Halo structure of light nuclei at the neuron drip line

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Introduction

Nuclei far from stability have presented a more general view of nuclear structure that is inaccessible with stable nuclei. Since the introduction of shell model to explain the structure of stable nuclei and the so-called magic numbers, much progress has been made to understand the evolution of nuclear structure away from the valley of stability. The neutron-rich side of the chart of nuclei is the ideal playground for mapping the shell structure evolution and ultimately understanding the underlying characteristics of the nuclear force that drives it. The size and distribution of matter in the nucleus have played a central role in understanding the general features of nuclear physics. In stable nuclei the neutron and proton distributions exhibit essentially identical radii. In contrast, for some light nuclei far from stability, which combine a large neutron excess with very weak binding, large differences have been found. Such "halo" systems are well described by a core, resembling a normal nucleus, surrounded by an extended valence neutron density distribution [1]. A nuclear halo is a structure with a dilute matter distribution which extends far beyond the core of the nucleus. All halo nuclei have the same features as having an extended low-density distribution (or a large nuclear matter radius) and low binding energies of valence nucleons surrounding the core. The study of structure of halo nuclei which are near or at the drip lines (including neutron-drip line and proton-drip line on the Z-N plane) has attracted the interests of many scientists and researchers all over the world.

In this work, we have studied the ground state decay of a large number of neutron rich light nuclei near the neutron dripline by using the Cluster Core Model (CCM) [2]. The halo nature of possible neutron drip line nuclei is studied via the minima in potential energy surfaces (PES), which in turn correspond to the most probable configuration. It is of great interest to see that in what way the angular momentum, deformation and orientation effects of the decaying fragments influence the potential energy surface (PES) behavior of these rare light nuclei.

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The Model

In the Cluster Core Model (CCM) we calculate the potential energy surface (PES) of a nucleus for its all possible cluster-core (A_2, A_1) configurations and look for a neutron-cluster + core configuration with a minimum potential energy that corresponds to a configuration formed with largest quantum mechanical probability. The fragmentation potential in CCM is defined as sum of binding energies of two fragments, Coulomb repulsion, nuclear proximity attraction between them and the rotational energy due to angular momentum ℓ:

$$V_R(\eta) = -\sum_{i=1}^{2} B(A_i, Z_i) + V_C(R, Z_i, \beta_{\lambda i}, \theta_i) + V_P(R, A_i, \beta_{\lambda i}, \theta_i) + V_\ell(R, A_i, \beta_{\lambda i}, \theta_i) \quad (1)$$

Here, $B(A_i, Z_i)$ are the experimental binding energies [3] and the binding energy for a cluster with x neutrons ($x \geq 1$)is taken to be x times that of the one-neutron binding energy i.e. $B(A_2 = xn) = x\Delta m_n$ which means that nucleons in these clusters are taken to be unbound.

Calculations and discussion

We have studied the fragmentation path for 13 cases of 1n halo nuclei and 11 cases of 2n halo nuclei at $\ell = 0$ and at arbitrary ℓ values ($= 4\hbar$ & $8\hbar$) using spherical and deformation (β_2) effects within optimally oriented hot configuration. It has been observed that angular momentum $\ell > 4\hbar$ seem to influence the fragmentation path of ^{11}Be, ^{14}B, ^{17}C and ^{19}C for 1n-halo and ^{8}He, ^{11}Li, ^{12}Be, ^{14}Be and ^{19}B for 2n-halo significantly. In other words deepest minima in potential energy surfaces (PES) occurs at 1n + core configuration for 1n halo and 2n + core configuration for 2n halo cases at lower value of angular momentum but the minima shifts to another cluster at higher angular momentum $\ell = 8\hbar$ (say) for spherical as well as deformed case as shown in Fig.1 for illustrative 1n-halo case of ^{17}C nucleus. Thus the lower angular momentum component up to $\ell = 4\hbar$ seems to play silent role, as expected in reference to ground state decay of 1n and 2n-halo systems. Interestingly the deformation effects also seem to be important for ^{22}O, ^{23}O, ^{24}O, ^{26}F, ^{29}Ne and ^{31}Ne in case of 1n-halo nuclear systems whereas the same seem to be contributing significantly for ^{17}B, ^{22}C, ^{23}N, ^{27}F and ^{29}F in case of 2n-halo nuclei. The most interesting aspect of this study is that although PES are modified with inclusion of deformation effects, but the 1n and 2n-halo status remains intact almost for all cases investigated here except for ^{17}B, ^{22}C and ^{29}F. The minima of PES in case of ^{17}B and ^{22}C nuclei are at 2n + core configuration for spherical case but it shifts to 1n + core configuration for ^{17}B nucleus and 4n + core configuration for ^{22}C nucleus with inclusion of deformations and orientation effects. However ^{29}F nucleus shows an interesting result which gives 2n halo nucleus for deformed case and 4n halo for spherical case as shown in Fig.2. Thus the angular momentum, deformation and orientation effects seem to influence the fragmentation path of majority of halo nuclei near the neutron-dripline and hence the information contained in present work is of relevance in reference to nuclear reaction dynamics and related phenomena at low energies.

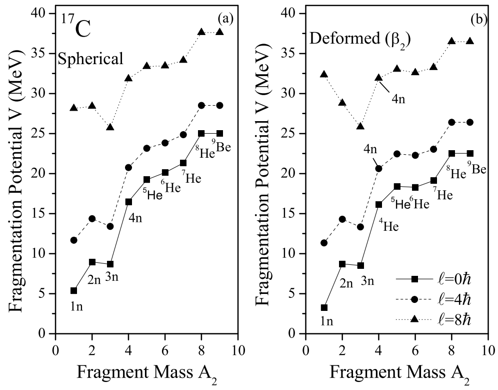

FIG. 1: Fragmentation potential for the decay of ^{17}C nucleus, plotted at different ℓ values for spherical and β_2-deformed choice of fragmentation.

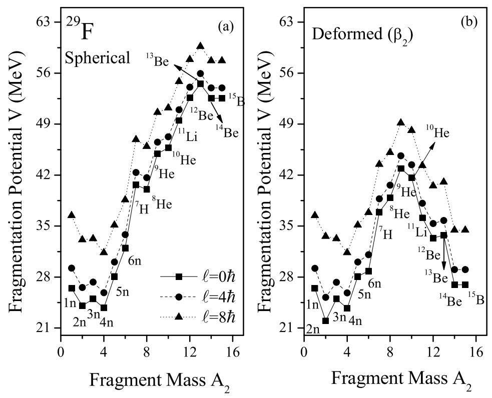

FIG. 2: Same as for Fig.1, but for ^{29}F halo nucleus.

References

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