The Angular Distribution of Cosmic-Ray Particles Scattered in 1 Cm of Platinum

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EXPERIMENTS on the scattering of cosmic-ray particles were first reported by Anderson,[1] and recently more extensive measurements were reported by Blackett and Wilson.[2] The results of both of these sets of data are, within experimental uncertainty, in agreement with theoretical expectation.

The two accompanying graphs represent the results of an investigation mentioned briefly in a recent abstract.[3] The theory of multiple scattering is discussed in a recent paper by Williams.[4] Providing $\beta \sim 1$, as is the case with most cosmic-ray particles, the angular distribution of scattered particles, for a particular energy, is given by the Gaussian distribution

$$N(\theta)d\theta = \frac{2N_0}{\pi\theta_m}\exp\left[-\frac{\theta^2}{\pi\theta_m{}^2}\right]d\theta, \quad (1)$$

where $N(\theta)d\theta$ = number of particles scattered between the angles θ and $\theta+d\theta$, without regard to sign; N_0 = total number of particles scattered; θ_m = mean angle of scattering for the energy under consideration $=(1.37\times10^3)/E$ deg. (Theoretical; E = energy in Mev.) (1) may be written as

$$N(E\theta)d(E\theta) = \frac{2N_0}{\pi(E\theta)_m}\exp\left[-\frac{(E\theta)^2}{\pi(E\theta)_m{}^2}\right]d(E\theta), \quad (2)$$

where $N(E\theta)d(E\theta)$ = number of particles scattered in such a way that the product of (energy of particle)$\times$(scattering angle) is between $(E\theta)$ and $(E\theta)+d(E\theta)$; N_0 = total number of particles scattered; $(E\theta)_m$ = mean product of energy$\times$ angle of scattering $=1.37\times10^3$ Mev-deg. (theoretical; E in Mev). (2) represents a universal curve independent of energy.

Only 55 particles among those measured were found to have an energy definitely below 500 Mev.* The observed distribution in $(E\theta)$ is given in Fig. 1, in which the theoretical curve drawn in is given by (2). There is a suggestion that the observed distribution is narrower than that predicted, as found by Fowler and Oppenheimer[5] for electrons of 5–17 Mev, although in view of the small number of particles (55), the discrepancy may well lie within the statistical fluctuations and experimental error. (With the scattering plate in the chamber, only half-lengths of track were available for measurement.) It should be mentioned that, in general, track distortions would cause straight (high energy) tracks to be recorded as curved (low energy). This difficulty would tend to narrow the observed distribution in the same way as recorded in Fig. 1. The experimental value for $(E\theta)_m$ was found to be about 1.4×10^3 Mev-deg., while the value predicted is 1.0×10^3 Mev-deg. The former is critically dependent, for so few particles, upon the few (but relatively heavily weighted) particles which happened to have occurred at large angles of scattering. Particles scattered more than four times the predicted mean angle of scattering were discarded as singly scattered, in accordance with Wentzel's[6] criterion.

Six hundred and seventy particles of energy $\gtrsim 500$ Mev were observed. Since the energies involved were beyond the reach of the method of measurement employed here, the method of Eq. (2) could not be used. Consequently, the observed distribution in angle alone was plotted. Now (1) refers to a particular energy, while the

[1] C. D. Anderson, Phys. Rev. **43**, 381 (1933).
[2] P. M. S. Blackett and J. G. Wilson, Proc. Roy. Soc. **A165**, 209 (1938).
[3] J. A. Vargus, Jr., Phys. Rev. **55**, 422 (1939).
[4] E. J. Williams, Proc. Roy. Soc. **A169**, 531 (1939).
* Throughout this communication, the energy values given are on the assumption that the particles are of electronic mass, according to the numerical relationship $E=300H\rho$ where E = energy in Mev; H = magnetic field in gauss; ρ = radius of curvature. The experimental measurement of $H\rho$ is a measurement of momentum. A set of particles with a given distribution in $H\rho$ will undergo multiple scattering in a manner independent of the masses of the particles, providing that β does not vary much from unity, as is the case with most of the particles. In short, under the circumstances, the usual convention, adopted here, of expressing momenta $(H\rho)$ measurements as energies (Mev) does not appreciably affect the comparison of experiment and theory, even though the particles are mostly of the penetrating type, and are presumably mesotrons.
[5] W. A. Fowler and J. Oppenheimer, Phys. Rev. **54**, 320 (1938).
[6] G. Wentzel, Ann. d. Physik **69**, 335 (1922).

