Scattering of β Radiation on a Thick Foil: Production of Transverse Polarization

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The $^{90}Sr+^{90}Y$ β rays are scattered by a thick lead foil so that the longitudinal polarization of the electrons is partially converted into a transverse one. This transverse polarization is measured with a Mott polarimeter, as a function of the total scattering angle between 30° and 140° and of the energy of the scattered electrons between 0.25 and 1.46 MeV. In this energy interval, the transverse polarization varies from about 16 to 28% of the longitudinal polarization of the incident beam. These results clarify the interpretation of the large longitudinal depolarizations observed in the backscattering of β rays by lead and reported in a preceding paper; in this connection it is possible to conclude that the disordering of the beam with a shrinkage of the polarization vector is the most important process. In the Appendix, some remarks on the dependence of the transverse polarization production on the scatterer atomic number are given.

1. INTRODUCTION

THE longitudinal depolarization suffered by a longitudinally polarized electron beam in the backscattering process has been investigated[1,2] by measuring the longitudinal polarization of the beam before and after the scattering. Large depolarizations have been observed in the backscattering around 162° of $^{90}Sr+^{90}Y$ β rays by a thick lead foil. In the energy range between 0.55 and 1.2 MeV, an average longitudinal depolarization equal to $(49.7\pm28.4)\%$ has been found. A comprehensive picture of the process that originates such depolarizations cannot be obtained on the basis of longitudinal polarization measurements alone; the observed depolarizations may be due to the cumulative effect of the rotation of the polarization vector of the beam with respect to the momentum (rotation process) and of a disordering of the beam with a shrinkage of the modulus of the polarization vector (disordering process). These two processes are always present in the interaction of a polarized electron beam with matter, as has been pointed out by Iddings *et al.*[3] In order to clarify the relative importance of the two processes, transverse polarization measurements are necessary since the rotation process originates a transverse component of the polarization of the beam after the scattering. In the present paper, an experiment is presented in which the results of such measurements are reported; this allows a discussion of the problem outlined above.

2. APPARATUS AND EXPERIMENTAL PROCEDURE

The longitudinally polarized electron beam is obtained by collimating the β rays emitted by a 100-mCi $^{90}Sr+^{90}Y$ source. The beam is scattered by a lead foil whose thickness is greater than the range of $^{90}Sr+^{90}Y$ β rays; the scattered electrons enter a Mott polarimeter, which is used to measure the transverse polarization. The geometrical arrangement of the source and of the scatterer is sketched in Fig. 1. The source and the scatterer can be rotated independently around an axis perpendicular to the scattering plane, so that the total scattering angle may be changed without modifying the vacuum in the scattering chamber.

In the Mott polarimeter the electrons scattered between 122° and 150° by a gold analyzer foil 3.18 mg/cm² thick are detected by two NE102A plastic scintillators connected through lucite light pipes to two 153AVP phototubes. The electronic equipment and the experimental procedure in asymmetry measurements are the same as in another experiment described in Ref. 4.

The asymmetry has been measured at the following values of the average total scattering angle: 35°, 50°, 65°, 75°, 90°, 105°, 120°, 135°; in each case the electrons scattered in an angular region of amplitude ±5° around these directions are accepted by the polarimeter. The scatterer positions were so adjusted that the incidence and reflection angles should be equal. In order to obtain statistically significant results, the asymmetries have been taken as average values in rather extended energy intervals: 0.25–0.38 MeV, 0.38–0.65 MeV, 0.65–0.92 MeV, 0.92–1.19 MeV, and 1.19–1.46 MeV. The total counting time of the present experiment was about 900 h.

3. RESULTS AND DISCUSSION

The measured asymmetries are collected in Fig. 2, in each energy interval, as a function of the total scattering angle on the lead foil. It appears that the asymmetry reaches the maximum value δ_M at the angle θ_M, while it is zero at $\theta=0°$ and $\theta=180°$ for obvious

[1] L. Braicovich, B. De Michelis, and A. Fasana, Nucl. Phys. **82**, 645 (1966).
[2] L. Braicovich, B. De Michelis, and A. Fasana, Phys. Rev. **145**, 952 (1966).
[3] C. K. Iddings, G. L. Shaw, and Y. S. Tsai, Phys. Rev. **135**, B1388 (1964).
[4] L. Braicovich, B. De Michelis, and A. Fasana, Nuovo Cimento (to be published).

symmetry reasons. The quoted asymmetries have the following meaning:

$$\delta = 100 P_t S r, \qquad (1)$$

where P_t is the transverse component of the polarization (in the plane of the first scattering suffered by the electrons), S is the well-known asymmetry function in single Mott scattering and r is the corrective factor to S, due to the fact that the analyzer foil has a finite thickness. This factor may be calculated on the basis of the theory given by Braicovich *et al.*[5]; the uncertainties in the calculation of this coefficient do not significantly affect the results of the present discussion. In order to obtain the values of the polarization P_t from the measured asymmetries, the values of the coefficient r have been calculated at all energies by means of an IBM 7040 computer; the calculation techniques are the same as those explained in Ref. 5. The ordinates in Fig. 2 are also expressed in polarization units.

