Measurement of the Angular Distribution of Tensor Polarization in Pion-Deuteron Elastic Scattering

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The angular dependence of the deuteron tensor polarization t_{20} in π-d elastic scattering has been measured for the first time. The results, at an incident pion energy of 142 MeV, are found to be in disagreement with all present theoretical predictions.

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In recent years, there has been considerable interest in π-deuteron elastic scattering. This reaction is sensitive to two processes which, although fundamental, are still incompletely understood: (1) the absorption of a pion by two nucleons, and (2) the interaction of two nucleons. Theoretical studies[1-3] of π-d scattering have reached a high level of sophistication, incorporating fully relativistic three-body theories, the $\pi^+ + d \to p + p$ absorption channel, and a relatively complex nucleon-nucleon interaction. There also have been calculations[4,5] which have included possible effects due to dibaryon resonances without, however, explicitly including the $\pi d \to 2p$ absorption channel. These theories give similar results for the differential cross section for π-d elastic scattering but differ significantly in their prediction of the deuteron polarization. Although some polarization observables have been measured[6,7] recently, there have been insufficient data to conclusively test the theories. We therefore have measured an angular distribution of the recoil deuteron tensor polarization[8] t_{20} in π-d elastic scattering at $T_\pi = 142$ MeV. The first measurement of an angular distribution of t_{20} in π-d scattering is in disagreement with *all* present theoretical predictions.

The measurements were performed at the low-energy-pion channel of the Clinton P. Anderson Meson Physics Facility (LAMPF). A schematic diagram of the experimental arrangement is shown in Fig. 1. A 142-MeV π^+ beam with an intensity of 2×10^8 π^+/s and a 2% full-width momentum spread was directed onto a CD_2 target. Deuterons emitted from the target were focused into the polarimeter by a quadrupole doublet. The scattered pions were detected by a plastic scintillator array. Measurements were taken for recoil deuterons at laboratory angles of 17.5°, 28.9°, and 40.9°. These angles correspond to pion scattering angles in the center-of-mass frame of 144.8°, 121.9°, and 97.8°, respectively. The CD_2 target thicknesses were 89 mg/cm^2 for $\theta_d = 17.5°$ and 28.9° and 46 mg/cm^2 for $\theta_d = 40.9°$. The basic features of the polarimeter are similar to those described in Ref. 9. The $^3He(d,p)^4He$ reaction was used as the analyzer for the tensor polarization t_{20}. The polarimeter used in the present work, however, can operate at deuteron energies as low as 27 MeV, substantially lower than the one described in Ref. 9. In order to match the properties of the scattered deuteron beam at LAMPF, the polarimeter was designed to have a large spatial and angular acceptance (62 cm^2 and $\theta \lesssim 5°$, respectively). The efficiency ϵ, defined as the ratio of the number of detected $^3He(d,p)^4He$ events to the number of incident deuterons, is the quantity measured with the polarimeter. The efficiency for a polarized beam depends on the efficiency ϵ_0 for an unpolarized beam, the polarimeter analyzing power T_{20}, and the deuteron polarization t_{20} according to the

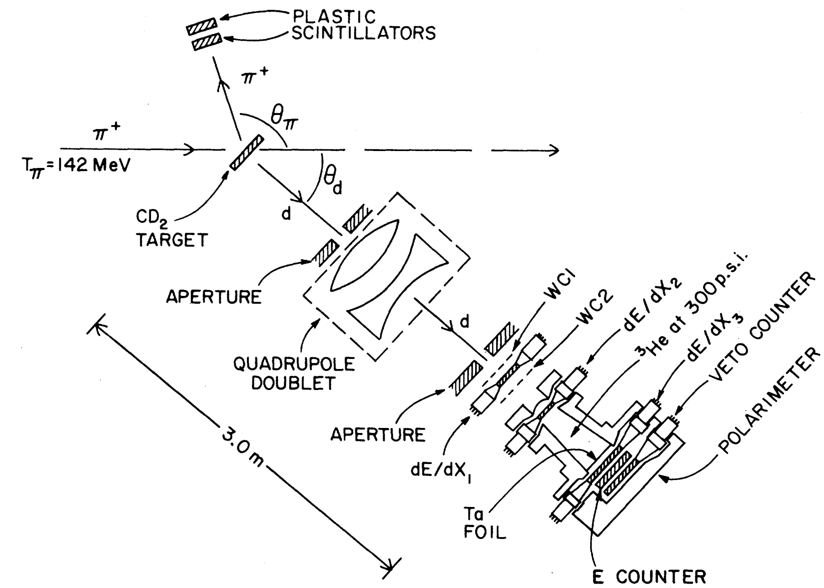

FIG. 1. Schematic diagram of the experimental arrangement at LAMPF.

