Fusion-fission of very light mass compound nucleus ^{28}Al* using the dynamical cluster decay model

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Introduction

For light compound nuclei with A_{CN} ∼40-80, the viability of fusion-fission (FF) process and the related reaction dynamics has been established [1], contrary to the predictions of the rotating liquid drop model (RLDM) [2] which advocates strong inhibition of FF as compared to the deep inelastic scattering process in this mass region. In other words, in very light mass compound nuclei with A_{CN} ∼30, the FF process is expected to be inhibited on the basis of the RLDM. However, some attempts have been made to explore the FF component in very light systems, and in one such attempt the decay of a very light mass compound nucleus (CN) ^{28}Al* produced in ^{18,17}O+^{10,11}B and ^{19}F+^{9}Be reactions is investigated at various center-of-mass energies $E_{c.m.}$ [3]. In this experiment, fully energy damped binary process is observed which is well supported by the statistical model calculations based on the transistion-state model (TSM) [3].

A systematic study [4] of FF process in light heavy-ion reactions suggests that RLDM can be extended to very light nuclei when the diffuse nature of nulcear surfaces and finite nuclear range effects have been explicitly taken into account, though the second order effects like the nuclear structure effects, proximity effects, the temperature-T dependence of the surface energy, etc., should also be included. This study suggests a very crude macroscopic picture of nuclear matter at high excitation energy and angular momentum to describe the collective nature of very light hot nuclei, considered as remnants of liquid droplets. Yet another systematic study [5], pertaining to the reaction dynamics of very light compound systems, predicts onset of the hindrance of the statistical processes (fusion, fission, etc.) at mass region with ${A_1}^{1/3}+{A_2}^{1/3}$ <4.7. This observation can be related to the atomic number of the nuclei for which the nuclear density distributions no longer present the volume saturation and are dominated by a nuclear surface alone.

A very light CN ^{28}Al* is studied here for the first time using the Dynamical Cluster-decay Model (DCM) of Gupta and collaborators [6]. Applications of the DCM have so far been made to the decay of light, medium, heavy and superheavy mass CN, successfully. In DCM, the concept of preformed clusters in nuclei leads to a non-statistical description for the decay of a CN to light particles (LPs; n, p and α-particles), the intermediate mass fragments (IMFs; both light and heavy), fusion-fission (FF) and quasi-fission (QF) processes. Different mass regions of the Periodic Table show different combinations of these processes or any one of them as a dominant mode and DCM seem to provide a decent description of all these decay modes. Therefore, it is highly motivating to investigate which mode of decay is dominant in the very light mass CN systems. The lightest CN studied so far on DCM is ^{48}Cr*, and ^{28}Al* offers an ideal example of a still lighter mass where sufficient data [3] is available over a range of incident energies.

Methodology

Based on the fragmentation potential at fixed relative separation R and T, and the scattering potential at fixed mass [and charge] asymmetry $\eta = \frac{A_1-A_2}{A_1+A_2}$ [$\eta_Z = \frac{Z_1-Z_2}{Z_1+Z_2}$] and T,

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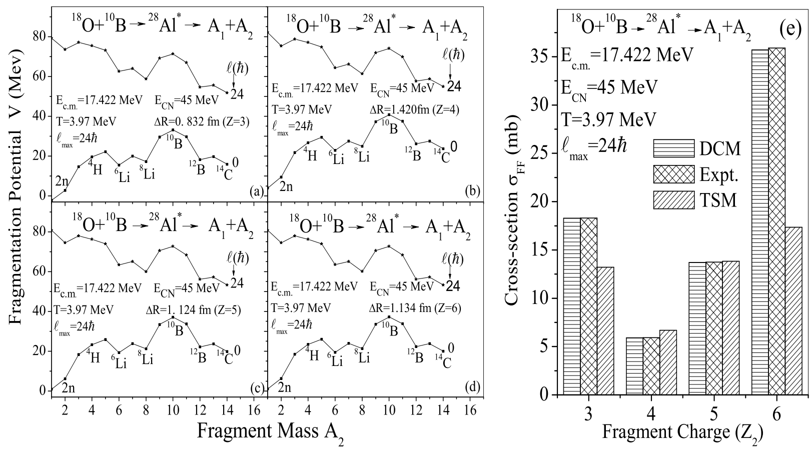

FIG. 1: (a)-(d) Fragmentation potentials calculated for the decay of ^{28}Al* formed in ^{18}O+^{10}B reaction at T=3.97 MeV for ℓ =0 and 24 $\hbar$ and for different ΔR's chosen to fit the experimental data of fragments with Z=3, 4, 5, and 6, respectively. (e) Calculated σ_{FF} for Z=3, 4, 5,6 fragments for the decay of ^{28}Al*, compared with the TSM calculations and experimental data [3].

we calculate the CN decay cross-section by using the DCM, worked out in terms of decoupled η and R coordinates. In terms of these coordinates, using ℓ partial waves, the CN decay cross-section is defined as

$$\sigma = \frac{\pi}{k^2}\sum_{l=0}^{l_{max}}(2l+1)P_0P; \qquad k=\sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \tag{1}$$

where the preformation probability P_0, referring to η motion, is the solution of stationary Schrödinger equation in η at a fixed R, and P, the WKB penetrability, refers to R motion. Both the quantities P_0 and P carry the effects of T and ℓ of colliding nuclei at a given $E_{c.m.}$. Here, $\mu = [A_1A_2/(A_1+A_2)]m$, is the reduced mass, with m as the nucleon mass.

Calculations and Discussions

Figures 1(a), (b), (c), (d) depict the calculated fragmentation potentials for the decay of ^{28}Al* into various mass fragments (LPs and IMFs) at T=3.97 MeV ($E_{c.m.}$=17.422 MeV) at two extreme ℓ-values. Note that the structure of potential energy surface (PES) does not change in going from ℓ=0 to ℓ_{max}-value (=24 $\hbar$). Intrestingly, however, the characteristic behaviour of LPs and IMFs is opposite to each other. In other words, at lower ℓ-values, the LPs are energetically more favorable (lower in energy), whereas the same is true of IMFs at higher ℓ-values. More significantly, the PES do not change for the different choices of ΔR to fit the data of fragments having Z=3, 4, 5, and 6, respectively (compare the PES of Fig. 1(a) with Figs. 1(b),(c),(d)).

In Fig. 1(e), the calculated FF cross-section σ_{FF}, corresponding to Z=3, 4, 5, 6 fragments for ^{18}O +^{10}B→ ^{28}Al* reaction, are compared with the experimental data [3], as well as the TSM calculations [3]. We notice that the DCM fitted σ_{FF} show a better comparison with the experimental data, as compared to TSM calculations. Further work is in progress.

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