THE DIURNAL VARIATION OF THE EARTH'S PENETRATING RADIATION AT MANILA, PHILIPPINE ISLANDS.

By Leopold J. Lassalle.

RUTHERFORD and Cooke[1] first called attention to the presence of a penetrating γ radiation, which they attributed to the presence of radio-active substances in the earth's surface. McLennan and Burton,[2] independently reported the discovery of a similar phenomenon. C. T. R. Wilson[3] had previously shown that the so-called "spontaneous ionization" of air in a closed vessel, which enabled it to conduct electricity, was also present when other gases were used; and that, further, the relative values of the ionization for these gases were approximately in the same ratio as those found for the same gases when acted upon by Becquerel rays. J. Paterson[4] called attention to the fact that the value of the ionization, when large vessels were used, was not proportional to the pressure, but tended towards a limit beyond which the ionization value was not increased by further increase of pressure. This pointed to the ionization being due to a feeble radio-activity of the walls of the vessel, the α rays from which were totally absorbed—under given conditions of size of vessel, of nature of gas, and of radio-activity of walls of vessel—for a given pressure. Since the relative values of the ionizations caused by α, β, and γ rays are, respectively, 10,000, 100, and 1, it is seen that the more easily absorbed α rays will practically determine the ionization in a vessel, the inside surface of which is radio-active. In order to test further this theory, Strutt,[5] used cylinders of the same dimensions but of different materials, and found the values for given pressures to vary with the material. Also, for different samples of the same material he found the ionization to vary. In the matter of reaching a maximum at a certain pressure, his results were in agreement with those of J. Paterson. Using one sample of tin-foil the maximum ionization was obtained at 29.8 inches pressure. For another sample of tin-foil the maximum was found at a pressure of 24.5 inches. This

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[1] Rutherford and Cooke, Amer. Phys. Soc., Dec., 1902.

[2] McLennan and Burton, Phys. Rev., 16, p. 184, 1903.

[3] C. T. R. Wilson, Proc. Roy. Soc., Vol. LXIX.

[4] J. Paterson, Proc. Camb. Phil. Soc., Vol. XII.

[5] R. J. Strutt, Nature, Vol. 67, p. 369, 1902.

investigator concluded that the ionization in a closed vessel was not spontaneous at all, but was due to the Becquerel rays from the walls of the ionizing vessel; and that radio-activity, instead of being rare, was everywhere present. It should be noted, in criticism of this conclusion, that the finding of different values for the radio-activity of different samples of the same material points to the activity being due to the presence of some of the rare radio-active substances as impurities in the metals of which the walls of the ionizing vessels were made, rather than to it being due to an inherent property of these metals. In order to reach some basis of comparison a crystal of uranium nitrate, having an exposed area equal to 48 sq. cm. was cemented inside of the cylinders. The rate of leak was then found to be thirteen times as great as when the most active sample of platinum was used for the ionizing chamber. The area of platinum exposed was 240 times that of the crystal. Therefore we may conclude that the uranium nitrate was about 3,000 times as active as the sample of platinum. Radium is about 100,000 times as active as uranium nitrate. So, the conclusion is reached that one part of radium to 300,000,000 parts of platinum would be sufficient to account for the observed activity. Prof. Armstrong,[1] in criticising this attempt to explain the nature of the ionization as being due to a radio-activity of the walls of the chambers, suggests that it might be due to some chemical change, such as oxidation. In answer, Strutt[2] makes the following clear-cut and concise statement, which undoubtedly furnished a basis for much of the later work on this very important subject:

"Prof. Armstrong suggests that the effect observed by myself and McClennan may be due to chemical change or to oxidation at the surface instead of to radio-activity. In speaking of the radio-activity of various metals, I mean that they exhibit effects differing only in degree from those shown by uranium and radium. These effects, observed experimentally, are as follows: (1) There is a leakage of electricity from a charged body in their neighborhood, the value of the leak being proportional to the E.M.F. for small E.M.F.s, and independent of it for large ones. (2) The effect varies with the pressure of the air in the chamber; being proportional to the pressure for small pressures; and, for large ones, independent of it, when E.M.F. is sufficient. (3) The rate of leak for positive electricity is the same as that for negative electricity. (4) The rate of leak does not depend upon the temperature. (5) When other gases are substituted for air the rate of leak is nearly proportional to the density of the gas, excepting for hydrogen, which

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[1] Prof. Armstrong, Nature, Vol. 67, p. 414, 1903.

