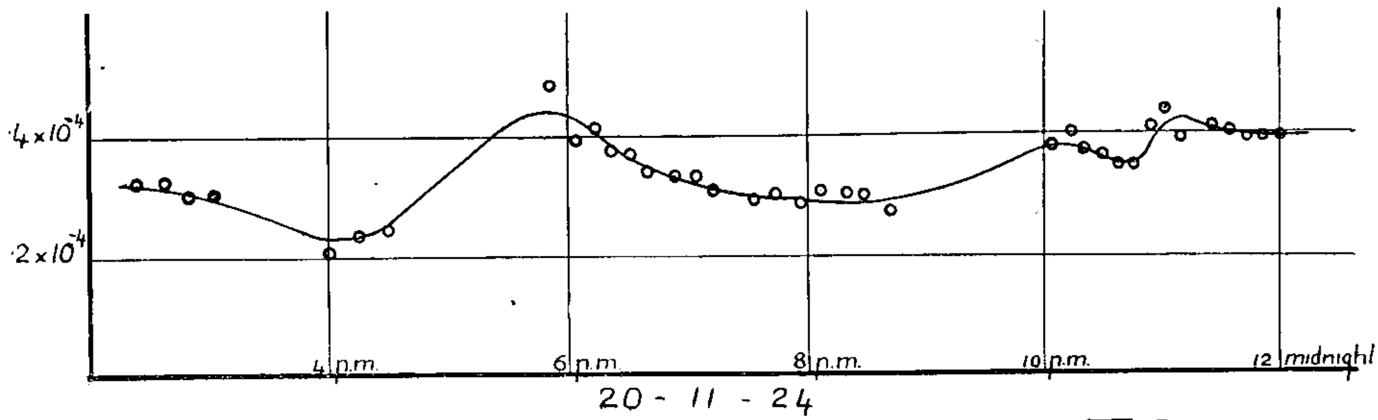

Figure III C

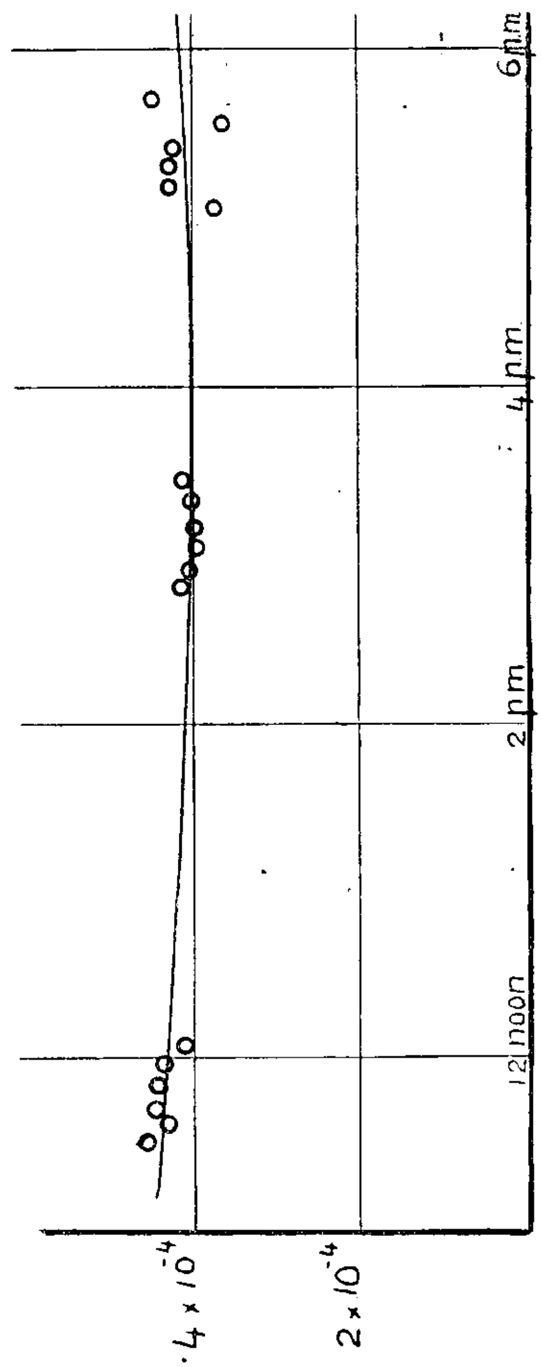

Figure III D
12 - 11 - 24

sible, though improbable, that the constant given above is 20 per cent. in error. It was not possible to use the method of observing the leak produced by a standard source of gamma rays, as we had no radium or thorium at our disposal.

