Proton-Proton Polarization at 170 Mev*

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The proton-proton polarization has been measured at 170 Mev. The data have been fit to a curve of the form $P=\sin\theta\cos\theta(\alpha+\beta\cos^2\theta)$, yielding $\alpha=0.31\pm0.09$ and $\beta=0.30\pm0.14$. A comparison is made with results obtained at other energies.

INTRODUCTION

DURING the past several years the group of Segrè, Chamberlain, Wiegand, and co-workers has been studying experimentally neutron-proton and proton-proton scattering.

Recently a polarized proton beam has been obtained from the cyclotron.[1] This has greatly increased the amount of information obtainable from scattering experiments.

Some of the results of experiments at about 315 Mev have been reported in the past. It is interesting to extend them to lower energies for several reasons: (a) at lower energies fewer partial waves are involved and the analysis ought to be simpler; (b) data at lower energies will supplement the data at 300 Mev and help in the choice of the correct set of phase shifts in case of multiple solutions. Chamberlain and Garrison[2] have investigated the angular distribution and Pettengill[3] has measured the total cross section at about 170 Mev.

We now report measurements on the polarization obtained by scattering at this energy. Similar work at 130 Mev has been done by Dickson and Salter[4] at Harwell.

APPARATUS

The beam used was rectangular in cross section, 2 inches vertical by $\frac{1}{2}$ inch horizontal. This was monitored at low beam intensities with two thin counters, called "*a*" and "*b*," and at high beam intensities with an argon-filled ion chamber. A three-counter telescope was used to detect the scattered protons. Absorbers were placed between the telescope counters Nos. 1 and 2, and between 2 and 3. The counters were plastic scintillators viewed by 1P21 photomultiplier tubes. Counter No. 1, the nearest to the target, was defining and was 1 in. wide by 6 in. high. The target used was a 1.0-g/cm² liquid hydrogen target.

BEAM

The 170-Mev polarized beam was obtained by degrading the 315-Mev polarized beam.[1] The beam intensity was approximately 1.5×10^4 protons/sec. Figure 1 shows the plan view of the cyclotron and experimental area. During most of the experiment the beam was degraded by beryllium bricks placed at position *A*. By placing the degrader before the bending magnet we could obtain a fairly monoenergetic beam. This beam had an energy of 174±10 Mev. Some data were taken with the beam degraded by graphite plugs at position *B*. This beam had an energy of 185±17 Mev.

EXPERIMENTAL PROCEDURE

The position of the beam at the hydrogen target was determined by exposing x-ray film to the beam. A transit at the rear of the experimental area, located approximately on the beam line, was trained on the center of the beam spot of the developed film. The scattering table was moved to place the center of the target windows on the center of the beam.

The beam energy and energy spread were determined by taking a Bragg curve with two ion chambers. The counters were plateaued against high voltage on the photomultiplier tubes. Counting rates were measured with variable delays in each of the counters. This gave the proper delay in each line and gave a measurement of the time resolution of the equipment.

In order to accurately determine the zero of Θ the counters were swept through the beam and the counting rate was measured for small angles. Figure 2 shows typical results for such measurements.

