Experiments to decide whether there exists a minimum range for particles of given Z equal to that calculated for complete stripping (using stopping material up to 120 (g/cm^2) in the form of photographic plates) are in progress.

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On the Energy of Cosmic Radiation Allowed by the Earth's Magnetic Field

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Curves giving proton energies (a) below which no energy is allowed by the earth's magnetic field, (b) above which all energies are permitted, for all latitudes in case (a), for latitudes from 0° to 40° geomagnetic in case (b), are given for the following directions: (1) vertical, (2) zenith angle 45°, north, south, east and west azimuths. In addition the distance and angular corrections due to the longitude effect are given for geographic latitudes up to 40°.

IN the course of discussions on the east-west asymmetry of cosmic radiation which took place on occasion of the Symposium on Cosmic Rays held at the California Institute of Technology in honor of Robert A. Millikan's eightieth birthday, it became clear that additional information on the energy of cosmic radiation allowed through the earth's magnetic field was required to interpret high altitude experiments now being carried out. Such information is presented in the curves given in this paper.

In Fig. 1 the lower curve, labeled E_1, gives the least energy that a proton must have in order to penetrate through the earth's magnetic field in the vertical direction at the geomagnetic latitude given by the abscissa. This energy is determined either by the Störmer cone or by the simple shadow cone,[1] the former for low latitudes and the latter for intermediate and high latitudes.

The upper curve labeled E_2 gives the energy that a proton must have in the vertical direction, at the geomagnetic latitude given by the abscissa, above which all energies are allowed by the earth's magnetic field. This energy limit is determined by the main cone.[2]

Between the upper and lower curves lies the region of penumbra, in which only certain energies between these two limits are allowed, in the given direction, and others are forbidden.[3]

At low latitudes (less than 15°) the dark bands predominate in this region and the least allowed energy is practically given by the lower curve. At intermediate latitudes (between 15° and 35°) the dark and light bands are about equally important, but one cannot predict without further very difficult analysis whether an energy between these limits will actually arrive in the vertical direction. At 20°, for instance, it is known, that only energies higher than those given by E_2 (main cone) can actually arrive. At high latitudes light bands predominate in the penumbra and the least allowed energy is practically given by the lower

[1] E. J. Schremp, Phys. Rev. **54**, 158 (1939).

[2] G. Lemaitre and M. S. Vallarta, Phys. Rev. **50**, 493 (1936).

[3] G. Lemaitre, Ann. de la Soc. Sci. de Bruxelles **54**, 162 (1935); R. Albagli Hutner, Phys. Rev. **55**, 614 (1939); Tchang Yong-Li, Ann. de la Soc. Sci. de Bruxelles **59**, 285 (1939); René de Vogelaere (unpublished, private communication to the author).

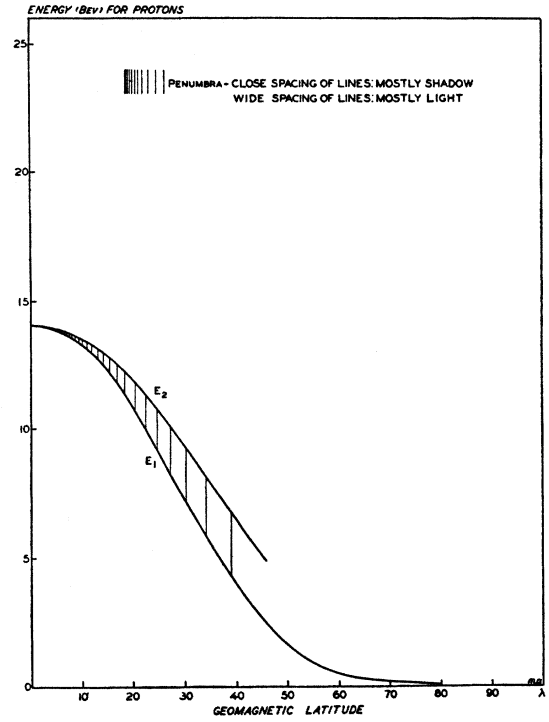

FIG. 1. Proton energies allowed by the earth's magnetic field in the vertical direction, as a function of geomagnetic latitude.

