HIGH-PRECISION MEASUREMENT OF PROTON-PROTON POLARIZATION BETWEEN 10 AND 20 MeV *

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The p-p polarization asymmetry has been measured at 9.6-, 15.6-, and 19.7-MeV laboratory energy with accuracy down to ±0.003. The interpretation of our results requires a significant spin-orbit term in the interaction.

There are few measurements of polarization in p-p scattering below 30 MeV. The measurement of Alexeff and Haeberli[1] at 3.3 MeV resulted in small positive values. However, Knecht et al.[2] have concluded that there is no way to reproduce such values with any combination of S, P, and D phase shifts, and hence that they must be in error. There is also a measurement[3] at 16.2 MeV at 50.2° c.m. that produced a value of 0.006 ± 0.007, and another[4] at 17.5 MeV at 45° c.m. with a value of 0.0125 ± 0.02. Clearly both experiments were not inconsistent with a very small polarization (positive or negative).

High-precision measurements at about 45° c.m. have been performed in the recent past in the region at and above 30 MeV.[5] The polarization is consistently positive and becomes zero at about 30 MeV. At low energies the polarization is an effect of higher order with respect to the spin-correlation parameters.[6] Most recent efforts have dealt with measurements of the latter.[7] However, at 11.4 MeV the scattering is overwhelmingly singlet, and thus the spin-correlation measurement ceases to yield useful information.

A high-precision measurement of the polarization in the range between 10 and 20 MeV may be helpful to the numerous groups[5,7-11] that have carried out analyses of nucleon-nucleon scattering below 30 MeV. We have measured the polarization asymmetry in proton-proton scattering at 9.6, 15.6, and 19.7 MeV, using the variable-energy polarized-beam facility of the Berkeley 88-inch cyclotron. The proton beam is produced with nearly 100% polarization by scattering of α particles from a liquid-nitrogen–cooled high-pressure hydrogen target. The beam energy was determined by measuring its range in aluminum. The alignment of the beam was effected by first mapping it with a slit mounted on a remotely controlled ionization chamber, and subsequently orienting the scattering table on the beam line using a telescope. Thereby an alignment to ±0.05° is accomplished. A similar accuracy is obtained in the alignment of the detector collimators. A spin-precession solenoid was used to reverse the spin of the proton beam. To restore the beam barycenter a magnet was used in conjunction with a split ionization chamber that was permanently monitoring the beam direction. In order to minimize and compensate for possible effects due to the spin-precession solenoid it was operated half the time precessing the spin clockwise, and half the time counterclockwise. Careful tests indicate that no asymmetry is produced by the spin-precession solenoid. The hydrogen target was a cell with a continuous aluminum window 0.0019 in. thick, operated at about three atmospheres at room temperature. The gas was 99.99% pure. The detection was effected with two pairs of CsI(Tl) scintillator detector telescopes and associated electronic circuitry as shown in Fig. 1(a).

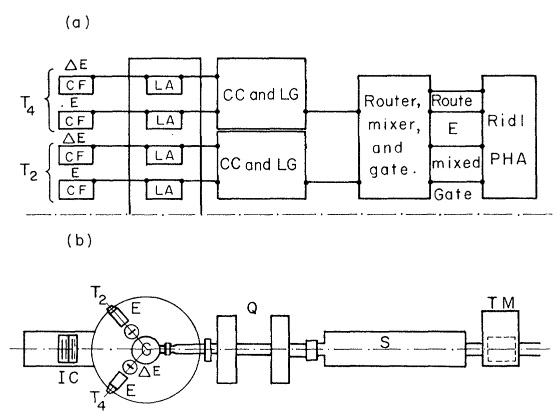

FIG. 1. Schematic drawing of the circuits and geometrical layout of the experiment. (a) Block diagram of the circuits. CF, cathode follower; LA, linear amplifier; CC, double coincidence; LG, linear gate; T_i, detector telescope. (b) Schematic drawing of the experimental apparatus. IC, ionization chamber; T_i, detector telescopes; Q, quadrupole lens; S, spin-precession solenoid; TM, tickling magnet (for the restoration of the beam barycenter).