[2] R. J. Strutt, Nature, Vol. 67, p. 439, 1903.

gives about one eighth the effect that air does. Every one of these points gives exact agreement between uranium and ordinary materials. On the other hand, I am not aware that any differences have been brought to light, except in magnitude of effect. Until such a difference should appear I think we may fairly and without dogmatism apply the maxim that similar effects are due to similar causes. In other words, we may conclude that the other substances, like uranium, are radio-active."

It was at about this time that Rutherford and Cooke, as previously mentioned, called attention to the result of experiments from which they concluded that a part, at least, of the ionization caused in a closed chamber was due to a penetrating radiation having its origin outside the chamber. They were able to reduce the ionization 30 per cent. by surrounding the chamber with lead sheets 3 cm. thick. A pig casting of lead, weighing 5 tons, and very much thicker than 3 cm., did not reduce the ionization any further. Surrounding the chamber with a considerable thickness of water reduced the ionization. Surrounding the instrument with wood or with brick increased the ionization, showing that these substances were radio-active or that a secondary activity was excited at their surfaces. Metals exposed outside the building for some time showed a marked increase in radio-activity over that which such metals had after having been carefully cleaned.

McLennan and Burton,[1] at about the same time reached the conclusion that, since they had been able to reduce the ionization in a closed vessel by 37 per cent., any explanation as to the cause of the ionization must take into account this penetrating radiation here shown to exist.

N. R. Campbell,[2] from a long series of observations which are very prettily analyzed, reaches the following conclusions:

(1) The influence which the walls of a containing vessel are known to exert upon the spontaneous ionization of the enclosed air, may be attributed to radiations proceeding from the walls. (2) That part of the radiation emanating from such substances as tin, zinc, graphite, and platinum is analogous to the secondary radiations excited by Röntgen and other such rays, being caused by the penetrating radiation which Cooke cut off with thick lead screens. (3) The coefficient of absorption of air for this radiation is comparable with that of air for α rays from radium. (4) The coefficient of absorption is different for different materials; and, therefore, it is improbable that the radiation is due to radio-active impurities. It is more probably due to an inherent property

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[1] McLennan and Burton, Phil. Mag., p. 699, Vol. 5, 1903.

[2] Norman R. Campbell, Phil. Mag., p. 531, Vol. 9, Ser. 6, 1905.

of the material. (5) That there is no evidence of the existence of rays, from ordinary materials, more penetrating than the α rays from radioactive elements. Finally, it is obviously of great importance to determine the nature of the rays from ordinary materials, their charge, their velocity, etc. The problem, however, will tax the ingenuity of the ablest experimenters.

This same line of investigation was continued by Alexander Wood.[1] He concluded that the ionization in a closed vessel was due, 1st to a penetrating radiation; 2d, to a secondary radiation caused by the penetrating radiation; and, 3d, to an intrinsic radiation from the walls of the vessel that is independent of the penetrating radiation. Some further results which he obtained are not pertinent to the matter in hand and so will not be considered here.

In a paper in 1905, A. S. Eve[2] concluded: (1) That the radium required to maintain a steady supply of emanation to the amount found per cubic kilometer of air near the earth is between 0.14 and 0.49 gm. (2) This amount of emanation and its successive products is sufficient to cause ions to be produced at the rate of 9.6 per c.c. per second. (3) The radium emanation in the air is probably sufficient to account wholly for the natural ionization in large closed vessels of non-radio-active materials, and for the rate of production of ions near the earth. However, in a paper in 1908, Eve[2] concludes, among other things, that the value of 4.5 ions per c.c. per second in a closed brass vessel as found by H. L. Cooke[3] cannot be attributed to the active matter in the atmosphere but that the radium present in the earth's crust is about of the right order of magnitude to account for it.

Wood and Campbell[4] concluded that there was a double diurnal variation in the ionization in a closed vessel, which appeared to be connected with the potential gradient changes in the atmosphere.

Wright, in Toronto, did not find such a diurnal variation.

G. A. Cline,[6] from a rather extended series of observations at Toronto, failed to detect a diurnal variation. He found that the penetrating radiation was greater after a fall of the barometer and smaller after a rise; the radiation was smaller when the ground was frozen and covered with snow than when it was bare and the temperature above freezing. The foregoing was for an open chamber. With a closed one he also

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[1] Alexander Wood, Phil. Mag., p. 550, Vol. 9, Ser. 6, 1905.

[2] A. S. Eve, Phil. Mag., p. 98, Vol. 10, Ser. 6, 1905.

[3] A. S. Eve, Phil. Mag., p. 189, Vol. 12, 1908.

[4] H. L. Cooke, Phil. Mag., p. 403, Vol. 6, Ser. 6, 1903.

