Tensor Polarization in π-d Scattering and Pion Absorption

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Angular distributions of the deuteron tensor polarization, t_{20}, in π-d elastic scattering at pion energies of 180, 220, and 256 MeV and an excitation function at $\theta_{c.m.}^{\pi} \approx 144°$ have been measured. The results suggest that all published calculations fail to include true pion absorption properly in the treatment of the πNN system. No rapid angular or energy dependence was found near pion energies of either 134 or 256 MeV, where other experiments have suggested the existence of dibaryons.

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Polarization effects in pion-deuteron elastic scattering are sensitive to both the pion-nucleon and the nucleon-nucleon interactions, two fundamental nuclear processes that are still incompletely understood. In the past few years, there have been sophisticated theoretical studies[1-4] incorporating relativistic three-body calculations and the coupling of the π-d elastic channel with the $\pi d \to NN$ absorption channel. All present calculations give similar results for the tensor polarization,[5] t_{20}, if true pion absorption is omitted, but they vary widely if absorption is included. The first measurement[6] of an angular distribution of t_{20} in π-d scattering, at 142 MeV, indicated that calculations with pion absorption need improvements to predict t_{20} correctly. In order to demonstrate that this is not an isolated effect at 142 MeV, we report here measurements of the tensor polarization, t_{20}, at $\theta_{c.m.}^{\pi} \approx 92°$, 120°, and 144° for pion energies of 180 and 256 MeV and at $\theta_{c.m.} \approx 92°$ and 144° for 220 MeV. Our measurements suggest that pion absorption is not taken into account properly in any present calculation.

Studies[7] of angular distributions of the vector analyzing power iT_{11}, together with calculations[8] which included effects of dibaryon resonances, suggested the presence of such a resonance near a pion energy of 256 MeV. Moreover, recent measurements[9] of t_{20} at lower energies indicated unexpected, strong oscillations in the angular distribution and a resonancelike excitation function. Therefore, an excitation function of t_{20} at $\theta_{c.m.}^{\pi} \approx 144°$ was measured at pion energies of 134, 142, 151, 180, 220, and 256 MeV. However, we find no rapid energy or angular dependence for t_{20} near either 134- or 256-MeV pion energy.

The π-d scattering experiment was performed at the P^3 channel at the Clinton P. Anderson Meson Physics Facility (LAMPF) with the setup shown schematically in Fig. 1. The π^+ beam intercepted a 5-mm-thick liquid deuterium target with a beam spot size of 20 mm (full width at half maximum). A pion momentum acceptance of 2% full width was used for energies below 151 MeV while a 4% bite was utilized at higher energies. A telescope consisting of three scintillators (labeled π1 to π3 in Fig. 1) identified the scattered pions in coincidence with the recoiling deuterons. The deuterons were detected at scattering angles of 18°, 30°, and 44° (lab) with an angular resolution of ±1.5° and a solid angle of 8.6 msr. They were focused by a quadrupole doublet and momentum analyzed in a dipole magnet with a bend angle of 35° before entering the polarimeter. The tensor polarization, t_{20}, of the deuterons was measured with the reaction $^3He(\boldsymbol{d}_{pol}, p)^4He$. If the polarimeter and the deuteron beam are rotationally symmetric around the beam axis, all polariza-

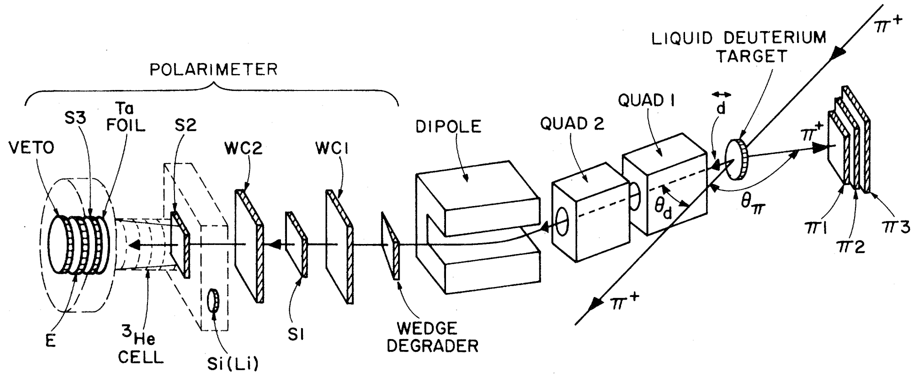

FIG. 1. Apparatus to measure t_{20} in π-d scattering (not to scale).

