Nonpionic effects in deuteron asymptotic observables

J. L. Ballot
Division de Physique Théorique, Institut de Physique Nucléaire, Orsay, France

M. R. Robilotta
Instituto de Física da Universidade de São Paulo, Caixa Postal 20516, 01498 São Paulo, São Paulo, Brazil

(Received 24 September 1991)

The contribution of nonpionic dynamics to deuteron asymptotic observables is investigated. It is shown that effects due to ρ and ω exchanges are negligible.

PACS number(s): 21.30.+y

I. INTRODUCTION

It is well known that pion dynamics dominates deuteron asymptotic observables, especially η, the D/S ratio, and Q, the quadrupole moment. However, as pointed out by several authors [1–7], this dominance is not complete, since there are many other mechanisms that can contribute. Among these, the main ones may be expected to be the pion-nucleon form factor and both correlated and uncorrelated multipion exchanges.

In a previous paper [6], we have discussed a procedure, employing a toy potential, that allows the unambiguous determination of the pion contribution to deuteron asymptotic observables as function of the pion-nucleon coupling constant. This means that the combined knowledge of the experimental value of this constant and of deuteron observables could allow one to assess the importance of nonpionic processes.

The question that now arises is to determine whether it is possible to disentangle the various individual effects. In this paper we tackle this problem in the framework of a specific model for the nucleon-nucleon interaction, namely, the potential developed by de Tourreil, Rouben, and Sprung (TRS) [8]. Our motivation for this choice stems from the fact that this potential incorporates the necessary dynamics, reproduces well the bound state and continuous observables, and is relatively simple. It is worth noting, however, that our procedure is independent of this particular choice and can be easily extended to other interactions.

The predictions of the TRS potential for η and Q and the corresponding pionic values for the same binding energy and strength of the πN coupling constant are displayed in Table I. It is possible to see that one is dealing with effects of the order of 5%.

TABLE I. Values for the asymptotic D/S ratio (η) and the quadrupole moment (Q_p) divided by the square of the S-wave asymptotic normalization (Δ_S) obtained by means of the de Tourreil, Rouben, and Sprung potential and an almost purely pionic interaction.

	$100\,\eta$	Q_P/A_S^2 (fm^3)
TRS	2.617	0.3551
Pion	2.722	0.3744

In order to isolate the various individual dynamical contributions to the asymptotic constants, we construct in Sec. II a hybrid potential, containing various free parameters that allow the interpolation between the toy and TRS potentials. The basic idea is to start from the toy results and then turn on, one by one, the various nonpionic effects and study their contributions to observables. This is done in Sec. III, where we also present our conclusions.

II. THE HYBRID POTENTIAL

The Schrödinger equation for our problem is written as

$$u''-(\alpha^2+mV_C)u=\sqrt{8}mV_T\omega\ , \tag{1}$$

$$\omega''-\left[\alpha^2+\frac{6}{r^2}+mV_D\right]\omega=\sqrt{8}mV_Tu\ , \tag{2}$$

where u and ω are the usual S and D components of the deuteron wave function, V_D indicates the combination

$$V_D=V_C-2V_T-3V_{LS}+6V_{L^2}+9V_{L12}\ , \tag{3}$$

and V_C, V_T, V_{LS}, V_{L^2}, and V_{L12} are respectively the central, tensor, spin-orbit, quadratic orbital angular momentum, and quadratic spin-orbit components of the NN potential. These terms are taken to be linear combinations of contributions coming from both toy and TRS potentials. The former contains a one-pion exchange potential (OPEP) tail and is regularized at the origin by means of monopole form factors, which are introduced by multiplying the πN coupling constant f by a factor $[(\Lambda^2-\mu^2)/(\Lambda^2+\mathbf{k}^2)]$, where Λ is a parameter that represents at once the πN form factor and other dynamical effects, such as multimeson exchanges. In order to allow for more flexibility, we use different values of Λ for the central and tensor components, which are denoted respectively by Λ_C and Λ_T. The toy potential is explicitly written as

$$V_C(r)=-f^2\mu[U_C(r)-\delta G(r)]\ , \tag{4}$$

$$V_T(r)=-f^2\mu U_T(r)\ , \tag{5}$$

where the radial functions have the form

$$U_C(r)=\frac{e^{-\mu r}}{\mu r}-\frac{\Lambda_C}{\mu}\frac{e^{-\Lambda_C r}}{\Lambda_C r}-\frac{1}{2}\frac{\mu}{\Lambda_C}\left[\frac{\Lambda_C^2}{\mu^2}-1\right]e^{-\Lambda_C r}, \tag{6}$$

