Exploring the break-up fusion and angular momentum in ^{14}N and ^{16}O reactions with ^{159}Tb using particle-γ-coincidence

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Introduction

Recent investigations into heavy ion (HI) collisions have shown that incomplete fusion (ICF) processes compete with complete fusion (CF) reactions at energies ≈ 4-7 MeV/A, challenging the earlier belief that its contribution would be negligible at such low energies [1]. In the CF process, for the angular momentum values $\ell < \ell_{crit}$, the entire projectile merges with the target nucleus, forming a composite system that eventually equilibrates into a compound nucleus (CN). In contrast to CF, for $\ell \geq \ell_{crit}$, the projectile may break into fragments, resulting in partial fusion, where one fragment fuses with the target nucleus to form an incompletely fused composite system (IFC), while the remaining fragment continues with minimal interaction. This projectile breakup leads to a significant suppression of the complete fusion (CF) cross section, both for weakly and strongly bound projectiles [1]. Various theoretical models have been proposed to describe ICF dynamics, which are tend to be accurate primarily at energies ≥ 10.5 MeV/nucleon [1]. In the present work, an attempt has been made to understand the role of input angular momentum (ℓ) in ICF reactions for two distinctly different strongly bound projectiles (^{16}O and ^{14}N) interacting with the same target ^{159}Tb by comparing the spin distributions (SD's) of the α-emitting channels [2,3].

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Experimental details

The experiments were conducted at the Pelletron Accelerator Facility of the IUAC, New Delhi, utilizing a ^{16}O ion beam directed at a thin, self-supporting ^{159}Tb target at approximately 5.6 MeV/nucleon [2]. The focus was on detecting particles in coincidence with prompt γ-rays, supplemented by singles data to identify various reaction channels. The self-supporting ^{159}Tb target, (99.9%) having thickness ≈1.7 mg/cm² has been used. The experimental setup for SDs measurements involved a Gamma Detector Array (GDA) coupled with a Charged Particle Detector Array (CPDA). The coincidences were recorded between the particle (Z = 1,2) and prompt γ-rays using different gating conditions corresponding to the given angular zones for each value of Z. The CPDs are designed to detect the slow and fast α-particles in each angular zone in coincidence with the prompt γ-rays. The CPDs at forward (F) angles (10°–60°) will detect both slow and fast α-components. Here slow α-components correspond to fusion-evaporation (CF) α-particles and fast α-components are directly associated with ICF reaction. The relative production yield has been estimated from the intensity and photo-peak area of characteristic prompt-γ transitions assigned to a particular reaction product. The relative production yields have been shown as a function of experimentally observed spin (J_{obs}) with normalized yield. However, in the case of ^{14}N + ^{159}Tb [2], the ^{14}N beam were produced form the

IPCR cyclotron on self-supporting ^{159}Tb target having energy 95 MeV. The silicon detector were used to detect the direct/fast α-particle (correspond to ICF) as well as compound/slow α-particle (correspond to CF). In order to constrained the contribution from the evaporation process, a 400µm thick annular aluminium foil is placed in front of Si detector. The γ-rays in coincidence with the α-particles were detected using Ge(Li) spectrometer. To cover the direct/fast α-particles, the Si detector were placed 0° to the beam (with detection range θ = 16.7°-32.6°) to the beam and 180° to beam to detect the compound α-particles with detection range of 147.4°-163.3°. The production yields of d, t, and 3H were suppressed by using ΔE-E counter telescope. The details of experiment can be found in Ref. [2].

Results and Conclusions

Entirely different SD patterns have been obtained for CF and/or break-up fusion processes. In CF, the SDs of xn/pxn/αxn channels identified in the backward-α-gated spectra reflects a robust feeding in the vicinity of broad range spin population towards the band head. However, the SDs associated with break-up channels (αxn) observed in forward-α gated spectra shows the narrow spin population indicating population of low-spin states are hindered and/or less fed in the case of break-up fusion. As a representative case, Fig.1 shows the SDs of ^{168}Lu residues populated via CF-α3n channel and ICF- α3n channel in the interaction of ^{16}O + ^{159}Tb at 95 MeV obtained from both backward and forward α-gated spectra As can be seen from this figure, the SD of ^{168}Lu residues identified in the backward-α gated spectra (i.e., CF-α3n channel) is found to be entirely different as compared to that obtained in forward-α gated spectra. From the measured SDs of ^{168}Lu residues, mean input angular momentum (ℓ) values have been extracted and found to be ≈ 7.3 ℏ for CF-α3n and 12.0 ℏ for ICF-α3n. In order to see the dependance of angular momentum on different projectiles with same target, the estimated ℓ-values are compared. To get the ℓ-values for ^{14}N projectile, the SD distribution of ^{166}Yb residues populated via α3n channel in ^{14}N + ^{159}Tb at 95 MeV has also been studied. The extracted ℓ-values from the SDs have been compared for α3n channel in ^{14}N + ^{159}Tb and ^{16}O + ^{159}Tb systems and are shown in Fig.2. As can be seen from this figure, the deduced mean input angular momentum <ℓ> for ^{16}O projectile is found to be higher as compared to the ^{14}N projectile as expected. This consistency in the observation of ℓ-values for the two projectiles carried out on the same target and at same energy clearly reflects the consistency in the experimental observation as expected. Further details will be presented.

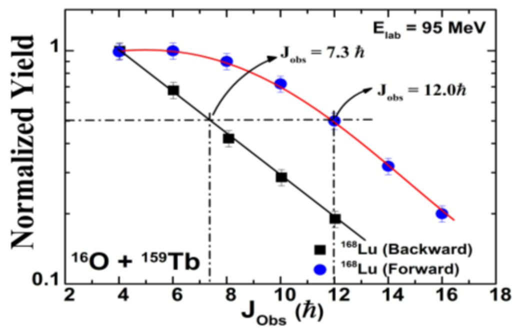

Fig.1: Experimentally determined SD of ^{168}Lu residues populated via CF-α3n and ICF- α3n channel.

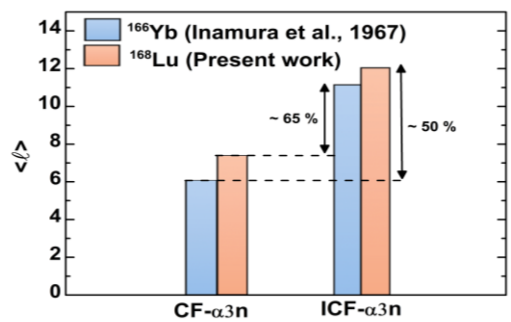

Fig.2: Comparison of <ℓ> values for ^{168}Lu and ^{166}Yb populated via same α3n channel through CF and ICF processes.

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