relation

$$\epsilon = \epsilon_0(1 + T_{20}\, t_{20}) .$$

The quantities ϵ_0 and T_{20} were measured in a separate experiment with use of the polarized deuteron beam at the Berkeley 88-in. cyclotron. The polarization of the beam from the cyclotron was determined with the use of the $^4\mathrm{He}(d, d)^4\mathrm{He}$ reaction, which has a known[10] analyzing power. As part of the calibration procedure, ϵ_0 and T_{20} were measured as a function of position, angle, and deuteron energy. For a given energy, the variation in ϵ_0 and T_{20} over the range of positions and angles was typically less than 10%. The precautions which were taken to ensure that ϵ_0 and T_{20} were unaffected in transporting the polarimeter from Berkeley to LAMPF included: (1) the electronics were assembled aboard the ANL data-acquisition trailer, adjusted at Berkeley, and moved without disassembly to LAMPF, (2) the energy of the deuteron beam was monitored at both LAMPF and Berkeley by a Si(Li) detector, and (3) alpha sources were deposited on the scintillators and the Si(Li) detector so that detector gains at LAMPF could be matched to those at Berkeley.

The background was reduced by several methods. Protons arriving at the polarimeter as a result of $(\pi, \pi' p)$ reactions in the target were rejected by requiring the proper time difference between the pion detector and polarimeter signals. A veto counter located at the end of the polarimeter eliminated particles with sufficient energy to traverse the E counter. Software filters on the scintillator pulse heights and timing further reduced the background. Residual background was measured with the use of CH_2 and C targets. For each of the three deuteron angles, approximately 500 $^3\mathrm{He}(d, p)^4\mathrm{He}$ events were accumulated. The background measured with the C and CH_2 targets was $\lesssim 5\%$ of the total number of events.

Sources of error that have been considered are (1) statistical errors at Berkeley and LAMPF, (2) errors in the correction for detector gain shifts, (3) uncertainty in the energy of the deuteron beam, and (4) the uncertainty in the $^4\mathrm{He}(d, d)^4\mathrm{He}$ analyzing powers from Ref. 10. The largest contribution to the error results from the statistical uncertainty in the measurement of ϵ at LAMPF.

The results are shown in Fig. 2, along with the measurement at $\theta_\pi = 180°$ ($\theta_d = 0°$) from Ref. 7, and the most recent theoretical predictions. Clearly, the present work is in disagreement with these calculations. In order to compare the present measurements with the theoretical predictions, the calculated values of the tensor polarizations t_{20}, t_{21}, and t_{22} were transformed from the center-of-mass system to the laboratory frame with the expression

$$t_{20}^{\,\mathrm{lab}} = \tfrac{1}{2} t_{20}^{\,\mathrm{c.m.}}(3\cos^2\alpha - 1) + \tfrac{3}{2} t_{21}^{\,\mathrm{c.m.}} \sin 2\alpha + \tfrac{3}{2} t_{22}^{\,\mathrm{c.m.}} \sin^2\alpha ,$$

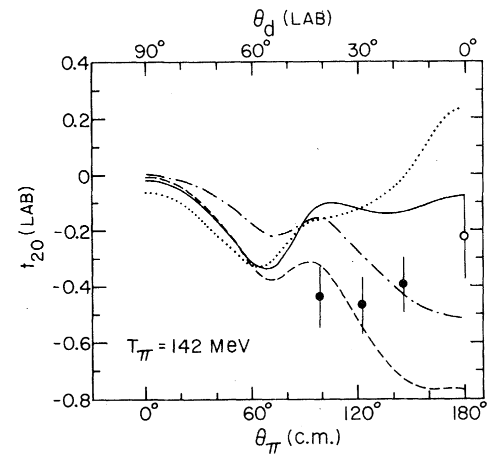

FIG. 2. Angular distribution of t_{20} at $T_\pi = 142$ MeV. The open-circle datum point is from Ref. 7 and the solid circles are from the present experiment. The dashed curve represents a calculation from Ref. 1 which does not include pion absorption. The dotted, solid, and dashed-dot curves represent calculations from Refs. 1, 2, and 3, respectively, which include absorption.

where $\alpha \equiv \theta_{\mathrm{lab}} - \theta_{\mathrm{c.m.}}$, and $\cos\theta = \hat{k}_{\mathrm{in}}{}^{\pi} \cdot \hat{k}_{\mathrm{out}}{}^{d}$. All of the predictions shown in Fig. 2 are relativistic, three-body calculations which include the effects of the true pion absorption channel, except for the dashed curve where absorption is not included. The major difference among the calculations[1-3] is the manner in which absorption is treated. Absorption is described in a somewhat microscopic manner in Refs. 1 and 2 in that the results depend explicitly on the πNN, $\pi N\Delta$, ρNN, and $\rho N\Delta$ coupling constants. Fayard, Lamot, and Mizutani[2] also include the P_{11} nonpole amplitude in the π-N part of the interaction. It is the P_{11} π-N or ρ-N amplitude which dominates the absorption process. In a more phenomenological approach, Betz and Lee[3] obtain an effective interaction potential to describe the $NN \rightarrow N\Delta$ transition. As one might expect, these three theories which treat the effects of absorption differently give rise to three very different predictions of t_{20} near $\theta_\pi = 180°$ where absorption has the largest effect.

