ANGULAR DISTRIBUTIONS OF ELECTRONS REFLECTED FROM A METAL SURFACE FOR OBLIQUE INCIDENCE

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A number of practical problems of radiation technology related to shielding, the shaping of electron distributions, etc. require the reflection coefficients and the spectral and angular distributions of electrons reflected from various metal targets. A theoretical description of the differential characteristics of reflected electrons runs into substantial difficulties. Satisfactory results are obtained only under a number of restrictions [1-3].

We have measured the angular distributions of 15-25 MeV electrons reflected from metal targets of various thicknesses for oblique incidence of the primary beam.

The measurements were performed at the LUE-25 linear accelerator [4] (Fig. 1). The distance from the exit window to the target is 15 cm. Metal targets 100 mm in diameter of various thicknesses were made of aluminum, copper, cadmium, and lead. The thicknesses varied from 0.46 to 13.6 g/cm², and the angle of incidence from 30 to 70°. To prevent the detector from seeing the electrons emerging from the lateral surface, a 12-mm-thick and 200-mm outside diameter lead shielding ring was placed around the target.

The detector was a 0.25-cm³ thimble chamber having aluminum walls 0.5 mm thick and was placed 15 cm from the target. The chamber and target were rotated by remote control. The sensitivity was determined by measuring the dependence of the chamber reading on the electron energy for a given incident flux. At energies of 10-25 MeV a thin 0.08-mm-thick tungsten target was placed along the path of the electron beam and the number of electrons incident on the chamber was calculated from the Molière distribution. In order to go over to the region of lower energies a thick tungsten target in which the average energy of the transmitted electrons was determined from the expression $E_{av} = E_0(1 - R/R_e)$ was placed along the path of the beam and the number of electrons incident on the chamber was determined from the diffusion, proportional to $\cos^2 \theta$. Here $R_e$ is the extrapolated range of electrons in tungsten, and $R$ is the target thickness in units of $R_e$.

Studies showed that the sensitivity of the chamber in the energy range from 1 to 25 MeV does not vary by more than 12%. The error in measuring the current is no more than 5%. All the measurements were performed in air in the plane of incidence. The diameter of the electron beam at exit from the accelerator did not exceed 10 mm. The background angular distribution of electrons was measured without the target and then with the target. The background varied from 2% for large values of $\theta$ to 50% for small values of $\theta$.

Figure 2 shows the dependence of the angular distributions of reflected electrons for $E = 25$ MeV on the thickness of lead and copper targets for an angle of incidence $\theta_0 = 50°$. For thick targets the position of the maximum in the angular distribution corresponds approximately to an angle of reflection equal to the angle of incidence. As the target thickness is decreased the maximum is displaced toward larger angles. Saturation begins when the thickness is approximately $R_e/2$ and the angular distribution of reflected electrons remains constant. Similar results are obtained for other angles of incidence.

Fig. 2. Angular distributions of reflected electrons $q$ as a function of target thickness in g/cm$^2$: a) lead $\bullet$ 0.57, $\times$ 1.13, $\circ$ 3.14, $\triangle$ 13.6; b) copper $\bullet$ 0.53, $\times$ 2.14, $\circ$ 4.45, $\triangle$ 13.35.

Fig. 3. Angular distributions of reflected electrons as a function of the angle of incidence for semiinfinite targets of a) lead and b) copper. For lead $t=13.6$ and for copper 10.57 g/cm$^2$: $\bullet$, $\times$, $\circ$ $\theta_0=30, 50, 70^\circ$, $\triangle$ calculated.

Figure 3 shows the dependence of the angular distributions of reflected electrons on the angle of incidence for semiinfinite copper and lead targets at $E=25$ MeV. The angular distributions of electrons reflected from copper and lead were measured at 15 and 20 MeV also, and for aluminum and cadmium at 15, 20, and 25 MeV. The curves obtained are similar to those shown in Figs. 2 and 3. As the angle of incidence is increased the angular distribution of reflected electrons becomes narrower for all elements over the whole energy range. Similar results were obtained for other thicknesses. The curves of Figs. 2 and 3 are plotted in relative units and are not normalized with respect to one another.

To investigate the possibility of a theoretical description of the results obtained the angular distributions of reflected electrons were calculated as in [3] by the equation

$$ W(\theta_f, \theta_0, \bar{E}_0, E_0) = \int_{0}^{E_0} R^\infty_\theta (f, E_f, E_0, E_0) \frac{\cos \theta_f}{\cos \theta_0} dE_f, $$

where

$$ R^\infty_\theta (f, E_f, E_0, E_0) = \frac{Z}{16\pi \ln \frac{2E_0}{E_f}} \frac{m}{E^3_f} \frac{\cos \theta_0 \cos \theta_f}{\cos \theta_0 + \cos \theta_f} \left[ 1 - \cos \Phi + \frac{Z \ln (18Z^{-1/2})}{4\pi \ln \frac{2E_0}{E_f}} \right], $$

$$ \times \frac{m}{E_0} \ln \frac{E_0}{E_f} \left[ \left( \frac{\cos \theta_0 + \cos \theta_f + (E_0 - E_f)}{E_f} \right) \ln \frac{2E_f}{E_0} - \frac{1}{E_f} \ln \frac{2E_f}{E_0} \right] \cos \theta_0 \cos \theta_f \left( \cos \theta_0 + \cos \theta_f \right) \left( \cos \theta_0 - \cos \theta_f \right) \frac{1}{E_0} \ln \frac{2E_f}{E_0} \frac{2E_f}{I_2} \cos \theta_0 \ln \frac{2E_f}{I_2} + \cos \theta_f \ln \frac{2E_f}{I_2} \right]^{-2} $$

is the differential coefficient for the backscattering of relativistic electrons from a semiinfinite target, $E_0P_0$ and $E_fP_f$ are the energies and moments of the initial and final states respectively, $\theta_0$ and $\theta_f$ are respectively the angles between the normal to the target and the directions of the incident and reflected electrons, $Z$ is the atomic number of the target nucleus, $I_2$ is the ionization potential of the target atoms, $m=0.511$ MeV is the electron mass, and $\cos \Phi = \frac{P_0 \cdot P_f}{P_0 \cdot P_f}$.