Unidirectional Measurements of the Cosmic-Ray Latitude Effect*

THOMAS H. JOHNSON AND DONALD N. READ
Bartol Research Foundation of the Franklin Institute, Swarthmore, Pennsylvania

(Received February 3, 1937)

Cosmic-ray intensities in the vertical direction, and in two inclined directions, 45° eastwards and 45° westwards from the zenith, have been recorded as a function of latitude. The apparatus, embodying several coincidence counter trains, was arranged for unattended operation and automatic recording. It has made several voyages between New York and southern Chile through the Panama Canal on ships of the Grace Line. A latitude effect of 12 percent was found in the eastern direction compared with 4 percent in the western direction. Two values for the vertical latitude effect have been found, one about 12 percent and the other about 20 percent, and it is uncertain in the present measurements which one is correct. The intensity in the vertical and western directions is strongly influenced by local anomalies in the earth's magnetic field, whereas eastern intensities agree more closely with the distribution expected if the earth's field were that of a dipole. Shower intensities, recorded on one voyage, showed less of a latitude effect than vertical rays.

IN the theory of the geomagnetic effects the intensity of cosmic radiation at the surface of the atmosphere depends upon the latitude and upon the two angular coordinates required to specify the direction. Absorption in the atmosphere introduces an additional dependence upon elevation and zenith angle. Extensive measurements have been made of the variation with latitude and elevation of the total intensity, integrated with respect to direction, and of the difference between eastern and western intensities at a variety of zenith angles, elevations and latitudes, but little attention has been given to variations of intensities from particular directions with respect to latitude. Some results of this nature have been reported by Auger and Leprince-Ringuet[1] by Pickering,[2] and by Clay, Bruins and Wiersma,[3] who have measured vertical intensities with coincidence counters mounted on shipboard for voyages across the equator, but no systematic survey has previously been attempted.

The results of such a survey will be of value in making an analysis of the primary cosmic radiation. Considering the matter from the opposite point of view, the theory of the geomagnetic effects as recently developed by Lemaitre and Vallarta[4] would enable one to calculate the intensity from each direction at every point on the surface of an earth whose field were that of an eccentric dipole, if the following data were given: (1) the functions giving the intensities in external space (outside the magnetic field) and their distributions with respect to magnetic rigidity, mv/e, of each type of radiation, positive and negative electrons, photons, protons, etc., and (2) the attenuation factors, functions of energy and atmospheric path length, corresponding to each type of radiation. The real problem is to reverse this procedure and to make such measurements of the variation of intensity with direction, elevation, and latitude as will lead to the derivation of the distribution functions and the attenuation factors. Since ionization chambers measure the intensities integrated with respect to the directional coordinates, they are not well suited to the requirements of this problem and unidirectional measurements which can be made with coincidence counters are preferable. The first of these to have been accomplished were the measurements of the east-west and north-south asymmetries and the variations of intensity with zenith angle which have now been made in a variety of latitudes and elevations.[5] As a second step in the program we are now engaged in a

* Preliminary accounts of this work were given before the American Physical Society in February and in December, 1936, and before the American Geophysical Union in April, 1936. Phys. Rev. **49**, 639 (1937); Atlantic City Meeting of the Am. Phys. Soc., Dec. 1936. Trans. Am. Geophys. Union p. 176 (1936); J. Frank. Inst. **222**, 647 (1936).

[1] P. Auger and L. Leprince-Ringuet, Comptes rendus **197**, 1242 (1933); Nature **133**, 138 (1934).

[2] W. H. Pickering, Phys. Rev. **50**, 495 (1936).

[3] J. Clay, E. M. Bruins, and J. T. Wiersma, Physica **3**, 746 (1936).

[4] G. Lemaitre and M. S. Vallarta, Phys. Rev. **50**, 493 (1936). The present state of the theory would enable one to make this calculation for the zone extending to thirty degrees on either side of the geomagnetic equator.

[5] These results have been summarized by Johnson, Phys. Rev. **48**, 287 (1935).

