A study of incomplete fusion in ^{19}F + ^{169}Tm system at projectile energies above the Coulomb barrier

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During the last couple of years, the presence of incomplete fusion (ICF) events in heavy-ion induced reactions at energies starting from the Coulomb barrier to well above it has become a topic of interest [1-3]. At these energies, generally the complete fusion (CF) process is considered to be a sole contributor [4] to the total fusion cross section. The presence of ICF events at such low energies has triggered a resurgent interest to understand the low energy ICF. In CF, according to the sharp cut-off model, the entire projectile gets completely fused with the target nucleus for the input angular momentum $\ell<\ell_{crit}$, where ℓ_{crit} is the critical angular momentum of the system. However, in ICF reactions, for $\ell > \ell_{crit}$, the projectile may break-up into fragments to provide sustainable input angular momentum. One of the fragments may fuse with the target nucleus, while the remnant moves in the forward direction without any interaction. Some of the available theoretical models have been able to explain the ICF data to some extent but only at higher energies (>10 MeV/A), however, none of them is capable to reproduce the experimental ICF data at very low energies around 4-7 MeV/nucleon. Further, the strength of ICF at low energies has been found to be sensitive to entrance channel parameters viz., (i) projectile energy (ii) driving input angular momenta (iii) mass asymmetry (iv) α-Q values of projectile (v) Coulomb effects etc., which are required to be systematically explored. In order to have a detailed study of the onset of ICF process and its influence on CF as well as on various underlying entrance channel parameters as mentioned above, an experiment was performed at the Inter University Accelerator Centre (IUAC), New Delhi, India. In the present work, excitation functions (EFs) for various residues populated via CF and/or ICF in ^{19}F + ^{169}Tm system are measured at energies ≈ 4-6 MeV/nucleon using off-line γ-ray spectroscopy. The analysis of EFs has been performed within the framework of statistical model code PACE4 [5].

The $^{19}F^{7+}$ ion beam produced from 15UD Pelletron Accelerator was focused on the ^{169}Tm target. To cover a wide range of energy in a single irradiation, energy degradation technique has been used. In the present work, three stacks each consisting of three target-catcher foil assemblies were irradiated with ^{19}F beam. The thickness of the targets (99.9%) was ≈ 1.2-2.5mg/cm^2. Keeping the half-lives of interest in mind, the irradiations were carried out, for ≈ 8-10 hrs of duration for each stack, in the General Purpose Scattering Chamber (GPSC) having in-vacuum transfer facility. The activities induced in the samples were recorded using a high resolution, pre-calibrated HPGe detector coupled to a PC with CAMAC. The efficiency and energy calibration within the specified geometry have been done using a standard ^{152}Eu source of known strength. The reaction residues of known γ-rays intensities have been identified and confirmed by decay curve analysis. The production cross-sections of the reaction residues populated via CF and/or ICF processes in ^{19}F + ^{169}Tm system were computed using standard formulations [4] and compared with the predictions of statistical model code PACE4 [5]. In this code, the level density parameter (a=A/K, where A is the mass number and K is a free parameter) has been varied (K = 9 to 12) to match the experimental data. In the present work the residues ^{185}Pt (3n), ^{184}Pt (4n), ^{184}Ir (p3n), ^{183}Ir (p4n), ^{183}Os (αn), ^{182}Os (α2n), ^{181}Os (α3n), ^{179}Os (α5n), ^{177}W (2α3n), ^{175}W (2α5n), ^{174}W (2α6n), ^{176}Ta (2αp3n), and ^{175}Ta (2αp4n) have been identified. To the best of our knowledge, the measurements for the system ^{19}F + ^{169}Tm have been carried out for the first time. As a representative case, Fig. 1(a) shows the EF of ^{184}Pt residues populated via 4n channel and compared with the corresponding PACE4 calculations.

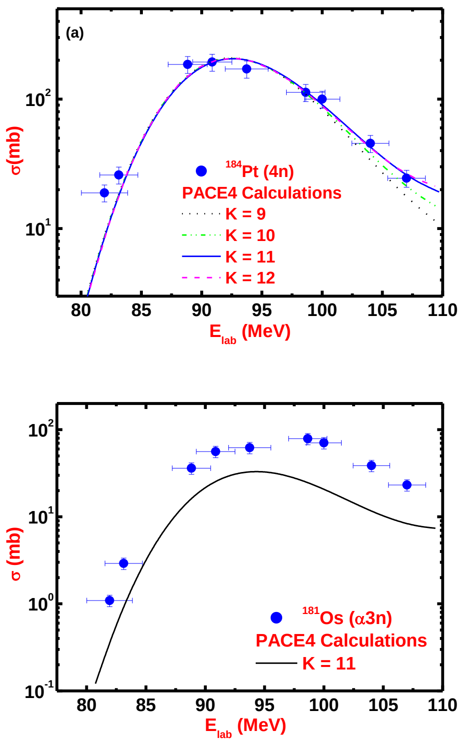

Fig. 1: (a) Experimental EF of ^{184}Pt (4n) populated in ^{19}F + ^{169}Tm system and compared with PACE4 predictions (see text). (b) The experimental EF of ^{181}Os (α3n) residue and its comparison with PACE4 (see text).

As can be seen from this Fig. 1(a), the experimental data is found to best fitted with theoretical calculations done using PACE4, for a=A/11MeV^{-1}. This confirms the production of ^{184}Pt (4n) residues solely via CF process. It has been observed that experimental EFs of all the *xn* and *pxn* channels were satisfactorily reproduced with the same set of parameters. In order to figure out, if α-emitting channels are populated via CF and/or ICF processes, Fig. 1(b) shows a typical EF of ^{181}Os (α3n) residues, which are expected to be populated via CF and/or ICF processes and compared with that estimated by corresponding PACE4 calculations. Further, it may be pertinent to mention that, the statistical model code PACE4 does not take into account the ICF calculations. As can be seen from Fig. 1(b), the experimental EF of ^{181}Os (α3n) residues are found to be significantly higher than PACE4 predictions for the same value of level density parameter which has been used to reproduce the EFs for CF residues. In the same way the experimental EFs for all the α-emitting channels are found to be enhanced as compared to their PACE4 predictions. The observed enhancement in the experimental EFs over the theoretically predicted ones indicates the contribution of ICF process in the population of residues involving α-particles in the exit channels. The incomplete fusion strength function (F_{ICF}) has been deduced and the dependence of the strength function on various entrance channels parameters has been studied. The present results have been compared with the existing data of ^{12,13}C + ^{159}Tb [3], ^{16}O + ^{159}Tb [4], and ^{19}F + ^{159}Tb [1] systems.

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