Understanding Polarization Observables in Pion-Deuteron Scattering

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With the same relativistic three-body theory which reproduces the pion-deuteron elastic and breakup differential cross sections, it is also possible to explain the energy and angular dependence of the reaction parameters iT_{11} and t_{20} throughout the region of the 3,3 resonance. This theory differs from other models in that it treats relativistically not only the space variables but also the spin variables and it has a much smaller contribution from pion absorption.

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Presently, the theoretical and experimental situation of polarized pion-deuteron scattering can be said to be one of considerable confusion. On the theoretical side, the predictions from various groups differ greatly, mainly as a result of the particular way in which they treat the pion-absorption channel,[1-4] although other problems arise if they include relativistic kinematics for the three particles[1,3] or only the pion.[2] Also, even though for polarization reactions the spin degrees of freedom are the most relevant variables, all of these models treat the spin nonrelativistically; that is, they assume that a spinor in a given reference frame looks the same when it is observed from another reference frame. From the experimental side, the early data[5,6] for the vector analyzing power iT_{11} contained strong oscillations which were interpreted as dibaryon resonance signals,[7,8] although in a new comprehensive set of measurements this oscillatory behavior has now disappeared.[9] In the case of the tensor polarization t_{20}, two different groups have measured contradictory sets of data at $T_\pi = 140$ MeV and $100° < \theta_\pi < 180°$; Holt and coworkers[10,11] found that t_{20} was negative with values of $t_{20} \sim -0.4$, while Grüebler and co-workers[12,13] found that t_{20} was strongly oscillatory with values of $0 \lesssim t_{20} \lesssim 0.6$, and where again the strong oscillations were interpreted as a dibaryon resonance signal. Finally, a recent set of measurements of t_{20} at four energies[14] found the interesting result that if the calculations were performed including pion absorption, they did not fit the data, while the theoretical results looked quite reasonable if pion absorption was neglected. I will try in the following to clarify this present situation of confusion.

In two previous Letters[15,16] I have described a relativistic three-body model and have used it successfully to explain the elastic and breakup differential cross sections in the region of the 3,3 resonance. In this model, the relativistic Faddeev equations are solved with the pion-nucleon interaction represented by the six S- and P-wave channels and the nucleon-nucleon interaction by the two S-wave channels. It assumes separable T matrices $t(p,p';s) = g(p)\tau(s)g(p')$ which are normalized to the experimental phase shifts and inelasticities and are extended to the off-shell region by means of form factors $g(p) = p^l/(\alpha^2 + p^2)$, where α is taken to be 1 GeV/c for the pion-nucleon channels[17-19] and equal to the Yamaguchi values[20] for the nucleon-nucleon channels after taking into account the minimal relativity factors.[21] The model treats relativistically not only the space variables but the spin variables as well, since the partial-wave decomposition of the equations is performed using Wick's three-body helicity formalism,[22,23] which takes into account the Lorentz transformation of the spin from the two-body c.m. frames to the three-body frame. This effect, the so-called "Wigner rotation of the spin in a Lorentz transformation," is neglected in other existing theoretical models of the pion-deuteron system,[1-4] but clearly if one is trying to understand polarization phenomena which are directly connected with the spin, this relativistic kinematical effect must be taken into account particularly if one goes to higher energies.

I do not treat the pion-nucleon P_{11} partial wave differently from the other pion-nucleon channels, as proposed by Avishai and Mizutani[24] and Blankleider and Afnan.[2] All the pion-nucleon T matrices are normalized to the experimental on-shell values for $s > (M+\mu)^2$ and are extrapolated to the unphysical region $s < (M+\mu)^2$ as $\tau(s) = \tau((M+\mu)^2)s/(M+\mu)^2$, where I have checked that the results are completely insensitive to which choice of extrapolation formula is used.[15] The fact that the P_{11} T matrix does not have a pole at $s = M^2$ does not mean that the contribution from the nucleon pole has been neglected, since in the physical region both pole and nonpole parts are automatically included if one uses the experimental P_{11} amplitude, while I have found that the contribution from the unphysical region is very small. What is not included by this procedure, however, is the contribution from the imaginary part of the nucleon pole (the delta function part) which has no effect at all in the two-body case but which gives rise to a cut in the three-body case beginning at $s=4M^2$ which is the contribution of the inelastic pion-absorption channel to the three-body-unitarity discontinuity relations. I have calculated the contribution of this cut separately for each term of the Born series and solved the integral equations by means of Padé approximants. I found that including the pion-absorption cut changes the differential cross sections and reaction parameters by less than 3%, so that the total contribution from the pion-absorption channel is quite small. This small effect of the P_{11} channel I consider a very important result, which is clearly in contradiction with those of the $NN \rightarrow \pi NN$ theory.[1-3] However, I should point out that since the pion-absorption cut is calculated by integrating over a delta function, it is essentially model independent so that it is the same in the present model as in the $NN \rightarrow \pi NN$ theory. Thus, the large effects obtained in the $NN \rightarrow \pi NN$ are *not* due to the pion-absorption cut which is the relevant contribution to unitarity, but to the decomposition of the P_{11} channel into a pole and a nonpole part, both of which are large in the physical region, although it is well known that the experimental P_{11} amplitude itself is very small. Since this decomposition is irrelevant for the requirements of three-body unitarity and in addition has the consequence of introducing large effects that were not present in the original P_{11} amplitude, very likely these large effects are spurious. This conclusion has also been reached recently by Ungricht *et al.*,[14] as already mentioned.

