tion energy of about 800 volts for the 2s state is about 8 times that for the 1s state. Owing to the assumptions and numerical approximations made in the calculations we can only rely on the order of magnitude of this result, which is consistent with the earlier theoretical conclusion that the activation energy is proportional to the square of the minimum possible energy for the process.

* The research reported in this letter has been sponsored by the Geophysics Research Division of the Air Force Cambridge Research Center, Air Research and Development Command.
[1] H. S. W. Massey and R. A. Smith, Proc. Roy. Soc. (London) A142, 142 (1933). See also N. F. Mott and H. S. W. Massey, *Theory of Atomic Collisions* (Clarendon Press, Oxford, 1949), second edition, p. 153.
[2] A number of misprints were found in reference 1. Further, we do not agree with their evaluation of the integral J_5. It is unlikely that the order of magnitude of their results will be seriously in error.
[3] J. P. Keene, Phil. Mag. 40, 369 (1949).

Azimuthal Variation of Cosmic Radiation for Zenith Angle 40° at λ = 19 N

B. Bhowmik and G. S. Bajwa
University of Delhi, Delhi, India
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The study of the azimuthal variation of cosmic-ray intensity provides an excellent method of determining the charge and energy spectra of primary cosmic rays. The azimuthal effect has been measured at Delhi with four identical triple coincidence telescopes of angular resolution 10°×20°. Each telescope consists of three trays each having a sensitive area of 100 sq cm. All the counters used are of the external cathode type, owing to Maze.[1] Lead filters of 10 cm thickness are used in every telescope to eliminate the soft component. The four telescopes are mounted on four sides of a rectangular wooden platform which in turn is fixed on a rotating shaft. The telescopes are kept at 40° zenith angle, the azimuthal angle of the cone of the telescope being 10°. This particular zenith angle was chosen because the east-west asymmetry was found to be a maximum at 40° zenith angle by Bhowmik[2] and Bajwa.

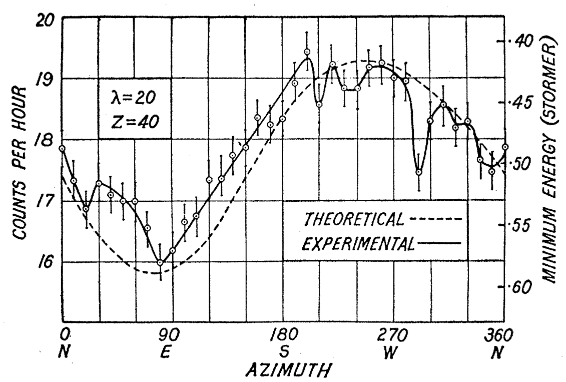

Fig. 1. Cosmic-ray intensity at different azimuths. Solid line: experimental curve at λ19 N, $z=40°$. Vertical stroke indicates probable error. Dotted line: minimum energy of arrival in Störmer units at λ20 N, $z=40°$.

The results obtained from observations recorded during the period December, 1951–April, 1952 are reported here. The mean curve of the four telescopes is given in Fig. 1, which shows a comparatively sharp minimum in the east and a broad maximum in the west. The azimuthal effect neglecting penumbra has been discussed by Lemaitre and Vallarta.[3] The dotted line has been computed from their work and shows the minimum energy required to break through the earth's magnetic field in a particular direction. The general nature of the variation is strikingly similar to the experimental curve. The east-west difference, instead of being maximum along the magnetic east west as predicated by the simple Störmer theory, is maximum along the 75°–255° line in accordance with predictions of Lemaitre and Vallarta.

Table I. Azimuthal variation.

λ=20 N Azimuth (α)	$E(\alpha, z)$ Milli-Störmer	$z=40°$ $I(\alpha, z)$ counts per hour	$(c-1)$
N 0°	510	17.65	0.446
30°	555	16.90	0.448
60°	585	16.35	0.449
E 90°	585	16.25	0.450
120°	555	17.00	0.447
150°	510	17.40	0.444
S 180°	460	18.60	0.446
210°	428	18.90	0.449
240°	415	19.15	0.448
W 270°	420	19.00	0.449
300°	440	18.55	0.449
330°	470	18.11	0.449
		Mean	0.448

The azimuthal variation is remarkably smooth in the eastern sky, while in the western azimuth there are quite a few humps which are due to the penumbral effect. According to Hutner,[4] the penumbral effect is confined to the western azimuth, particularly to the north-west quadrant for positively charged primaries in the northern hemisphere, while for negatively charged particles the pattern is mirror-imaged along the magnetic meridian. The absence of humps in the eastern azimuth, neglecting the one oscillation at 30°, will necessarily mean that all the primary cosmic rays are positively charged. At least the negatively charged particles are quite few in number or their secondaries do not reach sea level.

