Influence of α-separation energy on incomplete fusion of ^{6,7}Li in ^{89}Y

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Introduction

The complexity involved in the interaction between two heavy nuclei may lead to a variety of nuclear reaction processes, such as compound, precompound, and direct [1, 2, 3, 4, 5, 6, 7]. Due to weak binding of some stable nuclei, such as ^{6}Li (α+d, S$_\alpha$=1.474 MeV), ^{7}Li (α+t, S$_\alpha$=2.468 MeV), and ^{9}Be ($\alpha + \alpha + n$, S$_n$=1.665 MeV), incomplete fusion (ICF) is a competing mode of reaction even at low incident energies [1, 2, 3, 5, 6]. Also, the production of beams of radioactive nuclei (i.e., ^{6}He, ^{11}Li, etc.) has intensified the fusion research since the last few decades. It is also inferred that dynamics of ICF on different entrance channel parameters, like projectile energy, structures of the colliding nuclei, projectile target mass asymmetry μ, α-separation energy (S$_\alpha$), the Z$_p$Z$_t$ factor, and role of driving input angular momentum (ℓ) is not well understood. Gomes *et al.* [5] reported that the probability of ICF (P$_{ICF}$) decreases with decreasing target charge (Z$_t$) for ^{9}Be-induced reactions, which is unlike the study carried out by Jha *et al.* [6]. Besides, a systematic study [7] reported that ICF fraction (F$_{ICF}$) rises exponentially with mass-asymmetry (μ), target deformation parameter (β_2), deformation length ($\beta_2 R$), and neutron excess (N-Z) of target, whereas linear relation of F$_{ICF}$ with μ was observed earlier. This indicates the necessity of more experimental data to understand the clear picture of ICF with various entrance channel parameters.

Here, some aspects of the recently reported residues that are populated via CF-ICF processes in the ^{6}Li+^{89}Y reaction within the range 3.8 – 7.2 MeV/nucleon has been discussed [3]. Further, F$_{ICF}$ has been estimated for α-emitting channels in ^{7,6}Li+^{89}Y [1, 3] systems and the dependence of ICF fraction on entrance channel parameters, such as projectile energy, driving input angular momentum, α-separation energy (S$_\alpha$) of the projectiles (^{6,7}Li) has been analyzed.

Experimental details

The experiment was performed at the 14UD BARC-TIFR Pelletron facility, Mumbai, India. The ^{6}Li beam was shot on self-supporting pure (99.99%) natural ^{89}Y target foils of thickness between 2.0 – 3.0 mg/cm^2, were prepared by the proper rolling method. The thickness of catcher foils (^{27}Al) was between 1.5 – 4.0 mg/cm^2. The stacked-foil activation technique was employed, followed by off-line γ-ray spectroscopy, to measure the activity and production cross-sections of radionuclides populated through CF and ICF processes in ^{6}Li+^{89}Y reaction.

Results and discussion

The cross-sections of eleven residues, namely, ^{93m}Mo, ^{91}Mo, ^{90}Mo, ^{92m}Nb, ^{90}Nb, ^{89m}Zr,^{89}Zr, ^{88}Zr, ^{90m}Y, ^{87m}Y, and ^{87m}Sr, which are populated from the ^{6}Li+^{89}Y reaction through the CF and ICF mechanisms, were measured and compared with the statistical model code EMPIRE3.2.2. EMPIRE considers Hauser-Feshbach (HF) formalism for compound nucleus reactions and the exciton model for pre-equilibrium emission calculations. It has been found that experimentally measured cross-sections for xn/pxn channels are successfully explained by EMPIRE with enhanced generalized superfluid model level density. It confirms the production of these xn/pxn channels solely via the CF process. However, in the case of α-emitting channels,

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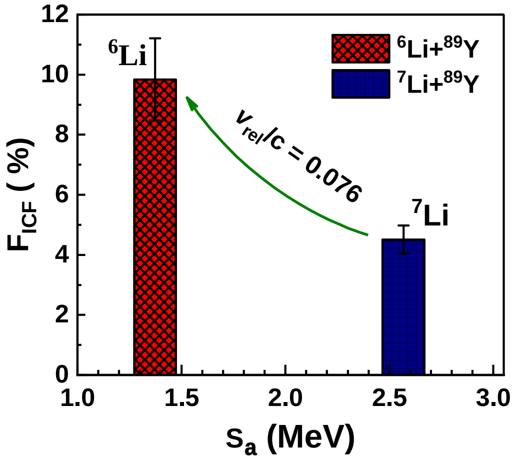

FIG. 1: Comparison of F_{ICF} (%) of ^{6}Li+^{89}Y [3] with ^{7}Li+^{89}Y reaction [1], at a constant relative velocity, $v_{rel}/c = 0.076$.

significant enhancement in the experimental cross-sections has been observed compared to those obtained from EMPIRE code, which uses the same input parameters to reproduce the xn and pxn channel residues. Hence, it can be pointed out that observed enhancement in α-emitting channels may be attributed to ICF and/or transfer followed by ICF. To estimate the strength of ICF, ICF fraction (F_{ICF}) has been deduced using the relation $F_{ICF}(\%) = (\sum \sigma_{ICF}/\sigma_{TF}^{theor})\times 100$, where σ_{TF}^{theor} is the total theoretical fusion cross-section (sum of all residues) predicted from EMPIRE. Further, to investigate the effect of entrance channel parameter on ICF, estimated F_{ICF} from the α-emitting channels of ^{7}Li+^{89}Y reaction [1] has been estimated and compared with ^{6}Li+^{89}Y [3] system by scaling the energy values ($E_{c.m.}/V_B$). We have observed that F_{ICF} is higher for ^{6}Li-induced reaction as compared to ^{7}Li throughout the energy range.

Further, F_{ICF} has been deduced for ^{6}Li+^{89}Y and ^{7}Li+^{89}Y reactions at a constant relative velocity (v_{rel}/c) = 0.076. The relative velocity (v_{rel}/c) was estimated from the relation $[2(E_{c.m.}\text{-}V_B)/\mu c^2]^{1/2}$, where V_B, c, and μ are the Coulomb barrier between the interacting nuclei, speed of light, and the reduced mass of the system, respectively. The F_{ICF} has been plotted against S_α in Fig.1 at a constant relative velocity. It can be seen from the figure that ICF fraction is small (≈4.5±0.5%) for high S_α value and it is relatively large (≈ 9.8±1.4%) for low S_α at a constant $v_{rel}/c = 0.076$ which follows the same trend as observed in ICF fraction analysis. It shades light on the role of S_α of weakly bound ^{6,7}Li nuclei showing ICF mechanism.

Moreover, the values of predicted maximum angular momentum (ℓ_{max}) using CCFULL code are ≈17$\hbar$ and ≈19$\hbar$ for ^{6,7}Li+^{89}Y systems, respectively at $E_{c.m.}$=31.4 and 31.6 MeV, respectively, which are in good agreement with those calculated from the relation $\ell_{max}=R\sqrt{2\mu_m(E_{c.m.}-V_B)/\hbar^2}$, where R is the maximum distance between two nuclei at which the collision leads to a reaction, and V_B is the Bass barrier at distance R, and μ_m is the reduced mass of interacting nuclei. Also, the fusion ℓ distribution suggests an ℓ-window below ℓ_{crit} for incomplete fusion in both the reactions.

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