The counter telescope was then swung to larger

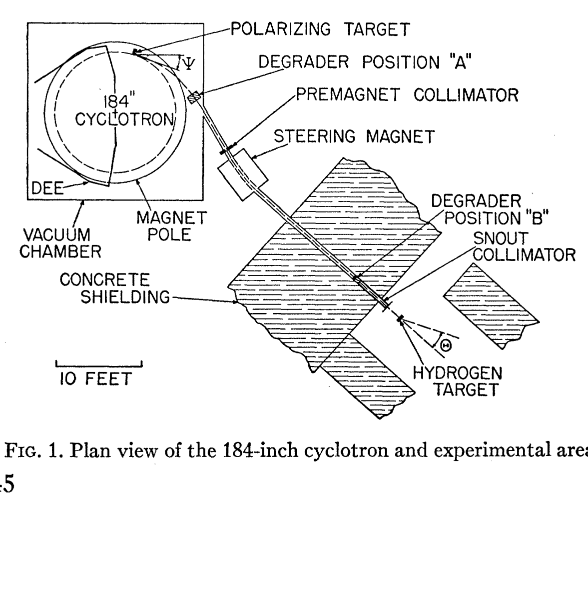

FIG. 1. Plan view of the 184-inch cyclotron and experimental area.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Chamberlain, Segré, Tripp, Wiegand, and Ypsilantis, Phys. Rev. **93**, 1430 (1954).
[2] O. Chamberlain and J. Garrison, Phys. Rev. **95**, 1349 (1954).
[3] Gordon Pettengill, University of California Radiation Laboratory Report No. UCRL-2808, December, 1955 (unpublished).
[4] J. M. Dickson and D. C. Salter, Nature **173**, 946 (1954).

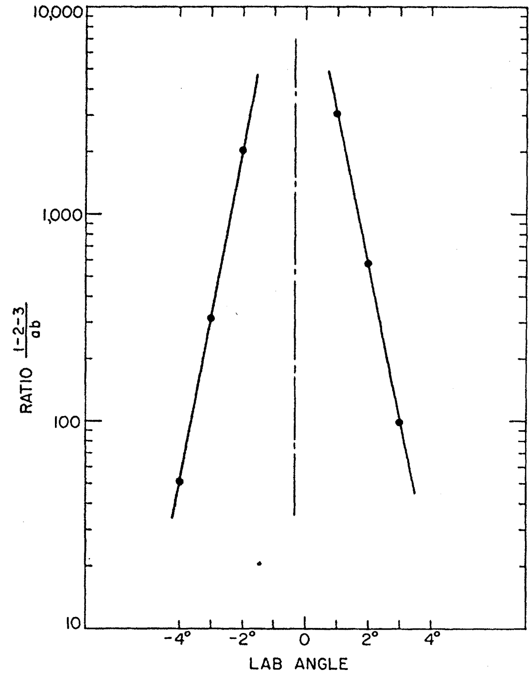

FIG. 2. Typical counting rate in telescope for small angles, *versus* lab angle Θ.

angles to measure asymmetries. At each angle the following counting rates were determined:

(*a*) *Target.*—The 1–2–3 coincidence counts per integrator volt with the target (either the 1.0-g/cm^2 H_2 target or the 2.18-g/cm^2 Be target) in the beam.

(*b*) *Blank.*—The 1–2–3 coincidence counts per integrator volt with a blank target in the beam. The blank target for H_2 was similar to the H_2 target except that it contained no H_2, while that for the Be consisted of no target at all. For this measurement an absorber equal in stopping power to the target was added to the counter-telescope absorber.

(*c*) *Accidentals.*—The 1–2–3 coincidence counts per integrator volt due to accidental coincidences. This was determined by adding a delay of 6×10^{-8} sec (the time between the cyclotron rf pulses) to counter No. 1. The accidental rate was determined to be negligible at all angles measured.

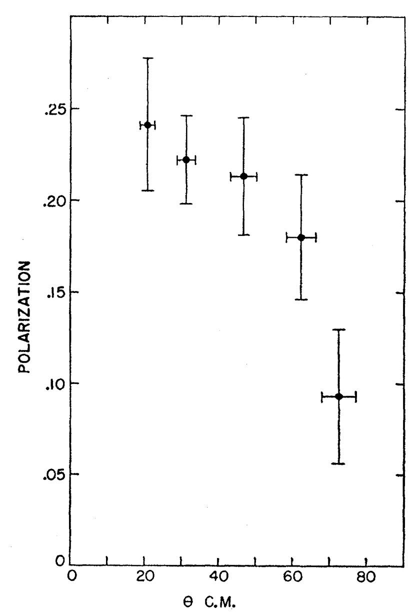

FIG. 3. Proton-proton polarization at 170 Mev, *versus* center-of-mass angle θ.