higher energy particles observed were of all energies above 500 Mev. To calculate the theoretical angular distribution to be expected, the energy distribution of Anderson and Neddermeyer[7] was used. (These measurements were made with full-length tracks, with no plate in the chamber.) A separate distribution for each 500-Mev range in the energy-distribution curve was plotted according to (1), and the curves added graphically. The resultant angular distribution to be expected is shown by the triangles in Fig. 2. The experimental value of θ_m is about 0.7 deg., while that to be expected from the energy-distribution curve is about 0.8 deg. The observed distribution involves no measurements of energy, except that these nearly straight tracks were above 500 Mev. It again suggests a slightly narrower peak than that predicted. However, in view of the statistical uncertainties of the energy-distribution curve used, the results shown in Fig. 2 may be regarded as indicating rather good agreement with the theory. A similar process applied to Blackett's[8] energy-distribution curve shows an even closer agreement with the scattering data presented, as shown by the circles in Fig. 2. The value of θ_m to be expected from this energy distribution is about 0.7 deg., as measured here. (However, since an energy-distribution curve is partly a function of the geometry of the measuring apparatus, this latter energy-distribution curve is not necessarily applicable to the apparatus at Pasadena, and the improved agreement may or may not be significant.) It is unlikely that such agreement with theory could hold above 500 Mev, together with a breakdown in the range below 500 Mev. Because more accurate energy measurements were involved in the comparison in Fig. 2, and the number of particles is much larger, the agreement found there may be considered as more significant than the discrepancy in the lower range (Fig. 1).

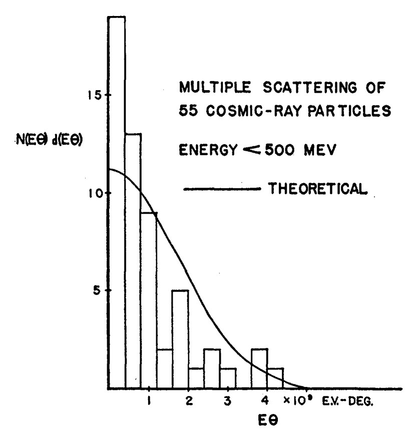

Fig. 1.

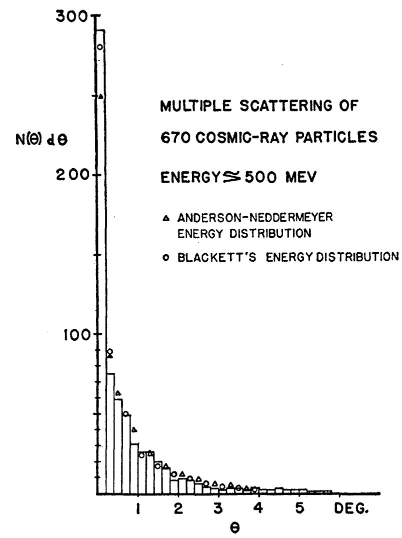

Fig. 2.

Williams[9] has pointed out the importance of scattering in connection with the anomalously low energy losses of cosmic-ray particles traversing metal plates. Since the scattering is independent of the mass of the particles and measurements to date on scattering do not indicate a breakdown of basic theory at high energies, indirect evidence is afforded that the theory of radiation is also valid for high energy particles, and further encouragement is given to the view currently held that the energy-loss anomaly is due to the heavier mass of the particles (mesotrons).

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[7] C. D. Anderson and S. H. Neddermeyer, Int. Conf. Phys. **1**, 173 (1934).

[8] P. M. S. Blackett, Proc. Roy. Soc. **A159**, 1 (1937).

[9] E. J. Williams, Phys. Rev. **53**, 433 (1938).