Pion-deuteron scattering and the ΔN interaction

H. G. Dosch
Institut für Theoretische Physik, Universität Heidelberg, D-6900 Heidelberg, West Germany

Sarah C. B. de Andrade and Erasmo Ferreira
Departamento de Fisica, Pontificia Universidade Catolica, Rio de Janeiro, RJ, Brazil

Gustavo Perez Munguia
Universidad Nacional Autonoma de Honduras, Tegucigalpa, Honduras
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We evaluate the contribution of a $J^P = 2^+$ dibaryon resonance to the forward πd amplitude, taking into account the fact that the deuteron is a loosely bound structure. Comparison with the data shows that these are well compatible with a resonance in the $^5S_2$, $I = 1$ Δ-N channel.

Remarkable structures have been observed in the experimental values of the cross sections for proton-proton scattering with polarized beam and target particles.[1] In particular, remarkable behavior of some amplitudes is seen to occur in the energy region close to the ΔN threshold ($\sqrt{s} \approx 2.15$ GeV). A phase shift analysis of Hoshizaki[2] and a coupled channel (NN, NΔ, ΔΔ) analysis of the isospin-one dibaryon system by Edwards and Thomas[3] both indicate independently the existence of resonances in the $^1D_2$ and $^3F_3$ partial waves at about 2.15 and 2.22 GeV, respectively. An important output of the latter analysis consists in the result that both resonances are strongly coupled to the ΔN channel.

The strong NΔ interaction near threshold is expected to have influence on observable quantities in πd collisions at intermediate energies. Such an interaction in the direct channel is not included in conventional three-body calculations of the πd system, and its contribution must be evaluated independently. Discrepancies still found[4–7] in the description of the πd experiments may be due to contributions of this sort.

Several papers[8] have dealt with the problem of adding the contributions of dibaryon resonances to the basic πd amplitudes. In all of these cases an arbitrary phenomenological πdB_2 interaction is assumed for each resonance and each appropriate angular momentum channel. The coupling parameters are then adjusted so as to fit experiments and eliminate discrepancies in the best possible way. The success of these attempts is not impressive, in spite of the arbitrariness of the parameters. Among other observed difficulties, it is seen that the energy dependence of the added contributions is not adequate.

In this Brief Report we describe the coupling of the πd system to the $^1D_2$ dibaryon microscopically, taking into account the loosely bound structure of the deuteron by evaluating the skeleton diagram of Fig. 1. This has as a consequence that (i) the coupling constant of the πdB_2 vertex is replaced by a function $F_\Delta(s)$, whose very characteristic s dependence is determined by the triangle diagram, and (ii) the formation of the dibaryon resonance results from the direct interaction of two baryons (NN or NΔ). In the present work we apply this model to the evaluation of the forward πd elastic amplitude and show that the energy dependence obtained may lead to an improvement in the description of the experimental data in a wide energy interval below and above the $^1D_2$ resonance mass.

The main off-mass-shell effects in the diagram of Fig. 1 result from the rapidly varying denominators. Therefore, in the evaluation of the integrals the terms in the numerators have been extracted from the integrals at their on-mass-shell values, whereas the complete variation of the denominators has been taken into account.

For the dNN vertex we neglect the D-wave contribution and for the remaining $^3S_1$ vertex we use a vertex function which is a relativistic generalization of the Hulthén-wave function (see Ref. 9). The πNΔ coupling is determined by the value of the Δ width. It turns out that the contributions with two nucleons in the intermediate state (Δ replaced by N in Fig. 1) are kinematically suppressed by a factor larger than 20. This suppression has two reasons: (i) The triangle diagram is enhanced near the threshold of an exterior instability. (ii) The D-wave threshold factor of the $^1D_2$-NN channel leads to a substantial reduction of the triangle diagram. For the same reason the formation of intermediate resonances with higher mass and higher angular momentum is also suppressed. We thus concentrate on the contribution of the possible Δ-N resonance in the $^5S_2$ partial wave.

The evaluation of the diagram of Fig. 1, especially the treatment of the exterior instability, is very similar to that given in Ref. 9. The contribution of diagram 1 to the spin averaged $J^P = 2^+$ πd forward scattering amplitude can be

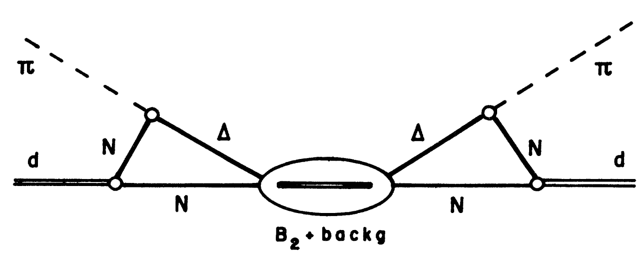

FIG. 1. Contributions of ΔN intermediate state interaction to πd elastic scattering. Kinematical factors strongly suppress the corresponding diagrams with nucleons instead of deltas.

