The Flux of Heavy Nuclei of the Primary Cosmic Radiation at Geomagnetic Latitudes $\lambda = 55°$ and $\lambda = 30°$

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SOME 200 tracks of primaries with atomic numbers between $Z=6$ and $Z=26$ in a stack of 58 specially prepared Eastman NTB plates* of dimensions 3 in. × 20 in., flown on October 27, 1948 for 5 hours at Camp Ripley, Minnesota (geomagnetic latitude $\lambda = 55°N$) at an altitude of 97,000 feet have been analyzed by the methods previously described.[1] The range and hence the energy could be accurately determined for 30 particles which stopped in the stack of plates (Fig. 1). Figure 2 shows the energies with which these particles entered the top of the atmosphere plotted against their atomic number Z. (Z was determined by measuring the δ-ray density as function of the remaining range.) Figure 3 shows the number of tracks stopping in the stack, plotted against the energy per nucleon. The lowest energies per nucleon, observed for nuclei of the carbon, nitrogen, oxygen group, lie in the interval $\epsilon = 0.37 - 0.40$ Bev. These values are very close to the geomagnetic cut off energy for vertical incidence at $\lambda = 55°N$:

$$\epsilon_{\text{cut-off}} = 0.35 \text{ Bev}^2 \text{ for completely stripped nuclei } (A = 2Z).$$

The sharpness of the lower energy limit of the distribution of Fig. 3 may be partly due to experimental reasons, since a systematic survey of tracks was made under 5-cm glass only.

The flux of nuclei $I(\lambda)$ of the C, N, O group at $\lambda = 55°N$ at the top of the atmosphere was calculated from the observed intensity, correcting for loss of nuclei by collisions in the glass and the air above the balloon:

$$I_{C,N,O}(55°) = (4.0 \pm 0.5)10^{-4} \text{ (nuclei/cm}^2 \text{ sec. ster).}$$

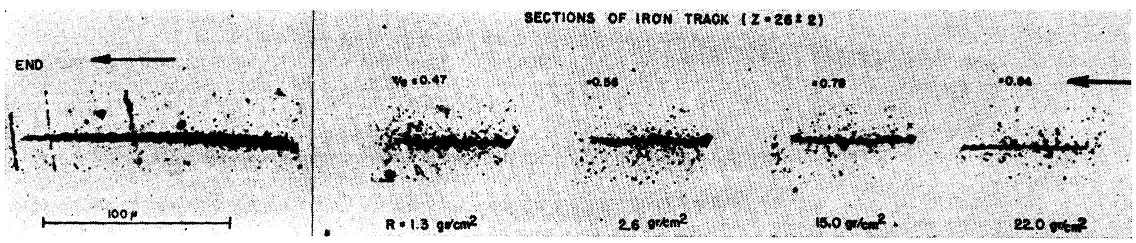

FIG. 1. Sections of G-track of a relativistic iron nucleus. The particle entered the top of the atmosphere with an energy $E=81$ Bev making an angle $\vartheta = 40°$ with the vertical. It entered the stack of plates with a kinetic energy of $E=62$ Bev and has been traced through 23 plates. It ends in the emulsion of the 24th plate, after a range in glass of $R=35$ g/cm².

