100 Bev correspond well to isotropic emission from a single center; the one event with energy between 100 and 1000 Bev does not have an obvious break in the angular distribution but might be explained as emission from two centers.

In considering the energy of secondary particles as a function of their angle of emission, we have examined the predictions of the two-center model under the assumption that the momentum spectrum of emitted particles is isotropic in each of the two systems. This model predicts the apparent constancy of transverse momentum, but makes the further prediction that the average transverse momentum should be lower, not only in forward and backward directions, but also around 90° in the $C$-system. The model also places definite restrictions on the values of energy and emission angle which the majority of the particles can have. These predictions should be susceptible to experimental test, particularly in jets with a wide separation between cones. The available experimental results from this and other published work have been studied and are seen to be readily understood in terms of the model, but are not yet sufficient to permit a definite conclusion.

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# Heavy Primary Cosmic Rays at Geomagnetic Latitude of 41°N

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This report includes the results from 9 balloon flights at geomagnetic latitude 41°N of altitude range from 70 000 to 100 000 feet. Only primaries of $Z \geqslant 10$ are considered. 2410 tracks are involved, in Ilford G-5 and G-0 emulsion exposures. Given are the charge spectra, flux, mean free paths, and angular distributions.

### INTRODUCTION

THIS paper represents an expansion of an investigation previously published.[1] The results are now based on an increase in the number of heavy nuclear tracks from 1082 to 2021. The emulsions containing these tracks were exposed at altitudes above 90 000 feet. Also herein included are the results of an additional 389 tracks in emulsions exposed in the 67 000-foot to

TABLE I. Percent of each $Z$ for each plate.

| Nuclear charge $Z$ | Plate number HHNII | 2601 | 4001 | 2588 | 1423 | 1480 | 37 A and B | LHNII | 3200 |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 21.5 | 26.8 | 20.2 | 16.4 | 19.0 | 29.1 | 18.8 | 24.2 | 36.2 |
| 11 | 13.6 | 14.2 | 12.0 | 12.6 | 14.2 | 17.1 | 12.4 | 12.8 | 14.7 |
| 12 | 16.6 | 18.6 | 19.5 | 11.4 | 13.1 | 12.4 | 16.1 | 15.9 | 8.6 |
| 13 | 9.5 | 9.1 | 11.6 | 13.9 | 13.6 | 12.4 | 12.2 | 14.7 | 9.1 |
| 14 | 8.6 | 6.7 | 5.6 | 11.4 | 7.7 | 10.5 | 10.2 | 9.6 | 9.5 |
| 15 | 5.3 | 5.2 | 5.6 | 6.3 | 7.1 | 4.2 | 7.5 | 5.1 | 5.6 |
| 16 | 2.4 | 2.8 | 3.4 | 1.3 | 1.7 | 1.2 | 2.7 | 3.2 | 3.0 |
| 17 | 3.9 | 2.8 | 2.2 | 5.0 | 3.0 | 3.5 | 3.0 | 2.5 | 3.9 |
| 18 | 2.4 | 1.4 | 2.6 | 5.0 | 2.3 | 2.3 | 2.2 | 0.6 | 2.2 |
| 19 | 2.4 | 2.8 | 3.0 | 2.5 | 4.1 | 1.6 | 2.5 | 3.2 | 1.3 |
| 20 | 2.3 | 1.4 | 2.2 | 5.0 | 2.3 | 0.8 | 3.0 | 1.3 | 2.2 |
| 21 | 3.1 | 0.7 | 1.9 | 1.3 | 3.0 | 0.4 | 2.7 | 1.8 | 2.2 |
| 22 | 1.3 | 1.4 | 3.0 | 1.3 | 4.1 | 1.2 | 2.2 | 1.8 | 0.4 |
| 23 | 1.7 | 0.7 | 3.0 | 1.3 | 0.6 | 0.4 | 1.7 | 0.6 | 0.4 |
| 24 | 2.4 | 2.2 | 2.2 | 2.5 | 1.7 | 0.8 | 1.1 | 1.3 | 0.4 |
| 25 | 1.2 | 0 | 0.4 | 1.3 | 0 | 1.6 | 0.3 | 0 | 0 |
| 26 | 1.7 | 1.4 | 1.5 | 1.3 | 1.7 | 0.6 | 1.1 | 1.3 | 0.4 |
| No. of tracks | 753 | 134 | 267 | 79 | 168 | 258 | 362 | 157 | 232 |
| Flux, $I_0$: multiply by $10^{-4}$ part./cm² sec sterad | 2.66±0.31 | 2.53±0.40 | 2.70±0.40 | 2.40±0.41 | 2.50±0.30 | 2.40±0.40 | 2.57±0.41 | 2.41±0.46 | 2.50±0.80 |
| Altitude (g/cm²) | 9.98 | 17.46 | 7.74 | 11.43 | 15.43 | 15.40 | 7.70 | 32.40 | 52.80 |
| Peaking angle | 54°±5° | 54°±5° | 60°±5° | 48°±5° | 57°±5° | 50°±5° | 55°±5° | 45°±5° | 45°±5° |

[1] O. B. Young and F. E. Harvey, Phys. Rev. **109**, 529 (1958).

