

THE DIFFERENTIAL CROSS SECTION  
AND THE NUCLEON ANALYSING POWER  
FOR THE  $n(d,nn)p$  PROCESS AT 65 MeV AS TOOLS  
TO IMPROVE THE JISP16 POTENTIAL\*

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The JISP16 nucleon–nucleon potential is applied to investigate the nucleon-induced deuteron breakup reaction at energy  $E = 65$  MeV. We use the formalism of the Faddeev equation to compute the differential cross section and the nucleon analyzing power. Our study reveals that this force delivers, in general, a qualitatively similar description of the exclusive cross section and the analyzing power for the studied reaction to the one based on the standard realistic nucleon–nucleon AV18 interaction. However, in some regions of the phase space the predictions for the differential cross sections based on the JISP16 and on the AV18 forces differ by more than 50% at  $E = 65$  MeV. Similar differences are observed for the nucleon analyzing power. Such specific parts of the phase space can be used to fine-tune the JISP16 potential parameters.

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## 1. Introduction

The JISP16 potential [1] is a realistic two-nucleon interaction that was derived through the inverse scattering method. Beside the two-nucleon data, the JISP16 model describes bound and resonant states of nuclei with  $A \leq 16$ . This feature provides the ability to study many-nucleon systems without explicit application of the many-nucleon forces. Although this model works well in the calculations of nuclear structure [2], inadequacies have been found in the description of some observables by the JISP16 model in the case of elastic nucleon–deuteron scattering [3]. The reason for the behaviour was identified in the P-wave components of this potential. It was also published

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in Ref. [4] that the absence of the long-range term in the two-nucleon potential leads to inaccurate predictions of the total photoabsorption cross section of the two-, three- and four-nucleon system.

The current study is aimed at identifying configurations of the nucleon-induced deuteron breakup reaction in which the behaviour of the JISP16 model differs from the standard realistic AV18 interaction. Such configurations can be used to improve the JISP16 model.

It is enough to choose five independent variables to specify the final kinematical state for the nucleon–deuteron breakup process. We chose the following variables: the polar and azimuthal scattering angles corresponding to the momenta of nucleon 1 ( $\theta_1, \varphi_1$ ) and nucleon 2 ( $\theta_2, \varphi_2$ ). We use the arc length  $S$  along the kinematically allowed locus in the  $E_1$ – $E_2$  plane to avoid situations with two physical solutions for the energy of nucleon 2 at given  $\theta_1, \varphi_1, \theta_2, \varphi_2$  and  $E_1$ . Scanning the whole three-nucleon phase space allows us to study more kinematical and dynamical aspects which have an impact on the cross section and the analysing power than it was done in the investigation of the elastic scattering process [3].

## 2. Formalism and results

Computation of the differential cross section and the nucleon analysing power was performed via calculating the transition amplitude. The latter was obtained using the framework of the Faddeev equations and is given as [5]

$$\langle \phi_0 | U | \phi \rangle = \langle \phi_0 | (1 + P) T | \phi \rangle, \quad (1)$$

where the auxiliary state  $T | \phi \rangle \phi$  fulfils the Faddeev equation, which reads

$$T | \phi \rangle = t P | \phi \rangle + t P G_0 T | \phi \rangle. \quad (2)$$

The initial state  $|\phi\rangle$  is composed of a deuteron and a relative momentum eigenstate of the induced nucleon,  $P$  is a permutation operator,  $G_0$  is the free 3N propagator and  $t$  is the solution of the Lippmann–Schwinger equation for the two-nucleon t-matrix for the NN interaction  $V$ . The final  $\langle \phi_0 |$  state describes the free motion of three nucleons in terms of the relative Jacobi momenta.

We chose the incoming nucleon energy  $E_i = 65$  MeV for our investigation of the JISP16 interaction. For this energy, we solved Eqs. (1) and (2) twice, once with the JISP16 model and once using the AV18 interaction [6]. Next, we calculated the differential cross section and the nucleon analysing power at a grid of points covering the whole phase space. We used a grid of 45 points for the  $\theta_1$  and  $\theta_2$  polar angles in the range of  $(0^\circ, 180^\circ)$ , 45 points for the relative azimuthal angle  $\varphi_{12} = |\varphi_2 - \varphi_1|$  in the range of  $(0^\circ, 180^\circ)$  for the

cross sections and in the range of  $(0^\circ, 360^\circ)$  for the nucleon analysing power, and a small step of 0.1 MeV along the arc length  $S$  parameter. At each point on this grid, we evaluated the transition amplitude and, consequently, the exclusive cross section and the nucleon analysing power with the JISP16 and AV18 NN potentials. The results for the AV18 force are used as reference values. In order to skip configurations which are immeasurable in practice, we employed additional threshold cuts for very low energies of the outgoing nucleons and/or very small values of the cross sections.

