# ATMOSPHERIC ELECTRICITY OBSERVATIONS ON THE FIRST CRUISE OF THE "CARNEGIE."

By Edward Kidson.

Observations for specific conductivity of the atmosphere and the detection of the presence of radio-active emanations were taken, in accordance with the Director's instructions, on the portions of the cruise between Falmouth and Madeira, Madeira and Bermuda, and Bermuda and New York. The plan was to devote alternate days to conductivity and radio-activity observations. This program was interfered with by bad weather and by the failure on some occasions of the Zamboni dry pile which was used to charge the collecting wire in the radio-activity experiments.

## I. Conductivity Observations.

These were taken with a Gerdien conductivity apparatus. The instrument and the method of use were similar to those already described by Messrs. Burbank and Dike in the Journal.[1] A uniform current of air is drawn by means of a fan through a cylindrical condenser, the inner cylinder of which is connected with the leaves of an aluminum leaf electroscope. The outer cylinder is 16 cm. in diameter and 35 cm. long, while the inner cylinder is 1.4 cm. in diameter and 24 cm. long. The capacity is 12.9 cm. The inner cylinder is charged to a potential indicated by the electroscope, and a current of air drawn through for a certain time, usually five minutes. The ions charged with electricity of the opposite sign to that of the inner cylinder will be attracted to it and gradually discharge it. Above a certain velocity the rate of discharge is practically independent of the velocity, the current being prevented from approaching saturation.

The electroscope was calibrated at the United States Bureau of Standards, Washington, D. C., on July 28, 1909, and again on April 15, 1910, hence before and after the cruise. There was a considerable increase in the sensibility between the calibrations. The mean of the two was used in the reduction.

If the time of exposure be five minutes, $V'$ the initial and $V''$ the final potentials, the suffixes $p$ and $n$ denoting whether the charge be positive or negative, $\lambda_p$ and $\lambda_n$ the conductivities for positive

[1] Ter. Mag., v. XII, 1907, p. 1; v. XIII, 1908, p. 119.

and negative electricity respectively, and $\lambda$ the total conductivity, then:

$$\lambda_p = K'.\log \frac{V'_n}{V''_n} \; ; \; \lambda_n = K'.\log \frac{V'_p}{V''_p} \; ;$$

$K' = \text{constant} = 1.6 \times 10^{-3}$ for the instrument used; $\lambda = \lambda_n + \lambda_p$.

The apparatus, when used, was placed on a gimbal stand amidships between the after observatory and the mainmast. (See Plate III, Position E.) From Falmouth to Madeira, and beyond to December 10th, it was mounted on a base, improvised aboard, which did not permit of its rotation; consequently, as the electroscope could only be read when the leaves were deflected in the fore and aft line, it was not possible always to turn the instrument directly into the wind, but it was always deflected slightly to windward from the normal position facing the stern. On December 13th the base was so modified as to permit of the rotation of the instrument, and thereafter it was turned into the wind during the exposure and turned back into the fore and aft line for the reading of the deflection. Observations of temperature and humidity by means of a psychrometer, and of the air pressure, wind, clouds, and state of the sea, were made by the observer during the experiments. Observations for natural leakage were made at intervals, and this seemed usually to decrease to a very low value during the observations. The mean value for the leakage, computed in the same way as the conductivity, was for negative charges $0.04 \times 10^{-4}$ and for positive charges $0.05 \times 10^{-4}$. No correction for leakage has been applied. When the wind was sufficiently strong to ensure the maximum current being produced, the fan was not rotated by hand, but the crank removed and the wind allowed to rotate it.

A summary of results obtained will be found in Table I. The observations were about equally divided between those for positive and those for negative conductivity and were made alternately. The tendency of the barometer is obtained from the "Carnegie's" barograph records. From November 23, 1909, to January 11, 1910, the conditions were very steady and there was a regular half-daily variation of the pressure, the maxima being in the neighborhood of midday and midnight. The approximate position of the ship is determined from the navigation observations.

