Proton-Proton Polarization at 16 Mev*

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The proton-proton polarization has been measured at 16.2±0.2 Mev and 25 degrees in the laboratory system, using the familiar double-scattering method, with hydrogen gas as second scatterer. Instrumental asymmetries were practically eliminated by using carbon and copper alternately as first targets. The polarization was found to be +(0.6±0.5)%. Theoretical implications of the work are discussed.

INTRODUCTION

ALTHOUGH measurements of nucleon-nucleon cross sections, polarizations, and triple-scattering parameters have been going on for a number of years,[1] the topic is still of considerable interest, and many such experiments have been carried out recently.[2] As shown by Wolfenstein,[3] at least nine independent measurements are required to specify completely the nucleon-nucleon interaction at any given energy. Two of these may be the differential cross section and the differential polarization. The ideal is to make all nine measurements at several energies, and thus obtain an unambiguous determination of the interaction as a function of energy.

Now most determinations of the nucleon-nucleon polarization have been made at high energies, since it was expected that the low-energy polarization would be zero. However, Hull and Shapiro[4] have shown that consistent fits which predict a nonzero polarization can be made to the 4-Mev proton-proton differential cross-section data. Recently, MacGregor[5] has analyzed the various low-energy proton-proton differential cross-section data, and has found that from 9 to 40 Mev, S, P, and D waves are required to give good fits, that a great multiplicity of such phase shift solutions exists, and that even a differential cross-section measurement to an accuracy of 0.1%. would be inadequate to resolve further the ambiguity. Hence, polarization measurements are suggested. Such a determination—the proton-proton polarization at 16.2 Mev and 25 degrees in the laboratory system—is reported here.

EXPERIMENTAL PROCEDURE

Measurements were made by means of the now familiar double-scattering method.[6] Figure 1 shows the geometry employed. Protons were accelerated by the Princeton 19-Mev FM cyclotron, and scattered from a carbon or a copper target. The scattered beam was collimated at 45 degrees and scattered once again from gaseous hydrogen at 25 degrees to the right and the left of the first scattering axis. Figure 2 shows the hydrogen scattering chamber, or polarimeter, in greater detail. A description of this chamber appears in the literature.[7] For this experiment, the 65-degree collimation vanes discussed there were replaced by 25-degree vanes.

Two types of instrumental asymmetry arise in this work: that due to misalignment of the apparatus, and that due to its finite geometry. This latter asymmetry comes about simply because the differential cross section of the first target nucleus is a function of angle, and the angular resolution of the hydrogen polarimeter is finite. The asymmetry may be reduced by reducing the solid angle accepted, but as this procedure also decreases an already low counting rate, it cannot be carried too far.

Through a straightforward, though laborious calculation,[8] an expression for this finite geometry contribution may be found. Using the data appropriate to the first and second scatterers employed in this experiment,[7,9–11] it may be shown that to about 1 or 2%, this asymmetry, Δe, may be written as

$$\Delta e = G(\sigma_1'/\sigma_1),$$

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[1] Oxley, Cartwright, and Rouvina, Phys. Rev. **93**, 806 (1954); J. M. Dickson and D. C. Salter, Nature **173**, 946 (1954); Chamberlain, Segrè, Tripp, Weigand, and Ypsilantis, Phys. Rev. **105**, 288 (1957); Marshall, Marshall, and DeCarvalho, Phys. Rev. **93**, 1431 (1954); DeCarvalho, Heiberg, Marshall, and Marshall, Phys. Rev. **94**, 1796 (1954); Kane, Stallwood, Sutton, Fields, and Fox, Phys .Rev. **95**, 1694 (1954); Meshcheryakov, Nurushchev, and Stoletov, Zhur. Eksptl. i Teoret. Fiz. **33**, 37 (1957) [translation: Soviet Phys. JETP **6**, 28 (1958)]; Palmieri, Cormack, Ramsey, and Wilson, Bull. Am. Phys. Soc. Ser. II, **3**, 204 (1958).

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[3] L. Wolfenstein, Phys. Rev. **96**, 1654 (1954).