In order to estimate the discrepancy between predictions of these two models for the NN interaction, we calculated an absolute value of the relative difference for the cross sections and the analysing power using the following formula:

$$|\Delta| \equiv |\Delta(\theta_1, \theta_2)| = \max \left[ \left| \frac{\text{Obs}_{\text{JISP16}} - \text{Obs}_{\text{AV18}}}{\frac{1}{2} (\text{Obs}_{\text{JISP16}} + \text{Obs}_{\text{AV18}})} \right| \right]_{\{\phi_1, \phi_2, S\}}, \quad (3)$$

where  $\text{Obs} = \frac{d^5\sigma}{d\Omega_1 d\Omega_2 dS}(\theta_1, \phi_1, \theta_2, \phi_2, S)$  or  $A_y(\theta_1, \phi_1, \theta_2, \phi_2, S)$ .

In Figs. 1 and 2, we show the differential cross section and the nucleon analysing power for  $\theta_1, \phi_1, \theta_2, \phi_2$  which yield big values of  $\Delta$ . We recognized these configurations as important for studying deficiencies of the JISP16 force. In the case of the cross section, shown in Fig. 1, the corresponding angles are  $\theta_1 = 42^\circ, \theta_2 = 66^\circ, \varphi_{12} = 178^\circ$  and for  $S = 62$  MeV,  $\Delta$  amounts to 44%. For the nucleon analysing power (see Fig. 2), we show a configuration with  $\Delta = -0.12$ , *i.e.* the prediction based on the AV18 model is relatively bigger by 12% than the one obtained with the JISP16 interaction. This  $\Delta$  is smaller than the maximal  $\Delta$  found ( $\approx 0.5$ ). However, for the presented

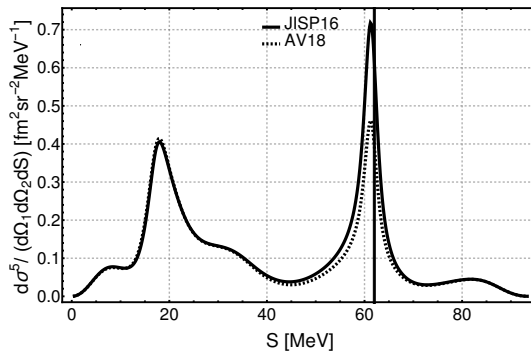


Fig. 1. The comparison of cross sections, predicted by JISP16 (solid line) and AV18 (dashed line) models, for the deuteron breakup reaction at  $E_i = 65$  MeV,  $\theta_1 = 42^\circ, \theta_2 = 66^\circ$  and  $\varphi_{12} = 178^\circ$ . The relative difference  $\Delta$  at  $S = 62$  MeV (marked with a vertical line) is 0.44.

configuration ( $\theta_1 = 74^\circ$ ,  $\theta_2 = 34^\circ$ ,  $\varphi_{12} = 178^\circ$ ,  $S \approx 75$  MeV), the analysing power reaches relatively big values, which facilitates collecting experimental data.

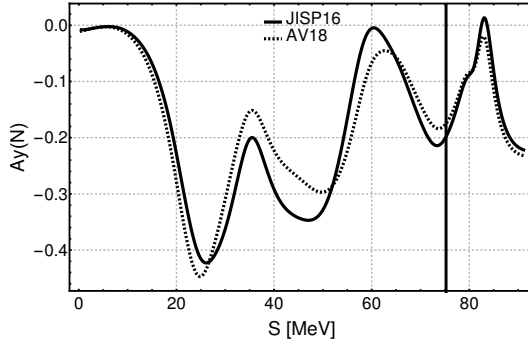


Fig. 2. The comparison of the nucleon analysing power, predicted by JISP16 (solid line) and AV18 (dashed line) models for the deuteron breakup reaction at  $E_i = 65$  MeV,  $\theta_1 = 74^\circ$ ,  $\theta_2 = 34^\circ$  and  $\varphi_{12} = 178^\circ$ . The relative difference  $\Delta$  at  $S = 75$  MeV (marked with a vertical line) is  $-0.12$ .

The observed differences between the JISP16 and the AV18 predictions may partly arise from the lack of the 3N interaction in our predictions based on the AV18 potential only. However, the magnitudes of the observed discrepancies suggest rather flaws of the JISP16 interaction than a strong contribution of 3NF. Anyway, the comparison of the JISP16 predictions with predictions based on the AV18+UrbanaIX interaction is definitely worth doing and such investigations are ongoing. Moreover, a comparison directly to the data is planned.

### 3. Conclusions

We have identified configurations in which the predictions of the cross section and the analysing power for the Nd breakup reaction at the energy of the incoming nucleon 65 MeV provided by the JISP16 model deviate significantly (up to 50%) from the results based on the standard realistic AV18 NN interaction. The found configurations can serve to detect and improve weaknesses of the JISP16 model which requires refinement, before it is applied in further studies of nuclear reactions.

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