written in the form

$$f_{\pi d}^{\rm corr}(s)=H\mathcal{F}_\Delta^2(s)T_{\Delta N\Delta N}(s)/3k \ , \quad (1)$$

where

$$H=\frac{16}{27}\frac{k^3}{m_\Delta m_N\sqrt{s}}\left[1-\frac{E_\pi}{2m_\Delta}\right]^2 g^2_{\Delta^{++}p\pi^+} \ , \quad (2)$$

where E_π and k are the total energy and momentum of the pion in the πd center-of-mass (c.m.) system, and $\sqrt{s}$ is the total c.m. energy. $F_\Delta(s)$ is an integral representation of the triangle diagram after summation over internal spin degrees of freedom:

$$\mathcal{F}_\Delta(s)=8m_\Delta m_N^2\int\frac{d^4q}{(2\pi)^4}\frac{F[(d-q)^2,q^2]}{(q^2-m_N^2)[(d-q)^2-m_N^2][(d-q-\pi)^2-m_\Delta^2+im_\Delta\Gamma_\Delta]} \ , \quad (3)$$

where $F[(d-q)^2,q^2]$ describes the deuteron vertex. The instability of the Δ resonance is taken into account using the complex mass $m_\Delta=1.211-i0.0499$ GeV.

In order to test independently the significance of a $J^P=2^+$ resonance in the ΔN system at a mass value $m_R=2.15$ GeV and a width $\Gamma\approx0.10$ GeV, we approximate the ΔN scattering amplitude by a Breit-Wigner $J^P=2^+$ resonance plus a real constant background, which simulates the combined effect of the nonresonant interaction in all partial waves. Thus

$$T_{\Delta N\Delta N}(s)=\frac{\gamma}{m_R^2-s-im_R\Gamma}+\alpha \ , \quad (4)$$

with γ and α as free parameters.

Comparison with the experimental scattering amplitudes requires that the contributions form the diagram of Fig. 1 be added to a background theoretical calculation in which the intermediate state ΔN interaction is not taken into account. The theoretical calculations of πd scattering amplitudes are relatively reliable in the forward direction, related to the total cross section by the optical theorem. For the total cross section at pion laboratory kinetic energies of 142, 180, and 256 MeV the solutions of relativistic Fadeev equations of Ref. 6 give $\sigma_T=171$, 233, and 146 mb, respectively, while the expansion of the Fadeev amplitude in a multiple scattering series as in Ref. 7 gives $\sigma_T=162$, 229, and 142 mb, respectively.

Since many more energy points are covered in the calculations of Ref. 7 than in other calculations, we have made the detailed analysis using "background" values obtained in Ref. 7.

In Fig. 2 we display a comparison between experimental and theoretical values of the total cross section. The dotted curve represents the theoretical calculations[7] with multiple scattering corrections, but without account of the intermediate state interaction in the direct channel; the solid curve represents the theoretical calculation including the ΔN intermediate state interaction of Eq. (1). The overall agreement with experiment is now improved. The best choice for the values for the parameters in Eq. (4) is

$$\gamma=0.82\ \text{GeV}^2,\quad \alpha=3.46 \ . \quad (5)$$

The large background term α in Eq. (4) is necessary in order to obtain a good fit, but the resonance term also is essential: A fit with no resonance term, but a complex constant background and the theoretical results of Ref. 7, yields a χ^2 value which is nine times larger than that of a fit with a

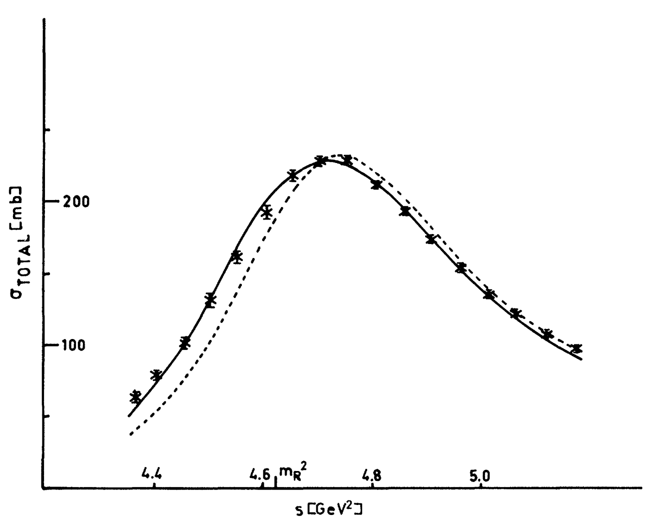

FIG. 2. Total charge averaged πd cross section. The experimental points are from Ref. 10. The dotted line represents the conventional calculation of Ref. 7. The full line represents the theoretical calculation including the correction due to the interaction in the Δ-N intermediate state.

