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The Latitude Effect in Cosmic Rays at Altitudes up to 29,000 Feet

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Accurate measurements with Neher recording electroscopes have been made both in Peru and in the Philippines on the cosmic-ray ionization of the atmosphere up to altitudes of 29,000 feet, with the following results: (1) In both localities the ionization rises essentially exponentially following a coefficient $\mu = 0.50$ per meter of water. This means that in the equatorial belt the ionization at 29,000 feet (two-thirds of the way to the top of the atmosphere) is about 50 ions per cc per sec., or half its value at the same altitude in the temperate zone. (2) If any longitude effect such as that which we have proved to exist at sea level exists at altitudes of 26,000 feet, it is inside the limits of our observational uncertainty, about 5 percent.

THE latitude effect at sea level first announced by Clay in 1927 has since then been made the subject of very extensive investigation by many observers,[1] but our knowledge of the even more important latitude effect at altitudes far above the earth's surface thus far rests upon comparatively meager dependable data. Bowen, Millikan and Neher have published exceedingly consistent observations made with Neher vibration-free electroscopes in airplane flights made in northern Canada (near The Pas, mag. lat. 64° N.), in northern United States (near Spokane, mag. lat. 54° N.), in southern United States (near Pasadena, mag. lat. 41° N.), in Panama, (mag. lat. 21° N.), and in Peru (mag. lat. 1° S.). Some of these flights reached the altitude of 29,000 feet (3.3 m of water or 2/3 of the way to the top) and all of them exceeded the altitude of 22,000 feet. These flights revealed the significant facts that (1) there is no latitude effect at all at altitudes up to 22,000 feet north of Spokane; (2) that at that altitude there is a reduction of 11.5 percent in the cosmic-ray intensity between Spokane and Pasadena; (3) that there is a still farther fall of 25 percent from the Spokane value between Pasadena and Panama, or 36.7 percent all told; and (4) that there is no change at all between Panama and Peru. Also, at very much higher altitudes, up to 55,000 feet (1 m of water or 90 percent of the way to the top of the atmosphere), the observations of Bowen, Millikan and Neher,[2] made with Neher electroscopes in the Fordney-Settle manned-balloon flight, and of Bowen, Millikan and Neher made with self-registering electroscopes sent up with sounding balloons, brought to light a latitude difference at this high altitude amounting to 40 percent between geomagnetic latitudes 52° N. and 42° N. Both of these observations, in magnetic latitudes 52° and 42°, have been twice roughly checked in different years, so that they may be depended

[1] The results obtained by many observers are summarized in an article by A. H. Compton, Phys. Rev. **43**, 387 (1933), and our own elaborate "Precision Survey" is found in Phys. Rev. **50**, 15 (1936).

[2] See curves in Fig. 6, p. 221, *International Conference on Nuclear Physics*, London, 1934; also Fig. 6, Phys. Rev. **46**, 650 (1934).

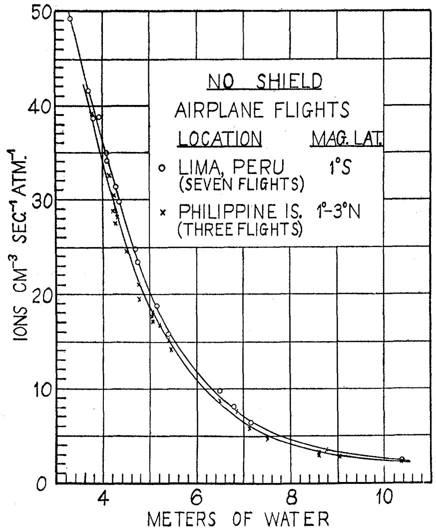

FIG. 1. Comparison between the altitude-ionization curves in Peru and in the Philippines at essentially the same geomagnetic latitude.

upon as to general order of magnitude. Clay has also reported some preliminary high altitude observations in Java.[3]

The present investigation extends the dependable observations on cosmic-ray intensities made with Neher electroscopes up to 29,000 feet in Peru, and, more important, fixes the extent of the longitude effect in the equatorial belt from sea level up to beyond 26,000 feet. The importance of this last observation arises from its bearing upon the much discussed question as to the fraction of the cosmic radiation that enters our atmosphere in the form of charged particles and the fraction that consists of photons. The very existence of the *longitude* effect at sea level discovered[4] independently early in 1934 by Clay and by Millikan and Neher, and shown by the latter observers to be represented by a 4 or 5 percent smaller sea-level cosmic-ray intensity in the equatorial belt on the Asiatic side of the earth than on the South American side, obviously means that a portion, at least, of the "nonfield-sensitive" sea-level intensity is the result of incoming charged particles of sufficient energy (about 10 billion electron volts) to get through the blocking effect of the earth's magnetic field even in the equatorial belt; for this blocking effect is larger on the Asiatic side of the earth than on the South American side, since the earth's magnetic field is known to be stronger in the Singapore region than in the Lima area.

