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ASYMMETRY OF DOUBLE MOTT SCATTERING OF 45–245 kev ELECTRONS

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By using double Mott scattering from gold, we have measured the asymmetry in the scattering of electrons, for energies 45 — 245 kev, using angles $\theta_1 = \theta_2 = 120°$.

1. INTRODUCTION

MOTT scattering of electrons is the most sensitive method for measuring their polarization, and has attracted the attention of experimenters in connection with nonconservation of parity in β decay. The sensitivity of the method is characterized by the quantity S which determines the azimuthal asymmetry of the scattering: $I \sim 1 + PS \cos \varphi$ where I is the intensity of the scattered electrons, P their degree of polarization, and φ the azimuthal angle. The quantity S depends on the polar angle, the electron energy and the atomic number of the scatterer. Since the asymmetry is expressed in terms of the product PS, to determine the polarization one must have reliable data concerning the value of S.

The function S was first calculated theoretically by Mott.[1,2] The most precise values for the case of scattering by mercury[3] and gold[4] were computed by Sherman and Nelson, neglecting the screening by the atomic electrons. The screening was included in the work of Mohr and Tassie,[5] Bartlett and Welton,[6] which showed that for electron energies around 120 kev the effect of screening is still very noticeable and that its effect on the value of S can amount to 10 — 15%. However, it is now not clear just how reliable these estimates are.

The quantity S can be found from an experiment on double Mott scattering of unpolarized electrons,[1] since in this case the asymmetry is equal to the product $S(\theta_1)\, S(\theta_2)$, where θ_1 and θ_2 are the angles for the first and second scatterings. The authors of [7] were the first to succeed in observing the asymmetry in double scattering. Later there was a whole series of experiments for the purpose of obtaining a quantitative measure of the effect. A Japanese group[8] obtained values for S in the energy range 60 — 120 kev. The data were almost half the theoretical values. These authors did not include the depolarizing effect of multiple scattering, which is probably the main reason for the large discrepancy.

The angular dependence of S was studied in papers by Pettus[9] and Nelson and Pidd.[10] The results quantitatively confirm the predictions of the theory. But the precision of these measurements is left in doubt, since the authors did not take into account multiple scattering in the scatterers and also apparently did not succeed in eliminating the effect of electrons scattered from the walls of the apparatus. In the present work, we have set ourselves the task of obtaining much more precise values of the function S for the energy range 45 — 245 kev, for an angle $\theta = 120°$. From the point of view of measurements of the degree of polarization, the value of S in the region of 120° is of most interest, since it reaches a maximum there.

2. MAIN FEATURES OF THE EQUIPMENT AND CONTROL EXPERIMENTS

Description of the arrangement. We used a rectifier which supplied voltages up to 300 kev, with a value known to ± 2%. After a preliminary magnetic analysis, the well-collimated beam of electrons 1 (cf. Fig. 1) 12 mm in diameter entered a chamber containing the first scatterer 2. Electrons scattered through an angle of 120° passed into another chamber containing the second scatterer 3, and after a second scattering at an angle of 120° ± 3° were recorded by a pair of Geiger ring counters 4 and 5, placed at a distance of about 20 cm from the second scatterer.

Scattering from the walls of the apparatus. Electron spectra. The main difficulties which must be overcome in an experiment on double scattering are due to unwanted scattering of the electrons from the walls of the apparatus. To reduce this effect, we provided "traps" at the points of maxi-

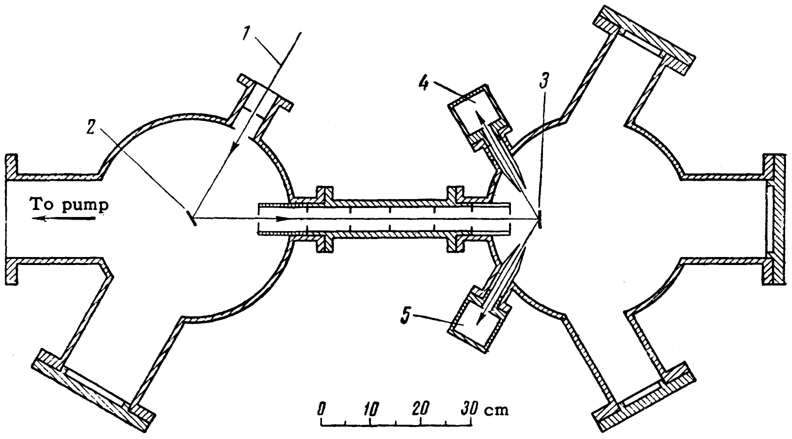

FIG. 1. Experimental arrangement: 1 – beam of accelerated electrons, 2 –first scatterer, 3 – second scatterer, 4, 5 – Geiger counters.

mum irradiation of the walls, the linear dimensions of the chambers were made relatively large (40 cm) and their internal surfaces were covered with Plexiglas. The separation of the first and second scatterers was chosen equal to ~ 75 cm, which enabled us to eliminate the direct bombardment of the second scatterer by electrons scattered from the walls of the first chamber and from the holder of the first scatterer.