[5] Wood and Campbell, Phil. Mag., p. 265, Vol. 13, 1907.

[6] G. A. Cline, PHYS. REV., p. 35, Vol. 30, 1910.

failed to find any regular diurnal variation, although there was a larger variation in the values at different times than when the open chamber was used. Different metals used for the chamber showed different activities; that for zinc being very low. The general conclusion was reached that the soil furnished by far the greater portion of the penetrating radiation present at the earth's surface at Toronto; and by comparison any that may have its source in the atmosphere or in the sun may be considered negligible in amount.

Ideal Method of Attacking Problem.—It has been pointed out a number of times that to be able to draw conclusions regarding the ultimate cause or causes of the radio-activity on the earth, it is necessary that a number of closely related phenomena be investigated at the same place, at about the same time, and by investigators working under the direction of one person. That the time and place should be the same is made necessary by the effect of geographical position, of climatic conditions, and of altitude upon the various radio-active constants the determination of which is to throw light upon the larger question of the radio-activity on the earth. The investigation should be conducted under one head so that it can be uniform and comparable; otherwise it is impossible to draw reliable conclusions from the rather disconnected data obtained. In short, there should be a cohesiveness, rather than an adhesiveness to hold together the various parts and make it one problem. There are four main heads under which the parts of this problem have been classified: (1) The determination of the radium content of the atmosphere. (2) The investigation of the nature and amount of active deposit on a negatively charged wire. (3) The qualitative and quantitative investigation of the penetrating radiation at the earth's surface. This investigation will give the necessary data to show whether there is a diurnal variation for the locality investigated. And (4) The determination of the value of the ionization of the atmosphere. There are two other closely related subjects that should be studied in connection with this problem. They may be classified as branches of the fourth main head above mentioned. They are: Potential gradient in the atmosphere, and nucleation of the ions in the atmosphere. It was under the inspiration of such an ideal scheme that Dr. J. R. Wright, professor of physics in the University of the Philippines, Manila, P. I., who was investigating the first of these four problems, started three members of his department on the three remaining problems. Due to the slowness with which it is possible to obtain apparatus at Manila, it was found necessary to deviate from the program. The result is that the first problem was thoroughly investigated, the report appearing in a paper by J. R. Wright and O. F. Smith.[1] The second problem was investigated by Mr. Blackwood, but no report of it has appeared to date. It was the intention of Wright and Smith to investigate the fourth problem. This paper is the report of the work done on the third problem.

Description of Instrument Used.—The instrument with which this investigation was carried on was a Spindler and Hoyer, aluminium-leaf electroscope, which had an ionization chamber 7.8 cm. inner diameter and a volume of 1850 c.c. A rod one mm. in diameter was connected to the leaf system of the electroscope, and was in the center of the ionization chamber. The electrical capacity of the chamber plus that of the electroscope was 8.6 E.S. units. The leaf could be read to tenths of a division, with a probable error of + or − two tenths. Fig. 1 is a photograph of the instrument. The larger of the three cylinders was used, throughout the observations, as the ionizing chamber.

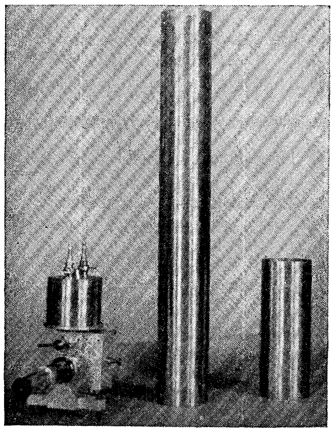
Fig. 1.

Procedure. — The procedure adopted was to seal off the ionization chamber, to connect one of the stop-cocks to an oil vacuum-pump, and the second to a drying tube and to a tube of cocoanut carbon, the two tubes being connected in series. The second stop-cock was closed and the chamber was exhausted to a vacuum of about two or three cm. Air was then slowly allowed to enter through the cocoanut carbon and drying tubes. In this way the chamber was filled with air that was dry and practically emanation free. Both stop-cocks were then closed and disconnected from everything outside. The chamber was not absolutely air-tight, but so long as the difference in pressure between the inside and the outside was small, there was very little tendency for air to leak out or in. The range of the one hundred scale divisions was from 346 down to 268 volts, assuring saturation voltages. To begin with the electroscope was simply charged and the deflection of the leaf for several hours observed.

