Role of projectile structure in low energy incomplete fusion reactions

M. Shariq Asnain[1,*], Mohd. Shuaib[1], Ishfaq Majeed[1], Vijay R. Sharma[2], Abhishek Yadav[3], Manoj Kumar Sharma[4], Pushpendra P. Singh[5], Devendra P. Singh[6], R. Kumar[7], R. P. Singh[7], S. Muralithar[7], Sunita Gupta[8], B. P. Singh[1,#] and R. Prasad[1]

[1]Nuclear Physics Laboratory, Department of Physics, Aligarh Muslim University, Aligarh-202 002, INDIA
[2]Departamento de Aceleradores, Instituto Nacional de Investigaciones Nucleares, Apartado Postal 18-1027, C.P. 11801 Ciudad de Mexico, Mexico
[3]Department of Physics, Faculty of Natural Sciences, Jamia Millia Islamia, New Delhi- 110025 , INDIA
[4]Physics Department, S. V. College, Aligarh-202 002, INDIA
[5]Department of Physics, Indian Institute of Technology Ropar, Rupnagar, Punjab- 140 001 , INDIA
[6]Department of Physics, University of Petroleum and Energy Studies, Dehradun-248 007, INDIA
[7]NP-Group, Inter University Accelerator Centre, Aruna Asif Ali Marg, New Delhi-110 067, INDIA
[8]Department of Physics, Agra College, Agra-282001, INDIA
*email:*asnainshariq@gmail.com , #bpsinghamu@gmail.com*

In recent years, several efforts have been made to understand the reaction dynamics of incomplete fusion (ICF) processes in heavy-ion (HI) collisions at energies from near the Coulomb barrier to well above it (i.e. ≈ 4-7 MeV/nucleon) [1-3]. Generally, at these energies, complete fusion (CF) process is one of the dominant mode of reaction to the total fusion (TF) cross-section. However, recent experimental data shows a significant observation of ICF reactions at these energies and has created a resurgent interest. The CF is said to occur at $\ell < \ell_{crit.}$, at which the composite system is formed via entire fusion of projectile with the target nucleus having pre-determined charge, mass and excitation energy. However, in the case of ICF, at $\ell \geq \ell_{crit.}$, the attractive fusion pocket vanishes. Hence, in order to restore the fusion pocket and to provide sustainable input angular momentum (ℓ), the projectile breaks up into fragments. One of the fragment fuses with the target nucleus leading to the formation of an incompletely fused composite (IFC) system of less mass and charge, while the remnant moves in the forward direction with the beam velocity. Several theoretical models have been proposed to study the reaction dynamics of ICF processes, in which the most widely used are (i) Break-up fusion (BUF) model [4], (ii) Sum-Rule model [5], (iv) Exciton model [6] etc. It may be remarked here that, the aforementioned models give satisfactory results upto some extent, of ICF data, at energies > 10.5 MeV/nucleon. However, they are unable to explain the ICF data below 10.5 MeV/nucleon. It may be pointed out that, at present, there is no theoretical model available which can explain the ICF data precisely at low energies. In addition to this, the role of entrance channel parameters viz. (i) input angular momentum (ii) type of the projectile and its energy (iii) mass asymmetry (iv) α-Q-value (v) Coulomb effect (vi) binding energy of the projectile etc. on the ICF dynamics is also of great importance and need to be systematically investigated. In the present work, an attempt has been made to understand the role of projectile structure on ICF reaction dynamics at low energies. The ICF probability for the systems, $^{12,13}C$ + ^{169}Tm [7, 8], ^{16}O + ^{169}Tm [9] and ^{19}F + ^{169}Tm [10], which involve different projectiles on the same target, has been deduced from the experimentally measured excitation functions (EFs). The experiments for the above mentioned systems were carried out at the Inter University Accelerator Centre (IUAC), New Delhi using the 15UD Pelletron accelerator facility. The $^{12,13}C$, ^{16}O and ^{19}F beams were allowed to focus on ^{169}Tm self supported target. In order to achieve a wide range of energies, stacked foil activation technique followed by off-line γ-ray spectroscopy has been used. Stacks consisting of ^{169}Tm targets (thickness ≈ 1-2 mg/cm^2), followed by Al-catcher foil (thickness ≈ 1-2.5 mg/cm^2)

were prepared. The stacks of target-catcher assemblies were irradiated separately at different beam energies in the General Purpose Scattering Chamber (GPSC) [11]. After the irradiation of stacks, the activities induced in each sample were recorded using pre-calibrated single HPGe detector coupled to a CAMAC based data acquisition system CANDLE. A detailed description of experiments is given elsewhere [10, 12]. The experimentally measured cross-sections for different reaction residues populated via CF and/or ICF processes in $^{12,13}C + ^{169}Tm$, $^{16}O + ^{169}Tm$ and $^{19}F + ^{169}Tm$ systems were measured and compared with the statistical model code PACE4 [13] predictions. It has been observed that experimentally measured cross-sections for *xn/pxn* channels are well reproduced by the PACE4 code. This confirms the production of these *xn/pxn* channels solely via CF mode, as expected. However, in case of α-emitting channels, significant enhancement in the experimental cross-section has been observed as compared to those obtained from PACE4 code. It may be pertinent to mention that PACE4 does not take the ICF contribution into account. Moreover, the EFs for α-emitting channels are calculated with the same set of input parameters that are used to reproduce *xn/pxn* channels. Hence, the observed enhancement in the EFs of α-emitting channels may be attributed due to the presence of ICF reactions at the energy range of interest. In order to understand the role of projectile structure on ICF reaction dynamics, the ICF strength function (F_{ICF}) for different projectiles viz. $^{12,13}C$, ^{16}O, and ^{19}F on the same target ^{169}Tm has been deduced from the EF data. Fig.1 shows the variation of F_{ICF} as a function of normalized beam energy (E/V_b). As can be seen from the figure, F_{ICF} values for different projectiles are different at the same reduced energy and the onset is found to be lowest for ^{19}F as compared to the other projectiles. Moreover, the F_{ICF} is found to increase with normalized energy, in general, for each system clearly indicating the energy dependence of ICF reactions. The difference in the behavior of F_{ICF} for different projectile in the entire range of energy may be due to different structural features of the projectiles. This strange behavior may be explained on the basis of α-Q-value of the projectile. Further details will be presented.

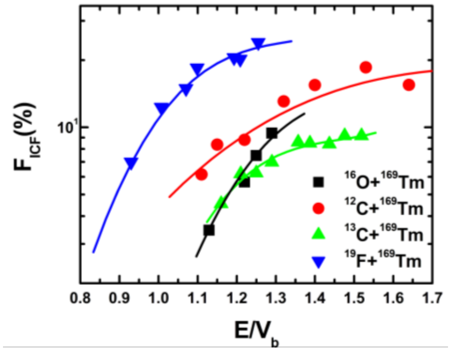

Fig.1: A comparison of F_{ICF} with normalized energy for various systems.

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