REPORT ON THE ATMOSPHERIC ELECTRICITY OBSERVATIONS MADE ON THE MAGNETIC SURVEY YACHT "GALILEE," 1907-08.

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In addition to the magnetic work on board the "Galilee," an attempt was made during her final cruise (Sitka, Honolulu, Marshall Islands, Christchurch, Callao, and San Francisco), 1907-08, to secure some observations at sea of the electrical condition of the atmosphere. These were intended to include potential gradient, conductivity, and the radioactive deposit on a charged wire.

The first, the determination of the potential gradient, after careful consideration of the conditions on board a sailing vessel, seemed quite impracticable, and no serious attempt was made to secure observations. The rolling of the ship, the flapping of the sails, and the varying positions of the yards and boom under various sailing conditions, all contributed to make the problem of reducing observations of potential gradient to a uniform basis too complicated to be undertaken. On board a steamer the conditions would be less variable and it might be possible to reduce readings to values for undisturbed sea by means of simultaneous observations in port with the vessel at anchor and the second collector and electroscope mounted on a raft at some distance from the vessel.

It was possible only once to secure potential observations at sea, viz., on the 7th of December, 1907, during a period of absolute calm, when even the long swell had almost died out, in latitude 22° 40′ south and longitude 170° 36′ east. A small skiff was put overboard, and the writer, assisted by Mr. D. C. Sowers, Magnetic Observer on the "Galilee," rowed out about 100 yards from the ship. The Elster and Geitel flame collector was set up on its ebonite rod, at a height above sea level estimated at 2 meters. Large, and extremely variable, potentials were obtained, varying rapidly from zero to potentials beyond the capacity of the electroscope. The mean value would be not far from 90 volts per meter. The conditions on this day were so abnormal that not much value can be assigned to the observations, though they encourage the assumption that the potential gradient over the sea is not so very different from that over the land.

Owing to breakage in the box of dry piles in transportation and the consequent failure of the means of maintaining a high potential on the charged wire, the radioactivity work was not satisfactory, as it was not found possible to reach a potential much above 1,000 volts, even with the box of dry piles opened to the hot sun. However, several exposures of a copper wire about 10 meters long were made during the first half of the voyage. In the neighborhood of land, as off the coast of Alaska and in Cook Strait, New Zealand, December 21, 1907, the observations showed conclusively the presence of radioactive emanation in the air, even with the low potential available for charging the wire. In Cook Strait a value for A (the "aktivierungszahl" of Elster and Geitel) of 40 was found, the deposit decaying to half value in about 40 minutes. But in the open sea no increase in the rate of discharge of the electroscope used for testing the exposed wire could be detected. With a better charging device it might be possible to obtain some result, but it would probably be only a very small fraction of that on or near land.

Rain water, caught as it fell and immediately evaporated to dryness, showed no sign of radioactivity. The electroscope readings were always difficult, and not of sufficient accuracy to detect extremely small effects. The electroscope was always placed so as to allow the leaves to swing in a plane parallel to the length of the ship, so as to eliminate the effect of rolling as far as possible, but the leaves were never quiet and their mean position had to be estimated.

The only really satisfactory instrument for regular use on board ship was the Gerdien apparatus for determining the specific conductivity of the air. An Ebert ioncounter was also included in the outfit, but its leakage was too great and the time necessary for a single determination too long, so no results were obtained with it.

The Gerdien conductivity apparatus was the same as used by Mr. J. E. Burbank in his work in Labrador during the eclipse of 1905.* 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 electrostatic units. The inner cylinder being charged to a known potential, read on the electroscope, air is drawn through for a measured interval of time, usually five minutes. The ions

* See Jour. Ter. Mag., v. XII, No. 3, Sept. 1907, pp. 97–104, for description of instrument.

of opposite sign to the charge on the cylinder will be attracted to it from the air passing by and a certain portion of the charge will thus be dissipated. Only those ions will reach the inner cylinder which have a sufficient velocity to carry them across the intervening space before they are carried by. Hence the number of ions reaching the inner cylinder is practically independent of the velocity of the air current so long as it is sufficient to prevent saturation currents from being established, and it is only necessary to avoid falling below a certain minimum velocity. Knowing the capacity and dimensions of the instrument and the time during which the air current has been passing, the specific conductivity of the air can be computed from the potential of the inner cylinder at the beginning and the end of the exposure.