The most serious discrepancy between the experiment and the theory occurs for the measurement near $\theta_\pi = 90$, where the three calculations which include absorption are in agreement. The single-scattering impulse approximation indicates that near $\theta_\pi = 90°$, sensitivity of t_{20} to both the π-N amplitude and the deuteron wave function is greatly diminished. In fact, t_{20} essentially reduces to a constant at 90° in this approximation. In all three calculations the effect near 90° of including the absorption channel is to increase t_{20} which worsens the disagreement with the data at $\theta_\pi = 98°$ and 122°. Thus, it is expected that while improving the description of the absorption channel may bring the empirical and theoretical values into better agreement at large angles, it will not yield the measured value of t_{20} near 90°.

We note that all three of these calculations have omitted the effects of a possible dibaryon resonance. In the energy region $T_\pi \sim 140$ MeV it has been suggested[4] that a $^1D_2$ dibaryon resonance may be excited in π-d scattering. Kubodera and co-workers have estimated the effect that the reported[11] dibaryon resonances would have on the π-d scattering amplitudes. They found that these resonances, because of the large values of spin and orbital angular momenta ($^{2S+1}L_J = {}^1D_2, {}^3F_3, {}^1G_4$), can produce oscillations in the angular dependence of the polarization observables. Moreover, Bolger *et al.*[6] have measured the angular dependence of the vector polarization at $T_\pi = 142$ and 256 MeV. At 256 MeV, oscillations were found and were consistent with the existence of a dibaryon resonance, whereas at 142 MeV no oscillations were found. In order to test the notion that the discrepancy between the measured and predicted values of t_{20} at 98° might be due to dibaryon resonances, a calculation was performed in the same manner as that of Kubodera *et al.*[4] A parameter, discussed in detail (as ϵ) in Ref. 4, represents the relative decay rate of the resonance to $l = j-1$ and $l = j+1$ where l and j are the orbital and total angular momentum in π-d scattering, respectively. If this parameter is assigned the value of -0.5, then the inclusion of the dibaryon resonances not only gives good agreement with the observed vector analyzing power, but also produces more negative values of t_{20} for $\theta_\pi > 60°$. In this example, $|t_{20}|$ changes by 0.1 for $\theta_\pi = 98°$ if the $^1D_2$ resonance is included. Although this simple calculation does not remove the present discrepancy, the indication is that the inclusion of a dibaryon resonance into a more sophisticated calculation, which includes the absorption channel, could lead to better agreement with the present experiment. Presently, it is not known what other physical phenomena would have the same effect.

Clearly, further theoretical development will be necessary in order to account for the present results. If, indeed, the dibaryon resonances are responsible for the discrepancy, then a knowledge of the energy dependence of t_{20} would be useful in order to further define the effect.

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Parity Nonconservation in the Reaction $^{19}F(\vec{p}, \alpha_0)^{16}O$

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A parity nonconservation asymmetry was observed in the reaction $^{19}F(\vec{p}, \alpha_0)^{16}O$. Longitudinally polarized protons with an energy of 670 keV hit a SF_6 gas target. The resonant proton capture leads to the 13.482-MeV, 1^+, $T=1$ state in ^{20}Ne. The analyzing power for this reaction was determined for six proton energies around 670 keV. The maximum of the analyzing power $A_{max} = (6.6 \pm 2.4)\times 10^{-3}$ was deduced from a best-fit interference curve to these points.

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The α decay of the $I^\pi = 1^+$, $T=1$ unnatural parity state at $E_x = 13.482$ MeV in ^{20}Ne to the ground state of ^{16}O is forbidden by parity and isospin selection rules[1] (see Fig. 1). An attempt to observe this decay, which is sensitive to the isovector component of the weak hadronic interaction, was undertaken by Disquê[2] in this laboratory. In order to populate this state this author used resonant proton capture in ^{19}F at 670-keV proton energy. An upper limit of $\Gamma_\alpha \leq 2\times 10^{-4}$ eV for the α-particle width of this decay was determined. The strong background of regular α particles from broad neighboring states in ^{20}Ne prevented the detection of the expected small group of parity-forbidden α particles.

A complete elimination of all regular α particles