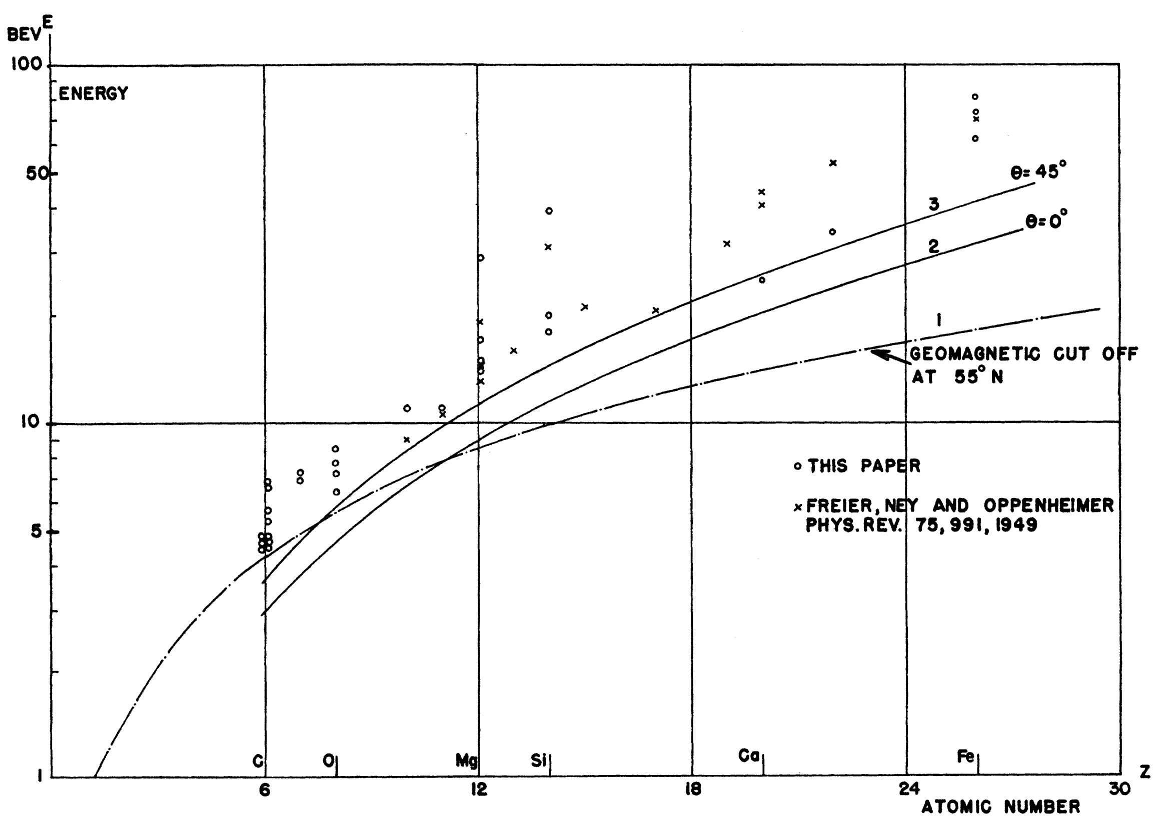

FIG. 2. Kinetic energy of 30 heavy primaries (in Bev) stopping in the stack of plates flown at Camp Ripley, Minnesota ($\lambda = 55°N$) plotted against their atomic number. Curve 1 gives the geomagnetic cut-off energy ($\epsilon = E/A = 0.35$ Bev per nucleon) for $\lambda = 55°N$. Curves 2 and 3 give the minimum energy necessary for the penetration through the 15.5 g/cm² of matter above the stack of plates for $\vartheta = 0$ and $\vartheta = 45°$, respectively.

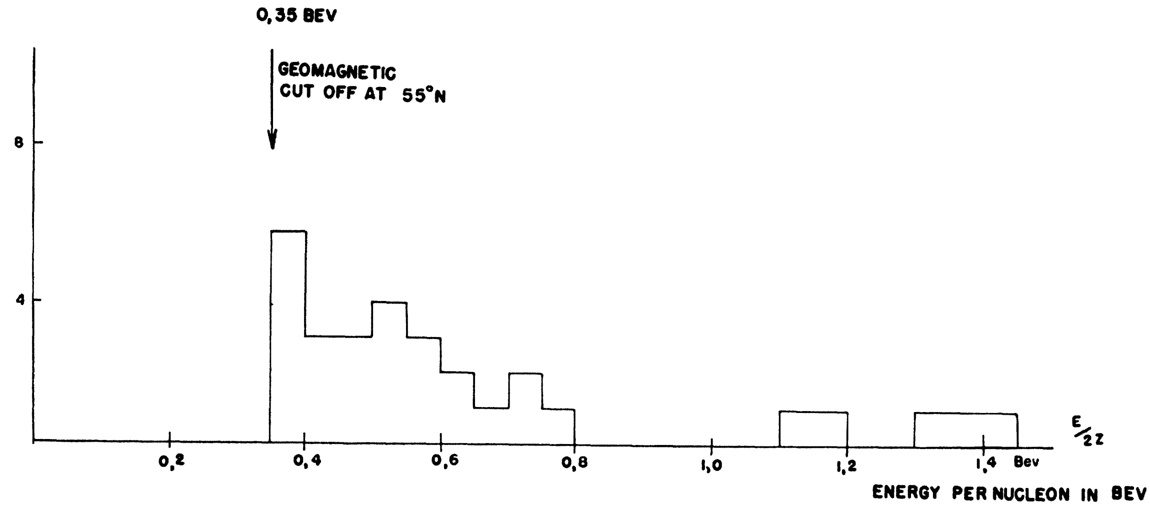

FIG. 3. Frequency distribution of tracks stopping in stack flown at Camp Ripley ($\lambda=55°$N) as function of the energy per nucleon. The minimum energy observed of 0.37 Bev/nucleon is equal to the geomagnetic cut-off energy at geomagnetic latitude $\lambda=55°$N.

The angular distribution corresponds to an isotropic distribution at the top of the atmosphere. For the heavier nuclei ($Z\geqslant 10$), for which the energy necessary for penetration down to 97,000 feet is greater than the geomagnetic cut-off energy, a lower limit,

$$I_{Z\geqslant 10}(55°)=(1.4\pm 0.4)\cdot 10^{-4} \text{ (nuclei/cm}^2\text{ sec. ster)},$$

was obtained for the flux at the top of the atmosphere.

