ANL/CP--73422

DE91 014458

PHOTODISINTEGRATION OF THE DEUTERON AT MEDIUM AND HIGH ENERGIES

T.-S. H. Lee

Argonne National Laboratory, Argonne, IL 60439-4843 USA

ABSTRACT

We report the results from a unitary πNN calculation of $\gamma d \rightarrow np$ reaction up to the Δ-excitation energy region, and the preliminary results from a light-front calculation at high energies.

I would like to report on the progress we have made recently in investigating photodisintegration of the deuteron at medium and high energies. Our approach is based on the assumption that the relevant nuclear dynamics can be described in terms of meson and baryon degrees of freedom. While this is known to be a very good assumption at low energies, it should break down at sufficient high energies. By examining how our predictions start to deviate from the data as the incident photon energy increases, we can provide some information about the interface between the meson-baryon picture and the quark-gluon picture of nuclear dynamics.

Within the meson-baryon picture, the amplitude of the $\gamma d \rightarrow np$ reaction is of the following form

$$T_{fi} = \langle np | \Omega^{(-)^{+}} \vec{J} | \phi_d \rangle \cdot \vec{\epsilon}_\lambda \qquad (1)$$

where ϕ_d is the deuteron wave function, $\vec{\epsilon}_\lambda$ is the photon polarization vector, $\vec{J}$ is the current operator, and $\Omega^{(-)+}$ is the scattering operator for the final np state. At energies $E_\gamma < 400$ MeV, it is sufficient to assume that the relevant degrees of freedom are π, N and Δ and Eq. (1) can be written as

$$T = \sum_{B_1B_2=NN,N\Delta} \langle np | \Omega^{(-)^{+}} | B_1B_2 \rangle \langle B_1B_2 | \vec{J} | \phi_d \rangle \cdot \vec{\epsilon}_\lambda$$

$$+ \langle np | \Omega^{(-)} | NN\pi \rangle \langle NN\pi | \vec{J} | \phi_d \rangle \cdot \vec{\epsilon}_\lambda \qquad (2)$$

The current operator has two components

$$\vec{J} = \sum_{B=N,\Delta} \vec{J}^{(1)}_{\gamma N \leftrightarrow B} + \vec{J}^{(2)} \tag{3}$$

The two-body operator $\vec{J}^{(2)}$ is due to π-exchange mechanisms. Contrary to most of the existing studies, the parameters of the current operators are predetermined in the study of $\gamma N \to \pi N$. In this work we use the currents constructed by Tanabe and Ohta[1]. Explicitly, their two-body one-pion-exchange current responsible for the $NN \to NN$ transition is of the following form

$$\vec{J}^{(2)} = \vec{J}^{(2)}_{contact} + J^{(2)}_{pionic} \tag{4}$$

with

$$\vec{J}_{contact}(\vec{k}) = - i(\tau_1 \times \tau_2)^z \left[f(q_1)^2 \frac{\vec{\sigma}_2 \vec{\sigma}_1 \cdot \vec{q}_1}{\omega_1^2} + f(q_2)^2 \frac{\vec{\sigma}_1 \vec{\sigma}_2 \cdot \vec{q}_2}{\omega_2^2} \right] . \tag{5}$$

$$\vec{J}_{pionic}(\vec{k}) = i(\tau_1 \times \tau_2)^z \, \xi(q_1, q_2) \, f(q_1) \, f(q_2) \times \frac{(\vec{q}_1 + \vec{q}_2) \, \vec{\sigma}_1 \cdot \vec{q}_1 \vec{\sigma}_2 \cdot \vec{q}_2}{\omega_1^2 \omega_2^2} \tag{6}$$

where $\vec{k}$ is the photon momentum, $\vec{q}_2 = \vec{q}$ is the momentum of the exchanged pion, $\vec{q}_1 = \vec{q} - \vec{k}$, $\omega_i^2 = \vec{q}_i^2 + \mu^2$, and $f(q_i)$ is a form factor. It is important to note here that the factor $\xi(q_1, q_2)$ in Eq. (6) is introduced to assure the gauge invariance. By using the procedure of Ohta[2], it is found that

$$\xi(q_1,q_2) = 1 - \frac{f(q_2) - f(q_1)}{q_2^2 - q_1^2}\left[\frac{\omega_1^2}{f(q_1)} + \frac{\omega_2^2}{f(q_2)}\right] \qquad (7)$$

Similar forms are also for the two-body one-pion-exchange current responsible for the $NN \leftrightarrow N\Delta$ transition. The details can be found in Ref. [1].