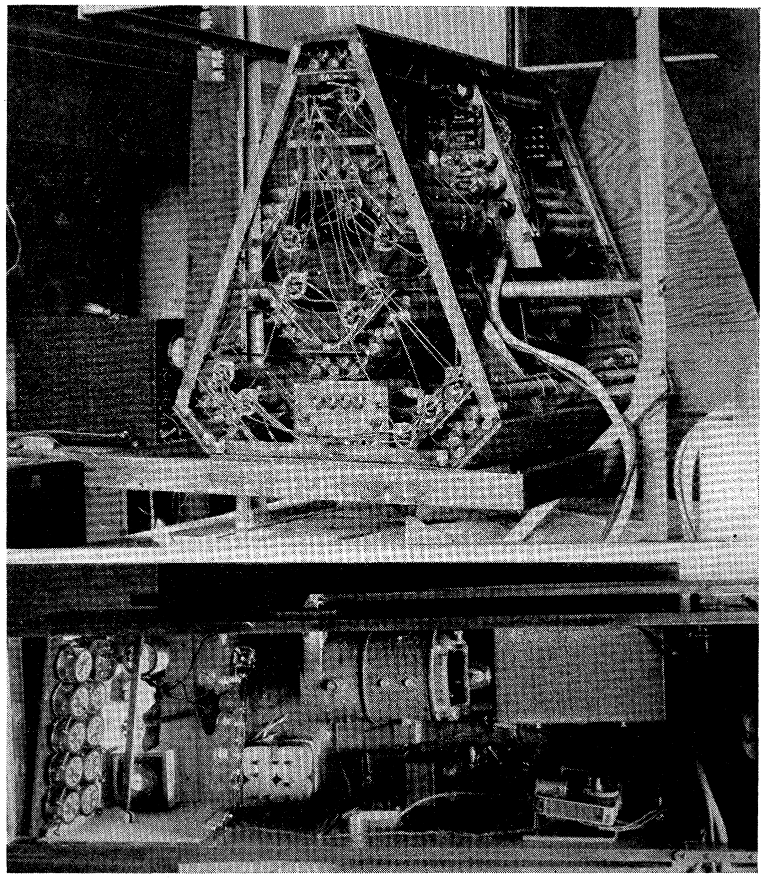

FIG. 1. (Top) Photograph of the "counter box" containing the counters and circuits for selecting the coincident discharges. The support is from two mutually perpendicular horizontal axes acting as a leveling gimbal. (Bottom) The "recording box," containing counter dials and other instruments, flood lights, camera, and power converters.

survey of the variations with latitude of the sea level intensities measured at several definite directions.

THE AUTOMATIC UNIDIRECTIONAL COSMIC-RAY RECORDER

Our intensity meter consists of a box containing six directional trains of triple coincidence counters, mounted on a leveling gimbal, and provided with an automatic recording device so that it can make extensive unattended voyages on shipboard and bring back photographic records, taken at hourly intervals, of the dial readings of various instruments. These include the counter dials, giving the numbers of coincidences recorded by each counter train, a barometer, a thermometer giving the temperature inside the counter box, a compass for coordinating readings with course directions, ultimately taken from the ship's log, a chronometer, and various voltmeters useful as trouble indicators. In its present set-up two of the counter trains are mounted vertically and four are inclined at 45° from the vertical in two opposite azimuths. No provision has been made for automatically adjusting the azimuthal orientation of the counter box since on the South American run, with which we have been engaged, a large part of the voyage adheres closely to the meridian. On future voyages this adjustment can be made manually by one of the ship's officers and recorded automatically. Power for the electrical circuits is taken from the ship's dynamo and control devices regulate the voltage. The counter box is shown exposed in Fig. 1 (top), and Fig. 1 (bottom) represents the box containing the recording equipment, the power supplies, and auxiliary apparatus. The arrangement of the counters is indicated in Fig. 2. The three elements of each triple coincidence train consist of bundles of six counters arranged to cover an area 20×11 cm². The outside units of each train are 50 cm apart so that the angular aperture within which half or more of the area is effective measures 12° in zenith angle by 23°. A detailed account of the apparatus is reserved for another publication.

During the summer of 1935 the equipment was mounted on the top deck of the Grace Liner Santa Barbara where it completed three voyages between New York 41°N and Valparaiso, Chile, 33°S geographic latitude. Because of some trouble with the recording apparatus, only one of these voyages resulted in a satisfactory record. After some improvements in the recording mechanism the apparatus was again installed in the spring of 1936 on the top deck of the Grace Liner Santa Lucia for five voyages between New York and Talcahuano, Chile, 36.5°S and on all of these voyages the records were good, although for a part of the time some of the individual counter trains have misbehaved.