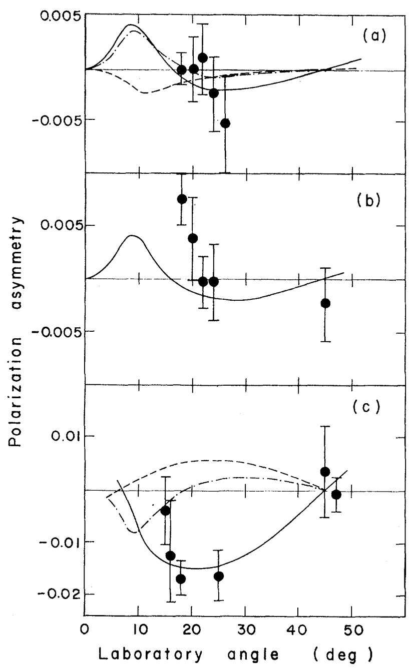

FIG. 2. Summary of experimental polarization asymmetry. The "theoretical" curves were calculated with programs adapted for the CDC-6600 computer, with slight changes from the originals of Knecht, Dahl, and Messelt (Ref. 2). (a) Data at 9.6 MeV. The solid line corresponds to ${}^3P_0=3.71°$, ${}^3P_1=1.71°$, ${}^3P_2=-2.29°$, ${}^1D_2=0.20°$. The dash-dot line corresponds to 2.75°, 1.25°, −1.75°, and 0.13° in the same order. The dashed line corresponds to 4.23°, −2.07°, 0.45°, and 0.14°; it gives the pattern typical of one-pion exchange. (b) Data at 15.6 MeV. The solid line corresponds to ${}^3P_0=4.2°$, ${}^3P_1=2.0°$, ${}^3P_2=-2.0°$, and ${}^1D_2=0.3°$. (c) Data at 19.7 MeV. The solid line corresponds to ${}^3P_0=7.73°$, ${}^3P_1=4.23°$, ${}^3P_2=-2.77°$, ${}^1D_2=1.19°$. The dash-dot line corresponds to the phases 9.04°, −2.96°, 1.84°, and 0.8°, consistent with one-pion exchange. The dashed line is obtained from the Dubna phases (Ref. 9) up to and including the D wave.

At 20 MeV the ΔE crystals were 0.010 in. thick at forward angles and 0.005 in. near 45° in the laboratory system. At lower energies the spectra were very clean without the coincidence requirement of the telescopes, and therefore the ΔE detectors were not used. The spectra were measured by setting the detectors at symmetrical angles with respect to the beam. Short runs were taken monitoring the total beam with a second ionization chamber, coupled to an electrometer integrating circuit and recycling unit. Our procedure has proven in empirical tests to provide asymmetries free of systematic errors down to about ±0.1 %. Figure 1(b) shows the geometrical layout of the experiment.

The 20-MeV data seem to be consistent with the trend as a function of energy established by the recent measurements[5] at 30 and 50 MeV and the Harvard results.[12] The implications of our polarization results can be explored in terms of S, P, and D waves. The reader is referred to Ref. 9 where the effect of including F waves is shown to be small at 23.6 MeV. Figure 2 summarizes our results (tabular values are available upon request).

In the light of our analysis we can state that the one-pion exchange assumption seems to be inadequate to account for the observed values of the polarization, and that a sizable amount of spin-orbit interaction is necessary to account for the observed node in the polarization. The addition of F waves may improve considerably the agreement with our data. Polarization effects, although small, seem to be a sensitive probe of the ill-known "intermediate range" region of the proton-proton interaction.

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[1] I. Alexeff and W. Haeberli, Nucl. Phys. 15, 609 (1960).

[2] D. J. Knecht, P. F. Dahl, and S. Messelt, Phys. Rev. 148, 1031 (1966).

[3] W. A. Blanpied, Phys. Rev. 116, 738 (1959).

[4] K. W. Brockman, Phys. Rev. 110, 168 (1958).

[5] C. J. Batty, R. S. Gilmore, and G. H. Stafford, Nucl. Phys. 45, 481 (1963), and references therein.

[6] J. Raynal, Nucl. Phys. 28, 220 (1961).

[7] H. P. Noyes, P. Signell, N. R. Yoder, and R. M. Wright, Stanford Linear Accelerator Center Report No. SLAC-PUB-269 (to be published), and references therein.

[8] G. Breit and R. D. Haracz, in High Energy Physics, edited by E. H. Burhop (Academic Press, Inc., New York, 1967), and references therein.

[9] S. I. Bile'kaya, Yu. M. Kazarinov, F. Lehar, and Z. Janout, Yadern. Fiz. 4, 892 (1966) [translation: Soviet J. Nucl. Phys. 4, 635 (1967)].

[10] R. A. Bryan and R. A. Arndt, Phys. Rev. 150, 1299 (1966).

[11] R. A. Arndt and M. H. MacGregor, Phys. Rev. 154, 1549 (1967).

[12] J. N. Palmieri, A. M. Cormack, N. F. Ramsey, and R. Wilson, Ann. Phys. (N.Y.) 5, 299 (1958).