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.

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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

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

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 $\beta\rightarrow 1$

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

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

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

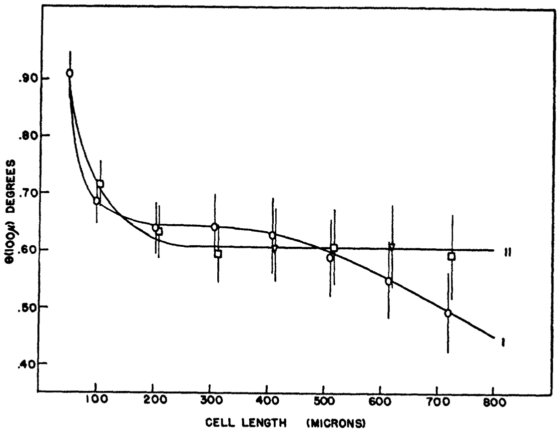

FIG. 1. Curve I: Results of scattering measurements on a long electron track when angles are measured between successive chords. Curve II: Results of measurements on the same track when angles are measured between chords drawn over small intervals "a" of the track and separated by distances $(a+ak)$.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

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

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

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

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

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

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

TABLE I. Summary of grain-counting data.

Energy interval, Mev	Average E/μ	Total number of grains	Total length of track (microns)	Grains per 100μ
2–5	7	1613	4778	33.8 ± 0.6
5–10	15	5777	16445	35.1 ± 0.4
10–15	25	7818	22149	35.4 ± 0.3
15–20	35	7933	21997	36.0 ± 0.3
20–25	45	6333	17541	36.1 ± 0.3
25–30	55	4947	13834	35.8 ± 0.4
30–35	65	5764	15732	36.6 ± 0.4
35–45	80	5092	13890	36.6 ± 0.4

in the ionization. The gains have been counted in an effort to detect a corresponding increase in grain density.

It has been found that an experienced observer can count grains consistently, and that the deviations from the mean of the number of grains in intervals as small as 180μ, for all tracks of the same energy and in the same plate, are roughly gaussian.

The grain-counting data for all tracks in the same 5-Mev energy interval have been grouped together and the results are shown in Table I. There is an observable increase in grain density of about 7 percent in the region $E/\mu=7$ to 40 or 60 after which the density is constant. This is roughly in agreement with the measurements on cosmic-ray particles of Pickup and Voyvodic[7] who report an increase of 10 percent from a minimum at $E/\mu=3$ to a constant value at $E/\mu=20$. Our results, like theirs, seem to favor the ionization theory of Wick.[8]

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Energy Response of NaI (Tl) Crystals to Alpha-Particles of Less than 10 Mev*

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RECENT investigation[1] of the response of NaI crystals as scintillation counters of charged particles has shown that, although the light output is essentially linear with energy of incident electrons, protons, and deuterons, there is nonlinearity in the response to alpha-particles of less than 10 Mev. The investigation described here was undertaken to determine in detail the shape of this nonlinearity.

In this experiment, energy control was accomplished by air attenuation and the particles were allowed to strike a freshly cleaved crystal face. To avoid the usual rapid moisture contamination of the crystal surface in the open atmosphere, the entire operation was performed in a dry-box, with signal and high voltage cables brought into the 5819 photomultiplier by means of airtight feed-through connectors. P_2O_5 was used as a drying agent, and no detectable deterioration of crystals cleaved in the box took place in a three-week period.

Two sources of alpha-particles were used, both thin to their own radiations. The first was a "thorium active" deposit yielding alpha-groups at 8.78 Mev and 6.04 Mev from ThC′ and ThC disintegrations, respectively. The second was Pu^{239}, giving 5.16-Mev alphas. Both sources were deposited on the ends of probe rods which passed through a light-tight, sliding seal in the end of the phototube housing. The $1\times1\times0.1$-cm crystal was held to the tube face by a wire clip, with a drop of mineral oil providing additional optical coupling.

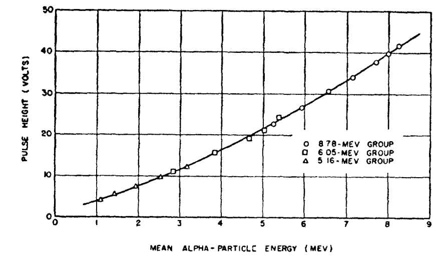

FIG. 1. Mean output pulse height as a function of computed mean energy.

The thorium probe was used in seven positions from 1.00 to 6.00 cm from the crystal, and the Pu source in five positions from 2.00 to 3.62 cm, the near position in each case being the limit at which the source backing reflected a significant amount of light back into the photocathode, producing spurious heightening of output pulses.

Appropriate range corrections for the local atmospheric pressure of 60.2 cm Hg were made, and the mean particle energies were computed from Bethe's range-energy curves.[2]

Output of the 5819 was fed into a low gain preamplifier for polarity inversion, through a Los Alamos model 503 pulse amplifier, and into a continuously variable single-channel pulse-height discriminator. Linearity of the electronic system was checked by applying standard pulses to the phototube anode resistor and observing the corresponding discriminator dial readings. No corrections were found necessary.

In Fig. 1, mean output pulse height for each probe position is plotted against computed mean energy. In every position, the peak of the pulse-height distribution could be determined to within one volt.

I wish to thank Mr. Hugh Stoddart of the Los Alamos cyclotron group for preparation of the sources used in this experiment.

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The Hyperfine Structure of $^2P_{\frac{1}{2}}$ State of the Stable Chlorine Isotopes*

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FROM observations of the hyperfine structure (hfs) interaction in an external magnetic field, the nuclear magnetic dipole coupling constants ($a_{1/2}$) for the $^2P_{1/2}$ metastable state of the stable chlorine isotopes have been obtained. As will be shown, the results of these measurements are in excellent agreement with recent work on the ratio of the nuclear magnetic moments of the two isotopes. Use has been made here of the atomic beam magnetic resonance method, as in previous work in the hfs of the $^2P_{3/2}$ state of chlorine.[1,2]

In Fig. 1 the interaction energy of an atom with $I=\frac{3}{2}$ and $J=\frac{1}{2}$ in an external magnetic field is displayed. An estimate of the hfs separation, ΔW, can be had from consideration of the form of the interaction[1,3]

$$\Delta W=h\Delta\nu=2ha=-\mu_0^2g_I\mathfrak{F}\frac{4L(L+1)}{J(J+1)}\langle r^{-3}\rangle_{\text{Av}},$$

where $\mathfrak{F}$ is a relativistic correction factor of order 1.0 for both the $P_{1/2}$ and $P_{3/2}$ states of chlorine, and the other symbols have their usual meaning. Since the hfs of the $P_{3/2}$ state is known quite accurately, and one may assume $(\langle r^{-3}\rangle_{\text{Av}})_{3/2}$ is equal to $(\langle r^{-3}\rangle_{\text{Av}})_{1/2}$ to