From the observations obtained no connection could be established between atmospheric pressure, humidity, wind, or cloud and

*Table I. Summary of Observations of the Specific Conductivity of the Atmosphere of the First Cruise of the "Carnegie."*

| Date | Local Mean Time | Duration | No. of Obs'ns. | $\lambda_p \times 10^4$ | $\lambda_n \times 10^4$ | $\lambda \times 10^4$ | $\frac{\lambda_p}{\lambda_n}$ | Temp. Cent. | Bar. | Tendency | Rel. Hum. | Wind | Clouds | Lat. N | Long. W of Gr. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1909 | h | h m | | | | | | ° | mm | | | | | ° | ° | |
| Nov. 10 | 9.9 | 1 01 | 8 | 1.28 | 1.34 | 2.62 | 0.96 | 11.2 | 772 | rising | 72 | NW×W 4-7 | 0-7 | 49.9 | 5.2 | Off the coast of England. |
| " 13 | 10.8 | 1 37 | 11 | 2.08 | 1.63 | 3.71 | 1.28 | 13.8 | 759 | falling | 77 | N 0-1 | 0-1 | 47.7 | 11.6 | Sunny. Ship rolling considerably. Obs. difficult. |
| " 15 | 11.3 | 4 00 | 24 | 2.81 | 2.53 | 5.34 | 1.11 | 12.7 | 760 | falling | 73 | E 1-3 | 1-9 | 44.6 | 15.5 | Sea moderate. Barometer rising slightly at commencement. |
| " 21 | 11.7 | 0 58 | 8 | 2.49 | 2.19 | 4.68 | 1.14 | 17.4 | 753 | rising | 75 | SW 0-1 | 1-8 | 39.9 | 17.6 | Sea moderate. Sunny. |
| " 23 | 12.8 | 1 52 | 12 | 1.90 | 1.42 | 3.32 | 1.34 | 17.8 | 768 | steady | 75 | ESE 2 | 6 | 35.0 | 16.5 | Sea smooth. |
| " 26 | 12.7 | 2 40 | 14 | 1.18 | 1.31 | 2.49 | 0.90 | 19.2 | 764 | steady | 64 | W 0-1 | 1-9 | 33.0 | 16 2 | Sunny. At anchor off Funchal, Madeira. |
| Dec. 4 | 9.5 | : 38 | 10 | 2.18 | 1.97 | 4.15 | 1.11 | 20.8 | 765 | steady | 66 | E 1 | 1-2 | 26.5 | 21.0 | Sea smooth. |
| " 6 | 10.1 | 2 51 | 20 | 1.93 | 1.76 | 3.69 | 1.10 | 23.3 | 764 | steady | 67 | ENE 3 | 2-6 | 23.1 | 25.5 | Sea smooth. Little sunshine. One slight shower. |
| " 7 | 10.5 | 3 10 | 23 | 1.99 | 1.69 | 3.68 | 1.18 | 24.0 | 763 | steady | 72 | SE 4 | 0-1 | 21.8 | 27.7 | Sea moderate. Instrument turned into beam wind. Fan not rotated. |
| " 9 | 10.3 | 0 51 | 8 | 2.34 | 1.83 | 4.17 | 1 28 | 23 9 | 763 | steady | 86 | NE 0-2 | 10 | 21.0 | 34.0 | Sea smooth. Rain squall put an end to observations. |
| " 10 | 10.4 | 3 08 | 20 | 2.03 | 1.67 | 3.70 | 1.22 | 24.0 | 763 | steady | 76 | NE 1-3 | 8-10 | 21.0 | 35.2 | Long smooth swell. Sunny. Trade wind. |
| " 13 | 10.0 | 2 53 | 20 | 2.29 | 1.95 | 4.24 | 1.17 | 24.4 | 761 | steady | 87 | NE 0-1 | 4 | 20.6 | 40.6 | Sea smooth. Sunny. New base used. Instrument turned into wind. |