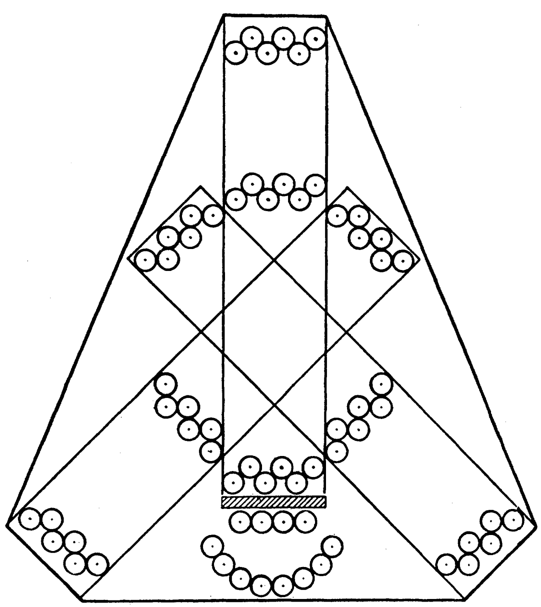

FIG. 2. The arrangement of counters. Coincidence trains are indicated by rectangles. The "out-of-line" arrangement below is for recording shower intensities.

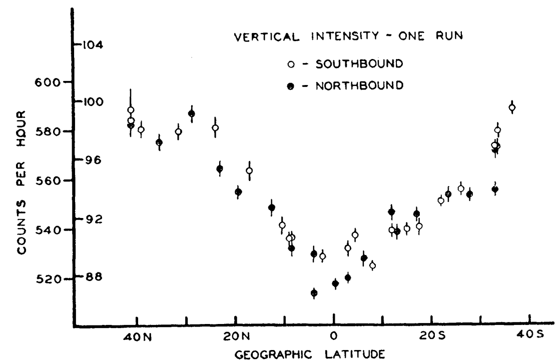

FIG. 3. Vertical intensity recorded on one voyage. Counts per hour and percentages of the high latitude value are plotted against geographic latitude.

TREATMENT OF DATA

In reducing the results the average counting rates for the twenty-four-hour period from midnight to midnight have been corrected for barometric fluctuations on the basis of the work of Johnson and Stevenson[6] who found a variation of 0.36 percent per mm Hg for the vertical intensity. The same correction has also been applied to the measurements at 45°, though eventually we will have more accurate determinations of the barometer effect and its dependence on direction and latitude. Since these corrections are always small no appreciable error is introduced by the present procedure.

In the case of the vertical intensities all of the readings are used, but a selection has to be made of the readings of the inclined counter trains since for a part of the time, in port and on certain parts of the voyage, the course deviates too far from the meridian. In the present report we have discarded readings for courses more than 45° from the meridian, and for the remaining readings on a typical voyage the average deviations were 18° southbound and 20° northbound.

As an illustration of the results, the intensities recorded by one of the vertical trains on one voyage are plotted in Fig. 3. The points represent the averages of the twenty-four readings from midnight to midnight plotted against average latitude. These are expressed as counts per hour on one scale and as percents of the high latitude value on another. The probable errors, indicated

[6] T. H. Johnson and E. C. Stevenson, Phys. Rev. **47**, 578 (1935).

by the length of the vertical lines drawn through the points, were calculated from the actual dispersion of the hourly readings and here, as with practically all of the probable errors calculated in this way, the agreement with the estimates based upon the total number of coincidences recorded is very close. In spite of this agreement the consistency of results recorded on different days at the same place was not always as good as might have been expected and the scattering of points seems to depend in some of the records upon other factors than the finite number of rays counted. The results have been examined for temperature effects by comparing day and night readings when the actual inside temperatures have not been satisfactorily recorded and, for the results represented in Fig. 3 and much of the other data, no such effect was found. On the other hand in some of the records temperature effects and other erratic variations, possibly caused by humidity changes, have made their appearance. Such variations have now been traced to the high resistors (3×10^9 ohms) used for stabilizing the counter discharges and we expect in the future to be able to overcome completely this type of trouble. In the results reported herein we believe we are free from effects of this nature except for some of the results represented in Fig. 4 recorded in and near New York harbor where severe fluctuations of temperature may have produced excessive humidity inside of the counter box.

The five best sets of measurements of the vertical intensity, adjusted to agree at the minimum, are plotted against geographic latitude in Fig. 4. Here the consistency is good except for points above 30°N where the ship leaves the Gulf Stream and severe fluctuations of temperature are liable to set in. Although no systematic dependence upon temperature to the extent of the fluctuations in this region was evident, the humidity effect noted above would be of a more

