Probing the in-complete fusion reaction dynamics using light-heavy-ions

Abhishek Yadav*
Physics Department, Aligarh Muslim University, Aligarh - 202 002, INDIA

Much interest has aroused to study the influence of in-complete fusion (ICF) on complete fusion (CF) in HI-interactions at energies ≈ 4-7 MeV/A. Kauffmann, *et al.* [1], in 1961 observed strongly forward peaked angular distribution of various light nuclear particles. In the same year, Britt and Quinton [2] also found similar observations at energies ≥ 10 MeV/A. Later, Galin et al. [3], termed these reactions as the *incomplete fusion reactions*. Since then, several dynamical models have been put forward to explain ICF reactions (for details see the ref. [4–6]). It may not be out of place to mention that none of the existing models provide satisfactory reproduction of ICF data at lower incident energies, hence, there is a need to have more and precise data to understand the reaction mechanism and also to develop proper theoretical model, which triggered a resurgent interest to study the underlying reaction dynamics. In addition to this, several contradicting dependences of the fraction of in-complete fusion (F_{ICF}), which is a measure of relative strength of ICF to the total fusion, have been discussed in recent reports [4, 5]. Hence, the dependence of ICF on the projectile type, incident energy, driving angular momentum (ℓ), binding energy and/or alpha-Q-value, mass-asymmetry & deformation of interacting partners etc., is also required to be explored.

In the present work, in order to explore some of the important issues related to the HI-reaction dynamics at energies near and above the barrier, several experiments have been performed at the Inter University Accelerator Center (IUAC), New Delhi. In the present thesis the complete, in-complete and pre-equilibrium reactions have been studied with the help of four set of measurements. (A) *Excitation functions (EFs)*: as a preliminary indication of ICF process [6–9]. (B) *Forward recoil range distributions (FRRDs)*: as a direct proof of fractional linear momentum transfer [10]. (C) *Spin-distribution measurements of residues*: to probe the entry state population in CF and ICF reactions [11]. (D) *Forward-to-backward yield ratio [$R_{Y(F/B)}$] measurements*: to study the pre-equilibrium (PEQ)-emission process [12].

The EFs for several radio-nuclides produced in $^{12,13}C+^{159}Tb$ systems via CF and/or ICF reactions at the energies ≈ 4-7 MeV/A have been measured employing the off-line γ-spectroscopy [6–9]. The measured EFs have been analyzed within the framework of statistical model code PACE4, which does not take ICF into account. The experimentally measured EFs of all *xn* and *pxn*-channels are found to agree reasonably well with their corresponding PACE4 calculations done with physically reasonable set of parameters [6]. Further, in order to figure out the production mechanism of α-emitting channels, the experimental EFs of all α-emitting channels have also been compared with the predictions of PACE4, using the same set of input parameters which has been used to reproduce *xn* and *pxn*-channels. The experimental EFs for α-emitting channels are found to be significantly enhanced as compared to the theoretical predictions, which points towards the observation of ICF contribution at these energies. For a better insight into the onset and influence of ICF the percentage fraction of ICF (F_{ICF}) has been deduced, which found to be sensitive to various entrance channel parameters. Most importantly, it

*Electronic address: abhishekyadav117@gmail.com

may be pointed out that the probability of ICF for ^{13}C projectile is noticeably smaller than for ^{12}C projectile in the entire energy range studied, which may be understood on the basis of the proposed '*alpha-Q-value systematics*'[7], details will be presented.

Further, to disentangle the CF and ICF events, the FRRDs for several residues populated in ^{12}C+^{159}Tb system, have also been measured at above barrier energies ≈ 74, 80 and 87 MeV [10], using the recoil-catcher technique. The CF and ICF events have been tagged by full and partial linear momentum transfer components, respectively. Analysis of the data indicates that the ICF has significant contribution which found to increase with the beam energy. An attempt has been made to explain the observations of in-complete fusion reactions in the light of SUMRULE model[10], based on sharp-cut off model. This model has been found to under predict the ICF cross-sections. As such, the diffuseness in ℓ-distribution has been suggested to explain the underlying reaction mechanism [10].

In order to investigate the dependence of ICF processes on driving input angular momenta, the particle (Z=1,2)-γ-coincidence experiment has been performed, for ^{12}C+^{169}Tm system at energies ≈ 5.6 and 6.5 MeV/A, using GDA-CPDA set-ups at IUAC, New Delhi [11]. The spin-distributions for direct-α-emitting channels (associated with ICF) have been found to be distinctly different than that observed for fusion evaporation (CF) channels. The present results have also been compared with the data of ^{16}O+^{169}Tm system at energy ≈ 5.6 MeV/A. The mean value of driving input angular momenta associated with various direct-α/2αxn-channels have been found to be higher than that observed for fusion evaporation xn/αxn-channels and increases with the α-multiplicity. The feeding intensity profiles derived from spin-distribution data, reveal that the CF products are strongly fed over a broad spin range, however, ICF residues are found to be less fed and/or the population of lower spin states are strongly hindered.

In the present thesis an attempt has also been made to study the PEQ-emission processes in heavy-ion reactions, using the forward peaking property of PEQ-particles, in ^{16}O+^{169}Tm interactions at ≈ 5.6 MeV/A [12]. A relatively high yield in the forward cone as compared to backward cone has been observed for the proton-emitting channels. The higher forward cone yields have been attributed due to the PEQ-emission. The maximum observed spin (J_{obs}^{max}) is found to decrease with the number of protons emitted from the composite nucleus during the equilibrium and/or pre-equilibrium decay. Further details of analysis and results will be presented.

I sincerely acknowledge all my experimental collaborators for their help & cooperation. The financial support received from the UGC during this work is highly acknowledged.

References

[1] Kauffmann, *et al.*, Phys. Rev. **121**, 206 (1961).
[2] H. C. Britt, *et al.*, Phys. Rev. **124**, 877 (1961).
[3] J. Galin *et al.*, Phys.Rev.**C 9**, 1126 (1974).
[4] P. R. S. Gomes, *et al.*, Phys. Rev. **C 84**, 014615 (2011).
[5] R. Rafiei, *et al.*, Phys. Rev. **C 81**, 024601 (2010).
[6] Abhishek Yadav, *et al.*, Phys. Rev **C 85**, 034614 (2012).
[7] Abhishek Yadav, *et al.*, Phys. Rev **C 86**, 014603 (2012).
[8] Abhishek Yadav *et al.*, Euro. Phys. Jour. WC **17**, 16019 (2011).
[9] Abhishek Yadav *et al.*, Euro. Phys. Jour. WC **21**, 08005 (2012).
[10] Abhishek Yadav, *et al.*, Phys. Rev **C 85**, 064617 (2012).
[11] Pushpendra P. Singh, Abhishek Yadav, *et al.*, Phys. Rev **C 80**, 064603 (2009).
[12] Abhishek Yadav *et al.*, Int. Jour. of Mod. Phys. **E 20**, 2133-2142 (2011).