| " 15 | 11.1 | 1 00 | 8 | 2.92 | 2.44 | 5.36 | 1.20 | 23.3 | 760 | steady | 76 | NE 6 | 8 | 20.0 | 43.5 | Sea moderately rough. Squally and drizzly, conditions bad. Mainsail producing uneven motion. Fan not rotated. |
| " 18 | 20.2 | 22 42 | 117 | 2.30 | 2.06 | 4.36 | 1.12 | 24.3 | 762 | steady | 52-92 | Calm | 1-7 | 20 | 48 | Sea glassy smooth. Sunny day. Clear. Light airs from N quarter at night. |
| " 28 | 11.5 | 1 04 | 8 | 1.52 | 1.34 | 2.86 | 1.13 | 25.4 | 767 | steady | 78 | ESE 3 | 9 | 23.0 | 57.8 | Sea moderate. |
| " 30 | 10.9 | 3 02 | 20 | 1.61 | 1.03 | 2.64 | 1.56 | 24.4 | 763 | steady | 84 | SW 5 | 1 | 25.2 | 61.7 | Sea choppy. |
| " 31 | 12.6 | 7 17 | 40 | 2.34 | 2.02 | 4.36 | 1.16 | 20.0 | 767 | rising | 76 | N×W 7 | 3-10 | 25.5 | 62.4 | Sea rough. Drops of rain or spray in air most of time. Observations difficult and uncertain. Fan not rotated. |
| 1910 | | | | | | | | | | | | | | | | |
| Jan. 3 | 11.0 | 3 12 | 18 | 2 64 | 2.02 | 4.66 | 1.31 | 19 3 | 771 | steady | 68 | NE 2 | 1-7 | 28.0 | 66.7 | Sea smooth. Conditions good. |
| " 6 | 10.7 | 3 02 | 18 | 2.69 | 2.25 | 4.94 | 1.20 | 18.4 | 774 | steady | 70 | SE 5 | 9 | 31.2 | 67.6 | Sea moderate. |
| " 7 | 10.8 | 3 14 | 20 | 3.03 | 2.26 | 5.29 | 1.34 | 19.0 | 774 | steady | 74 | SSE 4 | 9 | 32.1 | 64.9 | Reached shelter of Bermuda Islands towards close. |
| " 11 | 13.5 | 4 25 | 20 | 0.90 | 1.06 | 1.96 | 0.85 | 14.4 | 774 | rising | 64 | ENE 1-5 | 10 | . . . | . . . | At anchor, Hamilton, Bermuda. |
| Feb. 1 | 10.7 | 2 10 | 9 | 1.38 | 1.46 | 2.84 | 0.95 | 15.0 | 761 | falling | 87 | W 6 | 9 | 37.5 | 68.5 | Sea moderate. Squally. |
| " 6 | 9.8 | 0 39 | 4 | 0.56 | 0.42 | 0.98 | 1.33 | 10.1 | 762 | steady | 68 | NW 0-1 | 10 | 36.9 | 68.9 | Sea rough. Squally. |
| " 8 | 10.6 | 1 52 | 8 | 1.22 | 1.00 | 2.22 | 1.22 | 10.5 | 764 | falling | 63 | NW 0-1 | 10 | 34.9 | 70.1 | Sea moderate. |
| " 15 | 9.8 | 0 48 | 4 | 0.16 | 0.14 | 0.30 | 1.14 | 1.3 | 765 | steady | 78 | W 3 | 10 | . . . | . . . | Off New Haven, Conn., at anchor. Hazy. Snow on land, ice on sea. |
| " 17 | 10.9 | 1 44 | 8 | 0.35 | 0.39 | 0.74 | 0.90 | -0.7 | 765 | steady | 88 | NE×E 3 | 10 | . . . | . . . | Ship being towed along Long Island Sd. Weather thick and drizzly. Appearance of snow. Snow on land. |
| | Sums | . . . | 480 | 48.12 | 41.18 | 89.30 | 30.20 | | | | | | | | | |
| | Means | . . . | . . | 1.85 | 1.58 | 3.43 | 1.16 | | | | | | | | | |