Figure 1 shows the present predictions for the vector analyzing power iT_{11} at the twelve energies throughout the region of the 3,3 resonance measured recently by the Karlsruhe group.[9] As we see, with the exception perhaps of the case at 275 MeV, the model is able to reproduce quite well the shape of the data over the entire energy range, the main discrepancy between experiment and theory being that one lies consistently lower than the other by about one-third. (It is interesting that some of the data points from an older experiment[5,6] at five energies have now been renormalized downwards by exactly this amount.[9]) The most outstanding feature of the data as a function of increasing pion energy is the gradual development of a minimum in the forward direction simultaneously with the narrowing of the width of the central peak, which, as we see in Fig. 1, is a behavior also followed by the theory.

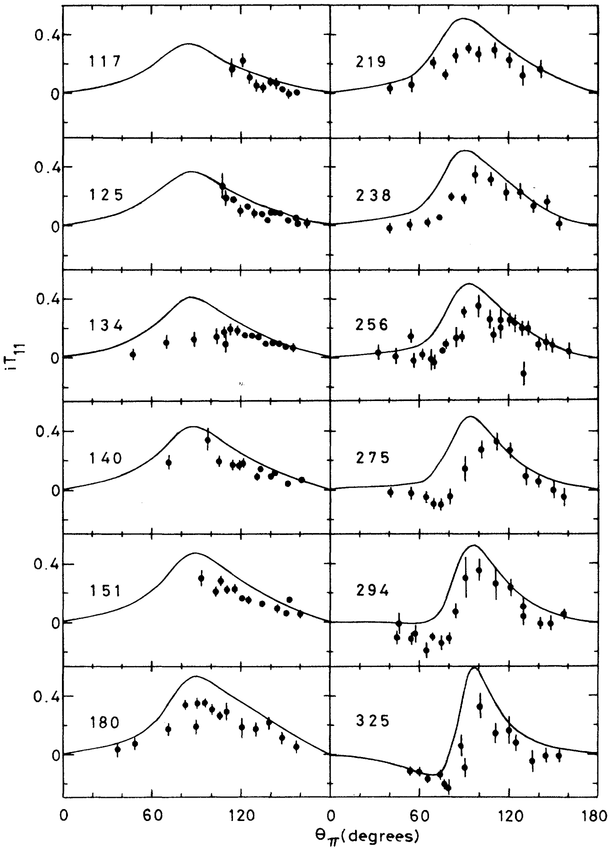

FIG. 1. The vector analyzing power iT_{11} in the center-of-mass system. The laboratory kinetic energy of the pion is given in megaelectronvolts for each case. The experimental points are from Ref. 9.

The tensor polarization t_{20} has also been measured recently[14] both as a function of energy and as a function of angle, although not as extensively as iT_{11}. I show in Fig. 2(a) the prediction for the energy dependence of t_{20} at a fixed deuteron recoil angle of 18°, and compare with the recent data of Ref. 14; we see that both agree quite well, particularly with regard to the fact that there is a minimum at an energy of approximately 210 MeV. Figure 2(b) shows the angular dependence of t_{20} at four different energies,[14] where we see that here also there is no obvious discrepancy between theory and experiment.

To conclude, I have found that contrary to other theories the contribution of pion absorption is very small. The present model, which has worked so well before to describe the elastic[15,25] and breakup[16] differential cross sections and the total cross section,[26] is also able to describe the energy and angu-

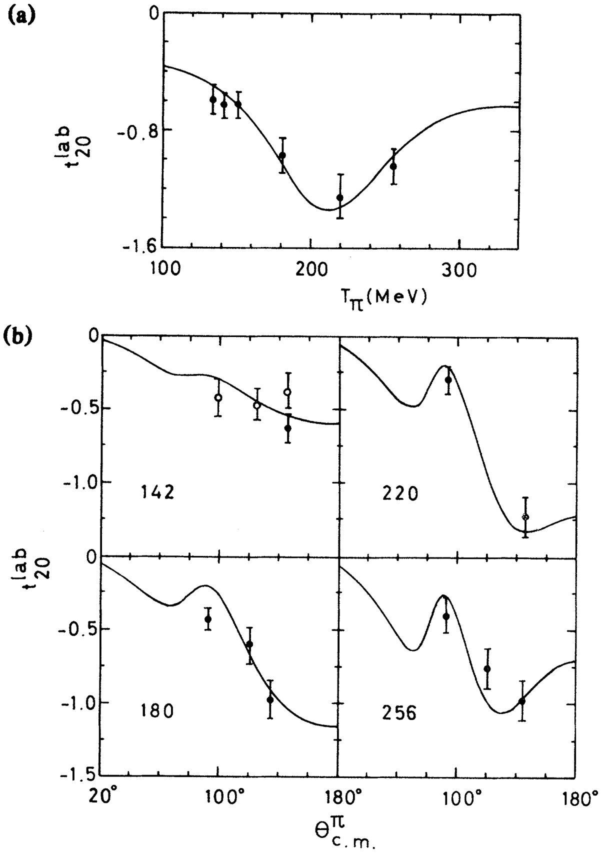

FIG. 2. The tensor polarization t_{20} in the laboratory system (a) for a fixed deuteron recoil angle of 18°, as a function of the kinetic energy of the pion; and (b) at four different kinetic energies of the pion given in megaelectronvolts for each case, as a function of the c.m. scattering angle of the pion. The experimental points are from Ref. 14.

lar dependence of the reaction parameters iT_{11} and t_{20}. No evidence has been found of a serious discrepancy between theory and experiment that may imply the presence of dibaryon resonance effects.

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