Effects of deformations and orientations on neutron-halo structure of light-halo nuclei

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Introduction

The availability of radioactive nuclear beams have enabled us to study the structure of nuclei far from the stability line, which in turn led to the discovery of neutron-halo nuclei. These nuclei, located near the neutron drip-line exhibit a high probability of presence of one or two loosely bound neutrons at a large distance from the rest of nucleons. These neutrons can be viewed as a halo surrounding a core composed of the remaining nucleons. So far, the neutron-halo nuclei have been limited to only the light nuclear systems, like ^{11}Be, ^{19}C (with a one-neutron halo), and ^{6}He, ^{11}Li (with two-neutrons halos), etc. These nuclei have a nucleon or a two-nucleons separation energy extremely small (<1 MeV), compared to ∼6-8 MeV for stable nuclei. The existence of proton-halos has also been observed in some proton-rich nuclei. However, relatively speaking, the presence of repulsive Coulomb interaction hinders the formation of proton halos.

The halo structure of a variety of neutron drip-line nuclei have been investigated [1] at the ground-state, by using the cluster-core model (CCM) model based on the core+valence neutrons picture. In order to extend this work, we apply the same (neutron) cluster-core model to analyse the influence of nuclear deformations and orientations on the fragmentation path of halo nuclei. The CCM find its basis in the well known Quantum Mechanical Fragmentation Theory (QMFT) where the halo nature of possible neutron drip-line nuclei is studied via the minima in potential energy surfaces (PES), which in turn corresponds to the most probable halo-configuration. Here we investigate the effects of nuclear deformations by accounting for the higher multipole deformations, like the octupole and hexadecapole, alongwith the role of different proximity potentials on the PES behavior of one-neutron halo nuclei.

Methodology

The potential energy in CCM comprises of binding energies, Coulomb repulsive interaction, additional attraction due to nuclear proximity force and centrifugal potential due to angular momentum:

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

B_i (i=1,2) are the binding energies of the two fragments, taken from experimental data of Audi-Wapstra [2]. Wherever the experimental B's are not available, the theoretical binding energies of Möller *et al.* [3] are used.

Calculations and discussion

The fragmentation behavior is studied for 13 cases of 1n-halo nuclei, which include ^{11}Be, ^{14}B, ^{15}C, ^{17}C, ^{19}C, ^{22}N, ^{22}O, ^{23}O, ^{24}O, ^{24}F, ^{26}F, ^{29}Ne and ^{31}Ne, using the CCM extended to include the deformations and orientations of nuclei. The calculations are done for the fragments taken as spheres, with quadrupole deformations β_{2i} alone having "optimum" orientations θ_i^{opt} [4], and with quadrupole, octupole, and hexadecapole deformations (β_{2i}, β_{3i}, β_{4i}) having "compact" orientations θ_i^c of 'hot' configurations [5]. We observe that, although the PES are modified, the 1n-halo structure remains intact in all cases, irrespec-

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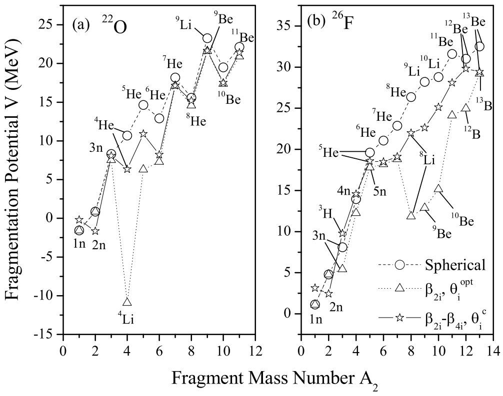

FIG. 1: The fragmentation potential using Blocki *et al.* nuclear proximity, for (a) ^{22}O and (b) ^{26}F nuclei, taking the two fragments as spheres, with β_{2i} alone, and (β_{2i}-β_{4i}) deformations at ℓ =0.

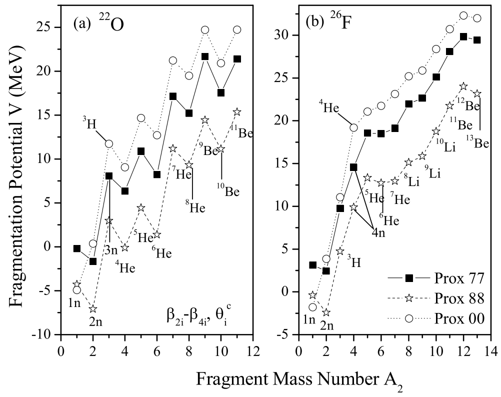

FIG. 2: Same as for Fig. 1, but for the use of proximity potentials Prox 77, 88, and 00 using (β_{2i}-β_{4i}) deformations and compact orientations.

tive of spherical or deformed choice of configuration up to β_2 alone. However, the inclusion of higher multipole deformations (β_2-β_4) of the decay fragments seem to influence the fragmentation path significantly for ^{22}O and ^{26}F nuclei, as is illustrated in Fig. 1 for ℓ=0 case. One can clearly see in Fig. 1 that the deepest minimum occurs at 1n+core configuration for spherical and β_2-deformed cases, which shifts to 2n+core configuration for the choice of deformations included up to hexadecapole (β_4) for ^{22}O and ^{26}F halo nuclei. Also, our analysis in Fig. 1(a) shows that ^{4}Li+core configuration is preferred over the 1n+core configuration for the case of β_{2i}-deformed choice of fragments. However, the most preferred cluster-core configuration for ^{22}O is 1n+core. We further observe that the fragments corresponding to minima in PES do not remain same in going from spherical to deformed (β_2-alone or β_2-β_4), specifically for ^{26}F nucleus which signifies that the fragmentation path of halo nuclei is significantly affected by the inclusion of deformation effects.

In order to check the anomaly of neutron-halo structure of ^{22}O and ^{26}F, with (β_2-β_4) deformations included, we investigate the role of different nuclear potentials on the halo structure of neutron-dripline nuclei by using different proximity potentials. Note that till now nuclear proximity of Blocki *et al.* is used in the framework of CCM, so also in Fig. 1. Fig. 2 shows the results of our PES calculation for (a) ^{22}O and (b) ^{26}F, using nuclear proximity potentials Prox 77, Prox 88 and Prox 00 having different isospin and asymmetry dependent parameters, and for β_2-β_4 deformed choice of fragments. We notice that the behavior of PES for Prox 77 and Prox 88 potentials is similar, although the depths of minima are quite different and gives 2n-halo configuration which shifts to 1n-halo with the choice of Prox 00. This clearly indicates that the choice of proximity potential, together with deformation effects, play a significant role in deciding the structure of halo nuclei.

References

[1] R. K. Gupta, *et al.*, J. Phys. G: Nucl. Part. Phys. **26**, L23 (2000); R. K. Gupta, *et al.*, *ibid.* **28**, 699 (2002).

[2] G. Audi, *et al.*, Nucl. Phys. A **729**, 337

[3] P. Möller, *et al.*, At. Nucl. Data Tables **59**, 185 (1995).

[4] R. K. Gupta, *et al.*, J. Phys. G : Nucl. Part. Phys. **31**, 631 (2005).

[5] R. K. Gupta, *et al.*, Phys. Rev. C **73**, 054307 (2006).