Experimental study of multiple scattering of 50-MeV electrons

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Angular distributions have been measured for electrons scattered in thin foils of Be, Nb, and Ta. The experimental results are well described by a Gaussian function $\exp(-\theta^2/\theta_W^2)$. The values obtained for the parameters θ_W are compared with the predictions of Moliere's theory[4] in the form $\theta_W = \theta_1(B-X)^{1/2}$ recommended by Hanson et al.,[2] who used $X = 1.2$. The value of X found in the present work is 0.82 ± 0.19.

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INTRODUCTION

The quantitative verification of the theory of multiple scattering of relativistic charged particles has up to the present time essentially been exhausted by three experimental studies carried out in electron beams with energies of 2.25 MeV,[1] 15.7 MeV,[2] and 600 MeV.[3] In these studies the angular distributions of electrons scattered by foils of various elements from beryllium to gold were measured. The experimental results of Hanson et al.[2] were compared with the multiple-scattering theory of Moliere[4], which is apparently at the present time the most satisfactory theory (see for example ref. 5).

According to this theory the distribution of the electrons in the total scattering angle θ can be represented with a high degree of accuracy[5] by the sum of two functions $f^{(0)}(\theta) + B^{-1}f^{(1)}(\theta)$, the first of which is the Gaussian function

$$f^{(0)}(\theta) \sim \exp(-\theta^2/\theta_W^2) \tag{1}$$

with a parameter

$$\theta_W = \theta_1 B^{1/2}, \tag{2}$$

in which $\theta_1 = 0.157Z(Z+1)tA^{-1}E_0^{-2}$, where Z and A are the atomic number and mass number of the scattering atom, t is the scatterer thickness in g/cm^2, and E_0 is the incident-electron energy in MeV. The value of B is determined from the transcendental equation

$$B - \ln B = \ln(\theta_1^2/\theta_a^2) - 0.154 \tag{3}$$

for $\theta_1^2/\theta_a^2 = 7800(Z+1)Z^{1/3}tA^{-1}(1 + 1.78 \times 10^{-4}Z^{-2})^{-1}$. The function $B^{-1}f^{(1)}(\theta)$ corresponds in the limit of large θ to the contribution of single scattering, and in the region $\theta < 2\theta_W$ amounts to about 10% (for $B \approx 10$) relative to $f^{(0)}(\theta)$.

Hanson et al.[2] showed that the experimental distributions obtained by them and also those of Mozley et al.[3] are well approximated by Gaussian functions with parameters

$$\theta_W = \theta_1(B-1.2)^{1/2} \tag{4}$$

for all foils in the thickness range 10^{-3}–10^{-2} radiation length, with a small (≈5%) deviation for Be. In the later work of Mozley et al.[3], which was carried out at a substantially higher electron energy and with an order of magnitude smaller foil thicknesses, the possibility of describing the experimental data in the convenient Gaussian form (4) was confirmed, even for Be.

The present work is an additional check of multiple-scattering theory in the intermediate electron-energy region, and also an attempt to evaluate experimentally the numerical value of the correction to B in Eq. (4).

EXPERIMENT

The experiment was carried out in the LU-50 electron linear accelerator at the Nuclear Research Institute, USSR Academy of Sciences. The experimental arrangement is shown in Fig. 1. The apparatus consisted of a tube of diameter 120 mm at the output of the accelerator beam pipe and connected with it to the common vacuum system. Inside the pipe were placed a collimator (Pb-Bi alloy) with an opening 2 mm in diameter and an eight-faced drum, three faces of which were covered with scattering foils. A vacuum seal on the drum axis permitted a face with an appropriate foil or an opening without a foil to be placed in the path of the collimated beam without destroying the vacuum. At a distance of 116.5 cm from the scatterer, and almost touching the foil on the end flange of the tube, was placed a glass plate (50 × 50 × 2 mm) which served as an electron detector. The scattering in the last foil (80 μ stainless steel) had practically no effect on the result, as a result of the small distance between it and the plate (less than 0.5 mm).

Before the experiment was started, the collimator was adjusted to be on the axis corresponding to the electron-beam direction. This was done by means of a gas-laser beam which permitted the axes of the collimator opening and the diaphragm at the accelerator output to be superposed by shifting the bellows in the tube containing the collimator. During the experiment the necessary shaping of the initial electron beam was carried out. By means of focusing and correcting magnetic lenses placed at various points of the beam pipe, a collimated beam with a divergence of 5×10^{-4} was obtained with a current in the Faraday cup up to 0.3 μA.