The values of P_{tM} corresponding to δ_M are summarized in Fig. 3 as a function of the energy of the electrons scattered by the lead foil; for the sake of comparison, the longitudinal polarization spectrum P_l of the electrons incident on the lead foil is plotted as a function of the energy of the electrons before scattering. Although there is no one-to-one correspondence between the energy before and after the scattering on the lead foil, the comparison between the two lines plotted in in Fig. 3 is meaningful, since the two polarizations do not vary too fast with the energy. The function P_l is

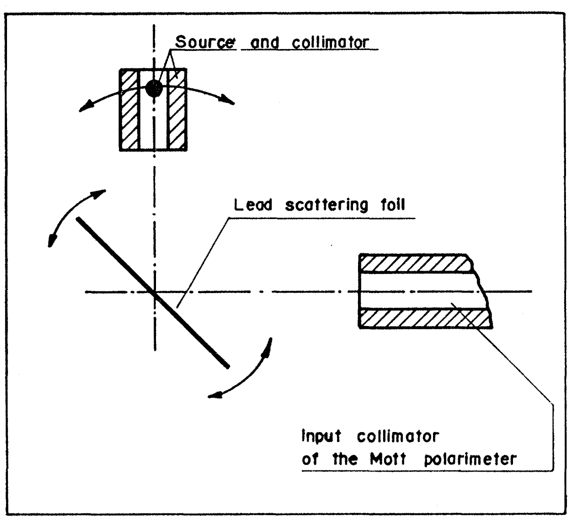

FIG. 1. Sketch of the geometrical arrangement of the source of the lead scattering foil and of the input collimator of the Mott polarimeter. The source and the scattering foil can be rotated around an axis normal to the drawing, as indicated by the arrows.

[5] L. Braicovich and B. De Michelis, Nuovo Cimento (to be published).

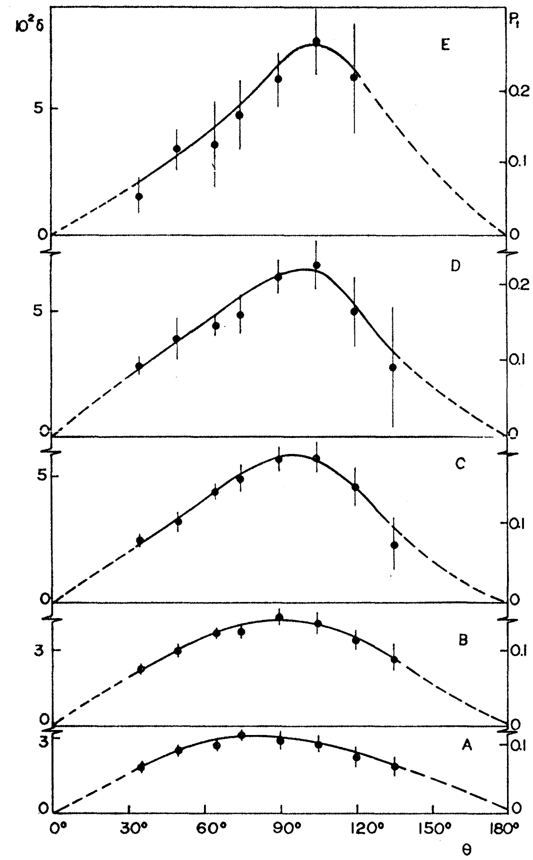

FIG. 2. The measured asymmetry as a function of the total scattering angle and of the energy of the electrons entering the polarimeter. Cases A, B, C, D, E refer to the average energy in the following energy intervals: 0.25–0.38 MeV, 0.38–0.65 MeV, 0.65–0.92 MeV, 0.92–1.19 MeV, 1.19–1.46 MeV. The ordinates are also given in polarization units.

plotted at energies greater than $\langle \bar{E}_1 \rangle + \langle \Delta E \rangle$, where $\langle \bar{E}_1 \rangle$ is the average energy in the first energy interval chosen in the measurements and $\langle \Delta E \rangle$ is the average energy loss suffered by the electrons in the scattering at $\theta_M = 78°$ on a thick lead target with an incidence angle equal to the reflection angle. The value of $\langle \Delta E \rangle$ has been measured in a separate experiment at electron energies equal to 0.45 and 0.60 MeV by means of a magnetic spectrometer and of a semiconductor detector. The longitudinal polarization P_l plotted in Fig. 3 has been obtained by the expression $P_l = (v/c)(1-d)$ where v/c is the helicity of $^{90}Sr + ^{90}Y$ β radiation[6] and d is the longitudinal depolarization in the source.[7] It is clearly seen that the transverse polarization created in the scattering varies from about 16 to 28% of the incident longitudinal polarization; this is an upper limit of the

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[7] L. Braicovich, B. De Michelis, and A. Fasana, Phys. Rev. **164**, 1360 (1967).