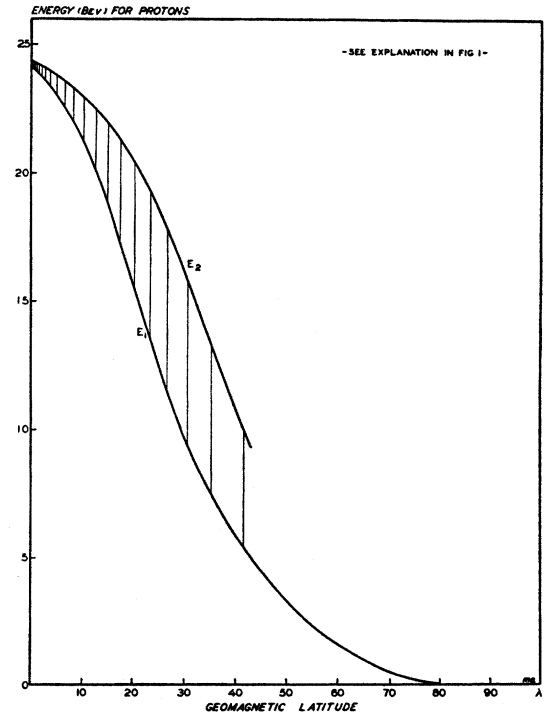

FIG. 2. Proton energies allowed by the earth's magnetic field in the direction 45° east, as a function of geomagnetic latitude.

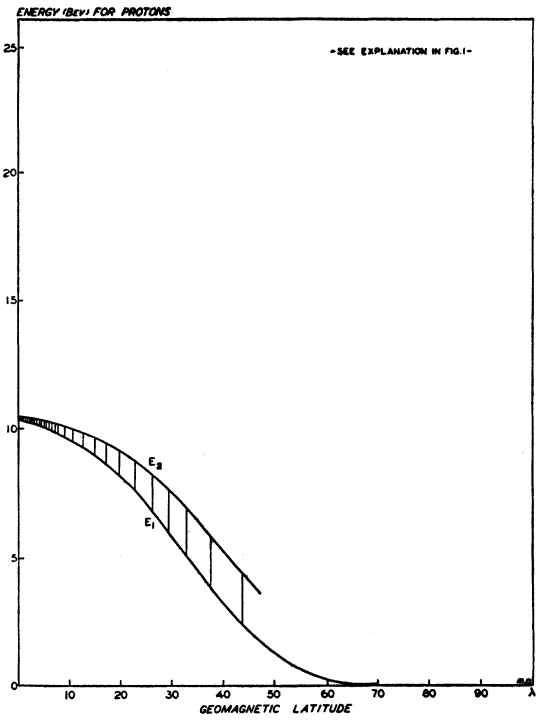

FIG. 3. Proton energies allowed by the earth's magnetic field in the direction 45° west, as a function of geomagnetic latitude.

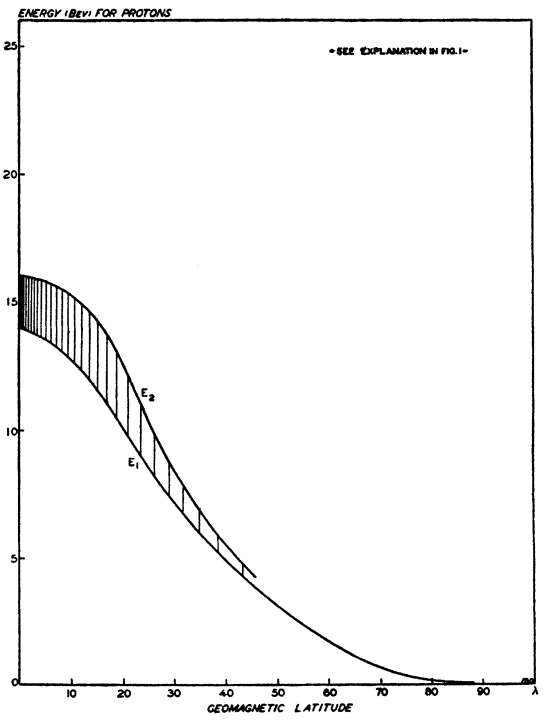

FIG. 4. Proton energies allowed by the earth's magnetic field in the direction 45° north, as a function of geomagnetic latitude.

