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Multiple Scattering of Electrons in the Gas of a Wilson Cloud Chamber

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The deviation from linearity of straight electron tracks appearing in a cloud chamber has been measured and found to be in agreement with that predicted by the theory of multiple scattering insofar as the energy of the electrons is known. The method described could be easily modified to give a more valuable and exact check on the theory of multiple scattering.

1. INTRODUCTION

SOME earlier reports[1,2] have suggested the presence of a new penetrating radiation, presumably a low mass neutral particle which decays at rest. There was some cloud-chamber evidence[3] that this assumption was correct. In order to evaluate the cloud-chamber data it was necessary to determine to what extent multiple scattering in the gas of the cloud chamber and turbulent motion of the gas affected the determination of electron energy. The effect of multiple scattering on curvature measurements has been discussed by Williams[4] and Bethe.[5]

2. EXPERIMENTAL ARRANGEMENT

In order to obtain data on multiple scattering in a gas, the cloud chamber was operated under conditions which were the same as those which prevailed when data on the supposed decay electrons were taken, except that there was no magnetic field. The cloud chamber contained air at atmospheric pressure and three aluminum foils 0.80 mm thick, spaced 5 cm apart. The chamber was surrounded by a ring, 19 cm thick and 21 cm high made of lead blocks, and was placed about four meters from the target of the cyclotron and almost in a direct line with the deuteron beam striking the target. The cyclotron was completely enclosed by water tanks of 120-cm thickness, and the tanks on the side between the target and the cloud chamber contained a saturated solution of boric acid.

In order to get an approximation to the energy of the electrons which produce the straight tracks which were measured, only those tracks were used which penetrated one or more of the aluminum foils. Since the minimum energy at which this can occur is known roughly, and the energy spectrum of electrons in the chamber under these conditions is known from data[6] taken with a magnetic field, one can assign an average energy to these tracks. The average kinetic energy will be assumed to be 1.5 Mev.

The actual quantity which was measured on the straight tracks was their deviation from

[1] G. K. Groetzinger, P. G. Kruger, and Lloyd Smith, Phys. Rev. **67**, 52 (1945).
[2] G. K. Groetzinger and Lloyd Smith, Phys. Rev. **68**, 55 (1945).
[3] P. G. Kruger and Lyle W. Smith, Phys. Rev. **68**, 104 (1945).
[4] E. J. Williams, Phys. Rev. **59**, 460 (1940).
[5] H. A. Bethe, Phys. Rev. **70**, 821 (1946).
[6] P. Gerald Kruger and Lyle W. Smith, Phys. Rev. **72**, 360 (1947).

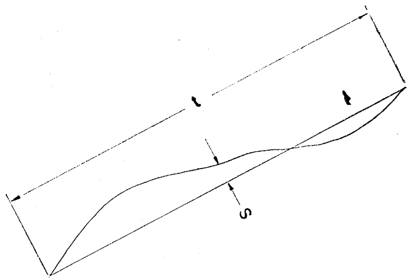

FIG. 1. Exaggerated shape of scattered track. S and t represent the quantities measured.

linearity. To do this the same measuring engine was used which was used to measure track curvature in the case when a magnetic field was present. The measured quantity was the perpendicular distance between the midpoint of the track and a straight line connecting the two ends. This is similar to the measurement of a sagitta of an arc in the case of curvature measurements. The following further criteria were used in selecting tracks for measurement.

(1) All sections of the track must lie in the same plane, and this plane must lie within 10° of the median plane of the cloud chamber.

(2) All sections of the track must be of the same age and density of ionization.

(3) There can be no obvious single scattering over the region of the track which is measured. The minimum angle at which single scattering can be detected is estimated to be 0.1 radian.

(4) Adjacent sections of the track, when extended, must meet in the foil.

Pictures of the tracks were taken with a stereoscopic mirror system and reprojected through the same camera and mirror system onto a ground glass screen for measurement. Because of the way in which the measurements were made the results will give the projection of the scattering angle on a plane, not necessarily the median plane of the cloud chamber.

In general, the track may have any sort of shape between its end points as is shown greatly exaggerated in Fig. 1. The quantities which are measured experimentally are t and S.

Rossi and Greisen[7] have given a formula, attributable to Fermi, which expresses the distribution of S as a function of the length of the track and the multiple scattering angle θ. By θ we shall always mean the projection of the scattering angle on a plane. This distribution of S is

$$P(S)dS=\frac{24}{\pi t^2\langle\theta^2\rangle_{\mathrm{Av}}}\exp\left(-\frac{24S^2}{t^2\langle\theta^2\rangle_{\mathrm{Av}}}\right)ds, \quad (1)$$

so that

$$\langle\theta^2\rangle_{\mathrm{Av}}=\frac{48\langle S^2\rangle_{\mathrm{Av}}}{t^2}=\frac{24\pi\langle S\rangle^2_{\mathrm{Av}}}{t^2}, \quad (2)$$

is the relation which we shall use to compare our results with the theory.

