Nuclear structure effects in the decay of α and non-α compound systems

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Introduction

The study of decay products of composite systems formed in heavy ion reactions helps to understand the role played by different processes in the fragment emission. The experimental studies in light mass region have been directed to understand the decay dynamics of compound nuclei formed in light mass region [1–3], for last couple of decades. These light composite nuclei show signatures of competing decay mode (deep inelastic orbiting) with partial entrance channel memory in addition to well known decay path of fusion-fission [1, 2] and show large deformations in the excited states [3].

In the present work, we study the comparitive nuclear structure effects in the decay of light mass α compound systems ^{28}Si* (^{16}O+^{12}C), ^{40}Ca* (^{12}C+^{28}Si) and non-α compound system ^{39}K* (^{11}B+^{28}Si) at nearly same excitation energy E^*_{CN}~67 MeV, within dynamical cluster decay model (DCM) of Gupta and Collaborators [4]. In α cluster nuclei the number of protons and neutrons are equal and these are multiple of alpha nucleus ^{4}He. It is relevant to mention here that the decay of ^{39}K*, ^{40}Ca* has been studied within DCM but with spherical consideration of interacting nuclei [5]. Since light nuclei are known to be deformed, therefore in the present work we take up study of these systems with quadrupole deformations and orientations of interacting nuclei considered. The experimental Z-distribution data shows enhanced yield near the entrance channel (Z=5) for these systems in comparison to Z=3,4 fragments, indicating presence of competing reaction mechanisms in their decay [2]. It is relevant to mention here that nuclear structure effects enters into DCM via preformed clusters, with certain preformation probability P_0, before tunneling the interaction barrier.

Methodology

The DCM [4] is based on quantum mechanical fragmentation theory and is worked out in terms of collective coordinates of mass asymmetry $\eta = (A_T\text{-}A_P)/(A_T\text{+}A_P)$ and relative separation (R) with effects of deformations and orientations duely incorporated in it. In terms of these collective coordinates, using the ℓ- partial waves, the decay cross-section is defined as

$$\sigma = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_c}(2\ell+1)P_0P;\ k=\sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \quad (1)$$

where ℓ_c, the critical angular momentum, penetrability P refers to R motion and is calculated using WKB approximation, P_0 refers to η motion and is given by sol. of stationary Schrödinger equation in η, at a fixed $R = R_a$,

$$\{-\frac{\hbar^2}{2\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}\frac{1}{\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}+V_R(\eta,T)\}\psi^\nu(\eta) = E^\nu\psi^\nu(\eta). \quad (2)$$

The minimized fragmentation potential ($V_R(\eta$,T) in eq. 2) is the sum of temperature dependent Coulomb, proximity, centrifugal potentials along with temperature dependent liquid drop energies and shell effects. For a fixed β_{λ_i}, the potential values for all possible mass (A) combinations corresponding to a given charge (Z) is minimized in mass coordinate (η) and gives the most probable/minimized potential for the outgoing fragments.

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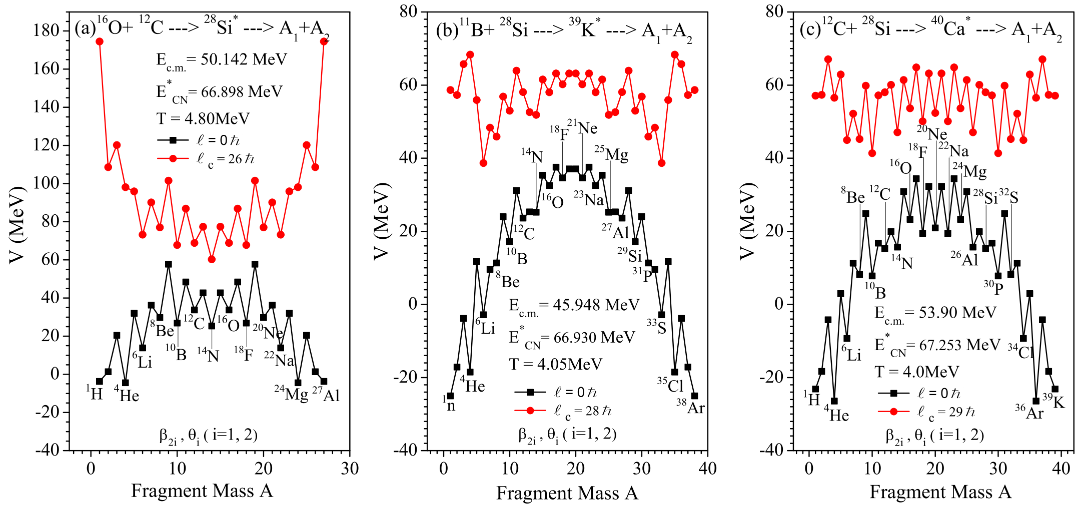

FIG. 1: (Color online) Variation of fragmentation potentials with fragment mass A for the decay of (a) ^{28}Si*, (b) ^{39}K* and (c) ^{40}Ca* at $E_{CN}{}^*{\sim}67$ MeV and for ℓ=0 $\hbar$ alongwith respective ℓ_c-values.

Calculations and Discussions

The Fig. 1 shows the calculated mass fragmentation potentials at ℓ=0 and the respective ℓ_c-values for the decay of α compound systems (^{28}Si*, ^{40}Ca*) and non-α compound system (^{39}K*) at nearly same excitation energy $E^*_{CN}{\sim}67$ MeV with quadrupole deformation and orientation of the outgoing nuclei included. We observes that at ℓ=0 $\hbar$, light particles, LPs or evaporation residues production is prominent while this trend is reversed by including the angular momentum effects and intermediate mass fragments, IMFs starts competing with LPs at higher ℓ values.
In α compound systems at ℓ=ℓ_c, there is strong minima for symmetric decay of ^{28}Si* while symmetric decay of ^{40}Ca* is having strong competition from neighboring fragments (^{18}F, ^{14}N) and lighter IMFs. Interesting enough, in case of non-α compound system ^{39}K*, the nearly symmetric breakup is favored neither at ℓ=0 nor at ℓ_c in comparison to the α compound systems (^{28}Si*, ^{40}Ca*). Further, we will look for the comparative penetrability of these minimized fragments or strongly preformed fragments through interaction barrier and try to fit the cross-section for ff and DIO processes in reference to the available experimental data [2]. Study is in progress.

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References

[1] S.J. Sanders, PRC **44**, 2676 (1991); C. Beck, PRC **53**, 1989 (1996); S.J. Sanders et al., Phys. Rep. **311**, 487 (1999).
[2] S. Kundu et al., PRC **78**, 044601 (2008); PRC **85**, 064607 (2012); Parm. J. Phys. **82**, 727 (2014).
[3] S. Kundu et al., PRC **87**, 024602 (2013).
[4] R. K. Gupta, *et al.*, PRC **71**, 014601 (2005); IJMPE **15**, 699 (2006); PRC **77**, 054613 (2008); JPG:NPP **36**, 085105 (2009); PRC **80**, 034618 (2009); PRC **90**, 024619 (2014); PRC **92**, 024623 (2015).
[5] G. Kaur et al., IJMPE **23**, 1450063 (2014).