Nevertheless this does not completely eliminate the background of scattered electrons. Electrons scattered from the walls of the first chamber can always strike the first scatterer, be scattered from it and enter the beam going toward the second scatterer. Similarly, electrons scattered from the walls of the second chamber can enter the counters. The second chamber had been used previously in an experiment for measuring the longitudinal polarization of β electrons.[11] Detailed studies made earlier and repeated for various electron energies in the present work showed that the effect of scattering from the walls is negligibly small.

To study the number of extraneous electrons which can reach the second scatterer from the first chamber, a series of control experiments was made. At the position of the second scatterer we placed a Geiger ring counter with a window which passed electrons with energy above 15 kev. Then the first scatterer was removed, and instead a thin foil was placed somewhat further from the center of the chamber along the axis of the primary beam, arranged so that electrons scattered from it could not enter directly into the second chamber, but gave a strong "illumination" of the walls of the first chamber. As was to be expected, no increase in counting rate was observed. Then another scatterer was placed at the entrance of the collimator leading to the second chamber. This scatterer was shielded from electrons directly scattered from the foil, but could be struck by electrons scattered from the walls. We thus succeeded in imitating the actual conditions of arrival of extraneous electrons at the second scatterer.

These experiments showed that there are extraneous electrons arriving at the second scatterer. There were very few at low energies, but their number increased markedly with increasing energy, and in the range 150 — 200 kev the fraction of such electrons reached 1.5 — 2%. Further study showed that these electrons have an energy which is several times smaller than that of the main group. Therefore their relative intensity is strongly increased at the second scattering, which can lead to considerable errors.

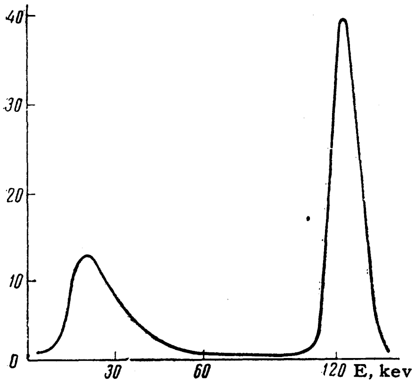

FIG. 2. Spectrum of doubly scattered electrons.

As an example we show in Fig. 2 the spectrum of the doubly scattered electrons, obtained under operating conditions using a spectrometer placed at the location of one of the counters. To get a sizeable counting rate, the resolving power was set equal to 10%, which explaines the rather large width of the main peak. Its true halfwidth did not exceed 2%. Similar spectra were measured over the whole energy range from 45 to 250 kev.

E, kev	S_{theor}(120°)	S_{exp}(120°)	$\Delta S/S_{exp}$, %	S_{exp}/S_{theor}
45	0,364	0,286	4	0.79
63	0.382	0.337	4	0.88
83	0.397	0.365	2.5	0.92
133	0,418	0.385	2,5	0.92
170	0,424	0.390	2.5	0.92
204	0,427	0,413	2	0,97
245	0,426	0,411	2	0,96

These measurements disclosed the following picture. The "soft" electrons begin to appear for accelerating voltages around 60 kv, their relative intensity increases rapidly with increasing accelerating voltage, and at 250 kv already exceeds somewhat the intensity of the main group. In addition, the "soft" electrons have an energy which is 4 — 6 times smaller than that of the main group, and between these groups there is a large energy interval from which electrons are practically absent. This made it possible to get rid of the extraneous electrons by using aluminum filters. The filter thicknesses were chosen by using the spectrometer. They increased with increasing primary energy, going from 0.3 mg/cm^2 at 45 kev to 12 mg/cm^2 for 245 kev. Later on, under operating conditions at several energies it was shown that a reduction of the filter thickness by $1\frac{1}{2}$ — 2 times did not change the measured value of S by more than 2%.

Scatterers. We used gold scatterers with thicknesses ranging from 16 to 200 μg/cm^2. The second scatterers were obtained by evaporating gold onto a film of collodion, whose thickness was 20 μg/cm^2 for the thinnest scatterers. The fraction of electrons scattered from the film was found experimentally by "difference" irradiation in the electron beam before and after depositing the gold. For the thinnest scatterers this fraction amounted to 6%. An aluminum sheet 0.1 μ thick was used as the backing for the first scatterers. The fraction of electrons scattered from the aluminum was 1 — 12%.

3. MEASUREMENTS AND RESULTS

Treatment of multiple scattering. As the measurements of the value of S^2 for different scatterer thicknesses showed, the depolarizing effect of multiple scattering is very large even for relatively thin layers. For example, the thickness of second scatterer, for which the value of S^2_{exp} is reduced by a factor of 1.3 relative to the value for zero thickness, is 350 μg/cm^2 for 245 kev, and 140 and 50 μg/cm^2 for energies of 133 and 60 kev. Because of this, at each energy we made measurements for several (usually six or seven) scatterers and extrapolated the results to zero thickness. For a correct extrapolation it is necessary to know precisely only the relative thicknesses of the layers. These were found to ~ 1% by comparing the intensities of electrons scattered from the various foils. To reduce the errors from the extrapolation, we used very thin scatterers; the extrapolated value of the asymmetry differed from the value obtained with the thinnest scatterer by no more than 5 — 8%. The only exceptions were the scatterers used for the measurements at 45 kev, for which this difference reached 15%. Here it was unreasonable to use thinner scatterers, because of the large increase in the corrections for scattering of electrons from the backing.