Formula.—From the formula

$$N = \frac{C \cdot \Delta E}{V \cdot t \cdot e}, \qquad (1)$$

the value of N, which is the number of ions per c.c. per second formed in

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[1] Wright and Smith, The Philippine Journal of Science, Vol. 9, No. 1, Sec. A, Feb., 1914.

the chamber, was determined. The source of the radiation that caused the ionization in the chamber may have been in the earth's crust, in its atmosphere, or in some source external to the earth. Also, it may have been resident in the material of which the chamber was made, either as an inherent property of such material or as a result of contamination with some radio-active substance. Any leak over the insulation, which would have to be corrected for, if present, was guarded against by carefully cleaning the amber insulation with absolute alcohol and by drying the air that was allowed to enter the chamber. An open vial of concentrated sulphuric acid placed inside the electroscope proper kept the air therein dry.

It is evident that the charge necessary to cause the voltage of an insulated system, of capacity C, to drop by an amount ΔE, is given by

$$Q = C\cdot\Delta E. \tag{2}$$

Also, if N ions are formed per c.c. per second within the ionization chamber of volume V, for t seconds, and if each ion carries a charge of e E.S. units, then

$$Q = NVte. \tag{3}$$

Eliminating Q from (2) and (3), there results

$$N = \frac{C\cdot\Delta E}{V\cdot t\cdot e},$$

which is (1). The value of 4.77×10^{-10} E.S. units, as obtained by R. A. Millikan, was used for e. C and V were known, and t and ΔE are the variables that were observed.

Preliminary Results. It soon became evident that the value of N varied within wide limits, depending upon the time at which the observations were taken. This led to preliminary sets of readings, taken as follows: The electroscope was charged and allowed to stand about an hour before the first reading was taken. From this time on, for the next thirty-six hours, each scale reading and the time at which it occurred were recorded. The next twelve hours were taken up in resting. A period of about a week was spent in this way. Since the time of the scale readings did not fall on the hours or the half hours, it was necessary to interpolate to find what the readings were at each hour. Then, the change in scale reading per hour, reduced to E.S. units of P.D., gave the ΔE for one hour, *i. e.*, for $t = 3{,}600$ seconds. From (1) the value of N for each of the twenty-four hours of the day was calculated. This was done for each day and then the mean of N for each hour was obtained.

TABLE I.

Date.	12:00 M.	1:00 A. M.	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00 A. M.	12:00 N.
5–18–13	....	....	....	....	....	....	....	....	....	....	....	....	....
5–19–13	1.14	1.28	1.14	1.07	1.06	1.07	1.13	0.80	0.73	0.73	0.71	0.72	0.99
5–20–13	....	....	....	1.03	1.14	1.21	0.91	0.69	1.01	0.51	0.62	1.62	1.00
5–21–13	1.52	1.21	1.13	1.15	1.13	1.17	1.02	0.86	0.87	0.55	0.57	0.59	0.65
5–22–13	....	....	....	....	....	....	....	....	....	....	1.40	1.41	0.83
5–23–13	0.81	1.58	1.22	1.13	1.13	1.17	0.99	0.94	0.65	0.73	0.81	0.82	0.90
5–24–13	....	....	....	....	....	....	....	....	....	....	....	....	1.50
5–25–13	1.26	0.87	1.49	1.14	1.44	1.22	1.23	1.13	0.61	0.46	0.79	0.91	0.83
5–26–13	....	....	....	....	....	....	....	....	....	0.62	0.63	1.23	1.24
5–27–13	0.91	1.00	1.06	1.24	1.03	0.96	1.05	0.97	1.22	0.93	0.66	0.70	1.37
5–28–13	....	....	....	....	....	....	....	....	....	0.57	0.66	0.89	...
5–29–13	1.39	1.08	1.01	1.08	1.13	1.18	1.29	0.68	0.93	0.72	0.59	1.09	0.49
5–30–13	....	....	....	....	....	....	....	....	....	....	....	....	....
5–31–13	1.05	1.35	1.40	1.28	1.25	1.22	1.01	0.85	0.84	0.51	0.42	0.71	1.02
6– 1–13	....	....	....	....	....	....	....	0.64	0.63	0.64	0.78	0.80	0.90
6– 2–13	1.10	1.03	1.11	1.30	1.28	1.36	1.24	0.81	0.72	0.77	0.92	0.87	0.83
6– 3–13	....	....	....	....	....	....	....	....	....	....	....	0.75	0.69
6– 4–13	1.35	1.24	1.14	1.02	1.17	1.11	1.21	0.68	0.68	0.69	0.66	0.75	0.80
6– 5–13	....	....	....	....	....	....	....	....	....	....	....	....	....
6– 6–13	1.39	1.25	1.24	1.00	0.94	0.95	1.13	0.96	1.15	0.89	0.62	0.50	0.74
6– 7–13	....	....	....	....	....	....	....	....	....	0.79	0.68	0.69	0.74
6– 8–13	1.00	1.18	1.27	1.10	1.15	1.06	1.30	0.87	0.76	....	....	0.65	0.72
6– 9–13	....	....	....	....	....	....	....	....	....	....	0.63	0.72	0.87
6–10–13	1.15	1.24	1.23	0.96	0.96	1.11	1.28	1.12	0.70	0.48	0.65	0.75	0.62
6–11–13	....	....	....	....	....	....	....	....	....	....	....	0.58	0.57
6–12–13	1.01	1.18	1.22	1.17	1.18	1.36	1.15	1.11	0.97	0.39	0.85	0.51	0.80
6–13–13	....	....	....	....	....	....	....	....	....	....	0.97	1.42	0.75
6–14–13	....	....	....	....	....	....	0.96	0.97	0.90	0.58	0.47	0.71	....
6–15–13	1.04	1.12	1.08	1.07	1.01	1.02	1.02	1.50	0.94	0.72	0.71	0.89	0.87
6–16–13	....	....	....	....	....	....	....	....	....	0.59	0.49	....	....
6–17–13	....	....	....	1.16	1.00	1.11	1.19	1.07	0.86	1.08	0.63	0.68	0.77
6–18–13	....	....	....	....	....	....	....	....	....	....	....	....	....
6–19–13	....	....	1.07	1.07	1.08	1.05	1.00	0.98	0.91	0.92	0.70	0.65	0.66
6–20–13	....	....	....	....	....	....	....	....	1.20	1.61	0.40	0.41	0.60
6–21–13	....	....	....	....	....	1.06	1.06	1.17	0.85	0.83	0.84	0.84	0.83
6–22–13	1.03	....	....	....	....	....	....	....	....	....	....	....	....
Mean divs. per hour........	1.143	1.186	1.187	1.116	1.122	1.134	1.114	0.940	0.862	0.720	0.700	0.829	0.843
Mean ions per c.c. per second......	8.06	8.35	8.36	7.87	7.92	8.00	7.85	7.63	6.08	5.08	4.94	5.81	5.95