The mean square average angle of scattering in a length of track t is[4, 5]

$$\langle\theta^2\rangle_{\mathrm{Av}}=\frac{4\pi e^4Z^2Nt}{(\mathrm{mc}^2)^2}\frac{(W/\mathrm{mc}^2)^2}{[(W/\mathrm{mc}^2)^2-1]^2}\ln\frac{\theta_{\max}}{\theta_{\min}}, \quad (3)$$

where Z is the atomic number, N the number of atoms per cm^3 of the scattering substance, and W is the total energy of the particle. $\theta_{\min}$ is determined by screening and is given by

$$\theta_{\min}=\frac{e^2Z^{\frac{1}{3}}}{hc}\frac{(W/\mathrm{mc}^2)^2}{(W/\mathrm{mc}^2)^2-1}. \quad (4)$$

We shall take $\theta_{\max}$ as the minimum angle (assumed to be 0.1 radian) which can be recognized as single scattering in the gas of the cloud chamber. Since from (3) we have $\langle\theta^2\rangle_{\mathrm{Av}}\sim t$, and we know from (1) that $\langle S\rangle^2_{\mathrm{Av}}/t^2\sim\langle\theta^2\rangle_{\mathrm{Av}}$, we shall expect the relation $\langle S\rangle_{\mathrm{Av}}\sim t^{\frac{3}{2}}$ to obtain for the various lengths of tracks which were measured. Table I gives the results of the measurements where C and $\langle S\rangle_{\mathrm{Av}}$ are the length of track and average deviation from linearity, respectively. Columns 4 and 5 give the experimental and theoretical values of the mean square scattering angle, respectively. The experimental value of $(2\pi^{-1}\langle S^2\rangle_{\mathrm{Av}})^{\frac{1}{2}}$ is included in the

TABLE I. Results of measurements on straight tracks. The first column gives the length of the straight track in cm over which the average deviation $\langle S\rangle_{\mathrm{Av}}$ has been measured. $(2\pi^{-1}\langle S^2\rangle_{\mathrm{Av}})$ gives the experimental value for this quantity. $\langle\theta^2\rangle_{\mathrm{Av}}{}^{\mathrm{exp}}$ and $\langle\theta^2\rangle_{\mathrm{Av}}{}^{\mathrm{theo}}$ give the experimental and theoretical values of the mean square scattering angle. The last column gives the number of tracks on which measurements were made over the lengths given in column one.

t(cm)	$\langle S\rangle_{\mathrm{Av}}$(cm)	$(2\pi^{-1}\langle S^2\rangle_{\mathrm{Av}})^{\frac{1}{2}}$	$\langle\theta^2\rangle_{\mathrm{Av}}{}^{\mathrm{exp}}$	$\langle\theta^2\rangle_{\mathrm{Av}}{}^{\mathrm{theo}}$	No. of tracks
3	0.0155	0.0156	20.2×10^{-4}	19.4×10^{-4}	163
4	0.0231	0.0234	25.2×10^{-4}	25.4×10^{-4}	107
5	0.0311	0.0288	30.5×10^{-4}	32.4×10^{-4}	44

[7] B. Rossi and K. Greisen, Rev. Mod. Phys. **13**, 268 (1941).

table as an indication of the consistency of the measurements, since if the distribution of S is gaussian this quantity should be equal to $\langle S\rangle_{Av}$.

Because of the fact that we know only an approximate value for W, i.e., 2 Mev, and that there is certainly some range of energies represented by the measured tracks, exact agreement with the theory cannot be expected. For instance, if W is taken to be 3 Mev, the theoretical results will be lowered by approximately a factor of two.

Figure 2 shows the experimental relationship between $\langle S\rangle_{Av}$ and $t^{\frac{3}{2}}$. Since this plot is a straight line we conclude that all of the measured deviations from linearity are due to multiple scattering and that any turbulence of the gas in the cloud chamber is negligible under these conditions. This is in agreement with the fact that no turbulence is observed visually in the cloud chamber.

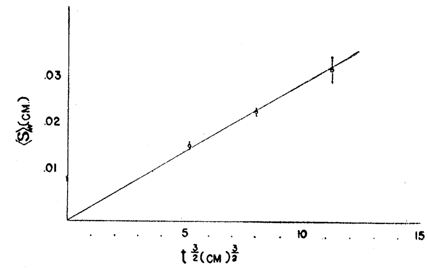

FIG. 2. Experimental relation between $\langle S\rangle_{Av}$ and $t^{\frac{3}{2}}$.

3. CONCLUSIONS

The distortion of straight electron tracks in a Wilson cloud chamber has been measured and found to be due to multiple scattering, within experimental error, the effect of turbulent motion of the gas not being observed. The magnitude of the multiple scattering is in agreement with the theory insofar as the energy of the electron is known.

It is obvious that the above method may be modified by injecting electrons of a known energy into a cloud chamber, e.g., from a Van de Graaff generator. This modification could give a more valuable and exact check on the theory of multiple scattering which at present has its only experimental confirmation in the scattering of electrons by thin foils. When a foil is used as the scattering substances certain rather arbitrary criteria[8] must be applied to insure that no large angle scattering masks the multiple scattering. Contributions due to large angle scattering can be completely avoided if the path of the electron can be observed over the whole region in which the scattering is measured.

[8] G. Wentzel, Ann. d. Physik **69**, 333 (1922).