Incomplete fusion reactions: A comparison of $^{12,13}C+^{159}Tb$ results

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Incomplete fusion (ICF) reactions have been recognized since mid-sixties by the very first experimental observations[1] of energetic α-particles emitted at energies > 10.6 MeV/A in heavy-ion (HI)-induced reactions. In case of ICF reactions, besides the formation of a fusion-like nucleus, forward peaked "fast α-particles" have been observed. However, in recent years the unexpected influence of incomplete fusion over total fusion has been observed at low projectile energies (i.e. $\approx$ 4-7 MeV/A) as well. Since, then the widespread theoretical and experimental efforts have been devoted to understand the observations [2–5]. The study of ICF reactions is still an active area of investigation due to complex nature of in-complete mass transfer and its ambiguous dependence on various entrance channel parameters viz., projectile type/energy, imparted input angular momentum (ℓ) to the system, α-break-up energy (Q_α), mass-asymmetry of the interaction partners, etc. Most of the studies have been carried out with projectiles such as ^{12}C, ^{16}O, ^{20}Ne, which are considered to have α-cluster structure. In fact the cluster structure has been suggested as one of the factors leading to forward peaked alpha particles in ICF reactions. However, no systematic studies have been carried out to ascertain this aspect. As such, a program has been undertaken to carry out some conclusive measurements using ^{13}C, ^{14}N and ^{18}O beams on different targets, which may provide a rich data set to understand the underlying dynamics. The present work is the first step in this direction, where, the excitations functions of $^{12}C+^{159}Tb$ [6]and $^{13}C+^{159}Tb$ (present work) systems at energies $\approx$ 4-7 MeV/A have been compared to study convincingly the effect of projectile on the reaction dynamics.

The experiments using off-line γ-ray spectroscopy have been performed at the Inter University Accelerator Center (IUAC), New Delhi, India. In order to cover a wide energy region in a single irradiation, energy degradation technique has been used. In the present experiment five stacks, each having three target-catcher foil assemblies were irradiated by ^{13}C-beam of energies $\approx$ 58, 70, 73, 85 and 88 MeV to cover a wide energy range. The isotopically pure (99.9%), self-supporting ^{159}Tb targets of thickness $\approx$ 1.2-2.5 mg/cm^2 were used. Keeping the half-lives of interest in mind, irradiations were carried out for $\approx$ 8-10 h duration for each stack. The produced activities have been recorded using a high resolution, pre-calibrated HPGe detector coupled to a PC through CAMAC. A 50Hz pulser was used to determine the dead time of the spectrometer. The efficiency and energy calibration of the detector in the specified geometry was carried out using a standard ^{152}Eu source of known strength. The over all error in the measurements are estimated to be $\leq 15\%$.

Reaction residues have been identified by their characteristic γ-lines, and confirmed by their decay-curve analysis. The production cross section (σ_{ER}) of the residues have been determined using the standard formu-

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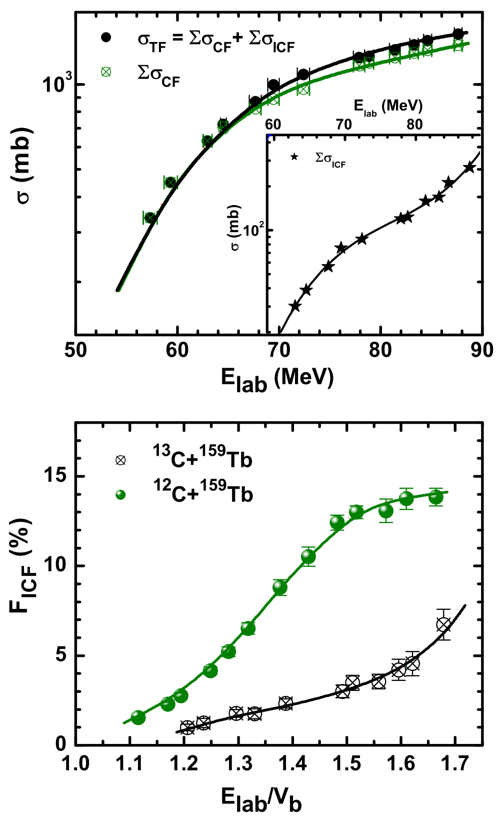

FIG. 1: (a) The total fusion cross-section plotted with complete and in-complete fusion cross-section against the projectile energy. (b) The deduced F_{ICF} (%) for $^{12,13}C$+^{159}Tb system have been plotted as a function of normalized projectile energy.

lation [5]. The excitation functions (EFs) of ^{169}Lu(3n), ^{168}Lu(4n), ^{167}Lu(5n), ^{167}Yb(p4n), ^{166}Tm(α2n), ^{165}Tm(α3n), ^{163}Tm(α5n), ^{162}Ho(2α2n), ^{161}Ho(2α3n) and ^{160}Ho(2α4n) radio-nuclides expected to be populated via CF and/or ICF of ^{13}C with ^{159}Tb have been measured. The measured EFs have been analyzed within the framework of statistical model code PACE4, which is based on the Hauser-Fashbach theory. The EFs for xn (x=3-5) and p4n-channels are satisfactorily reproduced by the theoretical predictions of code PACE4 using physically reasonable set of parameters [5]. A significant enhancement in the EFs of α-emitting channels have been observed, which may be attributed to the contribution from ICF process. The total fusion cross-section ($\sigma_{TF} = \Sigma\sigma_{CF}+\Sigma\sigma_{ICF}$) has been plotted with complete fusion ($\Sigma\sigma_{CF}$) and in-complete fusion ($\Sigma\sigma_{ICF}$) cross-sections against the projectile energy in Fig.1(a). An attempt has also been made to deduce F_{ICF}(%), which is a measure of relative strength of ICF contribution to the total fusion cross-section. The percentage F_{ICF} deduced as discussed above is plotted as a function of reduced incident projectile energy (E_{lab}/V_b) in Fig.1(b). As can be seen from this figure that the % F_{ICF} is higher for the ^{12}C as compared to ^{13}C projectile. A comparison of the present measurements with the data of ref.[6] on ^{12}C+^{159}Tb system indicates that apart from mass-asymmetry the alpha Q-value also plays an important role on the ICF reaction dynamics. The details of the measurements and analysis will be presented.

References

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