for by varying the amplifier gain. Lead shielding between the two counters minimized scattering between the crystals.

Figure 1 shows the single-crystal pulse-height distribution obtained in channel I for In^{111}. The two photoelectron peaks are associated with the 172- and 247-kev gamma-rays. Figure 2 shows the zero-delay coincidence spectrum obtained when channel II was adjusted to transmit only the 247-kev peak with a large slit width and channel I ranged over the entire spectrum. A coincidence peak is seen at the position of the 172-kev gamma-ray since the time resolution of the coincidence circuit is insufficient to prevent true coincidences at zero delay. The ratio of true to chance coincidences at the peak is about thirty to one. The introduction of a 0.1-μsec delay in channel I alone increased the coincidence rate by a factor of two, whereas the same delay introduced only in channel II practically eliminated true coincidences. This shows that the 247-kev gamma-ray is delayed with respect to the lower energy one and establishes directly the correspondence between the Cd^{111} 247-kev level and the 247-kev gamma-ray associated with the decay of In^{111}.

* This work was assisted by the joint program of the ONR and AEC.

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Zenithal Distribution of Low Energy Mesons

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(Received August 8, 1951)

IT is well known that the zenithal distribution of the integral meson spectrum at sea level obeys the empirical law $I_\theta = I_0 \cos^\lambda\theta$, where I_θ is the intensity of cosmic-rays making an angle θ with the zenith. The value of λ is approximately two. It has been shown,[1] however, that this law does not apply for the differential spectrum, in particular, in the momentum range 300–410 Mev/c.

In the present experiments a limited band in the spectrum was obtained by an arrangement of counters and absorbers such that the particles which stop in a block of lead are detected. In Fig. 1 the counters ABC define a beam which has passed through ababsorbers P_1, P_2, and P_3. P_2 and P_3 are each 5 cm thick. By observing the particles which are registered in ABC but not in D, a band of the spectrum is selected which is fixed in position by $P_1+P_2+P_3$ and in width by the thickness of Q_1. At the same time a second band of longer range and of width fixed by Q_2 can be studied by observing particles which register in coincidence in $ABCD$ but not in E. A group of counters G was included to exclude showers.

The whole apparatus was mounted in a steel frame that could be rotated about a horizontal axis. For the results described here $P_1+P_2+P_3=15$ cm of lead and Q_1 and Q_2 were each 7.5 cm thick.

The results were corrected for the background and for the scattering in the absorber. These corrections will be described when a detailed account of the experiment is published.

Table I shows the counting rate $\Delta I_{\theta D}$ for particles stopped in the absorber Q_1 and $\Delta I_{\theta E}$ for particles stopped in Q_2. Table II shows the values of λ calculated from $\log r/\log \cos\theta$, where $r=\Delta I_\theta/\Delta I_0$. Since the values of λ are far from constant, the $\cos^2\theta$ law is not applicable. A much better fit is obtained if a function of the form

$$r=(1-a\sin^b\theta)$$

is assumed. If $\log(1-r)$ is plotted against $\log\sin\theta$, the points fall on a straight line. The constants a and b have the following values: $a=0.98\pm0.02$, $b=1.47\pm0.12$, for the spectral band 300 to 410 Mev/c; $a=1.03\pm0.03$, $b=1.61\pm0.15$, for the spectral band 410 to 510 Mev/c.

TABLE I. Counting rates at various zenithal angles θ: $\Delta I_\theta D$ represents mesons with momenta between 300 and 410 Mev/c. $\Delta I_\theta E$ represents mesons with momenta between 410 and 510 Mev/c.

θ	0°	30°	60°	75°	80°
$\Delta I_{\theta D}$	3.59±0.10	2.33±0.18	0.75±0.03	0.19±0.02	0.18±0.02
$\Delta I_{\theta E}$	3.62±0.10	2.36±0.11	0.60±0.03	0.13±0.01	0.09±0.01

The measurements were extended to angles greater than 90° in an effort to detect particles coming upward from the earth. Upward moving particles are difficult to distinguish from particles scattered into the ABC telescope from the high flux of downward particles in Q_1 or into $ABCD$ from Q_2. Measurements with one or

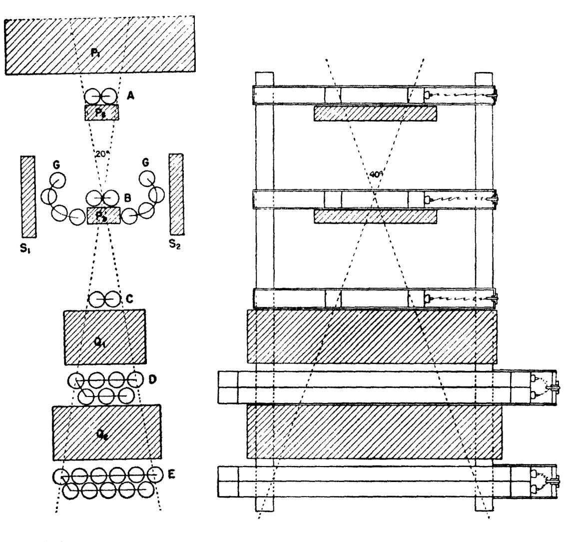

FIG. 1. Arrangements of counters and absorbers to measure the zenithal distribution.