At each angle the above measurements were made for scattering to the left and to the right. ("Left" and "Right" are as seen by an observer looking in the direction along which the beam is moving.)

The ratio of blank to target rates varied from about 0.35 at $\Theta=10°$ to about 0.10 at $\Theta=35°$ for the H_2 runs, and was about 0.05 for the Be runs.

With the beam degraded at position *A* (see Fig. 1), measurements were made on H_2 for $\Theta=10°$, 15°, 22.5°, 30°, and 35°. Beryllium measurements were made at 13°. Several runs were made at each angle for H_2. A run was made on Be each day to determine whether the beam polarization changed from day to day. These Be checks were in good agreement. Finally measurements were made at 13° with Be and the beam degraded at position *B*. This last measurement was made in order to determine the polarization of the beam, which was degraded at position *A*. The polarization of the full-energy (315-Mev) beam is known to be 0.76 ± 0.03.[5] It is assumed that the polarization of the full-energy beam is not changed appreciably in degradation.[6] Therefore, measurements made on Be with the beam degraded at *B* determine the polarization of Be at 13° at the degraded energy. When the beam is degraded at position *A* it is not guaranteed that the same component of the internal scattered protons is steered into the 46-inch collimator as is steered in with the full-energy beam. Thus measurements made on Be with absorber at position *A* served to calibrate the polarization of this beam.

TABLE I. Values of *p*-*p* polarization at mean scattering energy of 170±14 Mev.[a]

Θ	θ	Δθ	*e*	Δ*e*	*P*	Δ*P*
10°	20.8°	1.9°	0.183	0.025	0.241	0.036
15°	31.3°	2.5°	0.169	0.015	0.222	0.024
22.5°	46.8°	3.4°	0.162	0.013	0.213	0.032
30°	62.2°	3.9°	0.137	0.024	0.180	0.034
35°	72.4°	4.7°	0.071	0.028	0.093	0.037

[a] Θ is the lab scattering angle, θ is the center-of-mass scattering angle, Δθ is the rms angular resolution, *e* is the asymmetry, Δ*e* is the rms uncertainty in *e*, *P* is the polarization, and Δ*P* is the rms uncertainty in *P*.

[5] T. J. Ypsilantis, University of California Radiation Laboratory Report No. UCRL-3047, June, 1955 (unpublished).

[6] L. Wolfenstein, Phys. Rev. **75**, 1664 (1949).

RESULTS

Counting rates due to the target were determined by

$$I=(\text{Target})-(\text{Blank}).$$

Asymmetries were determined by

$$e=\frac{I(\Theta)_{\text{left}}-I(\Theta)_{\text{right}}}{I(\Theta)_{\text{left}}+I(\Theta)_{\text{right}}}$$

were $I(\Theta)_{\text{left}}$ refers to the target effect for a scattering at a laboratory angle of (Θ) to the left. The Be asymmetry for the position A degraded beam was 0.443 $\pm$0.013. The Be asymmetry for the position B degraded beam was 0.437$\pm$0.014. These agree within the statistical error of the measurements. Therefore the beam which was used for the H measurements (position A) had a polarization of 0.76$\pm$0.05. The results are summarized in Table I. The polarization as a function of θ is shown in Fig. 3. The errors quoted are due to counting statistics only.