The primary energy spectrum has been assumed to be $F(E)dE = (K/E^c)dE$ and the exponent has been computed from the present work as shown in Table I. If $E(\alpha, z)$ is the minimum energy of arrival in Störmers in a given direction α, z, and $I(\alpha, z)$ is the observed intensity, then

$$I_{(\alpha, z)} = \int_{E(\alpha, z)}^{\infty} (K/E^c)dE = -K/[(c-1)E^{c-1}(\alpha, z)].$$

The constant K has been evaluated from three pairs of points and the mean value of K thus found has been used in calculating $(c-1)$ in Table I. The exponent $c=1.45$ is in excellent agreement with Vallarta's[5] value.

In Fig. 2 the theoretical predicted intensity at λ=20 N and $z=60°$ for the energy spectrum $K/E^{2.8}$ in conventional units is compared with the experimental curve at λ=19 N and $z=40°$. The general agreement is encouraging. The penumbral method of working out the energy spectrum is much more sensitive compared to the method used in Table I. But the penumbral method cannot be fully exploited with the present accuracy of the observations. Further work is in progress.

The authors are greatly indebted to Professor P. Auger for some valuable discussions regarding the technique of construction

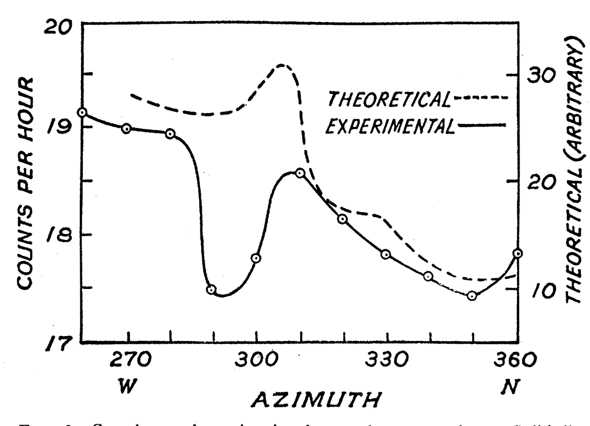

Fig. 2. Cosmic-ray intensity in the northwest quadrant. Solid line: experimental curve at λ19 N, $z=40°$. Dotted line: theoretical curve at λ20 N, $z=60°$ for energy spectrum $K/E^{2.8}$.

of external cathode counters during his visit to India. It is a pleasure to record our thanks to Professor R. C. Majumdar for his kind interest in the work. One of us (G.S.B.) is indebted to the AEC for the research fellowship granted to him.

[1] R. Maze, J. phys. et radium **7**, 165 (1946).
[2] B. Bhowmik and G. S. Bajwa, Indian. J. Phys. **25**, 561 (1951).
[3] G. Lemaitre and M. S. Vallarta, Phys. Rev. **50**, 496 (1936).
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A Narrow Angle Pair of Particles Produced in Hydrogen*

A. B. WEAVER, EARL A. LONG,† AND MARCEL SCHEIN
Department of Physics, University of Chicago, Chicago, Illinois

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A COUNTER-controlled cloud chamber[1] has been used to study penetrating showers and other energetic events produced by cosmic-ray particles in various materials, including liquid hydrogen, at sea level. The dewar containing the hydrogen was cylindrical, with an inside diameter of 15.2 cm and an inside height of 100 cm. The evaporation rate was such that the column of hydrogen was over 3 g/cm² (43 cm) for about 25 hours after a filling.

Figure 1 is a drawing of an unusual event which occurred in the liquid hydrogen. Tracks *A* and *B* trace to a point in the hydrogen $21^{+4.5}_{-3.0}$ cm above the visible part of the chamber. The stereoscopic pictures of this event were analyzed by reprojecting in the original cameras and by graphical means, using a low power microscope on the negatives. Both methods agreed within the limits of experimental precision.

