Nuclear Clustering - A cluster core model study

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Introduction

Nuclear clustering, similar to other clustering phenomenon in nature is a much warranted study, since it would help us in understanding the nature of binding of the nucleons inside the nucleus, closed shell behaviour when the system is highly deformed, dynamics and structure at extremes. Several models account for the clustering phenomenon of nuclei. We present in this work, a cluster core model study of nuclear clustering in light mass nuclei.

Methodology

Cluster core model (CCM) has been put forth by one us [1, 2] for the studies of halo structure of nuclei. In CCM the potential energy surface of a nucleus is calculated for its all possible cluster-core (A_2, A_1) configurations. For the studies of halo nuclei we look for a neutron(s)-cluster and/or proton(s) cluster + core configuration with a minimum potential energy, which in the language of the cluster-decay model means a configuration formed with the largest quantum mechanical probability. Similar model were also reported by Hansen and Jonson [3], where the halo nucleus ^{11}Li was approximated by a ^{9}Li core plus a dineutron consisting of two *unbound* neutrons. Extending the idea of neutron(s) and/or proton(s) clusters to heavier $x\alpha$ clusters (with x = 1 to 6) we studied the ground state clustering phenomenon of some light mass nuclei such as ^{28}Si and ^{56}Ni.

The potential energy for a α,cluster-core configuration (A_3, A_2, A_1) of a nucleus A $(=A_1 + A_{23} \rightarrow A_1 + A_2 + A_3)$; A_1 is the core and A_2 and A_3 are the cluster mass numbers) is defined as the sum of the binding energies and/or mass excesses (in MeV), the Coulomb repulsion, and the additional attraction due to nuclear proximity $V_{P_{ij}}$. The Coulomb interaction energy defines the force of repulsion between the two interacting charges.The coulombic potential energy is given by the formula

$$V_{C_{ij}} = \frac{(Z_i Z_j e^2)}{R} \tag{1}$$

where Z_i and Z_j are the atomic numbers of the mass fragments R_{ij} is the distance between the centre of the two fragments. The radius of each fragment is $R_x = r_0 A_x^{1/3}$. Here $r_0 = 1.2fm$.The two fragments are considered to be in touching configuration. So the distance of separation is the sum of the radii of the two fragments.

$$R_{ij} = R_i + R_j \tag{2}$$

The total energy is calculated as,

$$V_{ij} = -\sum_{i=1}^{3} B(A_i, Z_i) + \sum_i \sum_{j>i} V_{C_{ij}} + V_{P_{ij}}. \tag{3}$$

All possible binary combinations are generated. In the binary division for $A_2 \geq 5$ and $Z_2 \geq 2$, the element A_2 is assumed as A_{23} which further splits as an α particle and the remaining particle is considered as the third fragment as,

$$A \rightarrow A_i + A_{jk} \tag{4}$$

for binary fission

$$A \rightarrow A_i + (A_{jk} \rightarrow A_j + A_k) \tag{5}$$

$$A \rightarrow A_i + A_j + A_k \tag{6}$$

leading to three division and the fragments are assumed in a collinear arrangement (in a touching configuration). Here A_j is considered to be an $x\alpha$ where $x = 1, 2, ...$ based on the number of alpha particles present.

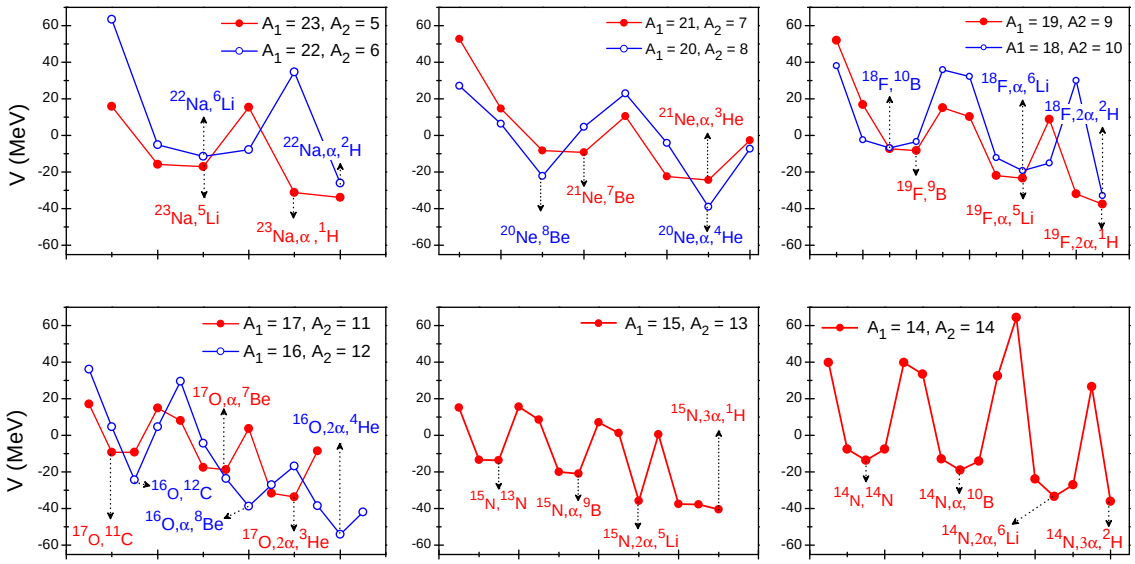

FIG. 1: Binary division and α - cluster associated ternary division potentials are shown for all possible mass and charge asymmetries of ^{28}Si.

Results and discussion

The methodology mentioned above is applied to various light systems such as $^{56}_{28}Ni$, $^{28}_{14}Si$ and $^{12}_{6}C$, however, we present the results corresponding to $^{28}_{14}Si$. Figure 1 presents the calculated PES for binary division as well as ternary division involving $x\alpha$ (with $x = 1$ to 3) as one of the clusters. The six panels present all the possible binary breakups for $A_2 \geq 5$ onwards upto $A_2 = 14$. In addition to the binary division, the potential energies are calculated for the collinear arrangements of the fragments involving possible α - clusters and associated particles and/or fragments. It is seen in the figure that for all possible A_2 preference is seen for α - associated breakup than the binary ones. For even A_2 the binary division as well as α - associated breakup possesses energy lower than its neighbouring odd mass A_2 values. Further, the energy corresponding to α - associated breakup has deeper valley with increasing size of A_2. In other words clustering seems more probable for symmetric breakups than asymmetric breakups. Further, study is warranted with inclusion of temperature and angular momentum in the model which will form the future scope of the work.

References

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