[4] M. H. Hull and J. Shapiro, Phys. Rev. **109**, 846 (1958).

[5] M. H. MacGregor, University of California Radiation Laboratory Report UCRL-5348, Livermore, 1958 (unpublished).

[6] See, e.g., L. Wolfenstein, *Annual Review of Nuclear Science* (Annual Reviews, Inc., Palo Alto, 1956), Vol. 6, p. 43.

[7] K. W. Brockman, Phys. Rev. **110**, 163 (1958).

[8] See, e.g., W. A. Blanpied, Atomic Energy Commission Report NYO-8140, Princeton, 1958 (unpublished), p. 88.

[9] W. A. Blanpied, Phys, Rev. **113**, 1099 (1959).

[10] I. E. Dayton, and G. Schrank, Phys. Rev. **101**, 1358 (1956).

[11] R. W. Peele, Phys. Rev. **105**, 1311 (1957).

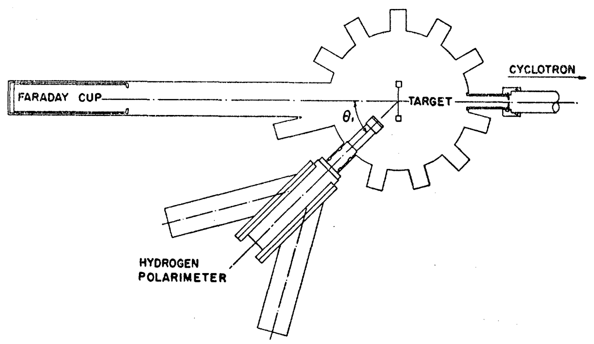

FIG. 1. Geometry of the double-scattering experiment.

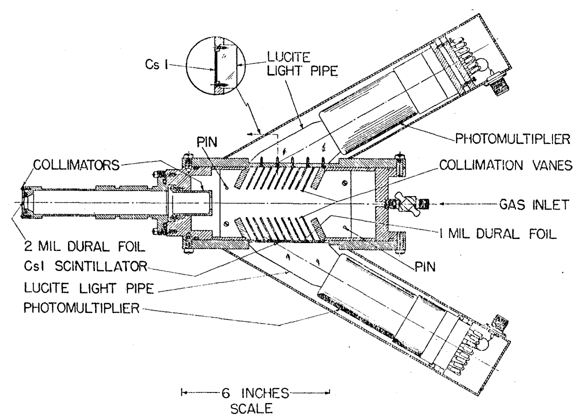

FIG. 2. Detailed top view of the gas cell, or polarimeter.

where σ_1 and σ_1' are, respectively, the differential cross section of the first target nucleus, and its first derivative with respect to angle, and G is a function of the geometry of the apparatus. Higher order terms involve the cross sections and polarizations of both targets, as well as their first and higher derivatives with respect to angle.

Since the polarization measured was expected to be small, it was desirable to eliminate the finite asymmetry, Δe, by experimental means. Consider measurement of the proton-proton polarization using a nucleus A as first scatterer. The measured polarization, $P_H(A)$, will be the sum of the true polarization, $P_H(t)$, and the apparent polarization due to the geometric effect:

$$P_H(A)=P_H(t)+\Delta e(A)/P_1(A),$$

where $P_1(A)$ is the polarization of protons scattered from nucleus A at the angle in question. A similar relation may be written for the case of a nucleus B. Now assume that the finite-geometry asymmetries are about equal for the two cases:

$$\Delta e(B)=\Delta e(A)+\delta e.$$

Then, subtracting the expressions in A and B:

$$P_H(A)-P_H(B)=\Delta e(A)\left[\frac{1}{P_1(A)}-\frac{(1+K)}{P_1(B)}\right].$$

Now the ratio K is a function only of the differential cross section of the first target nucleus and its first derivative at the angle in question. Therefore, it may be computed from known data. Thus the finite geometry asymmetry may be expressed completely as a function of measured polarizations, with a small correction, K, a function of the cross sections.