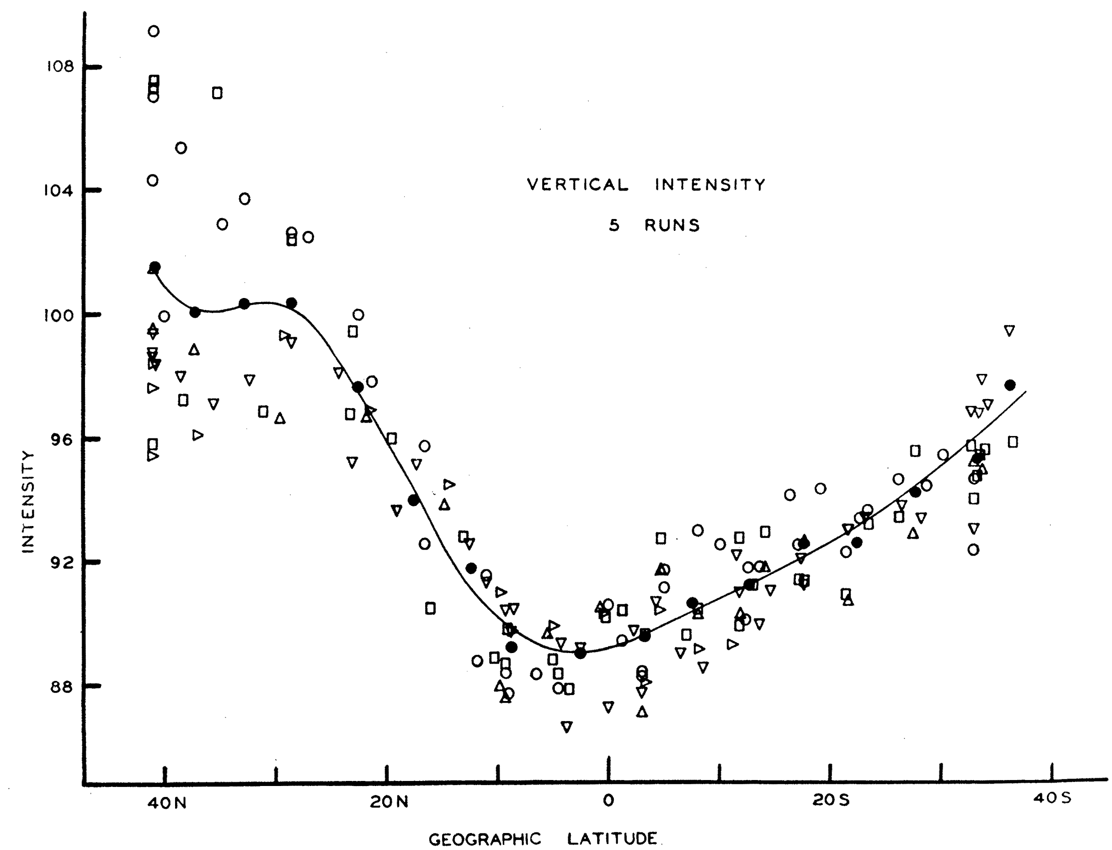

FIG. 4. Composite results of vertical counters. Different symbols indicate separate voyages.

subtle nature and we cannot place too much reliance upon the results recorded in the higher northern latitudes. Below about 30°N however the results seem dependable. The averages of the points lying within each five-degree range of latitude are represented by the black dots and by the smooth curve drawn through them. A similar representation of the results of the 45° inclined counters in the western and eastern azimuths is shown in Figs. 5 and 6. This is believed to be the first time that the strong dependence of the latitude effect upon direction has been given direct experimental demonstration although differences between the eastern and western latitude effects had to be expected in view of the east-west asymmetry found in the equatorial belt. The present results indicate a western latitude effect at this zenith angle of about four percent compared with an eastern latitude effect of about 12 percent expressed in terms of the high latitude value. The difference of 8 percent is in fairly good agreement with the value of the asymmetry measured directly at the equator.[5]

In the case of the vertical intensities the value of the latitude effect remains uncertain in the present measurements. The experimental points seem to divide into two rather distinct branches at about 30°N one of which seems to level off at this latitude with a total latitude effect of about 12 percent and the other continues to rise to New York harbor corresponding to a total latitude effect of 18 or 20 percent. We are not able to say at the time of writing which branch is correct or what the cause of difference is. Although we are looking for some such instrumental effect as that suggested above to clear up the discrepancy, at the same time it is perhaps not out of place to note that a somewhat similar discord exists in the ionization chamber results. In his summary of the results of Clay, Hoerlin, Prins and of his own world wide survey, Compton[7] gives a latitude effect of 8 percent between

[7] A. H. Compton, Rev. Sci. Inst. **7**, 71 (1936).