$$G(r)=\frac{1}{2}\frac{\mu}{\Lambda_C}\left[\frac{\Lambda_C^2}{\mu^2}-1\right]^2 e^{-\Lambda_C r}, \tag{7}$$

$$U_T(r)=\left[1+\frac{3}{\mu r}+\frac{3}{\mu^2 r^2}\right]\frac{e^{-\mu r}}{\mu r}-\frac{\Lambda_T^3}{\mu^3}\left[1+\frac{3}{\Lambda_T r}+\frac{3}{\Lambda_T^2 r^2}\right]\frac{e^{-\Lambda_T r}}{\Lambda_T r}-\frac{1}{2}\frac{\Lambda_T}{\mu}\left[\frac{\Lambda_T^2}{\mu^2}-1\right](1+\Lambda_T r)\frac{e^{-\Lambda_T r}}{\Lambda_T r}. \tag{8}$$

A discussion about the physical and geometrical meanings of these parameters, as well as contact with forms used by other authors can be found in Refs. [6,7].

A major limitation of the toy potential is that it does not include important dynamical effects such as ρ and ω exchanges. In order to allow them to be introduced gradually, we write the hybrid potential as the following linear combination of the toy and TRS potentials

$$\begin{aligned}V_C^{ST}(r)=&\alpha_{C,\pi}\{zY_C(\pi)F(r)+(1-z)[U_C(r)-\delta G(r)]\}\\&+\{x\alpha_{C,\rho}Y_C(\rho)+y\alpha_{C,\omega}Y_C(\omega)+zp_2Y_C(p_1 r)\}F(r)+zp_3\{1-F(r)\},\end{aligned} \tag{9}$$

$$\begin{aligned}V_T^{ST}(r)=&\alpha_{T,\pi}\{zY_T(\pi)F(r)+(1-z)U_T(r)\}\\&+\{x\alpha_{T,\rho}Y_T(\rho)+y\alpha_{T,\omega}Y_T(\omega)+zp_8Y_T(p_1 r)\}F(r)+zp_9\{1-F(r)\},\end{aligned} \tag{10}$$

$$V_{LS}^{ST}(r)=\{x'\alpha_{LS,\rho}Y_{LS}(\rho)+y'\alpha_{LS,\omega}Y_{LS}(\omega)+zp_6Y_{LS}(p_1 r)\}F(r)+zp_7\{1-F(r)\}, \tag{11}$$

$$V_{L12}^{ST}(r)=\{x'\alpha_{L12,\rho}Y_{L12}(\rho)+y'\alpha_{L12,\omega}Y_{L12}(\omega)+zp_4Y_{L12}(p_1 r)\}F(r)+zp_5\{1-F(r)\}, \tag{12}$$

$$V_{L^2}^{ST}(r)=z\{p_{10}Y_C(p_1 r)+p_{11}Y_C(\rho)\}F(r). \tag{13}$$

The components of the TRS potential are written following exactly the notation of Ref. [8] where all the details are found. The parameter x regulates the contribution of the rho meson to the central and tensor components whereas x' is related to the linear and quadratic spin-orbit terms. The variables y and y' play a similar role for the omega meson. The parameter z controls the phenomenological parts of the potential, which include both medium- and short-range contributions simulating at once the exchange of two uncorrelated pions, effects associated with the size of the nucleon and other multimeson processes. The TRS and toy limits are reached when all the variables are set equal to 1 and 0, respectively.

III. RESULTS AND DISCUSSION

In order to assess the influence of medium- and short-range effects over observables we fixed the πN coupling constant at the TRS value $g=13.465\,984\,84$, corresponding to $f^2=0.077\,9667$. We then looked for the value of δ that, for fixed values of all the other free parameters, would yield the TRS binding energy $E=2.2245$ MeV, which is slightly different from that employed in our previous paper. We have checked our calculations and found that this change of energy does not influence numerical results.