the conductivity. When, however, there was a visible fog or haze the conductivity was greatly reduced. This was noticed in some preliminary practice experiments at Falmouth and in Long Island Sound. Rain squalls of short duration did not produce any effect. As the conductivity is an extremely variable quantity, a very large number of observations is required before the connection with meteorological conditions can be thoroughly investigated. One effect that was noticed was that a low conductivity was invariably obtained when the vessel was in the neighborhood of land. This effect was heightened in Long Island Sound by the state of the atmosphere and probably by the presence of snow on the land and ice on some stretches of water.

Another noticeable fact is the persistent excess of the positive conductivity over the negative. The only occasions on which the reverse appeared to be consistently the case were while the ship was at anchor off Madeira and in Hamilton Harbor, Bermuda. This higher value of the positive conductivity is probably due chiefly to the accumulation of positive ions near the negatively charged Earth's surface. If this were so, then the effect should not be so noticeable in balloon observations, which I believe has proved to be the case.

None of the present theories seem sufficient to explain the high degree of ionization observed in the air.

On December 18th-19th continuous observations of the conductivity were taken over practically twenty-four hours, in order to discover, if possible, a diurnal variation. The day was exceedingly calm and fine, with a glassy sea with a smooth, low swell. The ship being without steerageway, no magnetic observations could be taken, so that the opportunity was considered good for the attempt. The results obtained are shown in Fig. 1.


FIG. 1. *Conductivity of the Atmosphere, December 18–19, 1909*

[Smoothed curves obtained by taking the mean of all observations between each determination of the leakage. Ordinates represent absolute specific conductivity times $10^4$. Continuous line represents the conductivity for negative electricity, and the broken line for positive electricity.

The curve was obtained by plotting the means of the values of positive and negative conductivity respectively, four to eight in number for each, obtained between each observation for leakage. The leakage experiment made a relatively long break, so that the method of grouping used was the most obvious one. The results point to a higher value of the conductivity at night than during the day, and to an almost constant value at night. This latter effect is more obvious if the individual observations be all plotted, when the variations are seen to be much greater and more irregular during the day time. It would be interesting to secure more of these continuous observations. I have been informed that "wireless" operators find a greater ionization at night than during the day, but do not know how accurate this statement is.

## II. Observations for the Detection of Radio-active Matter in the Atmosphere.

The method of observing was to measure the activity of a copper wire which had been exposed to the air while charged to a high negative potential. A fine, bare copper wire was suspended from an insulator in the main, weather rigging to an electroscope on a gimbal stand amidships, and thence to the charging Zamboni pile. The potential of the wire was indicated by the electroscope.

After being charged for a considerable time, usually about an hour, the wire was discharged, reeled up on a wire netting cylinder, and tested as quickly as possible for radio-activity. The testing apparatus was of the type used by Elster and Geitel, consisting of an Exner electroscope with a blackened discharging cylinder, the latter being surrounded by a cylindrical metal vessel which formed the ionizing chamber. The diameter of this vessel was 18 cm., and that of the discharging cylinder, 5 cm. The lid of the vessel could be removed for the insertion of the wire netting and collecting wire. The chamber would be practically free from air currents. Except on November 12th the length of the collecting wire was always 7 meters.

While the collecting wire was being exposed, the testing electroscope was charged and the rate at which its potential fell noted, in order to measure the natural leak. The latter was almost invariably found to decrease with time, sometimes very regularly, and was generally nearly constant and small by the time the radio-activity test was begun.

After the wire was inserted, the electroscope deflections were read at frequent intervals and the fall of the potential with time thus obtained. The results were plotted on cross-section paper, the ordinates representing potentials, and the abscissæ, times. A smooth curve was drawn through the points thus plotted, and from this smoothed curve an activity curve was drawn, the ordinate at any point of which was proportional to the gradient of the first curve at the time represented by the abscissa. The times were measured from the time of discharge of the wire.