TABLE I.

1:00 P. M.	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00 P. M.	Average for the Day.	Weather Conditions.
....	....	....	....	....	....	....	1.43	1.19	0.83	1.29	1.19	Fair
1.11	0.69	1.07	1.37	1.20	1.22	1.23	1.40	1.00	....	....	1.04	"
0.82	1.16	1.56	1.15	0.93	1.12	1.14	1.29	1.31	1.01	0.76	1.05	"
0.75	1.12	1.14	1.03	1.04	1.03	1.55	1.07	....	....	....	1.01	"
0.92	1.11	1.31	1.06	1.62	2.22	1.39	1.12	1.04	1.32	1.28	1.29	"
1.29	1.12	0.92	1.13	1.07	0.96	1.13	1.32	....	....	....	1.04	"
1.25	0.49	0.63	1.00	1.54	1.65	1.63	0.66	1.38	1.46	1.39	1.22	"
0.95	1.88	0.66	1.04	0.94	1.32	1.61	....	....	....	....	1.09	"
0.78	1.26	1.98	1.60	0.93	0.93	1.24	1.32	0.99	0.83	1.19	1.12	Light Rain
1.27	1.19	1.15	0.96	0.98	1.13	1.20	1.20	....	....	....	1.06	" "
....	....	....	....	2.39	1.38	1.56	....	....	....	....	1.24	Fair
0.55	0.44	1.05	1.65	1.09	0.98	1.22	1.62	0.94	....	....	1.01	"
....	....	....	1.28	1.19	1.62	1.43	1.13	1.21	1.17	1.32	1.33	"
1.23	1.25	0.93	1.02	1.14	1.06	1.32	1.74	....	....	....	1.08	"
1.02	0.91	0.87	....	....	1.34	1.59	1.43	1.53	1.09	1.18	1.02	"
0.96	1.22	0.96	1.27	1.40	1.30	1.24	1.09	0.27	....	....	1.05	"
1.15	1.15	0.94	1.14	0.96	1.05	1.48	1.44	1.26	1.11	1.04	1.09	"
0.79	1.14	1.37	2.26	1.25	0.74	....	....	....	....	....	1.05	"
....	....	....	....	....	....	1.25	1.28	1.24	1.17	1.26	1.24	Heavy rain
0.74	0.58	1.21	1.97	0.63	0.98	1.21	1.01	....	....	....	1.00	Fair
0.79	1.01	1.01	1.26	....	....	....	....	1.03	1.20	1.01	0.93	"
0.86	0.81	1.03	1.33	1.12	0.88	1.26	1.12	0.85	....	....	1.08	"
0.74	0.97	1.56	1.38	1.24	1.09	1.06	1.17	1.08	1.06	1.03	1.04	"
0.86	1.42	....	....	....	1.42	1.22	....	....	....	....	1.01	Rain
0.57	1.02	0.93	1.06	1.08	0.86	1.13	1.36	1.18	1.21	1.18	0.98	Fair
0.74	0.78	1.05	1.60	0.35	1.48	0.86	1.31	1.67	....	....	1.04	Heavy rain
0.88	0.93	1.30	1.32	....	....	....	....	1.03	1.05	....	1.07	Fair
....	0.85	0.89	1.40	1.36	1.39	1.05	1.08	1.17	1.18	1.18	1.01	"
0.79	0.84	1.02	1.20	1.12	1.05	1.11	0.99	....	....	....	1.01	"
....	....	1.23	1.02	1.29	1.21	1.71	1.33	....	....	....	1.11	"
0.77	1.09	0.99	1.28	1.19	1.01	0.92	1.03	....	....	....	0.99	Heavy rain
....	0.73	1.02	1.33	1.26	1.07	1.02	1.08	....	....	....	1.07	" "
0.79	1.08	1.16	....	....	1.10	1.43	1.11	0.97	1.06	....	0.99	" "
0.72	0.77	1.26	1.21	1.13	1.16	1.00	0.98	1.45	1.22	0.94	1.01	Fair
0.75	0.97	1.03	0.97	1.21	1.06	1.02	1.23	....	....	....	0.99	"
....	1.34	1.10	0.88	0.90	0.94	0.86	0.86	0.98	....	....	0.99	"
0.884	0.976	1.111	1.272	1.158	1.180	1.252	1.208	1.129	1.123	1.146	1.055	
6.26	6.88	7.81	8.96	8.15	8.31	8.82	8.50	7.95	7.90	8.06	7.43	

