Comprehension of Incomplete Fusion Dynamics from Excitation Function Measurements

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Introduction

Efforts have been put forth in understanding the competition between complete fusion (CF) and incomplete fusion (ICF) dynamics at intermediate energies [1,2]. In the ICF process, the projectile may break-up into two parts near the target nuclear field. One of the parts fuses with target nucleus leading to the formation of less massive composite system in comparison to the CF process where entire projectile amalgamation takes place with the target nucleus. The proposed theoretical models are unable to reproduce the experimental ICF data satisfactorily below 10 MeV/nucleon and ICF dependence on various entrance channel parameters is not well understood in this energy region. Thereby, the study of ICF dynamics is still an area of resurgent interest for many nuclear physicists. Britt and Quinton [3] firstly perceived the ICF signature in the break-up of projectiles like ^{12}C, ^{14}N and ^{16}O into α-clusters. A sharp cutoff approximation was approached to explain the ICF process, where the ICF probability is assumed to be zero for $\ell \leq \ell_{crit}$ and likely to be occurred for $\ell > \ell_{crit}$ [4]. However, some researchers [1, 5] found the ICF existence for $\ell \leq \ell_{crit}$. Recently, conflict with Morgenstern *et al.* [6] suggestions is observed and projectile structure in terms of alpha Q-value is also found to affect the onset of ICF [7]. In the present work, an attempt has been made to understand the ICF dependence on projectile structure along with mass-asymmetry from the excitation functions (EFs) measurement of evaporation residues for ^{13}C + ^{165}Ho system at energies ≈ 4-7 MeV/nucleon. This study may also be helpful to have a better picture of ℓ_{crit} window.

Experimental Procedure

Present experiment work was carried out at Inter University Accelerator Centre (IUAC), New Delhi. ^{165}Ho target foils of thickness ranging ≈ 1.0-1.5 mg/cm^2 and Al-foils having thickness ranging ≈ 1.5-2.0 mg/cm^2 were fabricated by using the rolling technique and thickness was measured by applying the α-transmission method. Al- foils were used as catchers as well as energy degraders. Two stacks each having four ^{165}Ho target foils backed by Al-foils was irradiated for about 7 hours using ^{13}C ion-beam in General Purpose Scattering Chamber (GPSC) to cover the energy range ≈ 56-88 MeV. Total charge collected at Faraday cup during the irradiation was used for beam flux calculation. The activities induced in each target-catcher foil were recorded by using a pre-calibrated (100cc) High Purity Germanium (HPGe) Detector coupled to CAMAC-based CANDLE software. The geometry-dependent efficiencies of the HPGe detector at various source detector positions were obtained by using the standard ^{152}Eu source.

Results and Discussion

The EFs of several evaporation residues ^{175}Ta(3n), ^{174}Ta(4n), ^{173}Hf(p4n), ^{172}Lu(α2n), ^{170}Lu(α4n) etc. have been measured in the interaction of ^{13}C with ^{165}Ho target in the present work. The independent cross-sections have been deduced using the formalism given in Ref. [2] and measured EFs are then compared with theoretical predictions based on code PACE-4, which gives only the CF contribution. In Fig.1(a), the EF for residue ^{174}Ta is displayed. This figure clearly shows that the experimentally measured cross sections well matched with theoretical predictions for free parameter value K = 10 out of parameter values K = 8-12. It infers that the residue ^{174}Ta is populated via CF process via emission of four neutrons from the compound nucleus ^{178}Ta. On the other hand, significant enhancement in measured cross-sections over theoretical prediction is observed in the EF of residue ^{172}Lu, as shown in Fig.1(b). This enhancement is attributed to ICF process and indicates that ICF process also contributes in the population of ^{172}Lu along with CF process. In the present work, we have also made an attempt to study the conflict between the suggestions of Morgenstern *et al.* [6] and recent aspects regarding the projectile structure effect on onset of ICF [7]. In Fig. 2, The ICF fraction (F_{ICF}) has been deduced for the system ^{13}C + ^{165}Ho and plotted along with F_{ICF} observed for previously studied systems at same relative velocity (v_{rel}) = 0.054c. The mass-asymmetry factor (μ_m) [$\mu_m = A_T/(A_P+A_T)$] for ^{16}O + ^{165}Ho, ^{12}C + ^{165}Ho and ^{13}C + ^{165}Ho systems are 0.912, 0.932 and 0.927 respectively. However, mass-asymmetry factor is smallest for ^{16}O + ^{165}Ho system but more F_{ICF} is observed for ^{16}O + ^{165}Ho system than that for ^{12}C + ^{165}Ho and ^{13}C + ^{165}Ho systems, as shown in Fig. 2. Hence, it may be indicated that projectile structure also affects the strength of ICF along with mass-asymmetry of interacting partners. It is also observed that F_{ICF} decreases with increasing the negative Q_α-value and is smallest for ^{13}C induced reactions with ^{165}Ho target. Further, findings regarding the ICF behaviour with projectile energy and contribution below ℓ_{crit} window will also be presented.

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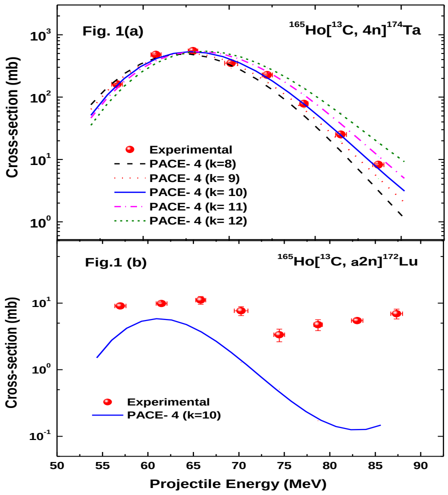

Fig.1: EF of residues (a) ^{174}Ta(4n) and (b) ^{172}Lu(α2n) produced in ^{13}C + ^{165}Ho system.

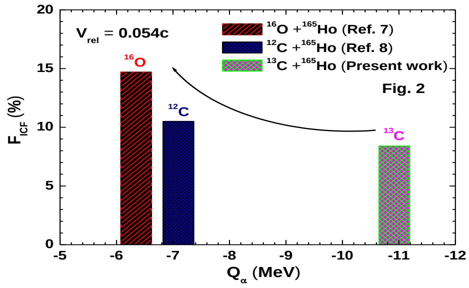

Fig.2: F_{ICF} for ^{16}O, ^{12}C and ^{13}C projectiles with ^{165}Ho against the Q_α-values at same v_{rel} = 0.054c.

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