tion effects, other than those due to t_{20}, cancel. The deuteron polarization, t_{20}, and the polarimeter analyzing power, T_{20}, are then related by

$$t_{20}T_{20} = \epsilon/\epsilon_0 - 1,$$

where the efficiency, ϵ, is defined as the ratio of outgoing protons to incoming deuterons and ϵ_0 is the efficiency of the polarimeter for unpolarized deuterons. The same polarimeter was used in previous measurements[6] of the tensor polarization in π-d scattering at 142 MeV and in an e-d scattering experiment[10]; the basic features were similar to those of an earlier polarimeter[11] which has been described elsewhere. The large spatial and angular acceptance of the polarimeter ensured complete transmission of the deuterons through the active volume of the polarimeter. The target thickness and solid angle were chosen so that the spread of the deuteron beam in position and angle was well within the polarimeter acceptance limits. With two wire chambers (WC1 and WC2 in Fig. 1) in front of the polarimeter, the deuteron trajectories were calculated. It was verified that the deuteron beam was well contained in the ^{3}He cell, and that the polarimeter was centered to better than one tenth of the deuteron beam width to provide axial symmetry.

The polarimeter calibration utilized a polarized deuteron beam from the 88-in. cyclotron at the University of California, Berkely, and involved measurement of the efficiency, ϵ_0, and the analyzing power, T_{20}, as a function of incident position, angle, and energy. The efficiency, ϵ_0, was remeasured at the Los Alamos National Laboratory tandem Van de Graaff accelerator and, within 2%, agreed with that obtained at Berkeley. During the π-d experiment, two Si(Li) detectors were used to map the deuteron beam energy as a function of position on the polarimeter both before and after each polarization measurement. A wedge-shaped absorber, located in front of the polarimeter, was adjusted for each measurement to match the dispersion of the dipole and to give a deuteron beam with optimal energy and smallest energy variation across the polarimeter entrance.

Several procedures were employed in order to identify clearly ^{3}He$(d,p)^4$He events and to reduce background. A deuteron was identified by software filters on the energy loss in the scintillators S1 and S2 and on the time difference between the pion and deuteron signals. In addition, a ^{3}He$(d,p)^4$He event had to have the correct energy loss and energy in the plastic scintillators S3 and E, respectively, correct time-of-flight through the polarimeter, and no veto signal. Residual background from the target cell and vacuum windows was found to be negligible by repeating the experiment with an empty target cell at several pion energies and deuteron angles.

The excitation function obtained at $\theta_{c.m.}^{\pi} \approx 144°$ is shown in Fig. 2. The error bars include sta-

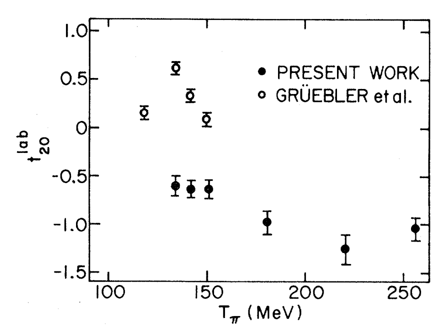

FIG. 2. Excitation function at $\theta_d = 18°$ (solid dots) compared with the results of Grüebler *et al.* (Ref. 9) at $\theta_d = 15°$ (open circles). The angular acceptances are $\pm 1.5°$ and $\pm 2.5°$, respectively.

tistical errors as well as relative uncertainties in the deuteron energy measurements and in the correction for scintillator gain shifts. In addition to these errors, there is an overall uncertainty of approximately $\Delta t_{20} \approx \pm 0.1$, due mainly to the errors in the deuteron energy measurement between calibration and experiment.

As shown in Fig. 2, our excitation function at $\theta_{c.m.}^{\pi} \approx 144°$ differs from recent data of Grüebler *et al.*[9] In their experiment the deuteron beam size, when the effects of second-order beam optics are taken into account, is comparable with the size of the polarimeter aperture (30 mm). Thus, a large fraction of deuterons detected in the front scintillator (also 30 mm diam in the experiment of Grüebler *et al.*) may not be fully transmitted through the ^{3}He volume. The transmission is very sensitive to the tune of the quadrupole triplet. This can result in a smaller efficiency and a systematic, momentum-dependent error towards more positive values for t_{20}. This problem is not encountered in the present work, since the deuteron beam size is comparable with that of Grüebler *et al.*, but the polarimeter aperture is 89 mm.