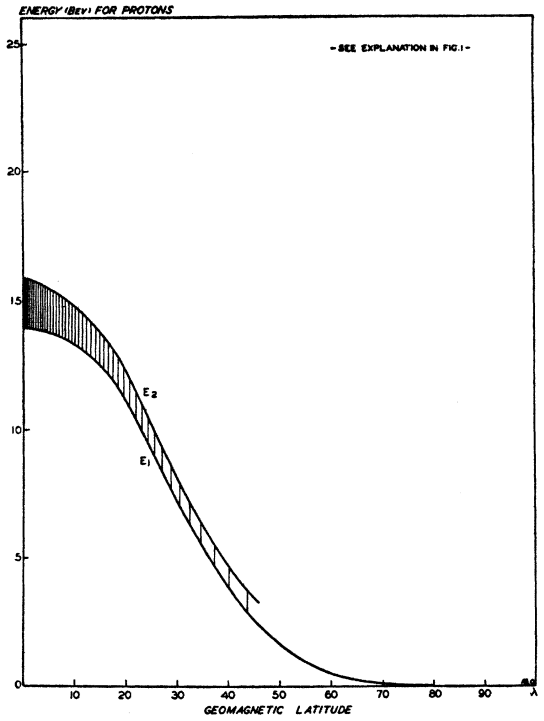

FIG. 5. Proton energies allowed by the earth's magnetic field in the direction 45° south, as a function of geomagnetic latitude.

curve E_1. This circumstance is indicated by the spacing of vertical lines between the two curves. Close spacing means that all energies between the two curves are ruled out, distant spacing signifies that all energies above the lower curve are practically allowed.

Figures 2 and 3 give the same information as Fig. 1, with the same explanation as in the preceding paragraph, but now for zenith angle 45° in the azimuths east and west, respectively. It is seen that in these cases the penumbra is quite important at certain latitudes.

Figures 4 and 5 give the same data for zenith angle 45° and azimuths north and south, respectively. It is seen that the energy difference responsible for the north-south asymmetry is much less than that responsible for the east-west asymmetry. However, since the allowed cones for positive particles are symmetrical, with respect to the meridian plane, to those for negative ones, the north-south asymmetry depends on the sum of positive and negative primaries, while the east-west asymmetry depends on their difference. Thus the knowledge of both the east-west and north-south asymmetries gives information on the ratio of positive to negative primaries. Therefore the north-south asymmetry should be studied experimentally as well as the east-west effect, in spite of the fact that the former is much smaller. It should also be noted that the penumbra hardly plays a part in the north-south effect. Curve E_2 in Figs. 4 and 5 has been determined from the main cone.[4]

The corrections to Figs. 1 to 5 because of the

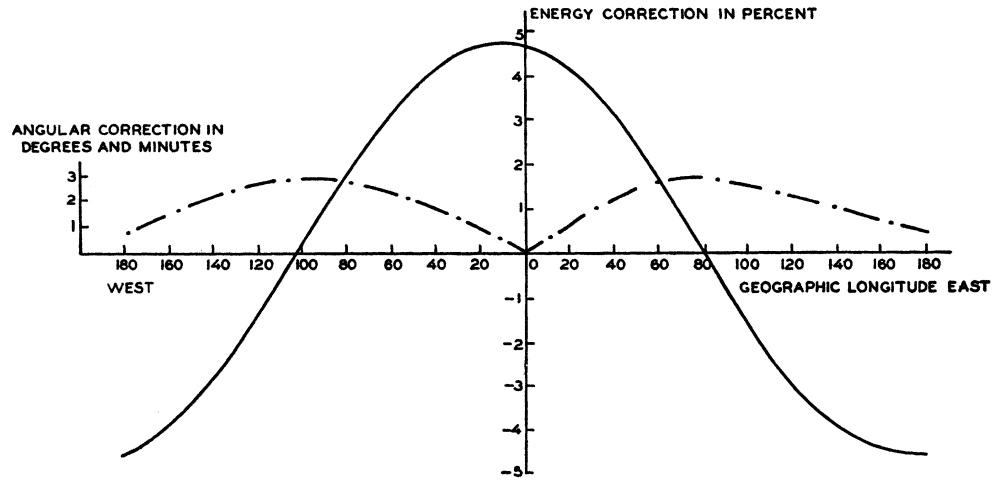

FIG. 6. Distance and angular (dotted line) corrections as a result of longitude effect along the geographic equator, as a function of geographic longitude.

[4] G. Lemaitre and M. S. Vallarta, Phys. Rev. **49**, 719 (1936); G. Lemaitre, M. S. Vallarta and L. Bouckaert, **47**, 434 (1935).

