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SCATTERING MEASUREMENTS WITH POLARIZED PROTONS BETWEEN 141 AND 314 Mev

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ABSTRACT

The purpose of this investigation is to determine the energy dependence of the polarization in proton-carbon scattering. A polarized proton beam, obtained by internal scattering in the 184-inch cyclotron at 13° from a beryllium target, was degraded, monitored, and scattered by suitable apparatus, and the scattered beam was detected in counters arranged so that the asymmetry e could be measured at two different thresholds for elastic scattering. Polarization was determined at seven different energies from 141 Mev to 314 Mev, at an angle of scattering near the maximum of polarization.

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I. INTRODUCTION

After the original discovery by Oxley and co-workers[1] of the spin polarization of high-energy protons by scattering from complex nuclei, several groups have observed and studied this phenomena.[2-6] Large polarization effects have been observed with protons between 100 Mev and 430 Mev, and the results have been explained with a fair degree of success by including a spin-orbit term in the conventional optical model.[7]

This note reports some measurements of the polarization P of protons of 141, 174, 212, 239, 272, and 314 Mev from a C target. This study was carried out for two main reasons: (a) the energy dependence of the polarization is an important quantity per se and no other similar study exists in this energy region. (b) Absolute values of the polarization are much more difficult to measure accurately than are relative values, and it seemed worth while for one laboratory to cover as wide an energy region as practicable.

At a given energy, the value of P has a strong angular dependence, with a maximum whose position is a function of energy. For instance for C this maximum is located at about 12° at 289 Mev[2,6] and at about 25° at 130 Mev.[5] It had been planned to measure the polarization at several angles at each energy so that the maximum value of P could be found for each energy. The cyclotron time available did not permit such a program to be carried out. Instead P was measured at only one angle at each energy.

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1 Oxley, Cartwright, and Rouvina, Phys. Rev. 93, 806 (1954).

2 Chamberlain, Segrè, Tripp, Wiegand, and Ypsilantis, Phys. Rev. 93, 1430 (1954); Phys. Rev. 95, 1105 (1954); Phys. Rev. 96, 807 (1954).

3 Marshall, Marshall, and de Carvalho, Phys. Rev. 96, 1081 (1951).

4 Kane, Stallwood, Sutton, Fields, and Fox, Phys. Rev. 95, 1694 (1954).

5 Dickson, Rose, and Salter, Proc. Phys. Soc. 68, 361 (1955), and private communication.

6 Robert D. Tripp, Thesis UCRL-2975.

7 Fernbach, Heckrotte, and Lepore, Phys. Rev. 97, 1059 (1955) (contains bibliography).

This angle was chosen by using the apparent 1/E dependence of the sine of the angle of maximum polarization shown by the results quoted above. Such a dependence is approximately predicted by Born-approximation calculations using the optical model.[8] This choice of angle seemed the least arbitrary of the choices that were considered.

II. EXPERIMENTAL ARRANGEMENT

The polarized proton beam of the 184-inch cyclotron is obtained by internal scattering at 13° from a Be target. The scattered beam passes through the fringing field, a collimator, a steering magnet, a set of quadrupole lenses, and a 0.5-in. wide, 2-in.-high collimator before entering the experimental area. There it has an energy of 320 Mev, an energy width of ± 4 Mev, and a polarization P = 0.76 ± .03.[2,6] The polarized beam is degraded by passing it through copper absorbers.[9] Two possible positions were considered for the beam absorbers: in front of the first collimator, or behind the last collimator. The first choice results in a narrow energy width of the degraded beams, but the orbits accepted by the system of collimators and magnets could be a function of absorber thickness, and thus this choice leads to an unknown uncertainty in the polarization P. The second position was therefore used. This choice leads to a broadening of the energy width of the beam and to an increase in the background in the experimental area. However, it insures a constant P of the incident beam for all incident energies.

Two slightly different experimental arrangements were used. In Method I the polarized beam, after emerging from the beam absorbers, was defined and monitored by scintillation counters No. 1 and No. 2 (each 1 by 4 by 3/8 in.) placed at 29 and 69 in. from the absorbers respectively. The 5.3-g/cm^2 C scatterer was placed perpendicular to the beam at 78 in. from the absorbers. The scattered beam was detected by a telescope consisting of counters No. 3 (1 by 6 by 0.25 in.), No. 4(2.5 by 8 by 3/8 in.), and No. 5 (3 by 9 by 3/8 in.). Absorbers were placed between counters Nos. 3 and 4 so that the energy threshold was close to that required for elastic scattering. Then 1-2-3-4 and 1-2-3-4-5 coincidences were recorded, allowing the simultaneous measurement of the asymmetry with two different thresholds.[10] The telescope was mounted at 28.5 in. from the C scatterer on the rigidly constructed table, which allowed rotation to azimuthal angles of 0° and 180°.