The instrument was at first mounted on a ship gimbal stand, which was placed on top of the forecastle, under the observing bridge for magnetic observations, and for one-half of the voyage the observations were made at that place. The location was, however, not satisfactory on account of the neighborhood of the galley smokestack, smoke from which often reached the instrument during calms or while sailing by the wind. Accordingly, on the cruise between New Zealand and Peru (on February 3, 1908) the gimbal stand was moved to the main deck, just forward of the main hatch and still under the bridge. Here there was no further trouble from smoke. There was never any spray on board during observations, as in weather rough enough for spray it was impossible to read the electroscope. The only use of the gimbal stand was to make it possible to balance the instrument during readings so as to get equal divergence with both leaves. During readings, the instrument was turned so that the leaves swung in a plane parallel to the length of the ship, while during the exposure it was turned so that the cylinder faced into the wind. The crank was rotated uniformly at a rate of about 80 turns per minute.

The electroscope was roughly calibrated at Sitka, Alaska, August, 1907, using dry cells and a battery of 200 cells of zinc-copper elements in a weak solution of magnesium sulphate. The method was very inaccurate and not much weight is given to the calibration. A second calibration was made in the Physical Laboratory of Canterbury College, Christchurch, N. Z. (January 7, 1908), with the permission and kind assistance of Dr. C. Coleridge Farr, to whom I take this opportunity of extending my thanks. This calibration, by potentiometer method, was very good, and agrees closely with a final calibration at the United States Bureau of Standards upon the return of the instrument to Washington (July 10, 1908). *The same pair of leaves was used throughout the voyage.* In the computation of the results the Sitka calibration is used from Sitka to Honolulu (August 10th to August 28th), the Christchurch calibration from Honolulu to New Zealand (September 23d to December 24th), and the Bureau of Standards calibration for the remainder of the voyage (January 16th to May 7th). The observations made between Sitka and Honolulu have not been included in the means, being considered as practice observations.

The results are shown in the accompanying table, where only the mean values for each day's observations are given. The columns $\lambda_p.10^4$ and $\lambda_n.10^4$ are computed from the observed fall in potential of the electroscope system by means of the formulæ $\lambda_p = K' \log \frac{V'_n}{V''_n}$ and $\lambda_n = K' \log \frac{V'_p}{V''_p}$ where K' is an instrumental constant, depending on the capacity and dimensions of the instrument and the time of exposure, V'_n is the initial negative charge on the system and V''_n is the charge remaining after exposure. For the instrument used, with a time of exposure of 5 minutes, $K' = 1.6 \times 10^{-4}$. λ_p is the specific conductivity of the air for positive electricity and λ_n that for negative.

$\lambda_p + \lambda_n = \lambda$, the total specific conductivity of the air. The ratio, $\frac{\lambda_p}{\lambda_n}$, of the specfiic conductivities, is also given for the mean conductivity for each day.

The temperature is that inside a thermometer shelter attached to the outside of the cabin. The barometer reading is that of an aneroid whose correction was known. The values of relative humidity are very rough, as there was no adequate means at hand for measuring it. The wet bulb thermometer was hung inside the thermometer shelter and no artificial ventilation applied. The values given are interpolated from the readings by the meteorological observer at 8:00 A. M., 12:00 noon, and 4:00 P. M. The direction and force of the wind and the state of the weather are indicated in the next two columns. Under "Weather," *b* signifies clear, *bc,* partly cloudy, and *c,* cloudy.

The noon position of the ship is given as the geographical location of the observations, as they were usually made within two or three hours of noon, and the rate of progress of the ship on days when the sea was not too rough for observing was not great enough to make the position in error by more than 15 or 20 miles.

