Formation and decay of resonance states in ^{9}Be and ^{9}B nuclei: Microscopic three-cluster model investigations

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We study the nature of the low-lying resonance states in mirror nuclei ^{9}Be and ^{9}B. Investigations are performed within a three-cluster model. The model makes use of the hyperspherical harmonics, which provides a convenient description of the three-cluster continuum. The dominant three-cluster configurations $\alpha+\alpha+n$ and $\alpha+\alpha+p$ in ^{9}Be and ^{9}B, respectively, are taken into account. Dominant decay channels for all resonance states in ^{9}Be and ^{9}B are explored. Much attention is paid to the controversial $1/2^+$ resonance states in both nuclei. We study effects of the Coulomb interaction on the energy and width of three-cluster resonances in the mirror nuclei ^{9}Be and ^{9}B. We also search for the Hoyle-analog state, which is a key step for alternative ways to synthesize ^{9}Be and ^{9}B in triple collisions of clusters in a stellar environment.

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I. INTRODUCTION

The resonance state is one of the challenging problems for theoretical physics, as well as for nuclear physics. There are common features of resonance states observed in a few- or many-channel systems. However, there are some specific features related to ways of the excitation or generation of resonance states and to ways of the decay of nuclear resonance states. It is well known that some resonance states are observed in one set of reactions and do not manifest themselves in another set of reactions. Special attention is attracted to the resonance states formed by three interacting clusters, i.e., resonance states embedded in the three-cluster continuum. Such resonance states have been repeatedly observed in nuclei that have well-determined three-cluster structures. This result suggests that bound states and many resonance states lie below and above, respectively, the threshold of the three-cluster continuum. In other words, bound states and a large part of resonance states in three-cluster nuclei are generated by an interaction of three clusters. As examples of such nuclei, we mention ^{5}H, ^{6}He, ^{6}Be, ^{9}Be, ^{9}B, and so on.

In the present paper, a microscopic three-cluster model will be used to study the nature of resonance states in ^{9}Be and ^{9}B. The dominant three-cluster configurations $\alpha+\alpha+n$ and $\alpha+\alpha+p$ are selected to describe the low-excitation energy region in these nuclei. The microscopic model formulated in Ref. [1] makes use of harmonic oscillator functions to describe the intercluster motion. The model is called AM HHB, which stands for the algebraic three-cluster model with the hyperspherical harmonics basis. The first application of this model to study the resonance structure of ^{9}Be and ^{9}B was made in Ref. [2]. Results presented in Ref. [2] were obtained with the Minnesota potential (MP). In the present paper, we use the modified Hasegawa-Nagata potential (MHNP) [3,4] and will show a very good correspondence between calculations and experiments. Based on this successful result, we pay much more attention to the $1/2^+$ resonance states and the Coulomb effects on the resonance states in mirror nuclei. In addition, we search for the Hoyle-analog states in ^{9}Be and ^{9}B.

There are many attempts to study the resonance structure of ^{9}Be and ^{9}B within various methods and models [5–13]. Those investigations have been dominantly performed within the cluster model and different variants of the resonating group method. In some cases, the determination of resonance parameters is carried out in the framework of models, where the three-cluster problem is reduced to a many-channel two-body system by representing ^{9}Be (^{9}B) as coupled-channel systems of $^8\mathrm{Be}+n$ ($^8\mathrm{Be}+p$) and $^5\mathrm{He}+{}^4\mathrm{He}$ ($^5\mathrm{Li}+{}^4\mathrm{He}$). Other groups of papers take into account that all resonance states in ^{9}Be and ^{9}B belong to the three-cluster continuum. The position of resonance states and their properties have been determined by using the complex scaling methodology or the hyperspherical harmonics basis. The latter allows one to incorporate proper boundary conditions for decays of a three-cluster system into three independent clusters, while the former allows one to locate resonance states in the continuum of many-channel and many-cluster systems.

A special attention is attracted by the $1/2^+$ excited states in ^{9}Be and ^{9}B. This is stipulated by two factors. First, the position of these resonances was obtained at different energies in various experiments. Some experiments claimed that there are no such resonances in ^{9}Be or ^{9}B. Second, different theoretical investigations suggested different energies

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