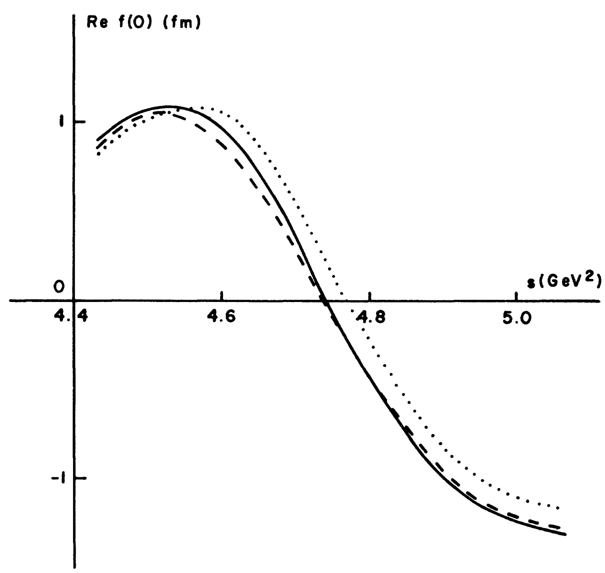

FIG. 3. Real part of the spin-averaged πd forward scattering amplitude. The full line represents the results obtained from experimental data (Ref. 10). The dotted line shows the theoretical background, and the dashed line includes the corrections already mentioned in the caption for Fig. 2.

resonance term plus a real constant background.

The inclusion of the same intermediate ΔN state interaction also significantly improves the agreement with the real part of the πd forward scattering amplitude (see Fig. 3).

If we add the intermediate state ΔN interaction to the calculated cross section of Ref. 6, agreement with experiment can be improved also. In that case the optimal parameters are

$$\gamma = 0.60\ \text{GeV}^2, \quad \alpha = 2 \ .$$

The constant γ in Eq. (4) can be related to the partial decay width of the $J^P = 2^+$ resonance into a N and a Δ by

$$\gamma \rho_{\Delta \mathrm{N}}(m_R) = m_R \Gamma^R_{\Delta \mathrm{N}} \ , \tag{6}$$

where $\rho_{\Delta \mathrm{N}}(m_R)$ is the phase space factor of the $N\Delta$ system at the value of the resonance mass. Inserting the complex mass for the Δ and using

$$\rho_{\Delta \mathrm{N}}(s) = \mathrm{Re}\{[s-(m_\Delta + m_\mathrm{N})^2 + i\Gamma_\Delta(m_\Delta + m_\mathrm{N})] \times [s-(m_\Delta - m_\mathrm{N})^2 + i\Gamma_\Delta(m_\Delta - m_\mathrm{N})\}^{1/2} \ , \tag{7}$$

we obtain a width of about 50 MeV, which rests well in the range obtained in the coupled channel analysis[3] for NN and NN $\rightarrow$ NΔ scattering.

The partial decay width into the πd system, evaluated by taking the vertex function at a resonance mass of $(2.15 + i0.06)$ GeV turns out to be about 10 MeV. It can hardly be compared with the parameters of Ref. 8 due to the strong energy dependence of the vertex function.

We may conclude that a $J^P = 2^+$ resonance at 2.15 GeV, coupled strongly to the ΔN channel, will have a small but characteristic direct influence on the πd forward scattering. The present analysis shows that the data are certainly compatible with such a resonance. According to the confidence in the theoretical calculations of Refs. 6 and 7, one may even interpret our results as an independent indication for such a resonance in the ΔN channel.

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[1]A. Yokosawa, Phys. Rep. 64, 47 (1980).
[2]N. Hoshizaki, Prog. Theor. Phys. 60, 1796 (1978); 61, 129 (1979).
[3]B. J. Edwards and G. H. Thomas, Phys. Rev. D 22, 2772 (1980); B. J. Edwards, *ibid.* 23, 1978 (1981).
[4]B. Blankleider and I. R. Afnan, Phys. Rev. C 24, 1572 (1981).
[5]N. Giraud, C. Fayard, and G. H. Lamot, Phys. Rev. C 21, 1959 (1980); C. Fayard, G. H. Lamot, and T. Mizutani, Phys. Rev. Lett. 45, 524 (1980).
[6]A. S. Rinat, E. Hammel, Y. Starkand, and A. W. Thomas, Nucl. Phys. A329, 285 (1979).
[7]E. Ferreira, L. P. Rosa, and Z. D. Thomé, Phys. Rev. C 16, 2353 (1977).
[8]K. Kanai *et al.*, Prog. Theor. Phys. 62, 153 (1979); K. Kubodera *et al.*, J. Phys. G 6, 171 (1980); C. Fayard *et al.*, Phys. Rev. Lett. 45, 524 (1980); A. Matsuyama and K. Yasaki, Nucl. Phys. A364, 477 (1981); E. Ferreira and G. Perez, J. Phys. G 9, 169 (1983); M. P. Locher and M. E. Sainio, Phys. Lett. 121B, 227 (1983).
[9]H. G. Dosch and V. Hepp, Phys. Rev. D 18, 4071 (1978).
[10]E. Pedroni *et al.*, Nucl. Phys. A300, 321 (1978).