Break up fusion studies in heavy ion interactions at low energies

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Much interest has been shown in recent years to study the influence of break up fusion called as in-complete fusion on the complete fusion (CF) processes in heavy ion (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 (ICF) reactions. Since then, several dynamical models have been put forward to explain ICF reactions (for details see the ref. [4, 5]). 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 contradictory 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 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 starting from threshold to 7 MeV/A, several experiments have been performed at the Inter University Accelerator Center (IUAC), New Delhi. In the present thesis the complete, and in-complete reactions have been studied with the help of two widely different set of measurements viz. (a) Excitation functions (EFs): as a preliminary indication of ICF process [6–10], and (b) Spin-distribution measurements of residues: to probe the entry state spin population in CF and ICF reactions [11–13]. A brief discussion on these two measurements are presented below.

$Excitation functions (EFs)$: A significant information on the involved reaction mechanism may be obtained on the basis of measurement and analysis of EFs. In the present work, two experiments on (a) $^{12}C+^{175}Lu$, and (b) $^{13}C+^{169}Tm$ systems have been carried out in the energy range from Coulomb barrier to about 7 MeV/A. The measured excitation functions have been analyzed within the framework of statistical model code PACE4 [14]. It may be pointed out that the code PACE4 is based on the complete fusion model and does not take incomplete fusion into account. A comparison of measured EFs with those predicted by code PACE4 indicates that xn and pxn channels are populated via complete fusion processes. However, for almost all the α- emitting channels an enhancement of measured cross-sections with that predicted by code PACE4 have been observed. This enhancement in the measured cross-sections as compared to the theoretical predictions may be attributed due to the ICF processes. In order to understand the sensitiveness of ICF on projectile energy and mass asymmetry of interacting partners, several comparisons have been made which reflects the importance of ICF on these parameters. Further, in order to study the effect of one neutron excess projectile on the onset and strength of ICF, comparison of the data for two systems involving

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^{12}C and ^{13}C projectiles have been made. It may be pointed out that the probability of ICF for ^{13}C projectile is found to be noticeably smaller than for ^{12}C projectile in the entire energy range studied, which may only be understood on the basis of the proposed alpha-Q-value systematics. A complete details of the work will be presented.

Spin-distribution measurements of residues: With a view to investigate the role of ℓ-values in successively opened ICF channels and to examine the possibility of populating high spin states in the final reaction products via ICF processes, a particle-γ coincidence experiment was performed using GDA-CPDA set-ups at the IUAC, New Delhi. In the present work, the spin distributions and feeding intensity profiles of CF and ICF products were measured at 83.5±1.5, 88.5±1.5, 93.5±1.5 and 97.6±1.4 MeV energies for the ^{16}O+^{159}Tb system. The spin distributions of CF and ICF residues were found to be distinctly different. The spin distribution of the residues identified from the backward gated spectra indicates a gradual monotonic increase in intensity towards the band head, which reveals broad spin population and /or strong feeding over and broad spin range during the de-excitation of these residues. On the other hand, for α-emitting channels identified from forward α- gated spectra, the intensity increases upto a certain value of J_{obs} and then remain constant down to band head. This pattern of spin distribution is believed to arise from narrow spin population only upto a certain value of J_{obs}. Further, the constant behavior of intensity for low spin states in ICF, α-emitting channels reveals the hindrance in population and almost no feeding for low spin states. The measured feeding intensity profiles for CF channels is found to show a sharp exponential rise towards the low spin states, which indicates a regular population with a strong feeding contribution for each γ transition upto minimum J_{obs}. The feeding intensity profiles for ICF channels are found to increase upto a certain value of J_{obs} and then gradually decrease towards band head, this indicates the low spin states are less populated in ICF channels. Such a feeding intensity pattern is expected to arise from narrow ℓ-window. An attempt has also been made to generate $<\ell>$ value systematics in terms of mass asymmetry of interacting partners. To the best of our knowledge, this has been done for the first time. Although the data is only for two systems but it indicates that the amount of mean input angular momentum fed through ICF channels increases with the mass of the target increases. Further details of analysis and results will be presented.

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References

[1] Kauffmann, et al., Phys. Rev. 121, 206 (1961).
[2] H. C. Britt and A. R. Quinton, 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] Vijay R. Sharma et al., Phys. Rev. C. **89**, 024608 (2014)
[7] Vijay R. Sharma et al., Phys. Rev. C. **84**, 014612 (2011)
[8] Vijay R. Sharma et al., Euro. Phys. Jour. WC **66**, 03079 (2014).
[9] Vijay R. Sharma et al., Euro. Phys. Jour. WC **17**, 16012 (2011).
[10] Vijay R. Sharma et al., Amer. Inst. Phys. CP **1524**, 201-204 (2013).
[11] Vijay R. Sharma et al., J. Phys. G: Nucl. Part. Phys. **42**, 055113 (2015).
[12] Vijay R. Sharma et al., Nucl. Phys. A **00** (2015)- Accepeted
[13] Vijay R. Sharma et al., Euro. Phys. Jour. WC **86**, 00046 (2015).
[14] A. Gavron, Phys. Rev. C **21**, 230 (1980).