These N's were plotted against times as shown in Fig. 2. While the curve is rather irregular, there certainly is a decided minimum at 11 A. M. and a decided maximum at 4 P. M. The mean N for the minimum at 11 A. M. is 5.2, and that for the maximum at 4 P. M. is 11.5. The maximum is, therefore, more than twice the minimum. The mean is practically the same whether it be obtained by averaging all the 24 values for the different hours of the day, or by averaging only the maximum and the minimum. The former method gives 8.05 for mean N, and the latter gives 8.35.

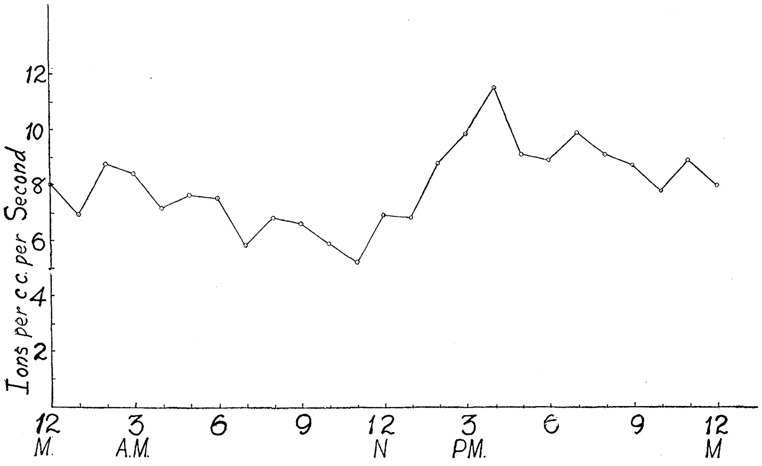

Fig. 2.

Final Results.—This preliminary test seemed conclusive in establishing the fact that there was a true diurnal variation in the value of the penetrating radiation at Manila. But it was felt that a longer series of observations was needed to determine more accurately the time of the maximum and of the minimum as well as their value and the value of the mean. With this object in view, the electroscope and ionization chamber were set up in a stone bungalow, the residence of the author, at 217 Valenzuela, Santa Mesa, Manila, P. I. This was considered a desirable location as it was far from any possible source of radio-active matter, such as might be present in the neighborhood of a physical or chemical laboratory. It was also at one of the highest spots in Manila, and the air had free access from all directions. Another important consideration, since readings extended over 36-hour periods, was that rest could be obtained between readings. Thanks are due to Mrs. L. J. Lassalle who frequently made the observations from five to ten A. M. Had it not been for this aid, it would not have been possible to observe 36 hours out of each 48, as was done.