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[8] B. J. Malenka, Phys. Rev. 95, 522 (1954).

[9] L. Wolfenstein, Phys. Rev. 75, 1664 (1949) has shown that no appreciable depolarization occurs when a beam of polarized protons is slowed down in an absorber.

[10] The 214-Mev measurement was carried out with only four counters.

The large number of secondaries produced in the beam absorbers can couse accidental coincidences between unrelated events traversing Counters 1-2 and 3-4-5 respectively. The accidentals were minimized by using fast electronics, (10^{-8} sec), running at favorable beam intensities, and shielding the telescope from the beam absorbers by use of thick lead blocks (Fig. 1). At 141 Mev and $\phi = 180^{\circ}$ where the accidental problem was worst, accidentals amounted to 17% of the true counts.

In Method II, the incident beam was monitored by an argon-filled ion chamber placed in front of the beam absorbers. The maximum size of the beam was defined by two collimators, 1-7/8 by 5 in. placed in the lead blocks (Fig. 1). The 3-4 and 3-4-5 coincidences were recorded. This method was useful at the higher energies where it made possible higher counting rates--at the expense of poorer angular resolution, however. At the lower energies the background became too large and Method I was used.

The experimental procedure used for the alignment, electronic check, choice of telescope absorber, and measurement of the asymmetry e was identical with that described elsewhere.[6] It should be noted that the precise electronic alignment check was made at each one of the beam energies and that this check was carried out with the telescope absorbers used in the actual measurement.

III. RESULTS AND DISCUSSION

The results obtained in this work are summarized in Table I and represented in Fig. 2. The errors shown in Table I are of statistical origin only. It is believed that errors due to the alignment and background subtraction are smaller than these. There is an additional uncertainty of 4% in the absolute values of P due to the uncertainty in the polarization of the incident beam. It is difficult to estimate the error introduced by the failure to cleanly separate the elastic from the inelastic scattering. This error is expected to increase with lower scattering energy, since the width of the diffraction peak varies roughly as $E^{-1/2}$ whereas the scattering angle chosen varied about as E^{-1}. It seems reasonable to take the differences in P obtained with the two thresholds as a measure of the uncertainty. This estimate shows that the possible error becomes large only at 141 Mev. At the other energies the asymmetries e measured with the lower thresholds are only slightly smaller than those obtained with the higher thresholds, and thus the high-threshold results represent a close lower limit to the correct polarization.

To estimate the influence of the finite angular resolution on the measurements of P it is necessary to know accurately the dependence of P with θ. At 289 Mev the data of Chamberlain, Segrè, Tripp, Wiegand, and Ypsilantis[2] indicate that $\sqrt{\overline{\theta^2}} = 0.9^{\circ}$ is small enough, but that a value of $\sqrt{\overline{\theta^2}} = 1.7^{\circ}$ might tend to lower the measured value of P if the angle θ is set at the maximum. It might be noted that the value of P obtained with Method I ($\pm 1.9^{\circ}$) at 214 Mev seems higher than that given by Method II ($\pm 1.7^{\circ}$) although the difference is not outside the statistical uncertainty.