Another stack of 25 electron sensitive Eastman plates, of dimensions 3 in.$\times$10 in. was flown on February 4, 1949 at geomagnetic latitude $\lambda=30°$ off the coast of Jamaica at an altitude of 93,000 feet.** An analysis of 100 heavy tracks of this stack yields the flux values

$$I_{C,N,O}(30°)=(3.0\pm 0.6)\cdot 10^{-4}\text{(nuclei/cm}^2\text{ sec. ster)},$$

and

$$I_{Z\geqslant 10}(30°)=(1.0\pm 0.3)\cdot 10^{-4}\text{(nuclei/cm}^2\text{ sec. ster)}.$$

Hence, the intensity of heavy primaries is reduced only by a factor 1.5 or at most 2 between $\lambda=55°$N ($\epsilon_{\text{cut-off}}=0.35$ Bev) and $\lambda=30°$N ($\epsilon_{\text{cut-off}}=3.4$ Bev). This unexpectedly small latitude effect shows that the majority of heavy primaries have energies of several Bev per nucleon, though at least some 10 percent of all the particles observed at $\lambda=55°$N have energies between 0.35 Bev and 0.6 Bev and stopped in the stack, while none of the 100 particles at $\lambda=30°$ stopped in the stack.

The following conclusions are drawn from these observations:

(1) If one assumes that the C, N, O nuclei are completely stripped of electrons before entering the earth's magnetic field it appears that this field alone determines the lowest energy with which particles enter the atmosphere even at magnetic latitudes as high as 55°N.[3]

(2) The great majority of heavy primaries have energies far in excess of the geomagnetic cut-off energy at $\lambda=55°$N. For these the energy loss per mean free path is small compared with their initial energy and hence, they will lose most of their energy in nuclear collisions. They therefore produce effects also on the secondary radiation observed at lower altitudes.

The flux of helium nuclei at $\lambda=30°$N has been determined to

$$I_{He}(30°)=(5.3\pm 1.0)\cdot 10^{-3}\text{(nuclei/cm}^2\text{ sec. ster)}.$$

Assuming the total flux of primaries to be

$$I_0=0.08\text{(nuclei/cm}^2\text{ sec. ster)},$$

we conclude that at $\lambda=30°$N only 70 percent of the primary nucleons can be protons, about 30 percent (15 percent neutrons) being contained in the component of nuclei with $Z=2$ to $Z=26$. No large fluctuations are therefore to be expected for the heavy primaries (with the possible exception of the small fraction having low energies), since such fluctuations would be reflected in the intensity of the total cosmic radiation measured at lower altitudes.

We wish to express our gratitude to Mr. R. Brent and Mr. R. Rickard who did most of the surveying.

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[1] H. Bradt and B. Peters, Phys. Rev. **74**, 1828 (1948).
[2] M. S. Vallarta, Phys. Rev. **74**, 1837 (1948).
[3] Freier, Ney, and Oppenheimer, Phys. Rev. **75**, 991, (1949).

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Mean Life Considerations in Relation to Curvature of Cosmic-Ray Paths in a Magnetic Field

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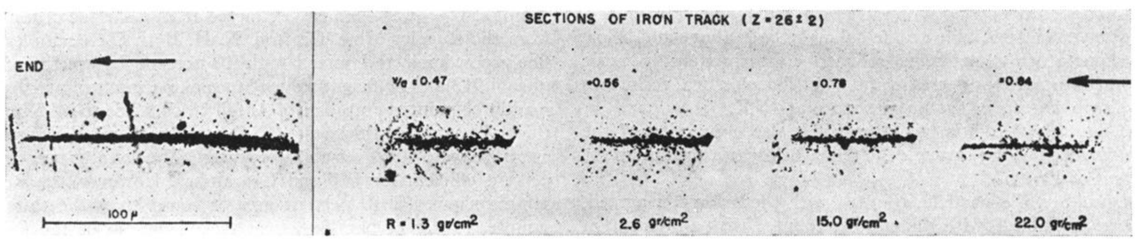
THE problem presented is as follows: Suppose we consider a pencil of cosmic-rays in a certain small solid angle and energy range.[1] It is of interest to consider the angular deviation which they have experienced from their point of birth. It turns out that if we assign the angular deviation, that quantity determines uniquely the fraction of the group of rays which has been lost in their journey from the point of birth. The result becomes uniquely determined, moreover, regardless of the nature of the energy loss along the path. The angular deviation is here to be understood as the angle turned through by the pencil of rays as projected on a plane perpendicular to the magnetic field, which field, for the purposes of the problem, may be taken as uniform everywhere.

Proof: If N is the number of rays in the pencil at any point along the path, and if dx is an element of path, τ the mean life of a particle at the instant when it is travelling in the element dx, and $\beta=v/c$, we have

$$dN/N=-(1/\tau)(dt/dx)dx=-dx/\beta c\tau. \qquad (1)$$



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