The main qualitative features of the influence of non pionic dynamics over η and Q are displayed in Fig. 1, where toy results are given in the left axis. In sector (a)

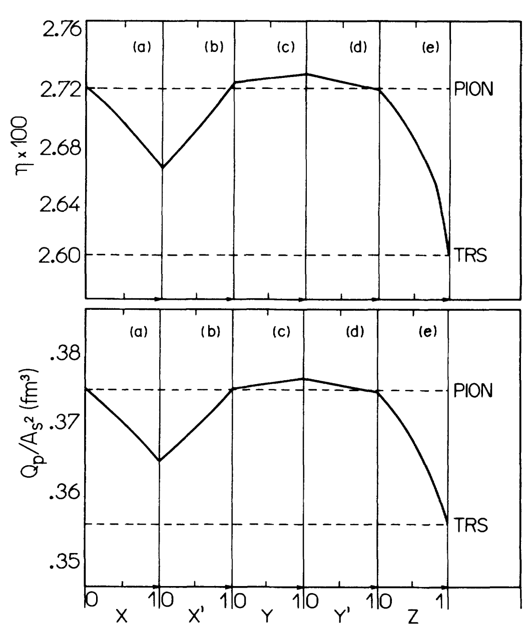

FIG. 1. Nonpionic contributions to η and Q_P/A_S^2. Sectors (a) and (b) correspond to effects due to ρ exchange in the central and tensor components [sector (a)] and in other parts of the potential [sector (b)]. Sectors (c) and (d) represent the same kind of contributions due to the ω meson. Other dynamical effects are represented in sector (e).

TABLE II. Nonpionic contributions to η and Q_P/A_{S^2}. The parameters x and x' correspond to effects due to ρ exchange in the central and tensor components (x) and in other parts of the potential (x'). Parameters y and y' represent the same kind of contribution due to the ω meson. Other dynamical effects are represented by z. The value 0 or 1 indicates absence or presence of a given component.

Interpolating parameters						
x	x'	y	y'	z	η	Q_P/A_S^2 (fm^3)
0	0	0	0	0	0.027221	0.37438
1	0	0	0	0	0.026649	0.36424
1	1	0	0	0	0.027260	0.37459
1	1	1	0	0	0.027322	0.37612
1	1	1	1	0	0.027210	0.37425
1	1	1	1	1	0.026175	0.35511

we introduce the contribution of the ρ meson to the central and tensor components, by varying the parameter x, and it is possible to see that it lowers the values of both η and Q_P/A_S^2. The full contribution of the ρ meson is obtained by adding the linear and quadratic spin-orbit terms. This is done in sector (b), where one notes a trend opposite to the previous one, yielding an overall tiny increase with respect to pionic values. The corresponding contributions of the meson ω are displayed in sectors (c) and (d), where one also finds a cancellation between central, tensor and spin-orbit effects. A better feeling for the extent of this cancellation may be obtained from Table II, where quantitative contributions are presented.

An interesting feature of our figure and Table II is that the combined contribution of ρ and ω exchanges is negligible. This means that dominant corrections to pionic values are due to the size of the nucleon and other processes such as uncorrelated two-pion exchanges. In the TRS potential these dynamical features are treated by means of phenomenological parameters. These are introduced in sector (e), yielding the TRS values for the observables. Thus, the main conclusion of this work is that the knowledge of the deviation between measured and pionic values of η and Q_P/A_S^2 may be an interesting source of information for the part of medium-range dynamics not associated with ρ and ω exchanges.

ACKNOWLEDGMENT

One of us (M.R.R.) would like to acknowledge the kind hospitality of the Division de Physique Théorique of the Institut de Physique Nucléaire at Orsay, where this work was performed. The Division de Physique Théorique, Institut de Physique Nucléaire–Orsay is "Unité de Recherche des Universités de Paris XI et de Paris VI associeé au CNRS."

[1] T. E. O. Ericson and M. Rosa-Clot, Phys. Lett. **100B**, 193 (1982).
[2] T. E. O. Ericson and M. Rosa-Clot, Nucl. Phys. **A405**, 497 (1983).
[3] T. E. O. Ericson, Commun. Nucl. Part. Phys. **13**, 157 (1984).
[4] T. E. O. Ericson and M. Rosa-Clot, J. Phys. G **10**, L201 (1984); Annu. Rev. Nucl. Sci. **35**, 271 (1985).
[5] J. L. Friar, B. F. Gibson, and G. L. Payne, Rev. C **30**, 1084 (1984).
[6] J. L. Ballot, A. M. Eiró, and M. R. Robilotta, Phys. Rev. C **40**, 1459 (1989).
[7] J. L. Ballot and M. R. Robilotta, preceding paper, Phys. Rev. C **45**, 986 (1992).
[8] R. de Tourreil, B. Rouben, and D. W. L. Sprung, Nucl. Phys. **A242**, 445 (1975).