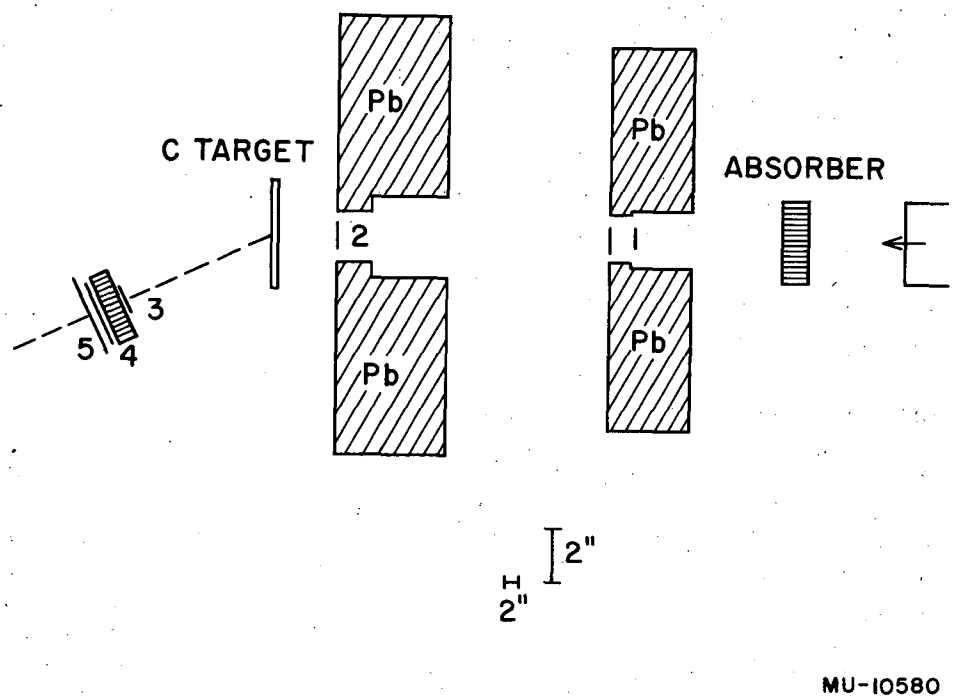

Fig. 1. Arrangement of absorber, collimators, target, and detectors in polarization experiment. (Note that horizontal and vertical scales are different.)

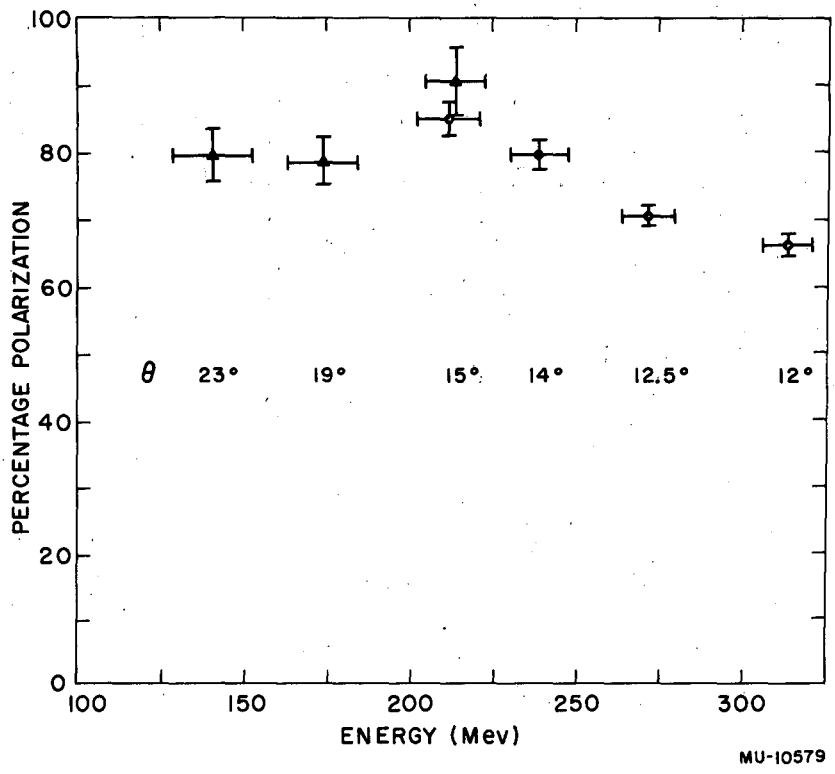

Fig. 2. Polarization as a function of energy from 141 Mev to 314 Mev.

Table I

Polarization from carbon

E (Mev)	ΔE (Mev)	t (Mev)	θ	$\sqrt{\overline{\theta^2}}$	E_{th} (Mev)	e (%)	P (%)	E_{th} (Mev)	e (%)	P (%)	Method
141	±6.5	20.3	23.0°	1.0°	129	60.5±3.0	79.6±3.9	118	52.3±2.9	68.8±3.8	I
174	±5.6	17.6	19.0°	1.0°	160	59.8±2.8	78.7±3.7	151	58.7±2.8	77.2±3.7	I
214	±5.3	15.6	15.0°	1.1°	200	68.8±3.9	90.5±5.1	--	--	--	I
212	±5.0	15.6	15.0°	1.7°	199	64.6±1.9	85.0±2.5	191	60.6±1.8	79.7±2.4	II
239	±4.6	14.5	14°	(1.7°)	229	60.6±1.7	79.7±2.2	222	60.1±1.7	79.1±2.2	II
272	±4.3	13.5	12.5°	(1.6°)	263	53.7±1.1	70.7±1.4	257	50.7±1.2	66.7±1.6	II
314	±4.0	12.5	12°	0.9°	301	50.3±1.2	66.2±1.6	295	48.3±1.2	63.6±1.6	II