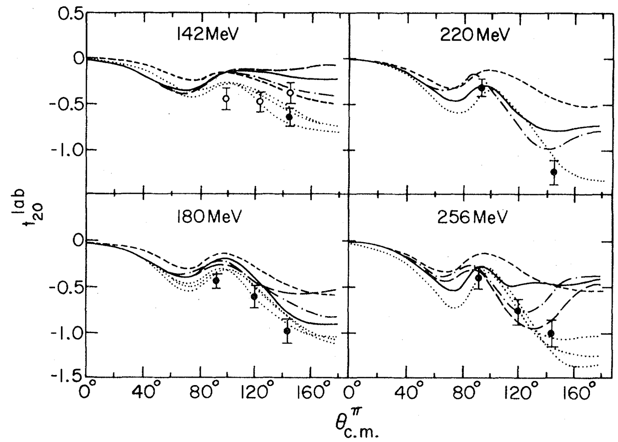

FIG. 3. Angular distributions at pion energies of 142, 180, 220, and 256 MeV. [Open circles are from the previous experiment (Ref. 6).] The calculations are from Blankleider and Afnan (Ref. 1) (solid curves), Betz and Lee (Ref. 2) (short-dashed curves), Fayard, Lamot, and Mizutani (Ref. 3) (long-dashed curves), and Rinat and Starkand (Ref. 4) (dot-dashed curves), all including true pion absorption. The dotted lines are results without P_{11} amplitude, i.e., without pion (Refs. 12–14) absorption.

Angular distributions at pion energies of 142, 180, 220, and 256 MeV are compared with recent theoretical predictions in Fig. 3. In order to compare the calculations with our data, we have transformed the calculated values of the tensor polarizations, $t_{20}^{c.m.}$, $t_{21}^{c.m.}$, and $t_{22}^{c.m.}$, from the center-of-mass system to the laboratory frame, including precession in the dipole magnet, with the expression[15]

$$t_{20}^{\text{lab}} = \tfrac{1}{2} t_{20}^{\text{c.m.}} (3\cos^2\beta - 1) - 2(\tfrac{3}{2})^{1/2} t_{21}^{\text{c.m.}} \sin\beta\cos\beta + (\tfrac{3}{2})^{1/2} t_{22}^{\text{c.m.}} \sin^2\beta;$$

$$\beta = \theta_{1\text{ab}}{}^{d} - \theta_{\text{c.m.}}{}^{d} + \theta_{\text{bend}}{}^{d}(E_d/M_d)(1-\mu_d), \quad \cos\theta_{1\text{ab}}{}^{d} = \hat{k}_{\text{in}}{}^{\pi}\cdot\hat{k}_{\text{out}}{}^{d}.$$

The total energy, rest mass, and magnetic dipole moment of the deuteron are denoted by E_d, M_d, and μ_d.

All calculations without a P_{11} πN amplitude, i.e., no pion absorption or P_{11} πN rescattering,[12-14] give very similar results (dotted curves in Fig. 3) and are remarkably close to the present experimental results. In fact, the curves with no P_{11} amplitude are in better agreement with the present work than any of the full calculations. It is well known that the P_{11} πN amplitude is necessary for pion absorption. The most widely used procedure is to divide the P_{11} amplitude into a rescattering part and an absorption part due to the nucleon pole. However, Mizutani *et al.*[16] showed that both the pole and the nonpole parts of this amplitude can be large and are basically not restricted by previous πN scattering data, even though the total P_{11} amplitude is relatively well known and small at low energies.

Since there is a coupling of the $\pi d \to \pi d$ and $\pi d \to NN$ channels in nature, it is believed[1-4] that absorption should have a large effect on t_{20} in πd scattering. Different calculations with pion absorption vary widely, indicating that they are very sensitive to the parametrization of the P_{11} πN amplitude. Thus, there is a strong indication that the present parametrizations of the P_{11} amplitude are incorrect. Moreover, Afnan and Blankleider note that the dominant absorptive effects in $\pi d \to \pi d$ and $\pi d \to pp$ occur in different spin-isospin channels.[17] Therefore, it seems possible that the absorption amplitudes can be adjusted to improve t_{20} without worsening the results for other observables. Further measurements of t_{20} at backward angles and high pion energies would certainly be helpful. Inasmuch as the present data show no strong energy or angular dependence, it seems unlikely that explicit inclusion of dibaryon resonances will be required in order to explain the results. This question, however, will be answered only after further development of the theoretical calculations.

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