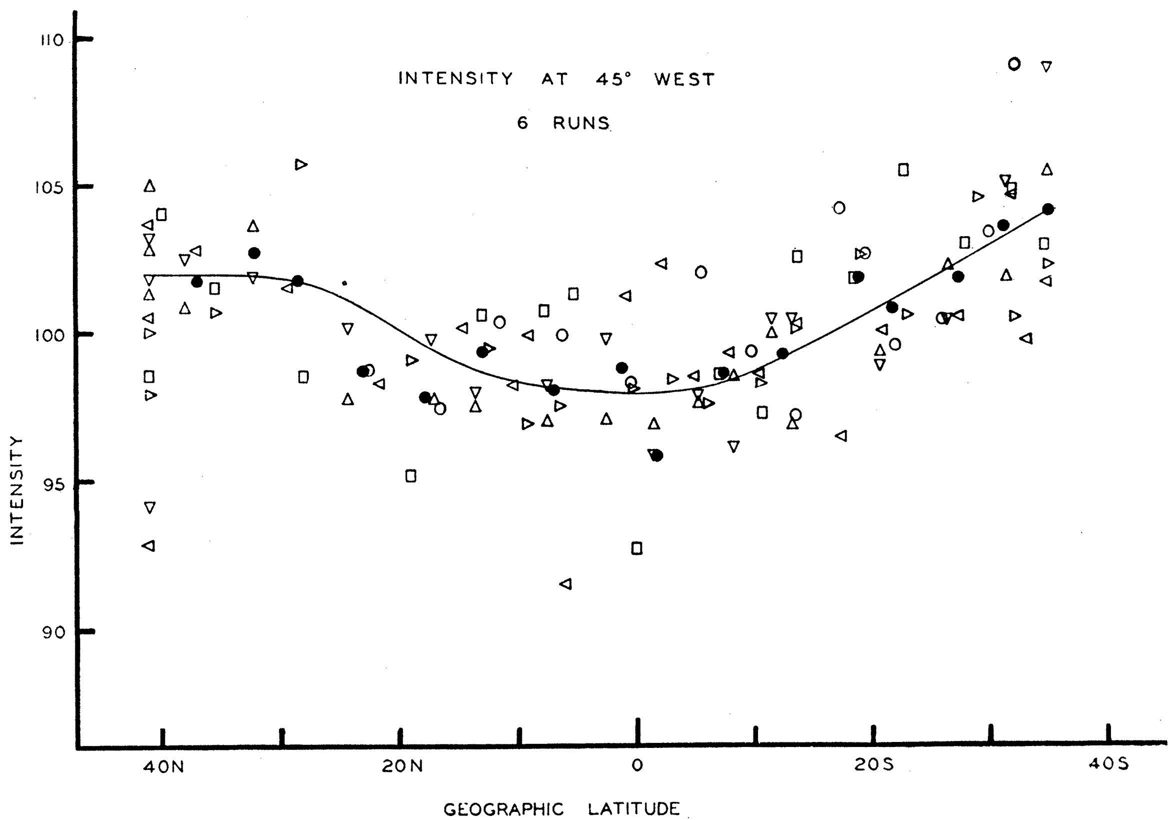

FIG. 5. Composite results of counter trains inclined 45° toward the west.