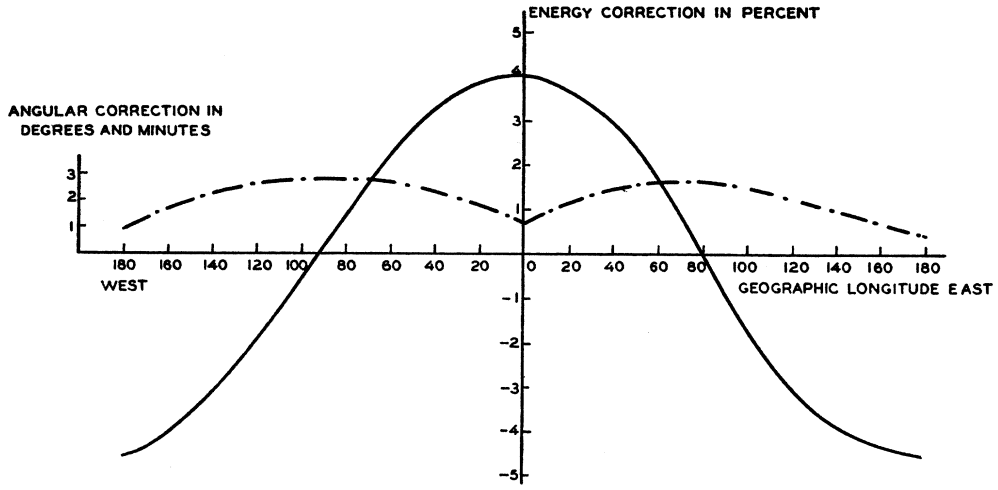

FIG. 7. Distance and angular corrections as a result of longitude effect at the geographic latitude 20° north, as a function of geographic longitude.

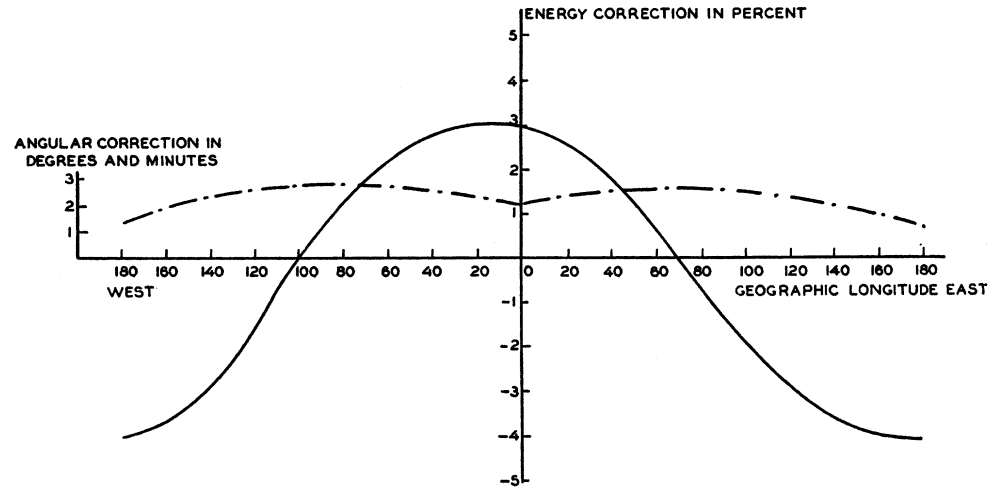

FIG. 8. Distance and angular corrections as a result of longitude effect at the geographic latitude 40° north, as a function of geographic longitude.

longitude effect are given in Figs. 6, 7 and 8, for geographic latitudes 0°, 20° and 40° north, respectively.

There are two corrections to be made. The first is the distance correction and takes into account the distance between the earth's magnetic center and the point of observation; the second (dot-dash curve) is the angular correction and refers to the angle between the magnetic vertical and the ordinary vertical of the point of observation.[5] The first is due to the fact that, according to Schmidt's analysis, the earth's magnetic center does not coincide with its ordinary center, the second depends on the circumstance that the line connecting the earth's magnetic center with the point of observation (magnetic vertical) does not always coincide with the ordinary vertical.

It is a pleasure to acknowledge the help of the Comisión Impulsora y Coordinadora de la Investigación Científica of Mexico which made this research possible.

[5] M. S. Vallarta, Phys. Rev. **47**, 647 (1935); G. Lemaitre, Nature **140**, 23 (1937).