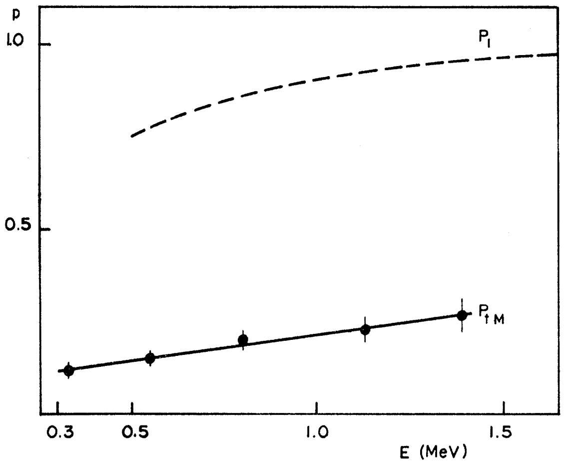

FIG. 3. The maximum value P_{tM} of the transverse polarization obtained in the scattering of $^{90}Sr+^{90}Y$ β rays from a thick lead foil, as explained in the text; these values are given as a function of the energy of the scattered electrons. The dotted line represents the longitudinal polarization of the electrons incident on the scatterer.

transverse polarization since these values refer to the scattering angle θ_M at which the transverse polarization is maximum.

In spite of the large statistical errors in the longitudinal depolarizations quoted in Ref. 2, it is possible to establish that, in backscattering of longitudinally polarized electrons by lead, the main process is the disordering of the beam rather than the rotation of the polarization vector. For instance, in the energy range between 0.55 and 1.2 MeV, the average longitudinal polarization after backscattering at 162° is equal to $(0.503\pm0.284)P_l$; the transverse polarization may be deduced by an analysis of the present measurements and is equal to $(0.06\pm0.01)P_l$.

The experimental results also point out the fact that the scattering process in the lead target is not single; in effect, the transverse polarization that would be obtained in single scattering at θ_M is equal to $0.60P_l$ on the average in the first energy interval (0.25–0.38 MeV) and to $0.45P_l$ in the last energy interval (1.19–1.46 MeV), as can be deduced from the polarization functions given by Motz.[8] These values of the transverse polarization are much greater than the measured ones and this fact indicates clearly that the disordering of the beam is due to multiple scattering.

ACKNOWLEDGMENTS

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[8] J. W. Motz, H. Olsen, and H. W. Koch, Rev. Mod. Phys. **36**, 881 (1964).

APPENDIX

In the preceding sections, the transformation of electron longitudinal polarization into a transverse one has been studied experimentally in the case of a lead scatterer; the knowledge of the dependence of this process on the atomic number of the scatterer is of some importance. In effect, many β-ray polarization measurements are carried out with a double scattering apparatus in which a first thick scatterer is used. In such cases the problem of the choice of the most convenient element for the first scatterer must be solved. From works already published, it is possible to deduce some information about the scattering from thick copper and aluminum foils.

With a double scattering apparatus consisting of a first thick copper scatterer and of a platinum analyzer 4.07 mg/cm^2 thick, Schatz *et al.*[9] measured an asymmetry equal to $(4.075\pm0.065)\%$ at 540 keV with the β rays of ^{32}P, whose polarization is v/c as is well known. By means of the values of the coefficient r defined in Eq. (1) of the present paper and calculated according to Ref. 5, it is possible to establish that the transverse polarization is of the order of 22% of the longitudinal polarization of the incident beam. Thus the transverse polarization obtained with lead and with copper are of the same order and the lead scatterer seems more convenient than the copper one, since it allows higher counting rates owing to the higher scattering cross section.

A stronger transverse component of the polarization may be obtained with an aluminum scatterer. From the measurements by Cuperman[10] carried out with ^{32}P, one may deduce that the transverse component is, at 0.70 MeV, nearly twice that obtained with a lead target. We may thus state that:

(i) An aluminum target is better than a lead target as far as the statistical errors are concerned; in effect a factor of 2 in the asymmetry can allow better measurements, although the counting rate is lower with aluminum. In the case of a thick aluminum target, the reduction of the counting rate is of the order of 2–2.5 times with respect to the lead target.

(ii) The lead target is better as far as the energy loss suffered by the electrons is concerned, since the energy loss and the straggling are lower in lead than in aluminum.

The two statements are incompatible and there is no general answer to the problem of the choice between a low-Z and a high-Z material for the first scatterer in a double scattering apparatus; this choice may be different in different experiments owing to particular reasons.

[9] G. Schatz, H. Rebel, and W. Bühring, Z. Physik **177**, 495 (1964).

[10] S. Cuperman, Nucl. Phys. **28**, 84 (1961).