Leakage tests with both ends of the outer cylinder closed to exclude air currents were made frequently and showed values for the leakage of about the same order as the probable error of a reading of the electroscope. Consequently no correction for leakage has been applied and the values of λ_n and λ_p are probably too large by about 0.10×10^{-4}.

The measurements of the specific conductivity give as a mean for:
$\lambda_p = (1.603)\ (10^{-4})$ *electrostatic units (from 258 observations) and*
$\lambda_n = (1.433)\ (10^{-4})$ " " *(from 260 observations).*

The mean ratio, $\frac{\lambda_p}{\lambda_n} = 1.12.$

The barometric pressure apparently affects the conductivity, as the mean values for λ_p and λ_n for 34 days with the pressure below 762.00 mm. are (1.61) (10^{-4}) and (1.46) (10^{-4}) respectively, while 24 days with the pressure 762.00 mm. or above, the mean values for λ_p and λ_n are (1.52) (10^{-4}) and (1.31) (10^{-4}) respectively. High barometer apparently causes a decrease of conductivity. This may, however, be due to the fact that the low barometric readings were nearly all within the tropics while the high readings were in higher and lower latitudes, so that the effect may be regional rather than directly due to the pressure.

No effect due to the relative humidity of the air is discernible. The mean values of the conductivities with the relative humidity below 80 are almost identical with those with the humidity above 80. But as noted above the values of humidity are not reliable.

It is of interest to note that the ratio $\frac{\lambda_p}{\lambda_n}$ is considerably above unity and that it is pretty consistently so, though there are several individual values of the ratio below unity. This was especially so in the portion of the voyage from the equator southward along the 170th meridian east, to New Zealand (November 19th to December 24th), where over a third of the values are below unity and the mean value is only 1.04. Throughout this region calms and light baffling winds were encountered, with some squalls—the usual "doldrum" weather. In regions of steady winds and settled weather conditions the ratio was almost invariably above unity. Most of the abnormally high values of the ratio occurred during cloudy weather, or under unusual atmospheric conditions.

In view of the fact that no measurable amount of radioactive deposit could be collected on a negatively charged wire while out in the open sea, it seems impossible to explain the value of the ratio, as has been attempted, by ascribing the greater rate of dispersion of a negative charge to the ionizing effect of the deposit collected on the negatively charged inner cylinder.[1]

It seems doubtful that the radioactive emanations can have any important influence on the ionization of the air thousands of miles from any land, and they certainly can not be the main cause of the ionization, which is as intense as on shore. We must look elsewhere for the ionizing agent, and the observations give little information as to its nature. It has been suggested that the air may contain charged particles from the friction of the wind on the sea, but there is no evidence that the ionization is greater during a wind than in a calm. The action of sunlight on the water might cause an ionization of the air, but the conductivity seems as great in cloudy as in fair weather.

If the conductivity were greater in regions of high pressure, that is, of descending air currents, it would seem possible that the ionization came from the upper regions of the atmosphere, ionized perhaps by cathode rays from the sun, but the observations show the reverse to be true.

If a penetrating radiation reached the lower layers of the atmosphere from some source external to the earth it might cause the observed ionization, as well as account for some of the phenomena of ionization in closed vessels, such as the diurnal variation of the rate of leak in a closed vessel screened on all sides except the top, which shows a pronounced midday maximum.[2]

No attempt was made to secure information as to the diurnal variation of the conductivity of the air at sea, a subject which should be investigated.

While the work done has served mainly to point out the difficulties to be encountered in using the present types of instruments at sea, still some information has been accumulated which may be of value in conjunction with future work undertaken in similar fields. Also, the probability that the earth-air current is of the same order of magnitude over the sea as over the land has been strengthened.

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[1] KURZ, Dissertation zur Erlangung der Doktorwürde, Giessen, 1907.

[2] STRONG, *Physical Review*, vol. XXVII, No. 1, July, 1908.