If, then, this longitude difference, small at sea level, is, like the latitude effect, large at high altitudes, the only possible interpretation would be that even the incoming equatorial cosmic rays are chiefly very high energy charged particles. If, on the other hand, it diminishes with altitude instead of increasing, the natural interpretation would be, since photons cannot possibly show either a longitude or a latitude effect at all, that the effect of the incoming photons preponderates over that of the incoming electrons—a result which would of course speak in favor of a large photonic component in the nonfield-sensitive rays that alone can get into the equatorial belt. It was, then, primarily to obtain new light on this point that a comparison was sought between the "altitude-ionization" curves in Peru and, in essentially the same geomagnetic latitude, in the Philippines. The results of this comparison are shown in Fig. 1.

The Peru curve was obtained as the result of seven different flights in which unshielded Neher self-recording electroscopes were taken up to altitudes which reached heights of 29,000 feet, two-thirds of the way to the top of the atmosphere. These flights were arranged for and in some cases made by S. A. Korff in collaboration with the Pan American Airways, the Compania de Aviacion Faucett, and by Mr. Hugh I. Wells, to all of which services we desire herewith to express great appreciation for their assistance. The satisfactory way in which all the points taken on these seven different flights, each point corresponding to a "leveling off" by the pilot for about an hour's time, fall on a smooth curve is evidence enough of the dependability of these measurements. The films corresponding to these flights were shipped back to us at Pasadena and there measured by H. V. Neher.

To obtain the second of the curves shown in Fig. 1, H. V. Neher went to the Philippines in November, 1935, and had an unshielded electroscope like that used in the Peru flights taken up in three flights made by Captain Kirby and Lieutenants Morrill and McGuire through the

[3] J. Clay, Physica **1**, 376 (1934); **2**, 183 (1935).
[4] Millikan and Neher, Phys. Rev. **47**, 206 (1935).

kind cooperation of the U. S. Army air-corps. Here again the consistency of the points attests the dependability of the curve.

The conclusions to be drawn from these two curves may be stated as follows:

1. *Within the uncertainty of the measurements* here estimated at five percent there is at 26,000 feet no difference between the cosmic-ray intensities in Peru and in the Philippines. The sea-level difference of four percent may continue up to the highest altitudes here reached, but the precision of the measurements is insufficient to determine whether it does or not. The difference cannot, however, be appreciably more than that.

2. In the equatorial belt on both sides of the world the cosmic-ray ionization rises essentially exponentially from sea level to an altitude of 29,000 feet with an apparent absorption coefficient of 0.5 per meter of water fitting well the upper part of the depth-ionization curve. In the temperate latitudes the coefficient that must be used to fit the observed curves equally well is only a little larger, namely, 0.55 per meter of water. This difference is sufficient, however, to make the ionization in the equatorial belt at 29,000 feet (about 50 ions cc/sec. in air at 1 atmos.) about 50 percent of its value at the same altitude in the temperate latitude 52, in which the Fordney-Settle flight was made. These results destroy the validity of the chief argument that has been advanced thus far for the great preponderance of the particle component over the photonic component of the cosmic rays which come into the earth's atmosphere in the equatorial belt.

We wish to express our appreciation to the Carnegie Corporation of New York and the Carnegie Institution of Washington as well as to the above-mentioned air services through whose aid the foregoing results have been made possible.

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The Heavy Particle Component of the Cosmic Radiation

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A large Wilson cloud chamber was used to study the heavy particles in the cosmic radiation. The chamber had a volume of 7 liters and an illuminated section 5 cm deep by 30 cm in diameter, so that there was no danger of confusing alpha-particle tracks with heavy cosmic rays. Heavy tracks made in the 1.5 seconds preceding the expansion were recorded. In 8500 pictures, about 80 heavy tracks were observed. Of these, 21 were made by particles of about the ionization of slow protons. Their paths could be seen in the illumination for distances equivalent to path lengths of from 13 to 45 cm in air. 45 less dense old tracks were observed that had an ionization noticeably greater than an electron track. Of the tracks that appeared to have tripped the counters causing the expansion, 14 were considerably heavier than electron tracks. Three disintegrations with heavy tracks apparently arising from the wall of the chamber were observed. Most of the other old heavy tracks were also probably of secondary origin. It is estimated that about one percent of the sea-level cosmic ionization is due directly to heavy particles.

Introduction

The analysis of the variation of the cosmic-ray intensity with altitude led Compton and Bethe[1] to propose that the primary cosmic radiation consisted in part of very high energy protons and alpha-particles. However, the Wilson cloud chamber photographs of the cosmic radiation did not seem to give much support to their hypothesis. Blackett[2] showed that the frequency of appearance and the magnitude and range of most of the heavy particles observed in cloud chamber photographs could be accounted for as contamination alpha-particles emitted from the walls of the chamber. Blackett and Occhialini,[3] reported two heavy tracks which were probably due to protons. In a large chamber located on

[1] A. H. Compton and H. A. Bethe, Nature **134**, 734 (1934).

[2] P. M. S. Blackett, Proc. Roy. Soc. **A146**, 281 (1934).

[3] P. M. S. Blackett and G. P. S. Occhialini, Proc. Roy. Soc. **A139**, 699 (1933).