Three-cluster resonance structure of $^{6}{}_{\Lambda}$Li and $^{7}{}_{\Lambda}$Li hypernuclei

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Content

The structure and nuclear reactions in hypernuclear systems are currently a topic of significant interest. Recent decades have provided a very large amount of new experimental data about hypernuclear systems, fueling numerous theoretical investigations. The interaction between Λ particles and nucleons leads to the formation of bound states in light hypernuclei, including the $^{6}{}_{\Lambda}$Li and $^{7}{}_{\Lambda}$Li hypernuclei. It is worth to note that $^{7}{}_{\Lambda}$Li exhibits the richest spectrum of bound states—four—compared to other light hypernuclei, while the ordinary ^{7}Li nucleus has only two. Additionally, experimental studies [1] have explored the overall properties of $^{7}{}_{\Lambda}$Li, revealing that adding a Λ hyperon to a weakly bound nucleus ^{6}Li, causes a notable decrease in its size.

In the present work, we study the structure of bound and resonance states of the $^{6}{}_{\Lambda}$Li and $^{7}{}_{\Lambda}$Li hypernuclei. For this aim, we adopted a microscopic three-cluster model, which was formulated in [2] and has been successfully applied to studying bound states and resonance states in the three-cluster continuum of light nuclei. In particular, this model has been applied to reveal properties of the Hoyle state in ^{12}C and determine Hoyle-analogue states in some light nuclei [3].

Within this model, the $^{6}{}_{\Lambda}$Li and $^{7}{}_{\Lambda}$Li hypernuclei are considered as many-channel systems comprising three-cluster configurations: ^{4}He+p+Λ and ^{4}He+d+Λ, respectively. The hyperspherical coordinates are used to determine the relative position of clusters, and the hyperspherical harmonics are employed to numerate channels of three-cluster systems. To reveal more explicitly the peculiarities of the hypernuclei of interest, we also consider ordinary nuclei ^{6}Li and ^{7}Li. Within the same mode, they are treated as three-cluster configurations, ^{4}He+p+n and ^{4}He+d+n, respectively. The Hasegawa–Nagata nucleon–nucleon potential [4] and the YNG nucleon–hyperon potential [5] adequately model the interaction of nucleons and nucleons with lambda hyperon in our calculations.

By employing the modified three-cluster model, we calculated the wave functions and energies of the bound states of the $^{6}{}_{\Lambda}$Li and $^{7}{}_{\Lambda}$Li hypernuclei, and also determined the channels that gave the maximum contribution to the wave function of these states. The correlation functions and mass root-mean-square radii of the bound states were calculated, which gave more detailed information about the most probable positions of the interacting clusters relative to each other and their compact form, compared to ordinary nuclei. The weights of the functions of a fixed oscillator shell in the wave functions of the bound states of $^{7}{}_{\Lambda}$Li unambiguously demonstrate that the lambda hyperon can be located inside the nucleus ^{6}Li with significant probability. It is also demonstrated that our model reasonably well reproduces existing experimental data for the energies of bound states.

By studying the phase shifts of the so-called 3-in-3 scattering, which describes processes in a three-cluster continuum, we discovered several resonant states that decay into three fragments (clusters). Some of these resonance states have a very small width. Analysis of partial widths leads us to the conclusion that the discovered resonance states are formed by one specific channel, which has a small coupling with other channels of the compound systems. Such small coupling between numerous channels is responsible for the formation of narrow resonance states in the three-cluster continuum of ordinary nuclei and hypernuclei.

The obtained results can be considered as a prediction of the existence of narrow resonance states and can be used for planning future experiments.

Reference

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