The electron energy was measured with a magnetic spectrometer (before the collimator) and was monitored

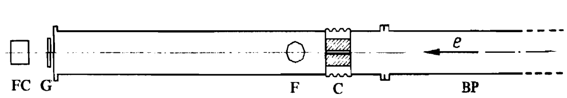

FIG. 1. Diagram of experimental apparatus: BP—beam pipe, C—collimator, F—scattering foils, G—glass plate, FC—Faraday cup. The arrow shows the direction of the electron beam.

during the entire experiment. The degree of monochromaticity of the electron beam was ±1.5%.

Electrons scattered in the foil produced in the glass plate a stable dark spot which was then photometered in an MF-4 microphotometer. In order to exclude saturation and nonlinearity effects in the darkening in the glass, for each foil we selected the average current and exposure time. With decreasing exposure a constant dispersion of the measured distributions was gradually achieved. The photometry was carried out with a photometer measuring-slit width from 0.1 to 0.5 mm, depending on the size of the darkened spot. The accuracy of reading the scale of the instrument was ± 1%.

The thickness of each scatterer in g/cm^2 was determined by weighing and contained an error from ± 0.5 to ± 2% for the various foils. Scattering foils of three elements were used: Be(Z = 4), Nb(Z = 41), and Ta(Z = 73) in the thickness range 3×10^{-4}—2×10^{-3} radiation length.

The measurements were carried out for a mean electron energy 50.1 MeV.

RESULTS

The measured angular distributions are shown in Fig. 2. They were fitted with Gaussian functions $\exp(-\theta^2/\theta_W^2)$; here the values of θ did not exceed $1.7\theta_W$. In the case of Be it turned out to be necessary to take into account the size of the collimated beam.

The values found for the parameters θ_W are given in the table. The errors in these values were calculated with inclusion of the errors in the values of t and E_0 and the accuracy in the photometry measurements. The table also gives values of θ_W calculated from Eqs. (2) and (4). The experimental values of θ_W were represented in the form $\theta_W = \theta_1(B - X)^{1/2}$ to obtain quantitative estimates of the value of X. For the foils used, these values turned out to be as follows:

$$X_{Be}=0.64\pm0.30, \quad X_{Nb}=0.97\pm0.35, \quad X_{Ta}=0.86\pm0.30.$$

The errors shown did not permit a noticeable dependence of X on t or Z to be observed. We therefore averaged the values obtained, which gave a value

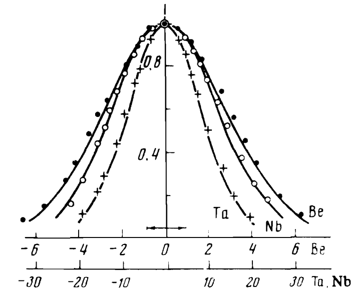

FIG. 2. Experimental distributions of scattered electrons. The abscissa shows the coordinate on the plate relative to the primary beam axis, and the ordinate shows the relative blackening. The curves were calculated with the parameters $\theta_W = \theta_1(B - 1.2)^{1/2}$. In the case of Be the size of the collimated beam is indicated.

Type of foil and thickness	Values* of θ_W		
	Calculation by Eq. (2)	Calculation by Eq. (4)	Experiment
Be, 0.015 g/cm²	0.360	0.322	0.343±0.009
Nb, 0.035 g/cm²	1.58	1.43	1.47±0.04
Ta, 0.012 g/cm²	1.15	1.03	1.06±0.03

*The angles θ are given in units of mc^2/E_0.

$\overline{X} = 0.82 \pm 0.19$, which at the 5% confidence level is consistent with the estimate of Hanson et al. as given in Eq. (4).

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[1] L. A. Kulchitsky and G. D. Latyshev, Phys. Rev. 61, 254 (1942).
[2] A. O. Hanson, L. H. Lanzl, E. M. Lyman, and M. B. Scott, Phys. Rev. 84, 634 (1951).
[3] R. F. Mozley, R. C. Smith, and R. E. Taylor, Phys. Rev. 111, 647 (1958).
[4] G. Moliere, Z. Naturforsch 2a, 133 (1947); 3a, 78 (1948).
[5] H. A. Bethe, Phys. Rev. 89, 1256 (1953).

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