The small amount of the activity and the uncertainty of the observations rendered it impossible to observe the activity direct by the time taken by the electroscope leaves to fall from one fixed deflection to another. Sources of error were:

(1.) The Zamboni pile used to charge the collecting wire often worked very poorly, so that the potential was not always high enough to collect the maximum amount of radio-active deposit, and it was sometimes difficult to determine when the charging began. In order to get any satisfactory results, the pile had to be warmed before use. The number of observations obtained was greatly reduced owing to this difficulty.

(2.) The natural leak of the electroscope was uncertain and variable.

(3.) Owing to the small range of deflections available, the electroscope usually had to be recharged several times during an experiment. This necessitated the opening of the ionizing chamber and the admission of fresh air, which caused an increase in the conductivity of the air in the chamber for a few minutes. This recharging also caused the curve of fall of potential to be constructed in several parts which had to be joined together in the manner that best fitted in with their curvature, thereby introducing considerable uncertainty. The electroscope was not sufficiently sensitive for accurate observation.

(4.) The continual rolling of the ship and consequent flapping and swinging of the electroscope leaves rendered the reading of the deflections extremely difficult and slow. The leaves had to be watched until a relatively quiet interval occurred, in which they appeared to be in their normal position, and the eye quickly transferred from one to the other, the deflection being noted. The method of reading finally adopted was to take five closely consecutive readings and take the mean for the mean time.

(5.) As the electroscope was calibrated only once, before the beginning of the cruise, the accuracy of the calibration curve is uncertain. One of the aluminum leaves was damaged before the ending of the cruise, rendering a second calibration impossible. This inaccuracy would probably seriously affect only the absolute values of potential, and not the relative values.

On days when a comparatively large quantity of deposit was collected and the conditions of observation were good, the curves obtained for the decay of the activity were fairly regular and similar in character. The deposit appears to be derived from radium emanation. Fig. 2 shows the curve obtained by taking the mean of six of the better curves.

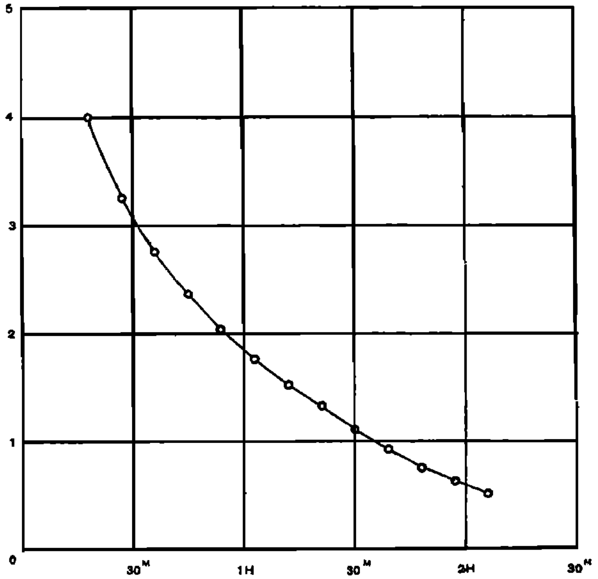


FIG. 2. *Mean curve showing the decay of activity with time of the radioactive deposit collected from sea air.* [The ordinates represent activities on an arbitrary scale.]

The following Table II shows roughly the relative amounts of activity collected on different days. The activity is measured by the fall of potential in volts produced in the electroscope by the deposit in one hour, starting fifteen minutes after the discharge of the wire. The capacity of the electroscope was about 15 cm.