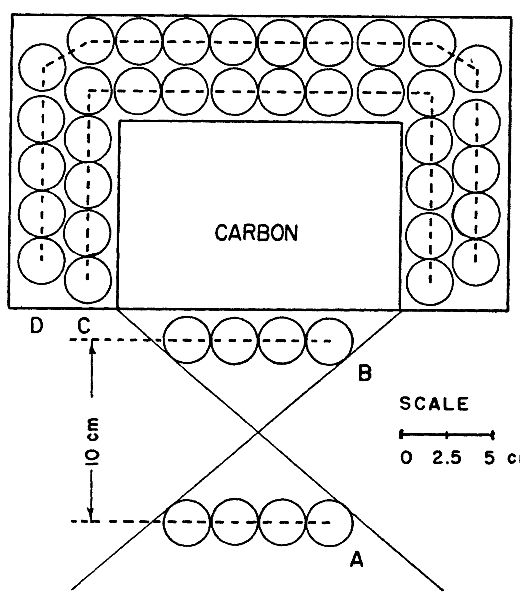

FIG. 2. Arrangement of counters and absorber to detect the upward flux of mesons.

TABLE II. Values of λ calculated from $\log r/\log \cos\theta$, where $r=\Delta I_\theta/\Delta I_0$.

	30°	60°	75°	80°
$\Delta\ \theta_D$	3.00 ± 0.53	2.26 ± 0.07	2.17 ± 0.08	1.71 ± 0.06
$\Delta I_{\theta E}$	2.97 ± 0.34	2.59 ± 0.08	2.46 ± 0.06	2.11 ± 0.06

both absorbers Q_1 and Q_2 removed showed that there appeared to be no significant increase in counts for angles greater than 90°.

Another experiment was performed to confirm this. The μ-mesons were detected by their decay electron using a delayed coincidence circuit. The arrangement of apparatus is shown in Fig. 2. Coincidences AB and CD with AB delayed were recorded. The circuit accepted delay periods from 1.2 to 7.2 microseconds but rejected counts where any counter in C or D was tripped at the same time as AB. In this way only μ-mesons coming upward into the block of carbon and stopping there were recorded. The background with the block of carbon removed was 0.42 ± 0.10 count per hour and the count with the block in place was 0.45 ± 0.06 per hour. Therefore, these results show no appreciable upward flux of mesons. Powell *et al.*[2] found an appreciable upward component using photographic plates exposed at high altitude on the Jungfrau, and Ritson[3] using counters observed an upward component of slow mesons from the ground at sea level.

In conclusion, the angular distribution (at angles between 0 and 80°) of cosmic-ray mesons in two momentum bands (300 to 410 Mev/c and 410 to 510 Mev/c) has been found to show a marked decrease in intensity near the zenith and a tendency to more isotropy for the larger angles. The phenomena which could contribute to this isotropic effect are: the scattering of particles through the atmosphere, the decay in flight on heavy mesons giving rise to lighter mesons, and the nuclear disintegration accompanied by a production of mesons. Backward radiation (at angles greater than 90°) measured in the same momentum bands was found to be of very low intensity.

The author wishes to thank Dr. W. Kraushaar for many interesting discussions and particularly Dr. D. C. Rose for his constant interest and help during the experiments.

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Multiple Scattering and Grain Density Measurements on Electron Tracks in G-5 Emulsions

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SEVERAL Ilford G-5 plates have been exposed to the x-rays from a 70-Mev synchrotron and a study made of the electron tracks from the pairs produced in the emulsion. The energy of each electron has been determined by the scattering method and in all a total of 13 cm of track has been grain counted.