Final Series Shows a Diurnal Variation.—Table I. is a complete record of the calculations for N obtained from the data taken during the period extending from May 18, 1913, to June 22, 1913. The calculations consisted of interpolations so as to get the scale readings at each half hour. Then, the difference between the readings for one mid-hour and the next gave the change in scale-readings per hour. It is evident that this difference is proportional to ΔE. Since C V, t, and e are constant for a given instrument, this difference is proportional to N, the number of ions per c.c. per second formed in the ionization chamber. In this case $N = 7.05 \times$ divisions per hour. In Fig. 3, N is plotted against time. The curve shows a decided minimum at 10 A. M. equal to 4.94 and a decided maximum at 4 P. M. equal to 8.96, the maximum being nearly twice the minimum. The mean obtained by averaging all 24 values is about 7 per cent. higher than that obtained by averaging the minimum and the maximum. The minimum N is practically 5 and the maximum is practically 9. *These observations seem to establish the fact beyond a doubt, that there is a true and decided diurnal variation in the value of the ionization in a closed vessel at Manila, P. I.* It would be very interesting to have observations of this nature extended over a whole year, so as to see whether or not the nature of the variation would change with changing seasons. These observations are for the end of the dry season, just before the beginning of the wet or typhoon season.

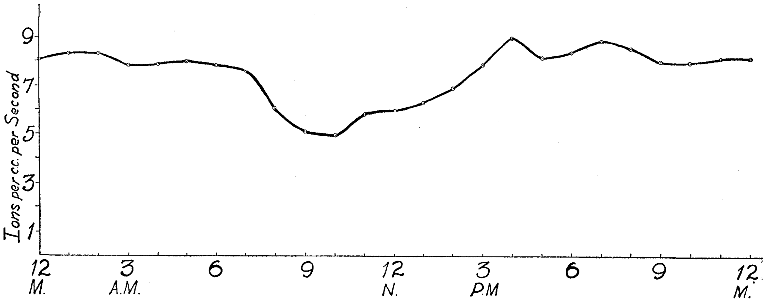

Fig. 3.

Further Deductions from the Data Obtained.—The results obtained do more than show a diurnal variation; they throw some light on the nature of the cause or causes of the ionization in a closed vessel. The possible causes are:

1. Radio-active gases in the vessel, but having their origin outside of it;
2. Radio-active impurities in the material constituting the vessel;
3. An inherent radio-activity of the material constituting the vessel;

4. A penetrating radiation from the radio-active matter known to be in the earth's crust;

5. A penetrating radiation from the radio-active matter known to be in the earth's atmosphere;

6. A penetrating radiation from the sun or other non-terrestrial sources. In addition, a leak over the insulation of the leaf system would cause a deflection of the leaf that would be supposed to be due to an ionization in the vessel. Therefore, we may classify as

7. A leak over the insulating system of the leaf.

The effect of (1) was practically eliminated by allowing the vessel to remain closed for about two weeks before the observations were taken. Radium emanation has a half-period value of 3.85 days; and in 15 days its activity will decay to about 7 per cent. of its original value. Also, the air allowed to flow into the tube, after it had been exhausted to a vacuum of about 3 or 4 cm., was passed over cocoanut carbon in a long tube, thus robbing it of almost all the emanation in the first place. Thorium emanation has a half-period value of 53 seconds, while for actinium emanation the value is 3.9 seconds. It is evident that even if some of these gases did enter at first, their activity would have decayed to practically nothing in two weeks.

It may be that either or both of 2 and 3 produce the ionization in the vessel. However, their effect in the present instance must have been small, for after sealing off the tube in the manner previously mentioned the mean value of N for each of several successive days was calculated. There was no indication of a gradual rise in the value of N, as would necessarily have been the case had there been any radio-active materials, either as impurities or otherwise, in contact with the air within the vessel. Also, there could hardly be any explanation of the diurnal variation in the value of the ionization having its origin in either 2 or 3. The only theory that it would be reasonable to advance would be that a temperature variation might cause the emanation from the inner walls of the vessel to be given off more rapidly when the temperature is high than when it is low. However, the temperature at Manila during fair weather is appreciably constant from 10 A. M, to 4 P. M.; and it is between these hours that N varies from its minimum to its maximum. It is therefore, reasonable to conclude that the effect of 2 and 3 is small in this particular vessel.

