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Coulomb breakup of ^{37}Mg and its ground state structure

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Abstract

We calculate Coulomb breakup of the neutron rich nucleus ^{37}Mg on a Pb target at the beam energy of 244 MeV/nucleon within the framework of a finite range distorted wave Born approximation theory that is extended to include the effects of projectile deformation. In this theory, the breakup amplitude involves the full wave function of the projectile ground state. Calculations have been carried out for the total one-neutron removal cross section (σ_{-1n}), the neutron–core relative energy spectrum, the parallel momentum distribution of the core fragment, the valence neutron angular, and energy–angular distributions. The calculated σ_{-1n} has been compared with the recently measured data to put constraints on the spin parity, and the one-neutron separation energy (S_n) of the ^{37}Mg ground state (^{37}Mg$_{gs}$). The dependence of σ_{-1n} on the deformation of this state has also been investigated. While a spin parity assignment of $7/2^-$ for the ^{37}Mg$_{gs}$ is ruled out by our study, neither of the $3/2^-$ and $1/2^+$ assignments can be clearly excluded. Using the spectroscopic factor of one for both the $3/2^-$ and $1/2^+$ configurations and ignoring the projectile deformation effects, the S_n values of 0.35 ± 0.06 MeV and 0.50 ± 0.07 MeV, respectively, are extracted for the two configurations. However, the extracted S_n is strongly dependent on the spectroscopic factor and the deformation effects of the respective configuration. The narrow parallel momentum distribution of the core fragment and the strong forward peaking of the valence neutron angular distribution suggest a one-neutron halo configuration in either of the $2p_{3/2}$ and $2s_{1/2}$ configurations of the ^{37}Mg ground state.

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1. Introduction

With the advances made in the technology of producing nuclear species with relatively large neutron (N) to proton (Z) number ratios, it is now possible to extensively study nuclei near the neutron-drip line with $Z > 8$. During the last three decades measurements performed on mass, radius and spectroscopy of such nuclei have shown that they have structures that are at variance with those of their "near the line of stability" counterparts (see, e.g., [1–12], and [13–21]). With the advent of new generation of radioactive ion beam facilities, it has now become possible not only to produce medium mass neutron rich nuclei in the vicinity of the magic numbers but also employ them as projectiles to initiate reactions (e.g., breakup) on nuclear targets [22,23]. This provides excellent opportunity to perform quantitative study of the single-particle structure and the shell evolution in this region.

The notion of "magic" numbers is one of the most fundamental concepts in nuclear structure physics [24,25]. If large gaps occur between groups of single-particle orbits that are completely filled with nucleons (neutrons or protons), then these nucleon numbers are called "magic". The seven most established magic numbers are 2, 8, 20, 28, 50, 82, and 126. However, in several nuclei near the neutron-drip line, modifications to this shell structure have been observed [15]. In these cases the magic numbers evolve as a function of the neutron number – old magic numbers may disappear while new ones emerge and conventional shell gaps may break down. The region, where abrupt onset of changes in the magic numbers appears, is called island of inversion [26]. For example, rapid changes in nuclear structure and vanishing of the $N = 8$, and 20 shell gaps have been seen in neutron rich nuclei ^{12}Be [27], and ^{32}Mg [6] and ^{30,32}Ne [16], respectively. Examples of $N = 28$ shell quenching have been observed in ^{36,38}Mg [21] and ^{42}Si [28]. It is suggested in Ref. [26] that island of inversion near $N = 20, 28$ comes about because of the fact that the $\nu(sd)^{-2}(fp)^2$ intruder configurations (here ν represents a relative neutron state), in which two neutrons from the *sd* shell are excited to the *fp* shell, become so low in energy that they form the ground states for $Z = 10$–12 and $N = 20$–22 nuclei. This suggestion was confirmed subsequently by mass measurements of the neutron rich isotopes of Ne, Na and Mg nuclei [29]. Recently, this behavior has been shown to be a general phenomena that should occur for most standard shell closures far from the line of stability, and the mechanism behind this is found to be related to the importance of the nucleon–nucleon tensor interaction [30]. It is obvious that due to the intruder states, the single particle structure of the ground states of nuclei lying within island of inversion will not be the same as that emerging from the usual filling of the shell model states.

The mixing of neutron n-particle–n-hole (np–nh) intruder configurations of $\nu(sd)^{-n}(fp)^n$ character to the ground state, causes large deformation to nuclei in island of inversion near $N = 20, 28$, which is confirmed by the measured low excitation energies and $B(E2)$ values of the first excited states (see, e.g., Refs. [3,6,8,13,16,31]). It has been emphasized [26,32–34] that the deformation may also account for the enhanced binding energies manifested in some of the known nuclei in this region. The collective properties of neutron rich nuclei near $N = 20$ region are rather well described by state-of-the-art Monte-Carlo shell model calculations that allow for unrestricted mixing of neutron particle–hole configurations across the shell gap [35,36]. In Refs. [37,38], nuclei in the neighborhood of neutron-drip line have been systematically investigated in a model where one-particle motion is described within spherical as well as deformed