TABLE II

| Date | Latitude N | Longitude W. of Gr. | Time of Exposure | Activity | Remarks |
|---|---|---|---|---|---|
| 1909 | ° | ° | | | |
| Nov. 12 | 48.6 | 10.0 | 40 min. | 40 | Length of wire = 16 meters |
| 14 | 46.5 | 14.3 | 100 " | 35 | |
| 20 | 40.2 | 17.9 | 1 hr. | 75 | |
| 22 | 36.8 | 16.5 | 1 " | 45 | Potential too low for maximum effect |
| Dec. 3 | 28.0 | 19.0 | 1 " | 60 | |
| 8 | 21.0 | 32.0 | 1 " | 45 | |
| 11 | 20.8 | 37.4 | 30 min. | trace only | |
| 14 | 20.5 | 42.0 | 1 hr. | 20 | |
| 18 | 20.0 | 48.0 | 1 " | 5–10 | |
| 20 | 19.8 | 49.5 | 1 " | 35 | |
| 23 | 19.9 | 51.5 | 1 " | 30 | |
| 26 | 21.6 | 54.8 | 1 " | 20 | |
| 29 | 24.0 | 59.3 | 1 " | trace only | |
| 1910 | | | | | |
| Jan. 1 | 25.7 | 64.1 | 5 " | 55 | |
| 4 | 28.5 | 67.2 | 10 " | 30 | |
| 12 | Hamilton, Bermuda | | 15 " | 85 | |
| May 14 | Washington, D. C. | | 1 " | 50 | In Ontario grounds, A. M. |
| 16 | Washington, D. C. | | 1 " | 23 | In Ontario grounds, P. M. |

On December 16, 1909, latitude 20°.0 N., longitude 45°.8 W., the wire was charged to a high positive potential for one hour, but no active matter appeared to have been collected. On February 9, 1910, latitude 37°.1 N., longitude 70°.9 W., a fair amount of deposit was collected, but the electroscope had had a leaf damaged and replaced, so that the results are not strictly comparable with the previous ones.

On January 1st, 4th, and 12th, 1910, the charged wire was exposed for a long period, in order to detect if possible the pressure of thorium products in the atmosphere. On January 1st, after five hours, there appeared to be still left on the wire about three per cent of the activity exhibited ten minutes after discharging. This effect, however, may have been due to an increase of the natural leakage which was liable to take place in the increased dampness after nightfall. Unfortunately no determination of the leakage was made at the close of this experiment. On the other two days no sign of activity could be detected after a few hours. On January 12th the observations were taken in Hamilton Harbor, Bermuda, under good conditions, so that a very slight activity should have been detected. The evidence thus points to the absence of any considerable quantity of thorium emanation in the air over the ocean. Bermuda being a collection of small coral islands in mid-ocean, the air over it is not likely to differ much from that over the sea in radio-active properties. More observations are needed to decide the question as to the presence or absence of thorium emanation.

It will be noticed that on several days, when the vessel was very far from land, very little activity was collected; particularly is this the case on December 11th, 14th, and 18th. The region in which this happened was a very calm one, and the air had probably not been in contact with the land for many days. I am inclined to think, therefore, that the land is the chief source of the radio-active matter in sea air. This is what would be expected from determinations of the radium content of sea water. The fact that Dike in his observations on the "Galilee" in the Pacific could obtain no evidence of radio-activity except near land, also points to this conclusion. The Pacific Ocean being of so much greater an extent than the Atlantic, there should be much larger tracts over which the air had lost any radio-activity got from the land. The absence of thorium emanation would tend to confirm this theory.

It is easy to understand that the air in the North Atlantic between Newfoundland and England may at times have all been over land surfaces within a week. This may account for the results obtained by Professor Eve in this region.[2] Observations comparing the amounts of radio-activity over land and ocean are badly wanted.

I am indebted for assistance to Mr. D. F. Smith, the chief engineer of the "Carnegie," whose ingenuity was shown in the making of the necessary repairs and modifications of the apparatus with the limited means at his disposal and who took part in the observations on December 18th and 19th. Mr. Peters, the Commander of the "Carnegie," allowed me to devote as much time as possible to the work, and otherwise facilitated it in every possible way.

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[2] A. S. Eve, Ter. Mag., v. XIV, 1909, p. 25.