Nuclear Reaction Studies in Heavy Ion Induced Reactions

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Fusion reactions induced by Heavy Ions (HIs) play an utmost role in nuclear physics, as they enable us to study the properties of superheavy nuclei near and away from the stability line. Depending on the mass of interacting nuclei, projectile energy, excitation energy of the composite system etc., various HI reactions such as pre-equilibrium (PEQ) emission, quasi-fission (QF), complete fusion (CF) and fusion fission (FF) may occur after the projectile is entirely captured by the target nucleus. However, at projectile energy below 8 MeV/nucleon the reaction processes like fusion-fission, pre-equilibrium emission and quasi-fission are almost absent. Further, the studies based on HI reactions reveal, at projectile energy (≈ 4-7 MeV/nucleon) well above the Coulomb barrier the most dominating fusion processes are (i) complete fusion (CF) and (ii) incomplete fusion (ICF) [1-3]. Study of these fusion reactions has remained the subject of enormous interest for both theoretical and experimental nuclear physicists over the past two decades. Various efforts have been made to comprehend the CF and ICF reaction dynamics since its first observation by Britt and Quinton [4]. However, due to lack of proper theoretical model below 8 MeV/nucleon, which can reproduce the experimentally measured ICF data satisfactorily, the study of CF and ICF is still an interesting area of research work. In order to develop a proper theoretical model, the ICF dependence on entrance channel parameters such as projectile energy, mass asymmetry of interacting nuclei (μ_m), Coulomb effect (Z_PZ_T), projectile Q_α-value, projectile structure, target deformation (β_2) and input angular momentum (ℓ) values needs to be systematically investigated.

Moreover, several contradictory observations of ICF dependence on entrance channels have been reported, which also needs to be deeply understood. For instance, Morgenstern *et al.* [5] reported that ICF strongly depends on the degree of mass asymmetry in the entrance channel, which was later on supported by other studies. However, some recent studies suggested that the Morgenstern's mass asymmetry systematic is somehow a projectile structure dependent and can be better understood in terms of projectile Q_α-value. Shuaib *et al.*, [6] observed a linear growth of ICF with Coulomb effect (ZpZ_T) however, for the systems with the same values of ZpZ_T, the discrepancy has been observed [7, 8]. Recently, Singh *et al.* [9] reported the exponential growth of ICF with increase in target deformation (β_2), however, Kumar *et al.* [10] could not observe any schematic trend in ICF with β_2. In addition to this most of the experiments performed to study CF and ICF processes are limited to alpha (α) cluster structure projectiles such as ^{12}C, ^{16}O and ^{20}Ne. However, a very scarce data is available in the literature using non-alpha cluster projectiles. Keeping the above mentioned aspects into consideration and to have better understanding of CF and ICF, a series of experiments are planned using ^{13}C, ^{14}N, ^{18}O and ^{19}F ion beams with various targets. As a first step, in the present thesis, the CF and ICF reactions have been studied with the help of two widely different measurements (i) excitation functions (EFs) and (ii) forward recoil range distributions (FRRDs).

To explore the various queries related to CF and ICF reaction dynamics, the experimental work was performed at Inter-University Accelerator Center (IUAC), New Delhi, by employing the Pelletron accelerator facilities. The stacked foil activation technique has been implemented. The EFs of various evaporation residues (ERs) populated in the interaction of ^{12}C + ^{165}Ho, ^{13}C + ^{165}Ho, ^{12}C + ^{156}Gd and ^{13}C + ^{156}Gd systems in the energy region of ≈ 4-7 MeV/nucleon have been measured. The measured EFs of the populated ERs have been

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*Electronicaddress:*amusuhailtali@gmail.com* analyzed in the light of fusion evaporation code PACE4. This code takes only CF reaction cross section of the populated ERs into account. The ERs have been identified on the basis of their characteristic γ-rays and decay curve analysis. During the decay curve analysis, it has been observed that some of the ERs populated via *pxn*, *αxn* and *αpxn* are strongly fed by their higher charge precursor isobars through electron capture (EC) and/or β^+ process. The independent cross section for such residues was estimated using the Cavinato *et al.*, [11] formalism. It has been observed that the measured cross sections of the ERs populated via *xn* and *pxn* channels are in good agreement with the PACE4 predictions, implying that these residues are populated via CF process. However, in case of α-emission channels a significant enhancement from the PACE4 predictions is observed even after the deduction of precursor contribution, which is accredited to ICF process. The ICF fraction F_{ICF} (%) has been deduced and dependence of ICF on various entrance channel parameters is studied for a large number of projectile-target combinations. It has been observed that every entrance channel parameter plays some significant role in low energy ICF reaction dynamics. From the mass asymmetry and $Z_P Z_T$ systematic it has been observed that for the systems with the same value of mass asymmetry and $Z_P Z_T$, the difference in ICF is explained on the basis of Coulomb effect and projectile Q_α-value, respectively. Further, to understand the influence of projectile break-up on fusion cross section at projectile energies above the Coulomb barrier, the fusion function *F(x)* obtained from the CF cross section data for the ^{12,13}C induced reactions has been compared with the universal fusion function (UFF). A complete detail of the results will be presented.

To disentangle the CF and ICF events, FRRD of ERs populated in ^{12}C + ^{165}Ho and ^{13}C + ^{165}Ho systems have been measured at ≈ 88 MeV and ≈ 87 MeV, respectively. It has been observed from the present FRRD measurements, ERs populated via *xn* and/or *pxn* channels have a single Gaussian peak at large cumulative thickness. This corresponds to the entire momentum transfer from the respective projectiles ^{12}C and ^{13}C to the target nucleus ^{165}Ho, a characteristic of CF. Further, in the FRRD measurements of the ERs populated via *αxn, αpxn* and *2αxn* emitting channels, in addition to peak corresponding to CF, the Gaussian peaks at lower cumulative thicknesses are also observed. This clearly indicates the different linear momentum transfer due to fusion of various mass fragments (formed due to projectile break-up). The presence of more than one Gaussian peak at different recoil ranges in the populated ERs strongly reveals the presence of ICF process. Moreover, the measured recoil ranges for the ERs populated via CF and/or ICF are found to be in good agreement with the theoretically calculated mean recoil ranges estimated by using the code SRIM [12]. The F_{ICF} (%) estimated from the FRRD data are found to be in good harmony with that obtained from the EF analysis. A strong projectile structure effect has also been observed due to which ^{12}C projectile induced reaction is observed to show more break-up probability compared to ^{13}C projectile with the same target ^{165}Ho.

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