Multiple scattering theories[1–3] can be put in the form

$$\bar{\theta}(t)=K(t)\sqrt{t}/P\beta, \qquad (1)$$

where $\bar{\theta}(t)$ is the mean angle of scattering in degrees measured between tangents a distance t apart, t the cell length in units of 100μ, P the momentum$\times c$ in Mev, and $\beta=v/c$. $K(t)$ is the "scattering constant," and we find from Williams' theory[1,4] for G-5 emulsions and $\beta\rightarrow1$

$$K(t)=14.6+(234+148.5\log_{10}t)^{\frac{1}{2}}, \qquad (2)$$

and for a large angle cutoff in the measurements $=4\bar{\theta}(t)$

$$K(t)_{co}=(K(t)-25\pi/K(t))/(1-\pi/0.32K(t)^2). \qquad (3)$$

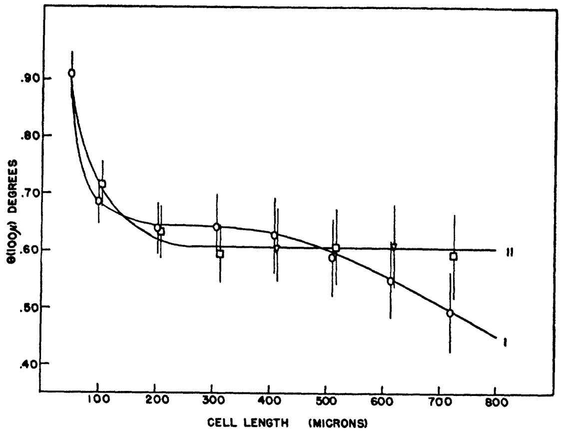

FIG. 1. Curve I: Results of scattering measurements on a long electron track when angles are measured between successive chords. Curve II: Results of measurements on the same track when angles are measured between chords drawn over small intervals "a" of the track and separated by distances $(a+ak)$. The squares are for $a=50\mu$. The triangles are for $a=100\mu$.

The values of $K(t)$ calculated from Eq. (2) agree to within 4 percent with the results of Gottstein *et al.*[5] using Moliere's[3] theory for $\beta=1$, over the entire range of t.

If, instead of measuring angles between tangents, the mean angle of scatttering $\bar{\alpha}(t)$ is measured between successive chords, it has been shown that

$$\bar{\alpha}(t)=(\tfrac{2}{3})^{\frac{1}{2}}\bar{\theta}(t). \qquad (4)$$

Therefore, multiplying Eqs. (2) and (3) by $(\frac{2}{3})^{\frac{1}{2}}$ the scattering constant appropriate to the successive chord method is obtained. For a cell length of 100μ ($t=1$) we get from Eqs. (2) and (3) $(\frac{2}{3})^{\frac{1}{2}}K(100\mu)=24.4$ and $(\frac{2}{3})^{\frac{1}{2}}K(100\mu)_{co}=22.6$.

The method used in this work to measure the scattering is a slight modification of Fowler's[6] coordinate method. Instead of measuring angles between successive chords as Fowler describes, angles between chords drawn over small intervals of the track and separated by given distances are measured. This procedure seems to give a better dependence of the measured mean angle on the cell length used in the measurement. As in Fowler's method the positions of the track $Y_1Y_2\cdots Y_k\cdots$ (above an arbitrary line) are taken at intervals "a" apart, then the first deviation D_1 between chords a distance $t=(a+ak)$ apart is given by the second difference $(Y_1-Y_2)-(Y_{k+2}-Y_{k+3})$. The mean angle of scattering $\bar{\psi}(t)$ measured in this way $=\langle|D|\rangle_{\text{Av}}/a$ and we find the relation

$$\bar{\psi}(t)=[(2+3k)/(3+3k)]^{\frac{1}{2}}\bar{\theta}(t), \qquad (5)$$

which corresponds to Eq. (4) for the successive chord method.

Figure 1 shows typical results of scattering measurements obtained using both methods on a 9-mm long electron track. The quantiy $\bar{\theta}(100\mu)$ obtained from the expression

$$\bar{\theta}(100\mu)=[K(100\mu)_{co}/K(t)_{co}][\bar{\theta}(t)/(t)^{\frac{1}{2}}] \qquad (6)$$

is plotted against the cell length t used in the measurement. $\bar{\theta}(100\mu)$ should be independent of the cell length except for small t, and here it is large because the "spurious" scattering is of the same order as the true scattering. Readings of position were taken at intervals of 50μ and the mean angle of scattering calculated for different t. For the larger cell lengths overlapping cells were used and the equivalent number of statistically independent readings calculated in each case to obtain the probable errors. Curve 1 is obtained from the measured $\bar{\alpha}(t)$ and Eqs. (4) and (6); curve 2 is obtained from the measured $\bar{\psi}(t)$ and Eqs. (5) and (6). It can be seen that a better dependence of the measured angle on t is obtained when $\bar{\psi}(t)$ rather than $\bar{\alpha}(t)$ is used.

The energies of the electrons available lie in the particular range (E/μ (kinetic/rest energy) $=7$ to 90) in which ionization theories predict an increase of a few percent up to a constant value