Experimental Evidence of Helicity Effect on the Energy-Loss Straggling of Electrons

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A simple experiment on the polarization straggling effect suggested by Braicovich is presented. A counting-rate asymmetry of the order of 1% is obtained. This result provides the first experimental evidence of the above effect.

I. INTRODUCTION

It has been suggested[1] that the energy-loss straggling suffered by a helical electron beam in magnetized foil depends on the relative polarization of the beam and of the electrons of the foil (this phenomenon is referred to below as the polarization straggling effect). It has also been pointed out that this effect could provide the basis for a new method for measuring β-radiation helicity. A theoretical study[2] based on the inclusion of spin-dependent terms in the straggling theory due to Landau[3] was later carried out by Dupasquier.

Here some experimental results are added to the theoretical ones given in a previous paper.[2] The first experimental evidence of the polarization straggling effect was obtained under conditions which were less favorable than those assumed for the theoretical model. For the present experiment, we used a simple apparatus, suitable for a preliminary examination of the phenomenon, and we did not attempt to fulfill all the conditions validating the available theory. Thus, no rigorous comparison between theory and experiment was attempted, and only qualitative considerations are made in what follows. Nevertheless, our results show that the polarization straggling effect is easily measurable even beyond the validity limits of the theory. The present work may therefore be considered an extension of the previous theoretical treatment given in Ref. 2.

II. EXPERIMENTAL APPARATUS AND PROCEDURE

Longitudinally polarized electrons were obtained from a 100-mCi $^{90}Sr + ^{90}Y$ source. A monoenergetic electron beam was then filtered by means of a magnetic lens (see Fig. 1). The pentagonal magnet poles focus the electrons at point B, the conjugate of point A where the source is located. The energy resolution of the lens is 3.7%, the transmission 1.65×10^{-4}. The spectrometer focuses the electrons only in the plane normal to the magnetic field.

The electrons suffer energy-loss straggling in a magnetized HCR foil,[4] 82 mg/cm^2 thick, inserted in the beam at image point B. The angle between the axis of the beam and the foil is 45°, so that a 0.707 fraction of the magnetization becomes effective in the measurement. The foil is magnetized by means of a suitable magnetic circuit,[5] and the magnetization can be reversed from the outside of the vacuum chamber; the fraction of oriented electrons is 5.1%.

The electrons emerging from the HCR foil within the angle $\pm 30°$ are detected by a cylindrical plastic No. NE102A scintillator which is coupled to an RCA No. 8575 phototube. The over-all resolving power of the magnetic lens plus the scintillation spectrometer system was measured as a function of the energy and can be expressed as follows:

$$\Delta E/E = 10^{-1}(0.1369 + 0.738/E)^{1/2},$$

where E is given in MeV.

The thickness of the HCR foil was chosen to give a most probable energy loss of greater value than the energy resolution in order to observe clearly

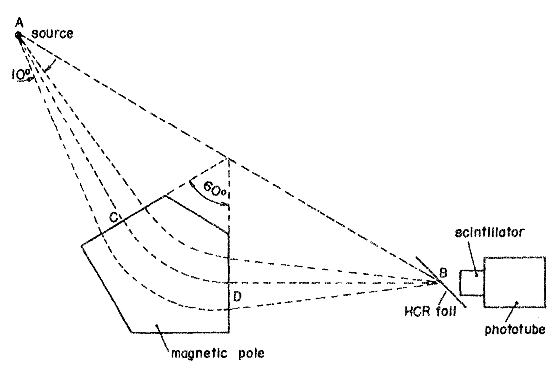

FIG. 1. Schematic view of the experimental setup.

the straggling distribution. It must be remembered that the theory given in Ref. 2 is valid in the limit of small energy losses and thus for foil thicknesses which are considerably less than that used in our experiment.

The backscattering of the electrons on the detector produces a rather flat pulse distribution extending from zero to the pulse amplitude that corresponds to the energy of the incident electrons. The area of this distribution amounts to 2.95% of the total area of the spectrum.

The experimental procedure was as follows: The straggling spectrum was measured by means of a 400-channel pulse-height analyzer (Laben Spectroscope Model No. 400); the magnetization of the foil was reversed every 400 sec, and records were kept of the counting rates C_p and C_a pertaining to parallel and antiparallel relative polarization. After subtracting background pulses, the counting-rate asymmetry $\delta = 2(C_p - C_a)/(C_p + C_a)$ was calculated as a function of the energy loss along the straggling curve. The values of C_p and C_a were averaged in a sufficiently large energy interval to achieve the desired statistical accuracy.

Great care was taken to reduce instrumental asymmetries to negligible entities. In this connection it is important to note the following points.