TABLE II. Flight and plate data.

| Plate | No. of tracks | Flux value, $I_0$ ($10^{-4}$ part./cm² sec sterad) | Attenuation MFP(λ) (g/cm²) | Altitude (g/cm²) | Date | Area scanned (cm²) | Time of flight (hours) | Calib. const. a | b | Thickness (microns) | Type of plate |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HHNII | 753 | 2.66±0.31 | 21.43±0.67 | 09.98 | February 11, 1956 | 97.46 | 8.4 | 0.082 | 0.2 | 600 | G-5 |
| 4001 | 267 | 2.70±0.40 | 24.80±1.0 | 07.74 | June 3, 1955 | 21.70 | 9.0 | 0.082 | 0.23 | 600 | G-5 |
| 37 | 362 | 2.57±0.41 | 21.29±0.95 | 07.70 | June 3, 1955 | 33.44 | 9.3 | 0.06 | 0.18 | 1000 | G-5 |
| 2588 | 79 | 2.40±0.41 | 24 | 11.43 | November 18, 1954 | 23.45 | 6.2 | 0.065 | 0.2 | 600 | G-0, G-5 200, 400 |
| 1423 | 168 | 2.50±0.30 | | 15.43 | May 8, 1952 | 32.14 | 7.7 | 0.075 | 0.2 | 600 | G-5 |
| 1480 | 258 | 2.40±0.40 | | 15.40 | October 7, 1954 | 60.00 | 7.5 | 0.081 | 0.2 | 400 | G-5 |
| 2601 | 134 | 2.53±0.40 | | 17.41 | February 5, 1954 | 34.70 | 7.0 | 0.057 | 0.2 | 600 | G-5 |
| LHNII | 157 | 2.41±0.46 | 23.39±0.91 | 32.40 | February 11, 1956 | 106.13 | 8.0 | 0.085 | 0.2 | 600 | G-5 |
| 3200 | 232 | 2.50±0.80 | 24 | 52.80 | January 24, 1955 | 280.0 | 8.0 | 0.072 | 0.2 | 600 | G-5 |

Average $I_0$ (without No. 2601) = 2.53±0.44×10⁻⁴ particles/cm² sec sterad (incomplete flight curve)
Average $I_0$ (with No. 2601) = 2.52±0.43×10⁻⁴ particles/cm² sec sterad

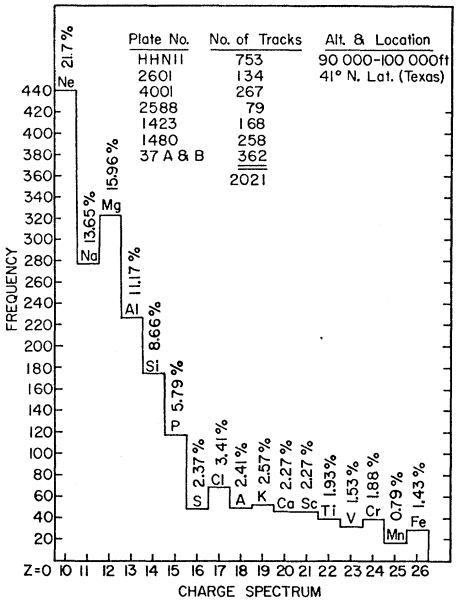


FIG. 1. Charge spectrum for 2021 tracks.

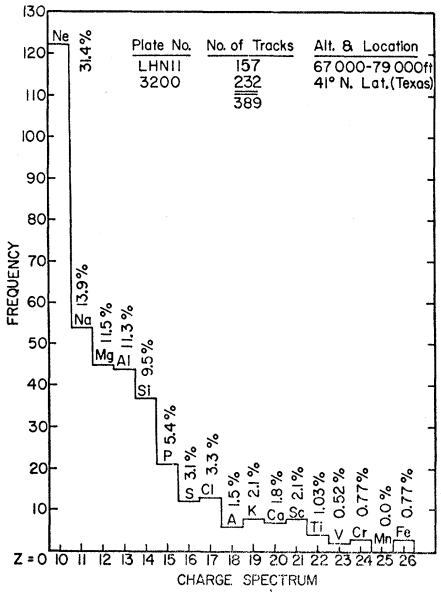


FIG. 2. Charge spectrum for 389 tracks.

73 000-foot altitude range. In the previous paper considerable attention was given to plate HHNII. One section containing 176 tracks gave results which were lower in attenuation mean free path than the figures from other plates. However, after HHNII was completely scanned, yielding 753 tracks, the results were raised from 19±0.7 g/cm² to 21.43±0.67 g/cm².

## EXPERIMENTAL METHOD

The experimental method has remained essentially unchanged. Angular distribution measurements have been added. While angles have been measured to within one degree, they are plotted more roughly, as the smaller divisions are not generally needed.

