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Three-body calculation of elastic and inelastic scattering of deuterons on ^{24}Mg

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Abstract

Deuteron–nucleus scattering is described using exact three-particle equations. The theory is formulated in an extended Hilbert space allowing the excitation of the target nucleus. Alt, Grassberger, and Sandhas equations for transition operators are solved in the momentum-space framework including the Coulomb interaction via the screening and renormalization method. The calculations are performed for elastic and inelastic scattering of deuterons on ^{24}Mg using the rotational model for the excitation potential. A reasonable agreement with the experimental data for the first excited state 2^+ of ^{24}Mg is achieved when the quadrupole deformation parameter $\beta_2 = 0.47$ is used. This new value is more consistent with the inelastic proton scattering data requiring $\beta_2 \approx 0.5$ than previous determinations $\beta_2 \approx 0.4$ based on two-body deuteron–nucleus models.

Keywords: Three-body scattering; Faddeev equations; Core excitation; Rotational model

1. Introduction

Inelastic reactions without cluster rearrangement provide possibility to extract the information on the properties of the involved nuclei such as energy levels and deformation parameters. Those features of a single target nucleus are obviously independent of the impinging projectile. Thus, a realistic reaction model should provide a consistent description for various reactions such as inelastic scattering of protons (p), neutrons (n), deuterons (d), or α particles. In practice,

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most often (p, p'), (n, n'), (d, d'), and (α, α') reactions are calculated using two-body projectile plus target nucleus models with deformed phenomenological optical potentials that allow the coupling between different internal states of the target nucleus. While for (p, p') and (n, n') reactions such models may be reasonable, they may be too rough for (d, d') reactions owing to the weak binding of the deuteron. Given the recent developments in three-body reaction calculations based on exact Faddeev [1] or Alt, Grassberger, and Sandhas (AGS) equations [2] for the proton plus neutron plus core $(p + n + A)$ system and including excitation of the core [3,4], it becomes possible to check the consistency between (N, N') and (d, d') reactions by using the same interactions in both cases. This will allow to asses the reliability of standard approximate (d, d') reaction calculations. As a working example the inelastic reactions on ^{24}Mg are chosen whose lowest states 0^+, 2^+ and 4^+ exhibit a fair rotational band structure of a deformed nucleus. Furthermore, the $^{24}\mathrm{Mg}(p, p')$ reactions analyzed with the rotational model provide the quadrupole deformation parameter $\beta_2 \approx 0.5$ [5–7] while the analysis of (d, d') reaction based on two-body models, i.e., neglecting the compositeness/breakup of the deuteron, yields $\beta_2 \approx 0.4$ [8,9]. Thus, it is important to resolve this inconsistency that possibly is caused by the inadequacy of the two-body treatment for the (d, d') reaction. Implementing the three-body Faddeev-type description for the (d, d') reaction and applying it to ^{24}Mg nucleus within the rotational model is the main objective of the present work. Previous attempts are inconclusive as they are limited in energy and lack convergence [4] or involve further approximations [10].

In Sec. 2 the three-body Faddeev-type reaction formalism allowing the excitation of the target nucleus is described. Results for the differential cross section of the $^{24}\mathrm{Mg}(d, d')$ reaction leading to the first excited state of ^{24}Mg are presented in Sec. 3; observables for the elastic scattering calculated simultaneously are shown as well. The summary is given in Sec. 4.

2. Faddeev/AGS equations including core excitation

For the description of three-particle reactions I use Alt, Grassberger, and Sandhas (AGS) equations [2] that are integral Faddeev-type equations for three-particle transition operators

$$U_{\beta\alpha} = \bar{\delta}_{\beta\alpha}\, G_0^{-1} + \sum_{\gamma=1}^{3} \bar{\delta}_{\beta\gamma}\, T_\gamma\, G_0 U_{\gamma\alpha}. \tag{1}$$

Here $\bar{\delta}_{\beta\alpha} = 1 - \delta_{\beta\alpha}$, $G_0 = (E + i0 - H_0)^{-1}$ is the free resolvent at the available three-particle energy E with the free Hamiltonian H_0, and

$$T_\gamma = v_\gamma + v_\gamma G_0 T_\gamma \tag{2}$$

is the two-particle transition operator for the pair γ in the odd-man-out notation derived from the respective pair potential v_γ. All potentials are assumed to be of short-range as necessary for the formulation of the standard scattering theory; to fulfill this requirement the proton-core Coulomb interaction is screened but the full Coulomb limit is recovered via the renormalization procedure explained below. The above standard scattering equations (1) and (2) are formally applicable also with the core excitation if the problem is formulated in an extended Hilbert space $\mathcal{H}_g \oplus \mathcal{H}_x$ where the two sectors correspond to the core being in its ground (g) or excited (x) state [3]. Furthermore, the extended free Hamiltonian H_0, in addition to the kinetic energy operator K, contains also the internal core Hamiltonian h_A normalized such that $\mathcal{H}_j h_A \mathcal{H}_i = \delta_{jx}\delta_{ix}\Delta m_A$ with Δm_A being the core excitation energy; $\Delta m_A = 1.369$ MeV for the first 2^+ excited state of