Study of the Multiple Scattering of Fast Charged Particles in a Gas. II. (Negative and Positive Beta-Particles)*

GERHART GROETZINGER,† WATTS HUMPHREY, JR.,‡ AND FRED L. RIBE§
Institute for Nuclear Studies, University of Chicago, Chicago, Illinois
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The experimental study of the multiple scattering of electrons in a gas has been extended to include electrons of momenta up to 10,200 gauss-cm. The results of these measurements are compared with predictions of various theories of multiple scattering. Furthermore, a parallel investigation of the multiple scattering of positrons has been carried out over the momentum range between 2000 and 9000 gauss-cm. The rms angle of multiple scattering for the positrons is found to be approximately ten percent less than for electrons of the same momentum.

IN a previous publication[1] (to be referred to as I) we described a method for determining the momentum and the multiple scattering of charged particles from their tracks in a "magnetic cloud chamber." Using electrons of momenta $H\rho$ between 2000 and 7000 gauss-cm, originating from a P^{32} source, an experimental scattering law was obtained for their passage through argon of one atmosphere and was compared with the results of various theories of multiple scattering.[2–6] The obtained experimental root-mean-square angle of scattering is represented as a function of $H\rho$ by the upper solid curve in Fig. 1 of the present communication.

The purpose of this investigation is to extend the experimental multiple scattering law to (decay) electrons of higher energies and to determine a similar law for positive beta-particles.

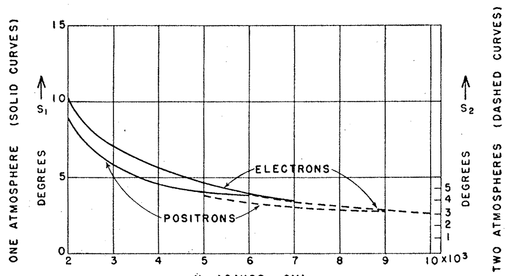

FIG. 1. Root mean angle of multiple scattering for electrons and positrons as a function of $H\rho$. The solid curves, in connection with scales s_1, refer to electrons and positrons in one atmosphere of argon, and the dashed curves in connection with scale s_2, refer to electrons and positrons in two atmospheres of argon. The scales are matched on the basis of the theoretical pressure dependence of multiple scattering.

A comparison of the multiple scattering of electrons and positrons is of interest in view of a recent investigation in which Seliger[7] observed that the ratio of the backscattering coefficients β^- and β^+ for electrons and positrons resulting from beta-decay with a maximum energy of about 0.5 Mev is approximately 1.3 in several media of atomic number between 4 and 82. It follows from theoretical considerations that large angle single scattering for relativistic particles is more pronounced for electrons than for positrons.[8] One might expect that this effect would account for the observed difference in the backscattering but will hardly affect the multiple scattering since tracks displaying large angle deflections are eliminated from considerations. However, Miller[9] remarks that backscattering also results mainly from the "cumulative effects of small angle single scatterings" but obtains nevertheless a theoretical ratio β^- to β^+ of 1.16. Consequently it is possible that a similar difference might occur also for the case of multiple scattering.

The cloud chamber used in this investigation and the method of taking pictures and analyzing the tracks were the same as in I. The determination of the error variance s_E^2 was repeated but, contrary to the procedure employed in the previous investigation, the variances s^2 were corrected individually before they were fitted to a second-order polynomial in $(1/H\rho)^2$. Positrons of momenta between 2000 and 6000 gauss-cm were investigated in one atmosphere of argon with an applied magnetic field of approximately 340 gauss, varying somewhat from exposure to exposure, conditions being similar to the ones in I. For the investigation of the scattering of electrons of momenta between 6000 and 10,200 gauss-cm, and of positrons of momenta between 5000 and 9000 gauss-cm, a magnetic field of approximately 680 gauss, varying somewhat for different exposures, and a pressure of two atmospheres were used. Use of this pressure guaranteed that for the section length of two centimeters in argon used here, the

* Assisted by the joint program of the ONR and AEC.
† Now at the Lewis Laboratory of the NACA, Cleveland, Ohio.
‡ Now at the Chicago Midway Laboratories, Chicago, Illinois.
§ Now at the Los Alamos Scientific Laboratory, Los Alamos, New Mexico.
1 Groetzinger, Berger, and Ribe, Phys. Rev. **77**, 584 (1950).
2 W. Bothe, *Handbuch der Physik* (Verlag. Julius Springer, Berlin, 1933), Vol. 22, II, p. 1.
3 E. J. Williams, Proc. Roy. Soc. (London) **169**, 531 (1939); Phys. Rev. **58**, 292 (1940).
4 S. Goudsmit and J. L. Saunderson, Phys. Rev. **57**, 24 (1940); Phys. Rev. **58**, 36 (1940).
5 G. Molière, Z. Naturforsch. **3a**, 78 (1948).
6 H. S. Snyder and W. T. Scott, Phys. Rev. **76**, 220 (1949).
7 H. H. Seliger, Phys. Rev. **78**, 491 (1950).
8 See e.g., N. F. Mott and H. S. W. Massey, *The Theory of Atomic Collisions* (Oxford University Press, New York, 1945), p. 81 ff.
9 W. Miller, Phys. Rev. **82**, 452 (1951).

condition of multiple scattering was fulfilled even for electrons (or positrons) of the highest energies.

