Incomplete Fusion Studies at 15UD Pelletron Energies

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In recent years the study of heavy ion (HI) induced reactions has been used as an important tool to understand the incomplete fusion reaction dynamics at energies near and above the Coulomb barrier [1, 2]. At these energies the complete fusion (CF) and incomplete fusion (ICF) are the dominant modes of reaction processes and has gained resurgent interest. The first evidence of ICF reactions was presented by Kauffmann and Wolfgang [3] by studying $^{12}C+^{nat}Rh$ system at ≥ 7-10 MeV/nucleon, where strongly forward peaked angular distribution of light nuclear particles were observed. Britt and Quinton [4] found similar observations in the $^{16}O+^{209}Bi$ reactions at energies ≈ 7-10 MeV/nucleon. In these measurements, significantly large yields of direct-α-particles of mean energy roughly corresponding to the projectile velocity at the forward angels have been observed. The results of these experiments suggest that the process involved in the production of fast-α-particles is the projectile break-up (BU), in the nuclear field of the target nucleus. Several dynamical models [5-8] have been proposed to explain the ICF reaction dynamics. These models qualitatively explain the experimental data at E/A ≥ 10.5 MeV, however, none of the existing models is able to reproduce the data obtained at energies as low as ≈4-7 MeV/nucleon, therefore, the study of ICF is still an active area of investigation.

Moreover, some of the most debated and outstanding issues related to low energy ICF reactions have been, (i) the effect of entrance channel parameters on the onset and strength of ICF, (ii) the usefulness of ICF to populate high-spin states in final reaction products, (iii) the localization of the angular momentum window, etc. In recent years, high quality data on excitation functions (EFs)[2,7], spin distributions (SDs) [9], and linear momentum distributions [10] of individual reaction products have been obtained at the Inter-University Accelerator Center (IUAC), New Delhi in different experiments. A brief description of measurements is presented here.

The first set of experiments is related with the measurement and analysis of excitation functions. The excitation functions (EFs) for a large number of reactions viz., $^{12}C+^{130}Te,^{159}Tb,^{165}Ho,^{169}Tm,^{175}Lu$, $^{13}C+^{159}Tb,^{169}Tm$, $^{16}O+^{181}Ta,^{159}Tb,^{169}Tm$ covering a wide range of projectile-target combinations have been measured employing the activation technique. The experiments have been performed using GPSC-setups at the IUAC, New Delhi. Experimental methodology and setup have been detailed in refs.[2,7, 11]. The measured EFs have been analyzed within the framework of theoretical model code PACE4. It may be pointed out that the code PACE4 is based on the complete fusion model and does not take incomplete fusion 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, 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. It may be pointed out that the experimental EFs for α-emitting channels are found to be significantly enhanced as compared to the theoretical predictions, which indicates 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 is found to be sensitive to various entrance channel parameters. A comparison of the ^{12}C and ^{13}C projectile indicates that the probability of ICF for ^{13}C projectile is smaller than for ^{12}C projectile on the same targets (^{159}Tb and ^{169}Tm) in the energy range studied, which may be understood on the basis of the proposed 'alpha-Q-value systematics' [2].

In order to study the fusion-incompleteness at slightly above barrier energies another set of experiments based on forward recoil range distribution (FRRD) of reaction residues populated via CF and ICF processes are measured at different energies. Several experiments were performed for different projectile-target combinations viz., ^{12}C+^{159}Tb, ^{16}O+^{169}Tm, ^{16}O+^{159}Tb, ^{16}O+^{181}Ta systems. Kinematically, the FRRD depends on the degree of linear momentum transfer from projectile to the target nucleus. The measured FRRDs indicates different linear momentum components corresponding to CF and ICF residues. Analysis of the data indicates that the ICF has significant contribution which is 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[5], 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.

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 for ^{12}C+^{169}Tm, ^{16}O+^{169}Tm, and ^{16}O+^{159}Tb systems, particle-γ coincidence experiments were performed using GDA-CPDA set-ups at the IUAC, New Delhi. 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 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 remains constant down to the band head. This pattern of spin distribution is believed to arise from the narrow spin population only upto a certain value of J_{obs}. Further, the constant behaviour 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 the band head, this indicates that the low spin states are less populated in ICF channels. Such a feeding intensity pattern is expected to arise from narrow ℓ-window. Further details of analysis and results will be presented.

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