Elimination of apparatus asymmetry. To eliminate apparatus asymmetries, the measurements with the gold scatterer were followed by measurements in which the first scatterer was replaced by a foil of aluminum. One must be very careful in such measurements. When one uses thick layers of aluminum, there is a noticeable "softening" of the electrons. For example, as was shown by the measurements with scatterer thickness 5 μ and accelerating voltage 45 kv, the energy spread of the scattered electrons is 30 — 40%. This can lead to errors, since it is very difficult to achieve the condition where the relative efficiency of the counters shielded by filters is energy independent to a high degree. In this connection we recall that an error of 1% in determining the apparatus asymmetry coefficient leads to an error of 5 — 10% in the value of S^2. For this reason we used quite thin layers of aluminum in the measurements: 1 μ for the lowest energies, 2 μ for energies 80 and 133 kev, and chose a foil thickness of 5 μ starting from an energy of 170 kev.

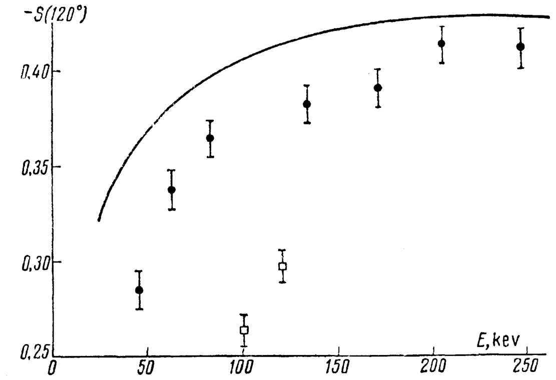

FIG. 3. Experimental results: ● — this paper; □ — data of[8]. The solid curve is the computation of[3,4], which does not include screening.

Corrections. The following corrections were made to the measurements of S. Corrections for:

1. Scattering of electrons from the backing of the gold layers, amounting to a total of 1 — 10% for both scatterers.
2. Polarization of electrons scattered by the aluminum in the measurements of apparatus asymmetry, 3 — 4%.
3. Finite angular spread, 0.5%.

The results of the measurements are given in the table. The last column gives the ratio of the experimental value of S to the value obtained from the computations.[3,4] The errors arising in the interpolation of the data of [3,4] do not spoil the precision of the computations, which are estimated by the author to be 1%. As we see from the table, the discrepancy between the theoretical values, which were obtained omitting screening, and the experimental values decreases with increasing energy. But even at energies of 200 — 250 kev, there remain small deviations amounting to 3 — 4% ± 2%.

Figure 3 shows the data of the present work, the results of Sherman's calculations,[3,4] and the data of Ryu[8] for energies of 100 and 120 kev. We are not aware of any other measurements of the value of S (120°) by experiments on double scattering.

In conclusion, we mention the work of Bienlein et al[12] who studied the asymmetry of Mott scattering, using the polarized electrons from Co^{60} as a source. They studied the angular dependence of S and its dependence on the atomic number of the scatterer. In their work the absolute values of S (120°) for energies of 120, 155 and 209 kev were obtained under the assumption that the polarization of the β electrons is exactly equal to the ratio of the velocity of the electron to the velocity of light. Such a determination of S is not an internally complete experiment, and the result may turn out to be wrong, since even in the case of allowed transitions one observes considerable differences in the polarization of the electrons emitted from different nuclei.[11]

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[1] N. F. Mott, Proc. Roy. Soc. (London) **A124**, 425 (1929).

[2] N. F. Mott, Proc. Roy. Soc. (London) **A135**, 429 (1932).

[3] N. Sherman, Phys. Rev. **103**, 1601 (1956).

[4] N. Sherman and D. Nelson, Phys. Rev. **114**, 1541 (1959).

[5] C. B. O. Mohr and L. J. Tassie, Proc. Phys. Soc. (London) **A67**, 711 (1954).

[6] J. H. Bartlett and T. A. Welton, Phys. Rev. **59**, 281 (1941).

[7] Shull, Chase, and Myers, Phys. Rev. **63**, 29 (1943).

[8] N. Ryu, J. Phys. Soc. Japan **7**, 125, 130 (1952); **8**, 804 (1953).

[9] W. G. Pettus, Phys. Rev. **109**, 1458 (1958).

[10] D. Nelson and R. Pidd, Phys. Rev. **114**, 728 (1959).

[11] L. A. Mikaélyan and P. E. Spivak, JETP **37**, 1168 (1959), Soviet Phys. JETP **10**, 831 (1960); Nuclear Phys. **20**, 475 (1960).

[12] H. Bienlein et al., Z. Physik **154**, 376 (1959); **155**, 101 (1959).

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