The hadronic matrix elements $\langle np|\Omega^{(-)+}|NN\rangle$, $\langle np|\Omega^{(-)+}|N\Delta\rangle$ and $\langle np|\Omega^{(-)+}|\pi NN\rangle$ of Eq. (2) are also the basic dynamical quantities determining both the NN and πd reactions up to the Δ excitation energy region. In the pioneering unitary calculation of Tanabe and Ohta[1], these matrix elements are generated from their unitary πNN model which fails to describe NN scattering of $\ell \lesssim 1$ partial waves. The main advance made by Tanabe and myself in the past year is to remove this deficiency by using the πNN model of Ref. [3], which gives a good description of NN phase shifts up to 1 GeV and very extensive NN and πd observables.

In Fig. 1 we show our result (solid curve) at E_γ=300 MeV. We see that by using a more accurate πNN model in calculating the hadronic matrix elements in Eq. (2), we obtain a better description of the shape of the angular distribution. In Fig. 2 we compare our predictions with the data from LEGS collaboration[4] at Brookhaven. Both the differential cross section and the photon asymmetry Σ can be satisfactorily described by our calculation. The improvements over that of Tanabe and Ohta(dotted curves) are also seen here.

To further improve the unitary πNN model in describing the data at E_γ<400 MeV, we need to consider two-body currents originating from short-range πNN interactions. The procedure developed by Riska[5] and Ohta[2] can be used to construct phenomenologically such two-body currents. Also the recently-developed meson-exchange $\gamma N \to \pi N$ models of Ref. [6] can be used to refine the parameters of the currents considered in this work.

To investigate the $\gamma d \to np$ reaction at GeV energies, we need to extend the model outlined above to include the excitations of higher mass nucleon resonances (N^*) and their couplings with πN, $\pi\Delta$, ρN and other two-pion channels. We also need to develop an approach to

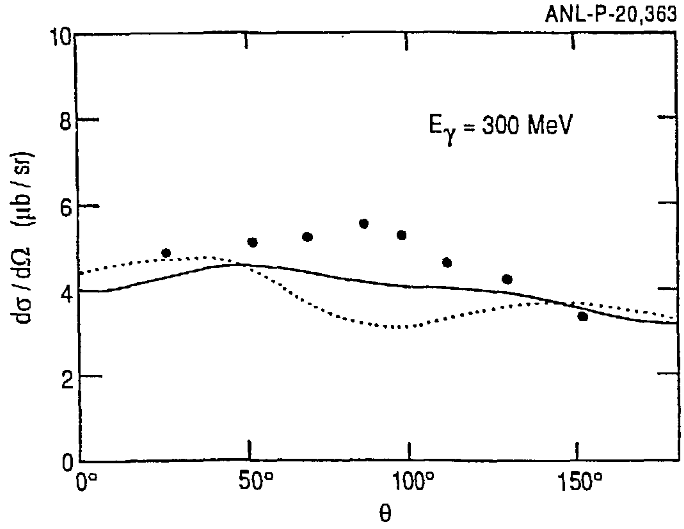

Fig. 1 Differential cross section of the $\gamma d \to np$ reaction at 300 MeV. The solid curve is from the present calculations using the πNN model of Ref. [3]. The dotted curve is from Ref. [1].

incorporate our model into a relativistic formulation of the problem. I will not discuss our on-going study of N^* excitations. I will only briefly report the progress we have made in developing a relativistic approach.

In a collaboration with F. Coester and L. Kondratyuk, we are investigating the $\gamma d \to np$ reaction within the light-front formulation[7] of relativistic quantum mechanics. The essential point is to define the generators of the Lorentz group such that the Lorentz boost is independent of interactions. It is then only a kinematic matter to evaluate the wave function of a fast-moving two-nucleon system from its rest-frame wave function. Such a simplicity does not exist in other formulations of relativistic quantum mechanics. The nontrivial part of the formulation of the $\gamma d \to np$ reaction is to define a current operator which transforms as a Lorentz four-vector and satisfies the gauge invariance condition. In a simple model consisting of only a NN potential and a one-nucleon current, we have succeeded in obtaining such a relativistic formulation. The calculation has been done by

