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Asymptotics of three-body bound state radial wave functions of halo nuclei involving two charged particles

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Abstract

Asymptotic expressions for the radial and full wave functions of a three-body bound halo nuclear system with two charged particles in relative coordinates are obtained in explicit form, when the relative distance between two particles tends to infinity. The obtained asymptotic forms are applied to the analysis of the asymptotic behavior of the three-body $(pn\alpha)$ wave functions for the halo ($E^* = 3.562$ MeV, $J^\pi = 0^+$, $T = 1$) state of ^{6}Li derived by D. Baye within the Lagrange-mesh method for two forms of the αN-potential. The agreement between the calculated wave function and the asymptotic formula is excellent for distances up to 30 fm. Information about the values of the three-body asymptotic normalization functions is extracted. It is shown that the extracted values of the three-body asymptotic normalization function are sensitive to the form of the αN-potential. The mirror symmetry is revealed for the three-body asymptotic normalization functions derived for the isobaric (^{6}He, ^{6}Li*) pair.

Keywords: Halo nuclei; Three-body asymptotic normalization function

1. Introduction

Study of structure of light exotic nuclei, lying near the drip lines and so-called halo nuclei is one of the most interesting topics of low-energy nuclear physics [1–13]. It has revealed a number of features inherent only for these nuclei but not for normal (non-halo) nuclei, such as rather low separation energies of the external (“valence”) nucleons, large radii and narrow peaks observed

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in the breakup probability distribution. Two-nucleon halo nuclei are particularly striking since the lowest breakup channel is a three-body (core + "valence" nucleons) channel because of the fact that their two-body subsystems are unbound. Therefore, for these nuclei a main term of the asymptotics of wave functions must be determined by proper three-body asymptotics [14].

For more than ten years several works have been devoted to the study of the asymptotics of three-body bound state radial wave functions of halo nuclei [15–19]. In Refs. [15,16], the asymptotic expressions have been derived for three-body systems with two neutrons for the case of short-range (nuclear) interactions. These asymptotics were derived in the context of hyperspherical coordinates for large values of the hyperradius R ($R \to \infty$), which means that either both of the Jacobi coordinates tend to infinity [17] or one of them tends to infinity and another of them is very small [16]. In [17], the result of [15] was generalized for three-body systems including two charged particles with taking into account Coulomb-nuclear interactions. The obtained asymptotic expressions contain an exponential function depending on the hyperradius R [14] but also involve a factor that can influence noticeably the asymptotic values of the three-body wave function for some directions in the configuration space determined by the hyperangle φ, where $\varphi = arctan(y/x)$ (x and y are a pair of modified Jacobi coordinates [14]). In Refs. [15–17], these asymptotic expressions have been compared with the asymptotic behavior of three-body ($nn\alpha$ and $\alpha\alpha n$) radial wave functions of the ^{6}He and ^{9}Be nuclei respectively derived in Refs. [20] and [21] within the framework of the multicluster stochastic dynamical model, respectively, where only two forms for the $n\alpha$ and $\alpha\alpha$ potentials are used. In Refs. [15–17], information was obtained about the three-body asymptotic normalization function (TBANF) as a function of the hyperangle φ. However, as is revealed in [15–17], the three-body radial wave functions of the ^{6}He and ^{9}Be nuclei [20,21] have a correct asymptotic behavior in an asymptotical region within the interval with narrow width. Besides, the binding energies of ^{6}He and ^{9}Be nuclei in the ($\alpha + 2n$)- and ($2\alpha + n$)-channels calculated in [20] and [21], respectively, differ noticeably from the experimental ones and, consequently, this circumstance may also noticeably influence the TBANFs [15–17].

In Ref. [18], the asymptotic expression has been derived for three-body radial wave functions of the halo nucleus with two valence neutrons in the context of the relative core-neutron coordinates for large values of each of them. It was revealed that the asymptotic expression obtained in [18] is not directly comparable to that derived in [15,16] but it becomes equivalent to the asymptotic form derived in [15,16] when the core is heavy. As a result, in Ref. [18], information about the values of the TBANFs has been obtained by means of comparative analysis of the obtained asymptotic forms with the asymptotic behavior of the corresponding model three-body ($nn\alpha$) wave functions for the ^{6}He nucleus derived within the Lagrange-mesh technique [3,22] by using the αn potential taken from [23]. There it was shown that the Lagrange-mesh approximate wave function for the bound ^{6}He state is in good agreement with the asymptotic expression over larger values of the relative core-neutron coordinates (up to 20 fm) and information was obtained about the TBANF as a function of the ratio of the relative core-neutron coordinates. It should be noted that in [3,22] the binding energy calculated for the ground state of ^{6}He is in excellent agreement with the experimental one for the employed nn and $n\alpha$ potentials.

In this connection it should be emphasized that the TBANF is a fundamental characteristic of the three-body bound system, which plays the same role as the asymptotic normalization coefficient of the radial wave function for the two-body bound system [24,25]. Consequently, the TBANF is determined by the dynamics of strong interactions and, so, carries information about two-particle (nuclear) interactions in the three-body bound system. For example, as is shown in [15–17], the extracted values of the TBANFs for the ^{6}He and ^{9}Be nuclei are highly sensitive to