Impact of entrance channel parameters on break-up fusion reactions

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The investigation of heavy-ion (HI) fusion reactions has been a major area of research to understand the mechanisms involved. In HI fusion, the interacting nuclei must approach each other close enough so that the nuclear forces between their nucleons become significant and form a compound nucleus (CN). Studying HI collisions may also provide insights into the feasibility of synthesizing super heavy elements (SHE) [1, 2]. However, the occurrence of breakup or incomplete fusion (BUF/ICF) reactions hinders the synthesis of SHE. Results of the recent experiments have shown that BUF reactions may occur alongside complete fusion (CF) reactions, even at energies $\approx$ 4–7 MeV/n. In the case of CF, the entire projectile is captured by the target nucleus with partial waves $\ell \leq \ell_{crit}$, forming an excited CN. In contrast, BUF involves higher partial wave values ($\ell > \ell_{crit}$). The presence of competing reactions, such as transfer, breakup, and pre-equilibrium (PE) emissions, complicates the experimental study of fusion processes in HI collisions. At relatively higher energies, breakup and PE emissions also compete, necessitating their consideration in the analysis. Several theoretical frameworks have been developed to describe the dynamics of BUF/ICF reactions[3–6]. These models have been effective in explaining BUF data at energies $\geq$ 10 MeV/nucleon. However, they do not provide a thorough explanation for reactions at energies $\approx$ 4 to 7 MeV/nucleon. As a result, the study of BUF reaction dynamics, at low energies, remains an open area of investigation.

In the present work, an attempt has been made to understand the effect of entrance channel parameters on ICF reactions at low energy. The excitation functions (EFs) for several reaction residues produced in the ^{16}O+^{174}Yb interactions at energies $\approx$ 4–7 MeV/nucleon have been measured. The experiments were carried out at the Inter University Accelerator Center (IUAC), New Delhi using the ^{16}O (7^+) beam produced by 15 UD Pelletron accelerator. The stacked foil activation technique followed by γ-ray spectroscopy has been used. Isotopically enriched ($\approx$97%) ^{174}Yb in oxide form (thickness $\approx$0.4-1.0 mg/cm^2) were prepared by vacuum evaporation technique. Self supporting Al-catcher/energy degrader foils (thickness $\approx$0.8-1.5 mg/cm^2) were also prepared by rolling technique. In order to cover a broad range of energies, Al-foils were used as energy degraders. Three stacks of target-catcher assembly (each consists of four target-catcher foils) were irradiated with different energies i.e., $\approx$99.32 $\pm$ 0.68, 97.19 $\pm$ 0.81 and 95.17 $\pm$ 0.83 MeV. The irradiations were carried out in the General Purpose Scattering Chamber (GPSC) and each stack was irradiated for $\approx$ 8-10 hours. The activities induced in each sample as a result of irradiation were recorded at

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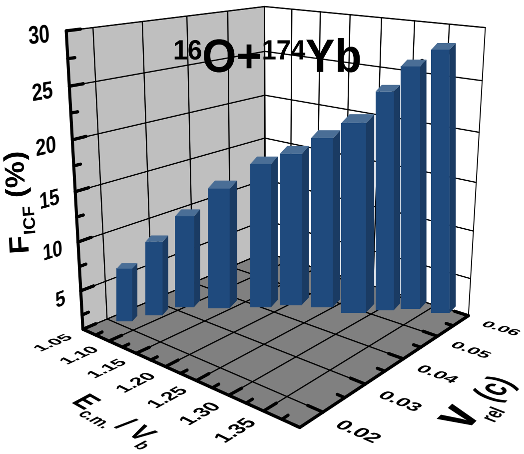

FIG. 1: Variation of F_{ICF} as a function of normalized beam energy and relative velocity (v_{rel}/c).

regular intervals using a clover HPGe detector coupled to VME based data acquisition system NIASMARS [7].

The residues populated in ^{16}O+^{174}Yb reaction are identified by their characteristic γ-rays and further confirmed by decay curve analysis. The production cross-section of the identified residues are measured and compared with the theoretical predictions of PACE4 [8] code. The level density parameter 'a' used in the present calculations has been taken as $a = A/10MeV^{-1}$. It is essential to highlight that PACE4 is a comprehensive fusion model that does not include any contribution from breakup reactions. The experimental EFs of xn/pxn channels are found to be in good agreement with the predictions of PACE4. This confirms that these residues are produced solely via CF process. Further, a significant enhancement as compared to the predictions of PACE4 has been observed in α-emitting channels which has been attributed to the BUF process.

In order to have a better understanding of ICF reaction dynamics, its strength function F_{ICF} has also been deduced. The variation of F_{ICF} as a function of normalized energy is shown in Fig. 1. The monotonic increase of F_{ICF} indicates its strong dependence on normalized energy. In the Fig. 1, the F_{ICF} is also presented as a function of relative velocity (v_{rel}/c). According to Morgenstern *et al.,* [9] ICF typically contributes significantly when v_{rel} exceeds 0.06c. However, in the present work, a significant contribution of ICF has been observed even for $v_{rel} << 0.06c$. The mean square angular momentum $<\ell^2>$ deduced from ℓ-distribution increases with energy almost linearly reaching highest value at $E_{c.m.}\approx$91 MeV. The observation of ICF at energies close to the barrier even for $\ell << \ell_{crit}$ suggests a broader distribution of angular momenta rather than a sharp cut off. Further, the dependence of incomplete fusion strength function on Coulomb factor modified by deformation parameter and mass asymmetry (μ) has also been studied. Further details of measurements and analysis will be presented.

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