In *p-p* scattering, the product of the polarization and the unpolarized differential scattering cross section, $P\sigma$, may be expressed as

$$P\sigma=\sin\theta\cos\theta\sum_{n=0}^{\infty}a_{2n}\cos^{2n}\theta.$$

The results of the 300-Mev experiments show that a good fit should be obtained by including in the sum only a_0 and a_2. If one assumes that the *p-p* unpolarized differential cross section is constant in the center-of-mass system, then he should expect $P(\theta)/\sin\theta\cos\theta$ to be expressible in the form

$$P(\theta)/\sin\theta\cos\theta=\alpha+\beta\cos^2\theta.$$

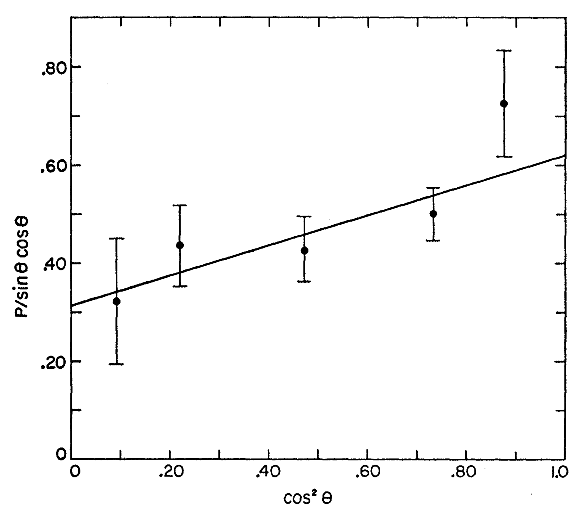

FIG. 4. $P(\theta)/\sin\theta\cos\theta$ *versus* $\cos^2\theta$. The solid line is the least-squares fit of the data to a curve of the form $\alpha+\beta\cos^2\theta$.

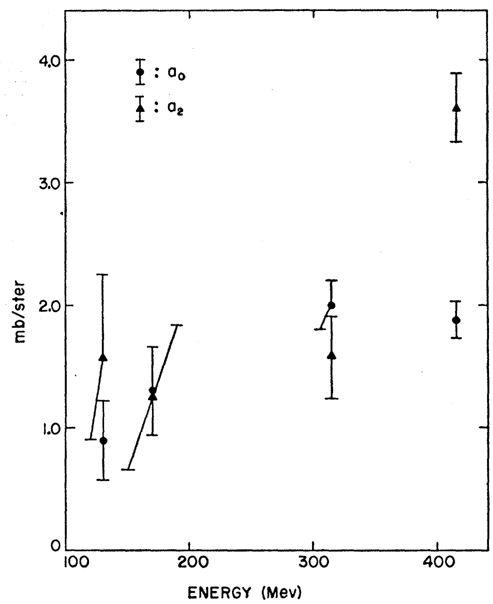

FIG. 5. Least-squares values for a_0 and a_2 in the expansion $P\sigma/\sin\theta\cos\theta=a_0+a_2\cos^2\theta$, *versus* energy.

Figure 4 shows $P(\theta)/\sin\theta\cos\theta$ *vs* $\cos^2\theta$ together with the least-squares fit to the data. The least-squares values of the parameters are

$$\alpha=0.31\pm0.09,\quad \beta=0.30\pm0.14.$$

The values of a_0 and a_2 are then simply the product of α and β above times the average value of the 170-Mev differential cross section,[3] which is taken to be 4.16 mb/sterad.

Figure 5 shows a_0 and a_2 *vs* energy. The data used were from Harwell[4] at 130 Mev, Berkeley at 170 and 300 Mev,[5] and Carnegie Institute of Technology[7] at 415 Mev. The errors are mean-square errors, and reflect the uncertainties in the asymmetries only, and not those in the differential cross section or beam polarization.

CONCLUSIONS

The existence of an appreciable $\cos^2\theta$ term in $P/\sin\theta\cos\theta$ indicates considerable contribution to the scattering by waves of $l\geqslant3$. The internal consistency of the data does not permit us to make any estimate of the $\cos^4\theta$ term.

ACKNOWLEDGMENTS

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[7] Kane, Stallwood, Sutton, Fields, and Fox, Atomic Energy Commission Report NYO-6569 (unpublished).