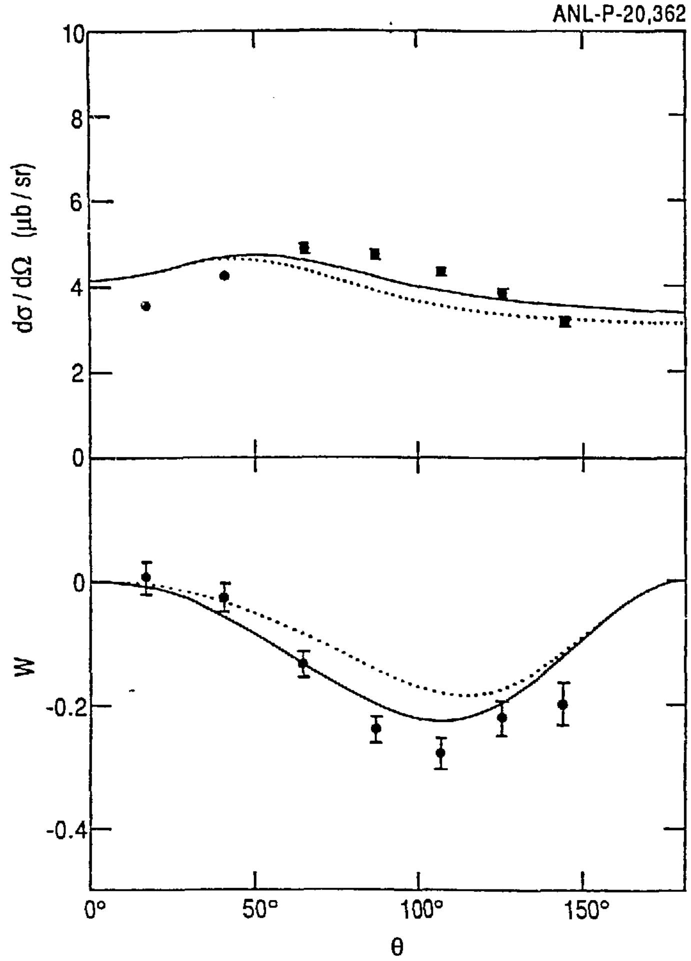

Fig. 2 Differential cross section and photon asymmetry at 192 MeV. The data are from LEGS collaborations[4]. The solid curves are from the present calculations using the πNN model of Ref. [3]. The dotted curves are from Ref. [1].

using the Paris potential. The calculated differential cross sections at several energies are the solid curves in Fig. 3. The dotted curves are from the impulse approximation calculation; i.e. setting $\Omega^{(-)+}=1$ in Eq. (1).

The difference between the solid and dotted curves in Fig. 3 clearly indicate that the final np scattering plays an important role; especially at very high energies. It is therefore not surprising that the model only gives a very qualitative description of the data, since

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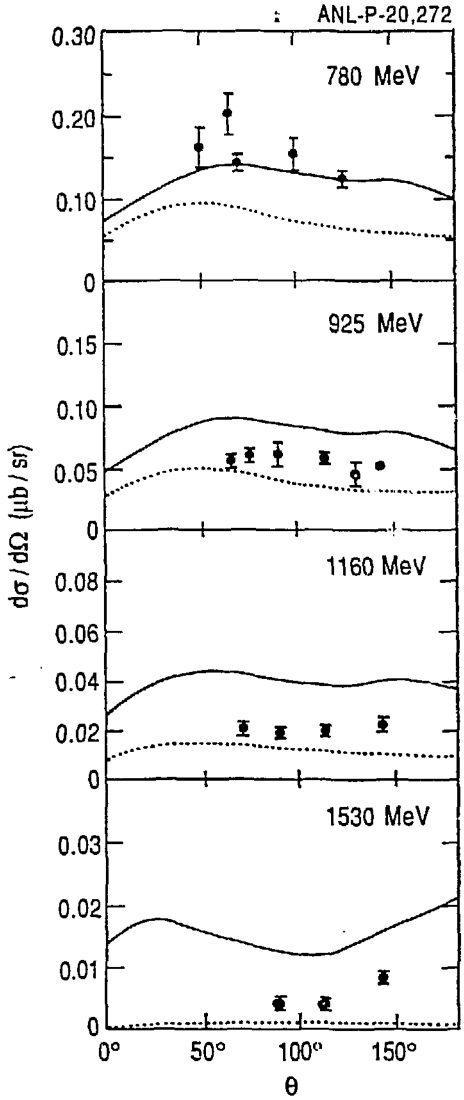

Fig. 3 The light-front calculation differential cross sections of the $\gamma d \rightarrow np$ reaction. Dotted curves are from impulse approximation calculations.

at such high energies the np scattering can not be described by the Paris potential. Nevertheless it is encouraging to see that the predicted shapes of the differential cross sections are qualitatively in agreements with the data. To carry out a realistic calculation, an NN model must be developed to describe NN data up to 4 GeV. In addition, the formulation must be extended to include two-body currents due to π, Δ and N^* degrees of freedom. All of these challenging tasks are needed to explore the interface between meson-baryon picture and quark-gluon picture of $\gamma d \rightarrow np$ reaction.

This work supported by the U.S. Department of Energy, Nuclear Physics Division, under contract W-31-109-ENG-38.

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