(i) An accurate magnetic shielding of the phototube was made, and as a result the gain difference of the spectrometer caused by reversal of the magnetization of the foil can affect the measured asymmetry by no more than 0.08%.

(ii) The instrument was carefully set up so that the plane in Fig. 1 was a reflection symmetry plane. In principle, this geometrical condition ensures that systematic asymmetries due to the bending of the trajectories in the magnetized foil are not present. The correct setting of the instrument is proved by the fact that the total area of the straggling curve measured with the HCR foil is not altered when the magnetization of the foil is reversed.

(iii) The instrumental accuracy was further checked by substituting the HCR foil with a copper foil of the same thickness and by measuring the counting-rate asymmetry caused by reversing the magnetization of the magnetic circuit.[5] In this case, the asymmetry is zero within statistical errors, as is expected of an instrument free of systematic errors.

III. RESULTS AND DISCUSSION

Counting-rate asymmetries were measured for electrons incident on the magnetized foil with an energy of 1332 keV. Asymmetry was not measured at energies lower than 320 keV owing to the excessive number of background pulses.

The measured asymmetries are plotted in Fig. 2 as a function of energy. In this figure, a logarithmic plot of the measured straggling curve is also shown. The lowest-energy asymmetry point in Fig. 2 represents the average in the energy interval 320–480 keV. The six successive points refer to intervals 105 keV wide, and the remaining points refer to intervals 52.5 keV wide.

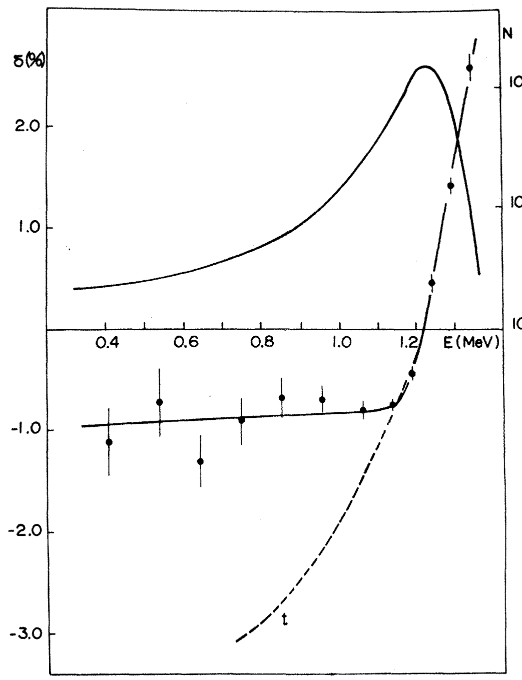

FIG. 2. Measured asymmetries plotted as a function of energy; line t gives the theoretical values obtained on the basis of Ref. 2 ; the experimental straggling distribution is shown on a logarithmic scale (N is the number of electrons collected in the unity energy interval during the whole experiment).

The asymmetry is of the order of 1% in a large energy interval corresponding to energy losses greater than two times the most probable energy loss. Thus, the existence of the suggested straggling polarization effect[1] is clearly indicated by the present experiment. In Fig. 2 the theoretical asymmetry values (line t) have been plotted with the sole purpose of demonstrating the common general features of theoretical and experimental values, although a strict comparison between theory and experiment is not possible, as explained above. The fact that the magnitude of the experimental values is lower than the theoretical one is not surprising, since the asymmetry is lowered by some processes that are neglected in the theory valid in the limit of small energy losses. In this theory, the following assumptions are made: (i) Each single electron-electron collision is supposed to take place at an energy equal to that of the incident beam; (ii) the lateral deflections, as well as the dependence of these deflections on the spin, are disregarded;

and (iii) the depolarization suffered by the beam in the magnetized foil is neglected.

In the calculation of the theoretical curve reported in Fig. 2, the actual resolving power of the apparatus was taken into account by folding the values given by the theory in Ref. 2 with the measured response of the spectrometer. It was noted that the most marked effect is due to the flat low-energy tail of the spectrometer response that is caused by the backscattering on the detector: For example the backscattering lowers the asymmetry by 44% at 703 keV. This means that stronger asymmetries could be obtained in an experiment in which backscattering on the detector was reduced. The helicity of the incident β radiation of $^{90}Sr + ^{90}Y$ was assumed equal to $(-v/c)$ on the basis of Ref. 6.

Finally, it has to be noted that the counting rate was about 1050 counts/min between 580 and 690 keV. On the basis of this figure, it is possible to say that the polarization straggling effect can be used to measure β-ray helicity with a source intensity as low as 1 mCi, provided that the transmission of the magnetic lens is improved by a factor of 30. This can be achieved by the technique suggested by Cross.[7]

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