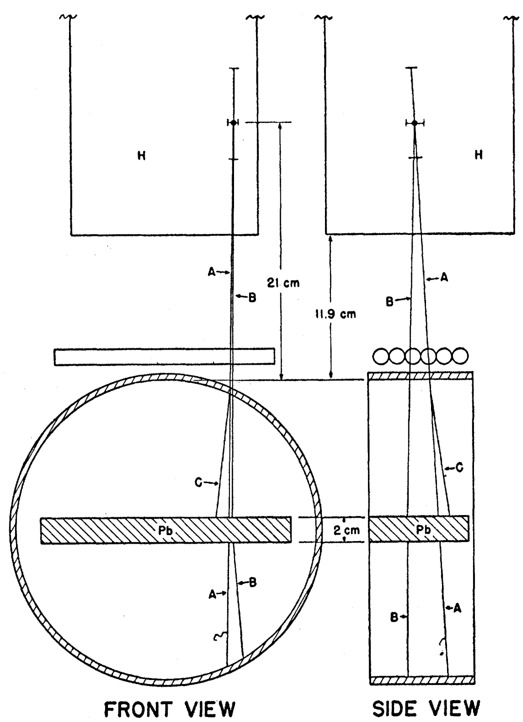

FIG. 1. Schematic drawing of a cloud-chamber event described in the text. The inner walls of the hydrogen dewar, the upper tray of counters, and the chamber are indicated. The rest of the counter control is omitted. The estimated accuracy in the location of the point of origin of the event is shown. An energetic δ-ray is visible along the track *A* in the lower part of the cloud chamber.

All three tracks, *A*, *B*, and *C*, of Fig. 1 are at minimum ionization. Measurements on track *A* indicate very little scattering in the 2-cm Pb plate (about 0.3°). According to the theory of multiple scattering, this corresponds to a momentum of 6×10^9 ev/*c*. Track *C* meets *A* at a point in the glass of the chamber and it can be interpreted as a knock-on electron stopping in the lead plate. If *A* is a π- or μ-meson or a proton, a knock-on electron ejected at an angle of 10°, which is the angle between *C* and *A*, should have an energy of approximately 10^7 ev. It would then be expected to stop in the lead plate.

The angle between tracks *A* and *B* is $4.3°\pm0.8°$. *B* is scattered in the lead plate through a projected angle of $5.4°\pm0.2°$. If this deviation should be due to small angle scattering in the 2 cm lead plate, it would indicate that *B* must carry a momentum of the order of 3×10^8 ev/*c*, if it is a π- or μ-meson. A proton whose momentum was low enough to correspond to this angle of multiple scattering would be well above minimum ionization. If the deviation should represent nuclear scattering, however, track *B* could correspond to a proton of energy greater than 10^9 ev. The probability that a proton will make a nuclear collision in 2 cm of lead is about 1 in 8.

A and *B* cannot be an electron pair because of the high energy of *A* which is inconsistent with an angle of only 4.3° between the two tracks. This is confirmed by the fact that no secondaries are formed in the lead.

The authors have found similar events at sea level under carbon and lead. In cloud-chamber pictures taken underground George[2] and Braddick *et al.*[3] found a number of pairs of penetrating particles very similar in nature to the pair described here. They report a cross section of 5×10^{-29} cm²/nucleon if the initiating particle is a μ-meson, a value quite consistent with the observation of such an event in hydrogen during the operating time of this experiment.

It is possible that some of the narrow pairs of penetrating particles produced in beryllium observed by Chang *et al.*[4] are of a similar nature.

It is highly improbable that the event in hydrogen represents the single production of a ζ_0-meson,[5] since the quoted *Q*-values would not agree with the observed angles and momenta. It is also improbable that the single production of a meson in a high energy nucleon-proton collision is responsible for the observed pair, *A*, *B*, because of the small angle between the two tracks. If the above described event in hydrogen is the same as that observed by George and by Braddick and collaborators underground, it is possible that this event is due to a nuclear interaction of a very high energy μ-meson in which the μ-meson produces other penetrating particles.

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† Institute for the Study of Metals, University of Chicago, Chicago, Illinois.
[1] The chamber was actually located in a magnetic field of 9000 gauss; however, due to unfortunate circumstances in the room the magnetic field could only be used for a fraction of the total running time.

[2] E. P. George (private communication).
[3] Braddick, Nash, and Wolfendale, Phil. Mag. **42**, 1277 (1951).
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[5] Danysz, Lock, and Yekutieli, Nature **169**, 364 (1952).

Interaction of Pions Originating in Penetrating Showers*

R. L. COOL AND O. PICCIONI
Brookhaven National Laboratory, Upton, New York

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THE total interaction cross sections[1] of high energy pions with carbon, paraffin, and lead have been obtained in a study of the secondary particles emitted in the penetrating showers of cosmic radiation at 11,000 feet. The hodoscope of 196 GM counters in Fig. 1 recorded the trajectories of the secondary particles generated in the penetrating showers in the C and Pb above the tray *A*. Coincidences (*AA′CDE*) selected the penetrat-