Carbon and copper were chosen as the two first target nuclei partially because they satisfy the criterion of having the ratio (σ'/σ) almost equal at 45 degrees. Further, both their cross sections[10,11] and their polarizations[7,9] are known, and are reasonably high at this angle. Using published data in the relation developed for the finite asymmetry, the true polarization is

$$P_H(t)=1.71P_H(\mathrm{C})-0.71P_H(\mathrm{Cu}).$$

It may be shown that misalighment asymmetry is a strong function of the ratio (σ_2'/σ_2) for the second target[8]; in the case considered here (hydrogen), this quantity is very small.[12] A previously discussed alignment procedure was followed,[7] and runs were made alternately with the polarimeter rotated through 180 degrees about the axis of first scattering. Therefore, contributions due to misalignment were much smaller than those due to the finite geometry or the statistical uncertainty.

A graphite disk and a pure metallic copper foil, each about 1 Mev thick at 18 Mev, were used as first scatterers. Hydrogen gas at a pressure of 100 psi served as second target. Pure hydrogen rather than an organic foil was used in order to remove all ambiguity concerning the pulse height of the twice scattered protons. These protons were detected by scintillation counters which consisted of CsI(Tl) crystals and DuMont-6292 photomultiplier tubes. Pulses were shaped by cathode followers, and analyzed by an RIDL 200-channel pulse-height analyzer, modified to act as two 100-channel analyzers.

The system was calibrated using protons singly scattered from gold at 30 degrees. Energy of the second scattering was computed from kinematical considerations, and from known energy losses in targets and foils.[13] For this purpose, it was assumed that all scattering took place at the half thickness of each target. Incident energy was adjusted so that the scattering in the hydrogen took place at the same energy for both the carbon and the copper first targets. This second-scattering energy was 16.2 ± 0.2 Mev.

Background was due chiefly to neutrons produced in the first target and in the brass walls of the scattering chambers. It was measured by evacuating the second chamber, and running for an integrated beam current equal to that of the main run. Sufficient shielding was introduced so that at the proton-proton pulse height,

[12] J. L. Yntema and M. G. White, Phys. Rev. **95**, 1226 (1954).
[13] Aron, Hoffman, and Williams, University of California Radiation Laboratory Report UCRL-121, 1949 (unpublished).

background was negligible for carbon; somewhat larger, but still small for copper. Therefore, it was felt that subtraction was warranted, and no coincidence technique was employed. Data were taken alternating the copper and carbon targets in an exactly reproducible manner; a background run followed each main run.

This experiment was hampered by the very small beam current available from the Princeton cyclotron; at the first target this current was usually about 6 to 8 millimicroamperes. Even with the thick targets and large apertures employed, the counting rate on each side was only about 1 every 3 minutes. For the point reported, running time was something over 100 hours.

RESULTS AND CONCLUSIONS

The value of the proton-proton polarization at 16.2 ± 0.2 Mev and 25 degrees in the laboratory system, measured by the method discussed above, is $+(0.6\pm0.5)\%$, where the sign convention is specified by the sign of the vector product of the incident by the scattered wave vectors, in agreement with Wolfenstein.[6] The uncertainty is statistical, and was computed from the well-known expression for probable error.

MacGregor's phase-shift analysis[5] showed that there are four different types of solution that fit the differential cross-section data equally well; these four types differ chiefly in the magnitude and sign of the three P-wave phase shifts used. Within each category of solution a great ambiguity still exists, owing to the multiplicity of S-D phase-shift combinations for each P set.

The fact that the present result is positive eliminates two phase-shift types, and knowledge of its magnitude —even with the quoted uncertainty—should serve to reduce somewhat the ambiguity within the two remaining types.[14] However, MacGregor has indicated that to find a unique set of phase-shifts, not only must the angular distribution of the polarization be known to about 1%, but triple-scattering parameters[3] must be measured as well. Unfortunately, such measurements with the Princeton cyclotron seem to be out of the question at present. To halve the statistical uncertainty on the present point would require an increase in running time by about a factor of four, and triple-scattering experiments are certainly unthinkable with the small beam current available. Such measurements must await the advent of the polarized ion sources now being developed for accelerators.

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[14] M. H. MacGregor (private communication).