## RESULTS

The results are given in Tables I and II and Figs. 1–5.

Flux, $I_0$, has been obtained by extrapolation to the top of the atmosphere. The various values agree well, regardless of the altitudes of the balloon flights.

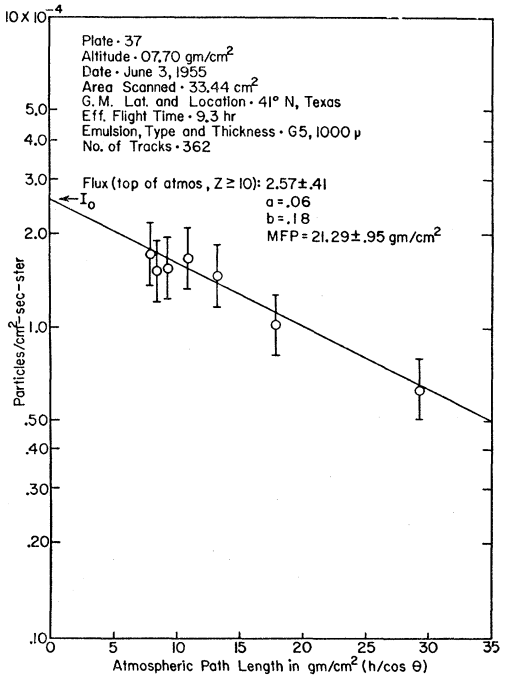


FIG. 3. Flux for plate 37.

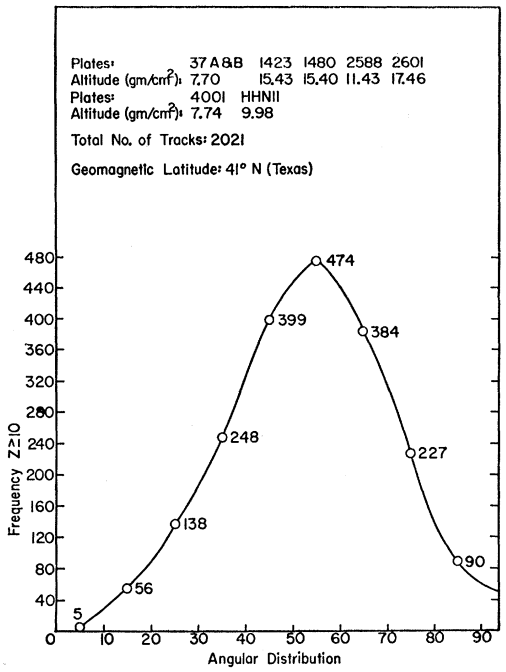


FIG. 4. Angular distribution for 2021 tracks.

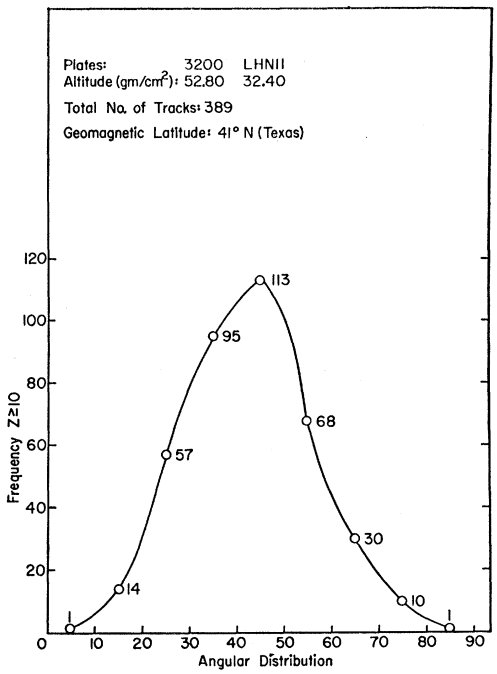


FIG. 5. Angular distribution for 389 tracks.

The charge spectrum is given for each plate in Table II. The results are combined for all plates exposed at about the same altitude in Figs. 1 and 2. For the data contained in Fig. 1 the altitudes of exposure were in the 90 000-foot to the 104 000-foot range. For the other, the altitudes were lower, being in the 67 000-foot to 79 000-foot range. The relative abundance in percent is given for each $Z$. However, a reader must observe that the lower the altitude of exposure, the less reliable the abundance ratios become, owing to the more rapid absorption of the heavier elements by the atmosphere and to the heavy nucleus breakups which have fragments large enough to be included among nuclei of $Z \geqslant 10$. This effect is clearly shown by comparison of the two charge spectra.

The angular distributions for each plate are given. The peaking angle, measured from the zenith, for each plate is listed in Table II. Absorption by the atmosphere causes the peaking angle to become smaller as the altitude decreases.

The attenuation mean free path, $\lambda$, has been determined separately for six of the nine plates listed, with the results listed in Table I. These six values average 23.1 g/cm$^2$. The consistency is within about 6% from the mean.

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