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Microscopic three-cluster model of ^{10}Be

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Abstract

We investigate spectrum of bound and resonance states in ^{10}Be, and scattering of alpha-particles on ^{6}He. For this aim we make use of a three-cluster microscopic model. This model incorporates Gaussian and oscillator basis functions and reduces three-cluster Schrödinger equation to a two-body like many-channel problem with the two-cluster subsystem being in a bound or a pseudo-bound state. Much attention is given to the effects of cluster polarization on spectrum of bound and resonance states in ^{10}Be, and on elastic and inelastic $^6\mathrm{He}+\alpha$ scattering.

Keywords: Resonating group method; Cluster polarization; Three-cluster microscopic model

1. Introduction

The aim of the paper is to investigate elastic and inelastic scattering of alpha particles on ^{6}He nucleus. It is well-known that this nucleus is weakly bound, as the energy of its ground state is 0.973 MeV. One may expect that this nucleus can change its size and shape on interaction with other nucleus or, in other words, it can be polarized. We are going to study effects of ^{6}He polarization on parameters of $\alpha+{}^6\mathrm{He}$ scattering. As polarization is more pronounced at relatively small energies, we restrict ourselves with the energy range $0 \le E \le 10$ MeV.

To study spectrum of bound and resonance states in ^{10}Be, we make use of a three-cluster microscopic model. This nucleus is considered as a three-cluster configuration $^{10}\mathrm{Be} = \alpha + \alpha + {}^2n$, which allows us to take into account two binary channels $^{10}\mathrm{Be} \Rightarrow {}^6\mathrm{He} + \alpha$ and $^{10}\mathrm{Be} \Rightarrow$

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^{8}Be + ^{2}n. In our model, ^{6}He is considered as a two-cluster system $\alpha +^{2} n$. Similarly, ^{8}Be is naturally represented as a system of two alpha particles.

It was demonstrated (see, for instance, [1]) that there is strong two-neutron spatial correlation in the ground state of ^{6}He. Thus, it is natural to approximate ^{6}He as two cluster system consisting of an alpha particle and a two-neutron system (dineutron). The dineutron is considered as a pseudo-bound state. Such approximation for the two-neutron system has been successfully applied, for instance, for theoretical analysis of the reaction $t\,(t,\alpha)\,nn$ in Ref. [2] and to study the bound state of ^{8}He in Ref. [3] within three-cluster model $^{8}\text{He} = \alpha + {}^{2}n + {}^{2}n$. We believe that such approximation for two-neutron system is quite reliable and allows us to study such a complicated system as ^{10}Be in a simple way.

It is well-known [4] that this nucleus has five bound states and large number of resonance states. The spectrum of the resonances is very dense and many of them are very narrow. The width of these resonance states does not exceed 300 keV despite the fact that there are two two-body and one four-body open channels. It is therefore interesting and challenging task to study properties of ^{10}Be nucleus, and reveal the nature of observed resonance states.

There are strong evidences that ^{10}Be is a deformed non-axial nucleus. Even in a simple approximation of the SU(3) model, which describes ^{10}Be as the Elliott multiplet $(\lambda\mu) = (22)$, this nucleus appears to be deformed one with two rotational bands $K = 0$ and $K = 2$, where K is a projection of the total orbital momentum on the intrinsic axis. Deformation of ^{10}Be has been studied within the Tohsaki–Horiuchi–Schuck–Ropke (THSR) wave function in [5] and the Antisymmetrized Molecular Dynamics (AMD) in [6].

In Ref. [5], the cluster model with the THSR wave function was used to study structure of rotational states in ^{10}Be. This function releases the concept of nonlocalized clusters in light nuclei. Due to the usage of an integral transformation over standard cluster parameters (generator coordinates), the authors obtained more flexible wave function of many-particle system. Within this model the nonlocalized dynamics of two alpha particles and a dineutron was investigated in detail. There was obtained a good agreement between the used model and other cluster models, and experimental results as well, concerning spectrum of the rotational bands constructed on the first and second 0^{+} states. To this end, the effectiveness of the THSR wave function is demonstrated in Ref. [7] for description of the bound $3/2^{-}$ state in ^{9}Be and the rotational band based on this state. There are many important ideas about formulation and realization of the nonlocalized concept of cluster structure in Ref. [7].

The structure of rotational bands was a subject of numerous theoretical investigations. The well-developed rotational bands was discovered in ^{10}Be. However, in many cases rotational excitations have been considered as discrete states, even though most of them lye in two- or three-body continuum. For instance, Descouvemont in [8] investigated the spectrum of ^{10}Be excited states up to 50 MeV above the ground state within a many-cluster model. A large part of the excited states belongs to the continuous spectrum. The existence of two new rotational bands was predicted in Ref. [8]. In Ref. [6] within the Antisymmetrized Molecular Dynamics, Kobayashi and Y. Kanada-En'yo performed detailed investigations of the 0^{+} excitations in ^{10}Be and dineutron correlations in wave functions of these states.

A four-cluster model with configuration $\alpha + \alpha + n + n$, which is based on usage of the molecular orbitals, was applied by Itagaki and Okabe [9] to study ground and rotational excited states in ^{10}Be. A large $E2$ electric transition probability between the states allowed the authors to select the states belonging to a specific rotational band. In Ref. [10] Itagaki et al. advanced the model, which was realized in [9], by including new cluster configuration $\alpha + t + t$. It was shown that

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