Neutron-triton elastic scattering

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The Kohn variational principle and the hyperspherical harmonics technique are applied to study the $n - ^3\text{H}$ elastic scattering at low energies. In this contribution the first results obtained using a non-local realistic interaction derived from the chiral perturbation theory are reported. They are found to be in good agreement with those obtained solving the Faddeev-Yakubovsky equations. The calculated total and differential cross sections are compared with the available experimental data.

The effect of including a three-nucleon interaction is also discussed.

I. INTRODUCTION

In the last few years the scattering of nucleons by deuterons has been the subject of a large number of investigations. This scattering problem is in fact a very useful tool for testing the accuracy of our present knowledge of the nucleon–nucleon (NN) and three nucleon (3N) interactions. Noticeable progress has been achieved, but a number of relevant disagreements between theoretical predictions and experimental results still remains to be solved [1, 2].

It is therefore of interest to extend the above mentioned analysis to four nucleon scattering processes. In this case, an important goal for both theoretical and experimental analysis is to reach a precision comparable to that achieved in the $N - d$ case. This is particularly challenging from the theoretical point of view, since the study of $A = 4$ systems is noticeably more complicated than the $A = 3$ one. Recently, accurate calculations of four-body scattering observables have been achieved in the framework of the Faddeev-Yakubovsky (FY) equations [3], solved in momentum space, and treating the long-range Coulomb interaction using the screening-renormalization method [4, 5].

In this contribution, the four-body scattering problem is solved using the Kohn variational method and expanding the internal part of the wave function in terms of the hyperspherical harmonic (HH) functions. Previous applications of this method [6, 7, 8] were limited so far to consider only local potentials, as the Argonne V18 [9] NN potential. Recently, for bound-states, the HH method has been extended to treat also non-local potentials, given either in coordinate- or momentum-space [10]. Here, we report the first application of the HH method to the four-body scattering problem with non-local potentials.

The potential used in this paper is the N3LO-Idaho model by Entem & Machleidt [11], with cutoff $\Lambda = 500$ MeV. This potential has been derived using an effective field theory approach and the chiral perturbation theory up to next-to-next-to-next-to-leading order. We have also performed calculations by adding to the N3LO-Idaho potential a 3N interaction, derived at next-to-next-to-leading order (N2LO) in Ref. [12] (N3LO-Idaho/N2LO interaction model). The two free parameters in this N2LO 3N potential have been chosen from the combination that reproduces the $A = 3$ binding energies [12]. The development of a 3N interaction including N3LO contribution is still under progress [13].

This paper is organized as follows. In Section III a comparison between HH and FY calculations is reported. We have performed this comparison for the N3LO-Idaho potential for incident neutron energy $E_n = 4$ MeV. Finally, in Section III, the theoretical calculations are compared with the available experimental data.

| Phase-shift | HH | FY | Phase-shift | HH | FY |
|-------------|----|----|-------------|----|----|
| $^1S_0$     | $-69.3$ | $-69.1$ | $^3P_0$     | $23.2$ | $23.3$ |
| $^3S_1$     | $-61.4$ | $-61.2$ | $^3P_1$     | $22.7$ | $22.5$ |
| $^3D_1$     | $-1.14$ | $-1.10$ | $^3P_1$     | $44.4$ | $44.5$ |
| $\epsilon$ | $0.77$ | $0.80$ | $\epsilon$ | $9.80$ | $9.64$ |
| $^1D_2$     | $-1.72$ | $-1.90$ | $^3P_2$     | $48.4$ | $48.7$ |
| $^3D_2$     | $-0.94$ | $-1.01$ | $^3F_2$     | $0.07$ | $0.09$ |
| $\epsilon$ | $2.74$ | $2.81$ | $\epsilon$ | $1.24$ | $1.26$ |

TABLE I: Phase-shift and mixing angle parameters for $n - ^3\text{H}$ elastic scattering at incident neutron energy $E_n = 4$ MeV calculated using the N3LO-Idaho potential. The values reported in the columns labeled HH have been obtained using the HH expansion and the Kohn variational principle, whereas those reported in the columns labeled FY by solving the FY equations [3].
II. COMPARISON BETWEEN HH AND FY RESULTS

The calculated phase-shift and mixing angle parameters for $n - ^3H$ elastic scattering at $E_n = 4$ MeV using the N3LO-Idaho potential are reported in Table 1. The values reported in the columns labeled HH have been obtained using the HH expansion and the Kohn variational principle, whereas those reported in the columns labeled FY by solving the FY equations [4]. As can be seen, there is a good overall agreement between the results of the two calculations.

III. RESULTS

The preliminary results for the $n - ^3H$ total cross section calculated with the considered potential models are reported in Figure 1. As already known, the calculated cross section with the AV18 potential overpredicts the experimental data at low energies, and is well under the data in the peak region [4,8]. The problem at low energies is cured when the Urbana-IX 3N force [14] is considered [8]. In the peak region the inclusion of this 3N force slightly decreases the cross section, increasing the disagreement with the data. On the other hand, using the N3LO-Idaho a better agreement with experimental data is found [4]. Including the N2LO 3N force, there is now a perfect agreement at low energy (in particular, in the minimum around $E_n = 1$ MeV). Also in the peak region a slight better agreement is observed. The origin of the remaining discrepancy is unclear, but it could be related to parts of 3N interaction not yet considered.

The quality of the agreement can be also seen by comparing the theoretical and experimental differential cross sections, available at $E_n = 1, 2, \text{and } 3.5$ MeV.

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FIG. 2: $n - ^3H$ differential cross sections calculated with the N3LO-Idaho (solid line) and the N3LO-Idaho/N2LO (dashed line) interaction models for three different incident neutron energies. The experimental data are from Ref. [16].

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