Disentangling of complete and incomplete fusion events

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The study of typical traits of heavy-ion (HI) reactions at energies around the Coulomb barrier (CB) on the basis of momentum transfer from projectile to the target nuclei has been a topic of resurgent interest[1–4]. In HI-reactions it has now been well established that heavy residues, resulting from full and partial-momentum transfer, may be populated via to as complete fusion (CF) and incomplete fusion (ICF) processes, respectively. Each of these processes leads to the characteristic velocity/momentum distribution of the reaction products. Hence, the reaction products formed via CF and/or ICF processes can be disentangled by measuring the forward recoil range distributions (FRRDs) and is a direct measure of the degree of linear momentum transfer (ρ_{LMT}) from projectile to the target nucleus. In case of CF the recoiling residues are trapped at relatively larger cumulative depth in the stopping medium as compared to ICF residues. The range of the ICF residues depends on the ρ_{LMT}, which is directly proportional to the mass-transfer. It is well recognized [3, 4] that the ICF reactions start competing with the CF reactions at energies ≈ 4-7 MeV/A, however, its dependence on several entrance channel parameters is still not well understood. Hence, in the present work an attempt has been made to disentangle the CF and ICF events from the measurement of FRRDs of residues populated in ^{12}C+^{159}Tb interations at above barrier energies. Further, the relative contributions of CF and ICF events have also been deduced from the FRRDs and their energy dependence has been studied.

The experiments using off-line γ-ray spectroscopy have been performed at the Inter University Accelerator Center (IUAC), New Delhi, India. The isotopically pure, self-supporting ^{159}Tb target of thickness ≈ 193 μg/cm^2 was bombarded separately at three different energies ≈ 76, 82 and 88 MeV using ^{12}C^{6+} beam . The irradiations have been carried out in the GPSC-setup having in-vacuum-transfer facility. In order to trap the recoiling residues a stack of thin *Al*-foils of sufficient cumulative thickness (individual thicknesses were ≈ 16-40 μg/cm^2) was used just behind the target. The recoiling products populated via CF and/or ICF are likely to be stopped at various cumulative depths in the Al-catcher foils. Keeping the half-lives of interest in mind, irradiations were carried out for ≈ 12-14 h duration at each bombarding energy. The produced activities in each *Al*-catcher-foil has been recorded using a high resolution, pre-calibrated HPGe detector coupled to a PC through CAMAC. The residues were identified by their characteristic γ-lines and confirmed by the decay-curve analysis. The measured intensities of the characteristic γ-lines have been used to determine the production cross-sections of the residues in each catcher foil using standard formulation [3, 4]. The over all error in the measurements are estimated to be ≤ 15%.

In order to obtain the FRRDs the normalized yields have been deduced for the residues ^{168}Lu(3n), ^{167}Lu(4n), ^{165}Lu(6n), ^{167}Yb(p3n), ^{165}Tm(α2n), ^{163}Tm(α4n), ^{161}Ho(2α2n) & ^{160}Ho(2α3n) and have been plotted as a

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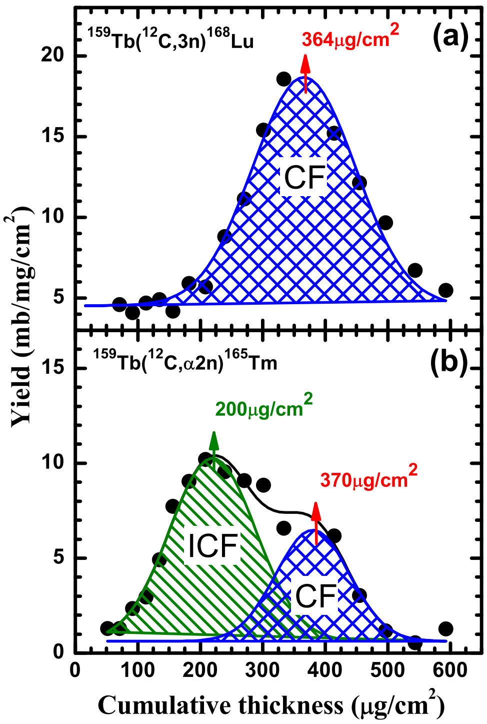

FIG. 1: $(a)-(b)$ The experimentally measured FRRD at $E_{lab} \approx 88$ MeV for ^{168}Lu(3n) residue, as expected has fitted by a single gaussian peak, shows full momentum transfer. However, FRRD for ^{165}Tm(α2n) has fitted by two gaussian peaks, which shows full and partial momentum transfer events.

function of cumulative catcher thickness. As a representative case, to show different ρ_{LMT} components in various CF and ICF processes the FRRDs for ^{168}Lu and ^{165}Tm residues populated via 3n and α2n-channels, repectively, have been presented in Figs. 1(a-b). The experimentally measured FRRDs of final reaction products in the stopping medium may give an indication of the ρ_{LMT} involved. The measured FRRDs have been fitted with Gaussian distribution for better analytical representation of data, and to deduce the value of most probable recoil ranges, R_p(exp).

As can be seen from these figures, the measured forward RRD for 3n-channel is fitted by a single Gaussian peak at $R_p^{CF}(\text{exp}) \approx 364 \pm 50\mu g/cm^2$, which clearly indicates the population of ^{168}Lu residues via CF process. Further, the experimentally deduced most probable recoil ranges R_p(exp) are found to agree well with R_p(th) (calculated using the code SRIM). However, the distribution for α2n-channel is fitted by two Gaussian peaks at $R_p^{CF}(\text{exp}) \approx 370 \pm 30$ and $R_p^{ICF}(\text{exp}) \approx 200 \pm 40\ \mu g/cm^2$. The residues ^{165}Tm are expected to have the contribution from both CF and/or ICF processes, which may be represented as;

(i) CF of ^{12}C;
$$^{12}C + {}^{159}Tb \Rightarrow {}^{171}Lu \Rightarrow {}^{165}Tm + \alpha + 2n;$$

(ii) ICF of ^{12}C (^{8}Be + α) fusion of ^{8}Be;
$$^{8}Be + {}^{159}Tb \Rightarrow {}^{167}Tm \Rightarrow {}^{165}Tm + 2n \quad (\alpha \text{ as a spectator})$$

The origin of peak [Fig.1(b)] at lower cumulative depth at $\approx 200 \pm 40\ \mu g/cm^2$ may be explained by the partial momentum transfer from projectile to target nucleus in an ICF-process. In order to study the energy dependence of CF and ICF processes an attempt has also been made to obtain the relative contributions of CF and/or ICF components at three different energies from the measured FRRDs. The details of the present work will be presented.

References

[1] D. J. Parker et al., Phys. Rev. C **30**, 143 (1984).

[2] E. Gadioli et al., Nucl. Phys. A **641**, 271 (1998).

[3] Devendra P. Singh et al., Phys. Rev. C **81**, 054607 (2010).

[4] Pushpendra P. Singh et al., Journal of Physics: Conference Series **282**, 012019 (2011).