The electrons whose scattering was investigated resulted from the decay of 30-sec Rh^{106} (maximum beta-ray energy = 3.55 Mev[11]) which in turn is a decay product of 1.0-year Ru^{106}.[10]

For the investigation of the scattering of the positrons a source was prepared by bombarding iron with deuterons in the University of Chicago 33-in. cyclotron. The main positron emitter obtained in this way is the 21-minute isomer of Mn^{52} with a maximum energy of 2.66 Mev.[11] The bombarded piece of iron was put into a cylindrical tube extending four centimeters into the chamber and closed inside the chamber by a thin aluminum foil. The source was then used for one to two hours after a bombardment.

The upper dashed curve in Fig. 1 represents in connection with scale s_2 the experimental mean square angle of scattering for electrons of momenta between 6000 and 10,200 gauss-cm in two atmospheres of argon. This curve is based on 54 electrons with momenta fairly evenly distributed over this momentum range. In connection with scale s_1 it represents the root-mean-square angle of scattering in one atmosphere of argon to be expected on the basis of theoretical considerations. Strictly speaking, the two scales s_1 and s_2 should be matched by taking into account the pressure dependence of both factors Q [Eq. (2) of I] and G [Eqs. (3a) to (3c) of I], whose product is equal to the mean-square-scattering angle. However, since the pressure dependence of Q varies from theory to theory and is at most slight, the matching was done by taking into account only the pressure dependence of G, which is the same for all theories. The two lower curves represent the results obtained from an analysis of tracks of 115 positrons with momenta between 2000 and 6000 gauss-cm obtained in one atmosphere of argon and 52 tracks of positrons of momenta between 5000 and 9000 gauss-cm obtained in two atmospheres of argon. In I we claimed an accuracy of 10 percent for our method of obtaining the root-mean-square angle of multiple scattering. It may be noted that the matching of the two pairs of curves (electrons and positrons) in the overlapping momentum range is in agreement with this claim. Arguments based on the matching of these curves necessarily neglect possible systematic errors. Such errors are, however, of little importance in the comparison of electron and positron scattering and the curves obtained for these two cases are sufficiently different from each other to indicate that the rms angle of multiple scattering of electrons is greater by an amount of the order of 10 percent than that of positrons of the same momentum.

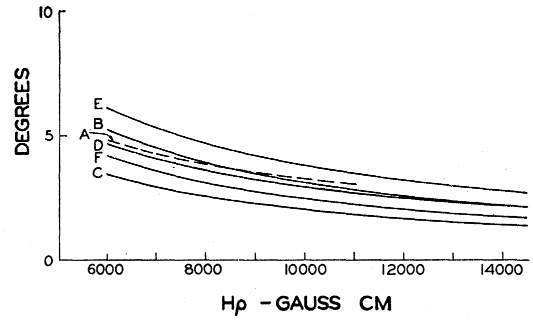

FIG. 2. Comparison of experimental root-mean-square angle with that following from theories of multiple scattering. Curve A: Experimental; curve B: Bothe; curve C: Williams ($\varphi_{max}=(\frac{1}{2}Q)^{\frac{1}{2}}$, $\varphi_{min}=(mc/p)\cdot(Z^{\frac{1}{3}}/137)$); curve D: Williams-Bethe ($\theta_{max}=0.1$ radian, $\theta_{min}=(mc/p)\cdot(Z^{\frac{1}{3}}/181)$; curve E: Goudsmit and Saunderson (Thomas-Fermi potential); curve F: Molière.

The nature of backscattering is sufficiently different from multiple scattering so that it is difficult to make a quantitative comparison of the present results with those of Seliger. It should be noted, however, that the effect is in the same direction and of the same order of magnitude.

In Fig. 2 our experimental results concerning electrons in the range of larger momenta are compared with the results of several theories of multiple scattering. The curves corresponding to the various theories are marked by the same letters as in I. The tendency of the theories to predict a somewhat greater dependence on $H\rho$ than is found experimentally prevails also at these higher momenta.

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Note added in proof.—A recent revision of Bothe's theory, in which the factor G has been reduced from 4.125 to 2.74 would move curve b in Fig. 6 of I and Fig. 2 of this communication down somewhat. (Private communication from W. Bothe.)

[10] The source was obtained from the Isotope Division of the AEC in Oak Ridge, Tennessee.

[11] Way, Fano, Scott, and Thew, *Nuclear Data* (National Bureau of Standards, Washington, D. C., 1950).