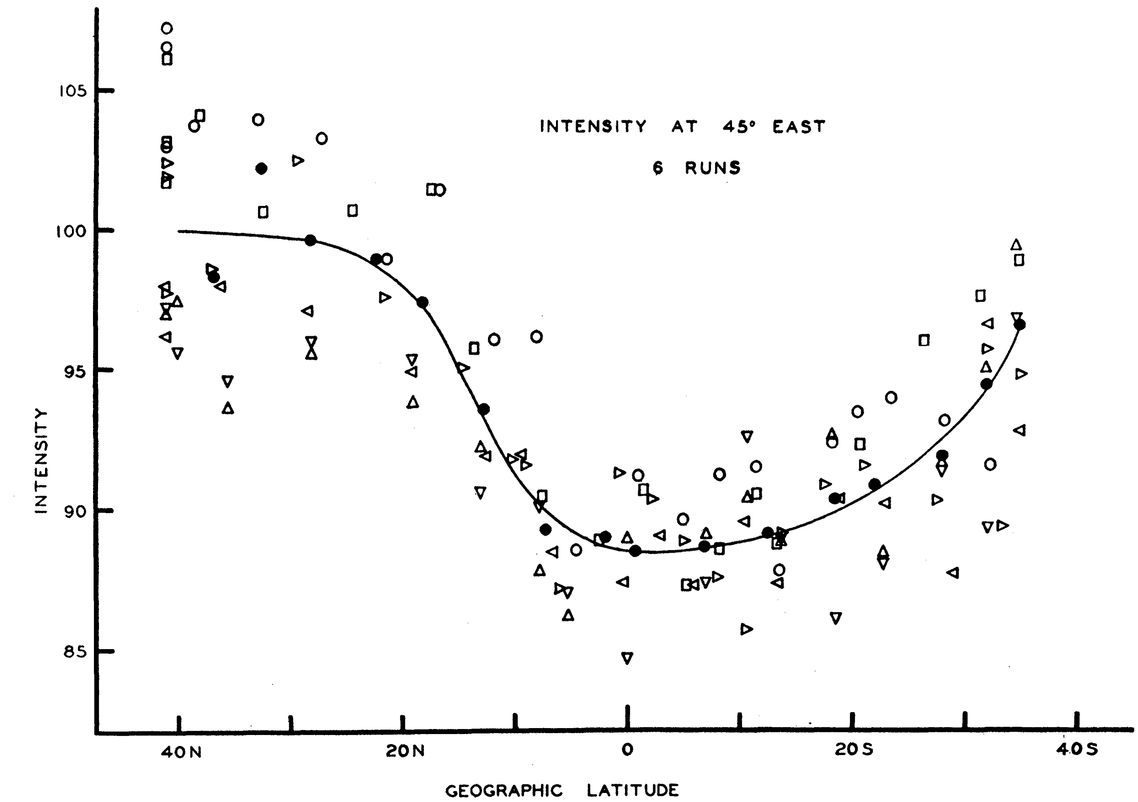

FIG. 6. Composite results of counter trains inclined 45° toward the east.

the equator and 30°N on the 75th meridian and an additional 5.5 percent increase from 30°N to 41°N. Millikan and Neher[8] on the other hand find an 8 percent increase over the same range from the equator to 30°N with less than a percent increase from there on up to higher latitudes. Allowing for a greater intensity in the vertical direction of the softer, field-sensitive rays, a greater latitude effect than that measured by the ionization chamber is to be expected. If, then, our 12 percent latitude effect is associated with Millikan and Neher's value of 8 percent, it turns out that our 20 percent value when reduced on the same scale just agrees with Compton's value of 13.5 percent.

In the curve of Fig. 4 representing the vertical intensity it is noted that the minimum occurs not at the geomagnetic equator, 12°S, but 15 degrees or so to the north of this point. At the same time it is noted that the curve is not symmetrical with respect to any point of latitude as it should be according to the theory based upon the simple dipole field. Both of these effects, attributable to local field anomalies, are here much accentuated because of the unidirectional character of the measurements, as compared with their appearance in the curves representing the ionization chamber measurements of Millikan and Neher along the same route, although some asymmetry with respect to the magnetic equator is readily noticeable in their results. Clay, Bruins, and Wiersma[3] have also called attention to similar effects in both ionization chamber and counter measurements. The intensities measured in the western azimuth, Fig. 5, also indicate a distortion due to local field anomalies, although here the points are somewhat more scattered, partly because of lower counting rates. In the eastern azimuth, on the contrary, the intensity has a more symmetrical distribution, although the minimum

[8] R. A. Millikan, Year Book of the Carnegie Institution **34**, 343 (1935); R. A. Millikan and H. V. Neher, Phys. Rev. **50**, 15 (1936).

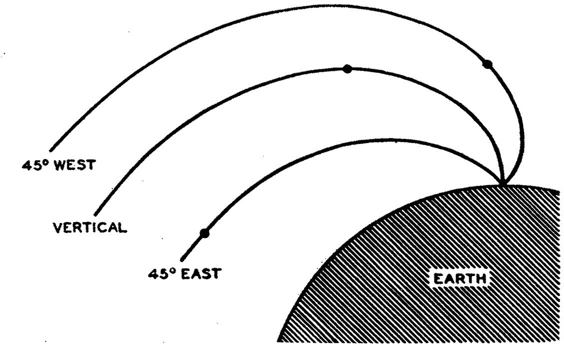

FIG. 7. Orbits defining the energy limits for rays incident from the east, vertical, and west in the plane of the magnetic equator.

still occurs somewhat north of the magnetic equator.