If radio-active matter in the sun furnished any appreciable cause of the ionization, one would expect the minimum to occur at night. However, there might be a lagging of the effect after the cause is removed. Even then it would be expected that the variation would give a more symmetrical curve than the one obtained. That is it would be reasonable to expect the period of highest value and that of lowest value to each extend over twelve hours, even though the former did not fall during the day and the latter during the night. The best evidence that the sun is not a factor is furnished by the work of Simpson[1] at Karasjoh in Norway, which shows that the active matter deposited on a negatively charged wire is about the same in amount in summer, as in winter when the sun does not rise above the horizon. Other non-terrestrial sources are so numerous that it would not be advisable to try to consider them here. Suffice it to say that it seems improbable that any other source, not on the earth, would be as likely to be the source of the ionization as would be the sun.

A leak over the insulation was guarded against by drying the air that entered the vessel and by freeing it from dust particles. It was also observed that, when the vessel was exhausted the leaf did not appreciably deflect for several hours. We may, therefore, say that the effect of 7 was very small.

Thus we have 4 and 5 left as the main causes of the ionization in the closed vessel. One cannot offer any explanation of a possible diurnal variation in the amount of radio-active matter in the soil in Manila. Since we assume the effect of all other causes excepting 4 and 5 to be small, and since the effect of 4 is assumed steady during the time over which these observations extend, the conclusion is forced upon us that the diurnal variation is a variation in the value of the penetrating radiation from the earth's atmosphere. Since N varies from 5 to 9, it is also evident that the effect of the active matter in the atmosphere is responsible at times for at least 4 ions per c.c. per second at Manila. The cause of the diurnal variation is probably that the air which sweeps over this locality at certain times has been over water for a long enough period of time to have lost some of its activity by decay. At other times the air comes from over the land, so that it is in radio-active equilibrium with the active matter in the earth's crust. That is, whatever activity it is gaining is equal to that which it is losing by decay. At a given season of the year there is a steady recurrence of sea and land breezes at Manila; so that it is to be expected that there will be a steady recurrence of the maximum and of the minimum for the ionization in a vessel if this ionization is due at all to the active matter in the atmosphere. In addition to the shifting of the air from land to sea and vice versa, due to temperature changes, there is generally another motion of the air, called a typhoon. There may also be vertical air currents. Since the

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[1] Simpson, Phil. Trans. Roy. Soc., *A*, 205, p. 61, 1905.

data to determine these three components is not at hand it is impossible to determine exactly the direction of the resultant at any time. While it would be rather difficult to determine these factors, they are necessary to a complete solution of the problem in hand. It is not to be expected that such a variation will be found at points where there are no considerable bodies of water near, over which the air might remain long enough to lose a considerable part of its activity.

It was thought possible that the value of N might be connected with the kind of weather which prevailed while the observations were being taken. Most of the five weeks were fair, but there was one period at the beginning of the fifth week when there were heavy rains for three days. There were two or three other days when there were heavy rains. The mean of N for all periods following heavy rains is 7.16 while the mean for the remaining time is 7.72. It is to be expected that following heavy rains the pores of the earth will be filled so that the radio-active gases will not be able to escape so readily. However, the data at hand from which to draw conclusions regarding this matter is rather limited as the difference is very small for clear and for rainy weather. The time to get data on this point is during the rainy season.

SUMMARY.

1. A diurnal variation in the value of N, the number of ions per c.c. per second formed in a closed vessel in Manila, was found, The maximum of 8.96 occurs at 4 P. M., and the minimum of 4.94, at 10 A. M. The mean for N is found to be 7.43.

2. It seems probable that the main causes of the ionization are the radio-active materials in the soil and the radio-active matter in the atmosphere.

3. Since there is no reason to suppose that the former of these two causes might have a diurnal variation, it must be that this variation is in the latter cause.

4. The air currents at Manila have a diurnal variation, sea breezes blowing at times and land breezes at other times. While the exact nature of the relationship cannot be established from the data available, it seems probable that the minimum must occur at a time when the air over the land is air that has blown from over the sea where it has previously remained long enough to lose a considerable portion of its activity by decay. The maximum, which is fairly steady from 3 P. M. to 6 A. M., must be due to the air which is over land during this period having previously been mainly over land for some considerable time.

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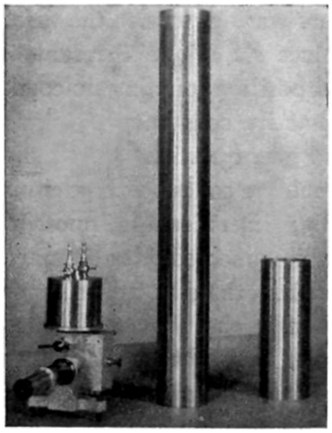

Fig. 1.