Soft Radiation.—The points plotted on curves A and B each represent a four or five minutes' observation; those on curve C one of six or seven minutes. They will vary about the mean on account of the probability variations in the number of alpha particles leaving the walls of the sphere per second. The amount of the soft radiation shows that not more than 12 alpha particles traverse the sphere in a minute (assuming that each produces 1.2 x 10^5 ions in its course), so that the probability variations will be large, especially for low pressures. It is of interest to note that the effect of the penetrating radiation at one atmosphere is less than that of 6 alpha particles per minute traversing the whole sphere.

Diurnal Variation.—A general analysis of our results seems to suggest a diurnal variation of regular type, on which is superposed large and rapid fluctuations of a more irregular nature. There appears also to be very considerable variation of the effect over a longer period.

The most extreme case of the irregular rapid variation which we have observed is seen starting with great suddenness at about 9 a.m. on 14.11.24, after a very steady 24 hours. For the week prior to 13.11.24 conditions had been very steady, and the rapid fluctuations of the 14th were at first attributed to some experimental fault that had suddenly developed, but none that could explain the fluctuations was found. During the week following the 14th the variation of the penetrating radiation was similar to that of the 14th, though not quite so erratic. On the whole, the value was considerably lower than for the preceding week.

In general we find from our short term of experimenting that the effect tends to be low and variable on hot, cloudless days, and higher and steady during colder southerly weather. We also find that the effect is higher during the night than during the day, the principal maximum occurring at 5 a.m., and the minimum at 5 p.m. These maxima and minima are liable to be masked by what we are considering as superimposed fluctuations, and on one day in particular we observed a local maximum of about 3.8 in the arbitrary units used in the graphs at 4.30 p.m., while at 10 p.m. the effect was as low as 2.0. Unfortunately that day's observations ended at that point.

The times at which our maxima appear do not correspond with those given by other workers. The local time of our principal maximum is nearly 12 hours different from the local time of the maximum found at Manilla (11), while as our longitude is only about 30 degrees different we disagree in Greenwich as well as in local time. The time of our maximum disagrees with that given by Downey (10), both according to local time and to Greenwich time.

It is stated (11) that in Kohlberg the penetrating radiation is greatest in the day and least at night. This is the opposite of what we have found.

Before speculating as to the reasons for these differences further experiments must be made to discover whether our diurnal maximum always occurs at the same time.

Causes of the Effect.—The principal probable sources of the penetrating radiation will now very briefly be considered from the point of view of our results.

(1) Gamma rays from the soil. The radiation due to this cause would, of course, be constant. It might be expected to produce 4 or 5 ions per c.c. per second if it were not cut off. Our observations have been made over a concrete floor. Downey (10) found that the effect over concrete was the same as that over water, which would indicate that the radiation from the soil was completely cut off. In view of the low value we have found for the effect and of the large fluctuations, there seems good reason to believe the same is the case in our observations. The walls of the laboratory are of brick.

(2) Radio-active deposit precipitated from the atmosphere on the roof. This effect might be expected to be marked in our experiments. The roof of the laboratory is about 15 feet above the sphere, and is of galvanised iron, lined only with thin pine boarding. King (13) estimates the radiation due to this cause to produce 1 to 2 ions per c.c. per second. The effect would, of course, vary with meteorological conditions. Such fluctuations as those shown at the right of curve B cannot, however, be due to this

cause. It is conceivable that there might be temporary rapid depositions, giving rise to sudden increases in the ionisation, but this ionisation must decrease at a slower rate, as even if the supply of active deposit is not replenished its hard gamma rays cannot fall to half value in less than half an hour.

(3) Other causes. The contribution of the gamma radiation from the emanation in the air is negligible. Further experiment is necessary before we are in a position to speculate as to the nature of the remainder of the radiation.

Our intention is next to attempt to eliminate the effect of the active deposit on the roof.

In conclusion, we wish to thank Dr. L. A. Bauer, of the Carnegie Institute, who very kindly presented us with literature on this subject.

REFERENCES.

(1) Kunsman, Phys. Rev., October, 1920.

(2) Millikan and Bowen, Proc. Amer. Phys. Soc., May, 1923.

(3) Otis, Proc. Amer. Phys. Soc., May, 1923.

(4) Otis, Proc. Amer. Phys. Soc., May, 1923.

(5) Kolhörster, Deutsch. Phys. Gesell., Verh., July, 1914

(6) Millikan and Otis, Proc. Amer. Phys. Soc., April, 1924.

(7) Gockel, Phys. Zeits., June, 1920.

(8) Downey, Phys. Rev., August, 1922.

(9) Fruth, Phys. Dev., August, 1923.

(10) Downey, Phys. Rev., November, 1920.

(11) Lassale, Phys. Rev., February, 1915.

(12) Kahler, Phys. Zeits., June, 1920.

(13) King, Phil. Mag., October, 1913.