A dependence upon direction of the distortion of the intensity curves due to local field anomalies finds a qualitative explanation in the dipole theory of the orbits although the introduction of the real field into the theory has not yet been accomplished. The three critical orbits, corresponding to positive rays of lowest energy incident in the plane of the equator from the directions 45°E, the vertical, and 45°W are shown in Fig. 7. These have been calculated from Störmer's equation[9] with $\gamma=-1$, which is exact for orbits in this plane. A circle on each orbit indicates where the ray begins its last 90° deflection before it strikes the earth, and it is evident that this appreciable part of the total deflection takes place in a much more localized region in the case of the western and vertical orbits than in the case of the eastern orbits. Hence any localized magnetic intensity producing alterations in the field of the dipole should have more of an influence on the energy limits of western and vertical orbits than of eastern orbits and this in turn will be reflected in the intensity distribution. Actually there is fairly close correspondence of the western and vertical intensity curves with the local horizontal component of the magnetic field as indicated in Fig. 8. In these directions the minimum value of the cosmic-ray intensity occurs at the same latitude as the maximum value of H. The eastern cosmic-ray intensity, on the other hand, corresponds more closely to the field calculated from the dipole.[10] It is clear that these effects of the local field must be taken into consideration in interpreting the results in terms of the energy spectrum and the composition of the primary radiation.

SHOWER INTENSITIES

In addition to the directional telescopes, the apparatus also contains an arrangement of counters for recording cosmic-ray showers. These counters, indicated in the lower part of Fig. 2, were covered with 1.6 cm of lead. The upper row of counters were connected together as a single unit, those below were alternately connected to form two units, and coincidences between the three units were recorded. During the 1936 runs this circuit developed troubles early in the season, and no consistent data were obtained. The 1935 voyage, however, resulted in a fairly consistent set of values for the shower intensities, and these are represented in Fig. 9. A variation of from 6 to 10 percent is indicated, and this is in accord with results reported by Johnson[11] in 1934 that shower intensities show less of a latitude effect than the vertical radiation. The same conclusion has also been reached by Pickering.[2]

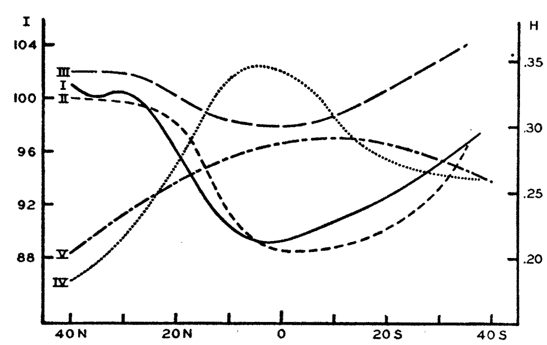

FIG. 8. Illustration of the correspondence between cosmic-ray intensity, I, and horizontal magnetic field, H. Curve I, vertical cosmic-ray intensity, percent of high latitude value; II, eastern cosmic-ray intensity; III, western cosmic-ray intensity; IV, horizontal component of magnetic field in gauss along the South American course of the Grace Line; V, horizontal component of magnetic field calculated from the eccentric dipole by J. Bartels.

[9] Eq. (5) of reference 5.

[10] J. Bartels, Terr. Mag. and Atm. Elect. **41**, 225 (1936).

[11] T. H. Johnson, Phys. Rev. **47**, 318 (1935).

We are very much indebted to Mr. R. R. Adams and other officers of the Grace Line who have allowed us to place the apparatus on the ships and have cooperated wherever the need arose. The expenses incurred in attending the apparatus and keeping it in condition have been offset by grants from the Carnegie Institution of Washington, and funds from the same source have been used for assistance in reducing the data. For this, acknowledgment is due to President John C. Merriam and the Committee on Cosmic-Ray Investigations.

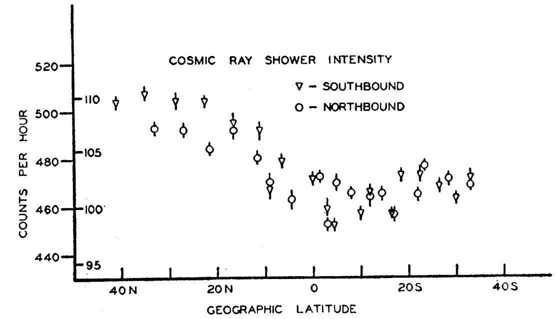

FIG. 9. Intensity of cosmic-ray showers plotted against geographic latitude.

