Linear and compact 3α-structure of ^{12}C

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Nuclear clustering and α conjugate structure of light nuclei has been studied extensively by various theoretical models as well as by various experimental methods. These studies give an important nuclear structure information viz., the highly deformed nuclear configurations. Complex structures such as triangular, tetrahedral and linear chains of alpha particles were predicted and appropriately assigned to the excited states. Recent calculations of topological solutions coming from the Skyrmion model [1] predict a D3h symmetry for the ^{12}C ground state as an equilateral triangle of B = 4 Skyrmions, modeling three alpha particles.

In this work, we investigate all possible three body breakups of ^{12}C nucleus within three cluster model [2]. To study all the possible three body fragmentations, we impose the following condition on the masses: $A_1 \geq A_2 \geq A_3$ to avoid repetition of the fragment combinations. Here, the fragment denoted by A_1 is the heaviest among all the three fragments and the fragment A_3 is the lightest among all the fragments. All the three fragments may have the same mass, with A_1, A_2 and A_3 as the mass numbers of the three fragments. For ^{12}C the possibility of various third fragments are from $A_3 = 1$ to 4 with A_3 = 1 and A_3 = 4 defining the limiting case of the neutron and/or proton numbers as a third fragment and true ternary case with all the fragments having a mass 4, respectively.

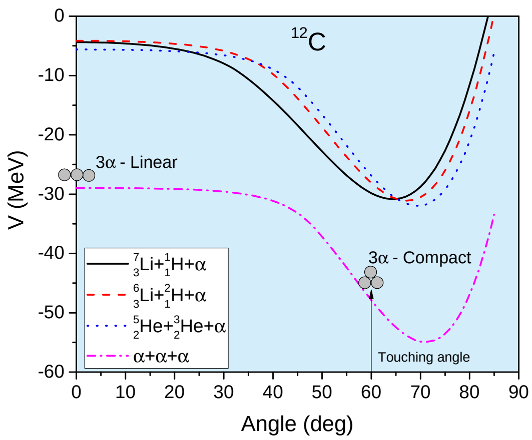

FIG. 1: The potential as a function of angle. The triangular configuration is at the touching angle.

To calculate the fragmentation potential energy, we consider the center of the middle fragment A_3 is fixed at the origin and the other two fragments A_1 and A_2 are on either side of the middle fragment.

The potential is calculated as a function of angle θ between the line passing through the centers of the middle fragment and the other two fragments (See Fig. 1 of [2]). The potential is calculated from an angle $\theta = 0$, corresponding to a linear arrangement of the three fragments as shown in Fig. 1, and arrangements corresponding to a triangle or compact configuration is reached for some angle (referred to as the touching angle), where all three fragments surfaces are touching each other. Beyond the touching angle, the fragments considered at the either sides of the middle fragment would start to overlap.

The distance between the centres of the interacting fragments R_{ij} can be written as,

$$R_{32} = R_3 + R_2; \; R_{31} = R_1 + R_3, \qquad (1)$$

$$R_{12} = \sqrt{R_{23}^2 + R_{13}^2 + 2R_{23}R_{13}\cos 2\theta} \qquad (2)$$

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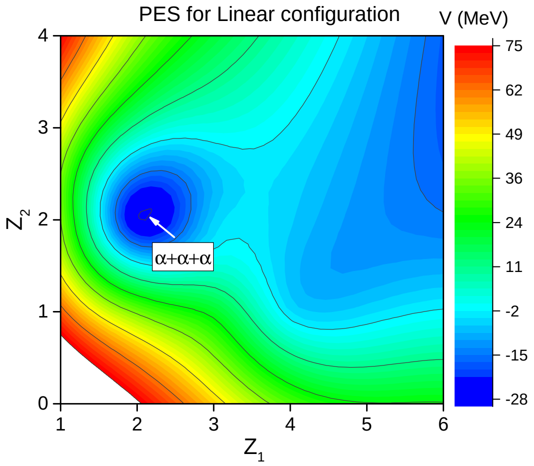

FIG. 2: The PES for all possible three body interaction in linear configuration.

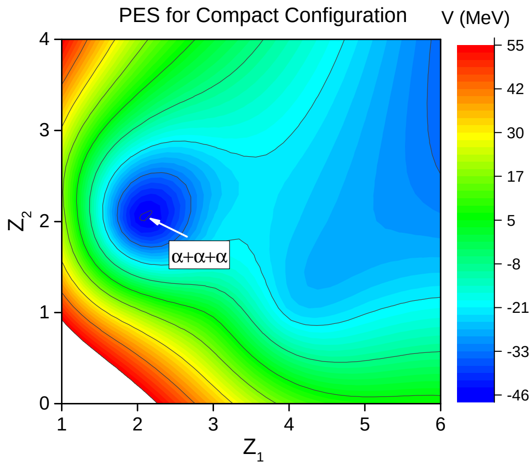

FIG. 3: The PES for all possible three body interaction in compact configuration.

The radius of each fragment is defined by $R_x = r_0 A_x^{1/3}$; with $r_0 = 1.16$ *fm*. At any angle, the center of mass can be defined as,

$$\mathbf{R_{cm}} = \frac{m_1\mathbf{R_{31}} + m_3\mathbf{0} + m_2\mathbf{R_{32}}}{m_1 + m_2 + m_3}, \quad (3)$$

where m_i's are masses of i^{th} fragments in MeV and $\mathbf{R_{ij}}$ is the distance vector between i^{th} and j^{th} nuclei.

$$\mathbf{R_{31}} = -R_{31}\cos\theta\hat{i} + R_{31}\sin\theta\hat{j} \quad (4)$$

$$\mathbf{R_{32}} = R_{32}\cos\theta\hat{i} + R_{32}\sin\theta\hat{j} \quad (5)$$

The potential between the three (spherical) fragments is defined to be the sum of the total Coulomb potential $V_{Cij}(\theta)$ taken from [3], total nuclear potential, and the sum of the mass excesses of the fragments, is given as

$$V_{tot}(\theta) = \sum_{i=1}^{3} m_x^i + \sum_{i=1}^{3}\sum_{j>i}^{3} V_{ij}(\theta) \quad (6)$$

where m_x^i are the mass excesses of the three fragments in energy units.

$$V_{ij}(\theta) = V_{Cij}(\theta) + V_{Pij}(\theta). \quad (7)$$

The proximity potential V_{Pij}, is defined as,

$$V_{Pij} = 4\pi\overline{R}\gamma b\phi(\xi). \quad (8)$$

Figs. 2 and 3 present the potential energy surface (PES) of all possible ternary breakups of ^{12}C corresponding to linear (light fragment at middle) and compact configuration. Deepest minimum in the PES indicates the existence of $\alpha + \alpha + \alpha$ structure out of all possible breakups with compact configuration preferred over linear configuration. The obtained results supports earlier predictions of preference of compact 3α structure. The role of excitation energy, angular momentum, moment of inertia will be studied.

Acknowledgments I. Sreeja, acknowledges University Research Fellowship awarded by Bharathiar University, Coimbatore -641046.

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