E = energy of the incident beam at the center of the C scatterer;
ΔE = rms energy spread of this beam;
t = thickness of C scatterer in Mev (the thickness was determined by intensity considerations;
θ = polar scattering angle;
$\sqrt{\overline{\theta^2}}$ = rms angular resolution (this quantity was measured experimentally, except at 272 and 239 Mev, where it was calculated);
E_{th} = lowest-energy proton which, starting at the center of the C scatterer, was detected by the telescope (the two values given at each beam energy correspond to Counters 3-4 and 3-4-5 in the telescope);

$$e = \frac{I(\phi=0^\circ) - I(\phi=180^\circ)}{I(\phi=0^\circ) + I(\phi=180^\circ)}$$ where I is the intensity of the scattered beam at the azimuthal angle θ;

= the polarization calculated from the observed value of e assuming a polarization of 0.76 for the incident beam.

The results presented in Table I can be compared with the measurements by Chamberlain et al.,[2,6] who obtained P = 66.1 ± 1.7% at $\theta = 13^{\circ}$ and 313 Mev, and P = 67.4 ± 1.9% at $\theta = 11.8^{\circ}$ and 289 Mev. Dickson et al. have obtained P = 88 ± 12% at 24° and 130 Mev,[5] and Baskin and Chestnut[11] have reported P = 91 ± 1% at 15° with 230-Mev protons. The agreement with the results reported in Table I is good.

It must be emphasized that except at 314 Mev the values of the polarization P reported in Table I probably do not represent the maximum value of P at each energy. It is clear, however, that the polarization increases with decreasing beam energy down to 214 Mev, and there is evidence for a decrease below that energy. Even at 141 Mev, however, the observed value of P is higher than the maximum value at 314 Mev.

Since the agreement between the results for C reported here and those reported elsewhere is good, it seems worth while to compare the maximum values of P obtained from other elements at the various laboratories. For Beryllium P = 76.0 ± 1.1% at $\theta = 13^{\circ}$ and 316 Mev,[2,6] P = 82 ± 1% at $\theta = 15^{\circ}$ and 230 Mev,[11] and P = 82 ± 3% at $\theta = 25^{\circ}$ and 130 Mev.[5] It appears that the energy dependence of the polarization from Be is different from that of C.

In a first Born-approximation calculation with the optical potential, the maximum value of P is independent of the shape of the scattering potential or of the strength of the spin-orbit term; it depends only on the ratio W_0/V_0 where V_0 and W_0 are the strengths of the real and imaginary part of the scattering potential.[8] Using the energy dependence of V_0 and W_0 as determined from neutron cross-section data,[12] one finds a slow and steady decrease of P, between 300 and 140 Mev.

More accurate calculations using phase shifts in W.K.B. approximations have been done at 300 Mev[7,13] and 130 Mev.[14] Although the results agree in a general way with the angular distributions observed at these energies, the detailed fit is not too good, and depends strongly on the angular form used for the optical potential. It is therefore difficult to say whether the experimental energy variation of P could be reproduced by carrying out such calculations at the intermediate energies, using parameters

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[11] Baskin and Chestnut (reported by E. M. Hafner), Proceedings of the Fifth Rochester Conference, 1955.

[12] T. B. Taylor, Phys. Rev. 92, 831 (1953); I. Shapiro and J. M. Teem (private communication).

[13] R. M. Sternheimer, Phys. Rev. 97, 1314 (1955)

[14] R. M. Sternheimer, private communication (to be published in Phys. Rev.).

that agree with other data. While the strength of the spin-orbit term in the scattering potential does not appear to affect the maximum value of P in Born approximation, the more accurate calculations of Sterheimer[14] on Fe at 130 Mev show that in fact it does. It seems possible therefore that the energy dependence of P can be reproduced by introducing an energy-dependent strength for the spin-orbit term of the optical potential. Whether such a procedure would amount to more than numerology would depend on whether the energy variation of P from many elements could be predicted with the same parameters. Such calculations are lengthy; it is preferable therefore to first measure the energy dependence of P with several rep-sentative target elements, and to use relatively small energy steps to observe the detailed structure. Because of the conversion of the 184-in. cyclotron to higher energies, it was not possible to carry out such a program in this laboratory.

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