APRIL 1, 1937 PHYSICAL REVIEW VOLUME 51

Effects of Certain Liquids on the OH Vibrational Band of Alcohol

WALTER GORDY*
University of North Carolina, Chapel Hill, North Carolina
(Received December 26, 1936)

Transmission curves for several different concentrations of methyl alcohol in dioxane, methyl cyanide, isopropyl ether, benzene and carbon tetrachloride, and of ethyl alcohol in dioxane were obtained in the region 2.55 μ to 3.15 μ. Dioxane, methyl cyanide, and isopropyl ether were found to shift the OH vibrational alcohol band to the shorter wave-lengths and to increase its intensity appreciably. There appeared to be no definite relationship between these changes and the electric moment of the solvent molecule. It is suggested that these variations indicate some type of interaction of the solvent molecule with the OH group. It may be possible to interpret the results as indicating a linkage of the solvent molecules with those of the alcohol through the formation of hydrogen bonds.

IN a recent study of the infrared absorption spectra of alcohol-acetone mixtures, marked shifts and intensity changes appeared in the fundamental vibrational band of the OH alcohol group and of the CO group in acetone, while other bands were apparently constant. Dipole interactions of these groups, possibly through the formation of proton bonds, were offered as interpretation of these variations. Investigation of the OH alcohol group has been continued to determine what effects certain other solvents, which differ widely in chemical structure and in dielectric constants, exert upon this band.

The resolving instrument and the cell windows were the same as those used in the previous investigation.[1] For all the measurements the absorbing layer was kept at the constant thickness of 0.002 cm. The effective slit width was approximately 0.03μ

Measurements were made of methyl alcohol solutions in dioxane, methyl cyanide, isopropyl ether, benzene, and carbon tetrachloride, also of ethyl alcohol solutions in dioxane. The alcohol concentrations varied from 6 percent to 50 percent (by volume) in each of the solvents. The percentage transmission of these solutions for the region 2.55μ to 3.15μ are shown in Fig. 1. The effects of dioxane on the OH alcohol band are given in Fig. 1 A. The bottom curve represents the transmission of pure methyl alcohol. The strong broad band having maximum absorption at 2.9μ is the fundamental vibrational band of the OH group. From a comparison of this curve with the curves for the different mixtures it will be observed that the influence of the dioxane is to shift the OH band to the

* Now at Mary Hardin-Baylor College.
[1] Walter Gordy, Phys. Rev. **50**, 1151 (1936).

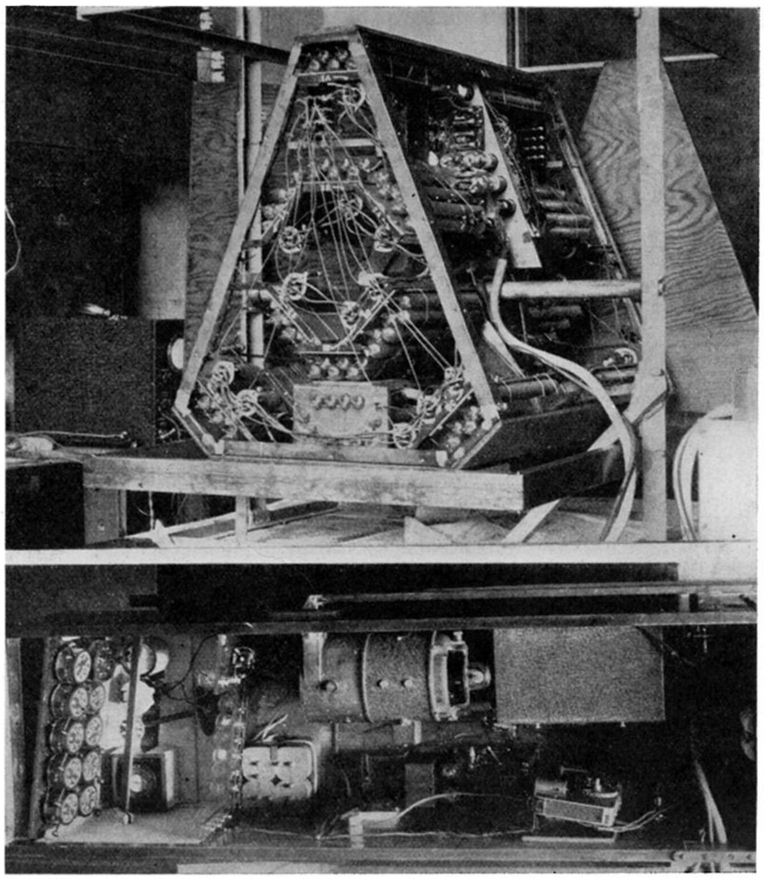

FIG. 1. (Top) Photograph of the "counter box" containing the counters and circuits for selecting the coincident discharges. The support is from two mutually perpendicular horizontal axes acting as a leveling gimbal. (Bottom) The "recording box," containing counter dials and other instruments, flood lights, camera, and power converters.