How does projectile structure affect incomplete fusion? The case of $^{14}N+^{169}Tm$

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In recent years, the study of incomplete fusion (ICF) reactions has got resurgent interest after observation of its strong influence on complete fusion (CF) processes at energies ≈ 4-7 AMeV [1-2]. In ref. [1-2], high quality data have been achieved at the Inter-University Accelerator Center (IUAC), New Delhi using alpha-cluster structure beams (viz; ^{12}C, ^{16}O) with medium mass target nuclei. In previous studies, the onset and strength of ICF have been studied in terms of different observables, viz; projectile energy and entrance channel mass-asymmetry. Despite the fact that the probability of ICF increases with projectile energy, we observed a significant contribution of ICF even at energy as low as 7 % above the fusion barrier. The unexpected presence of ICF at such a low energy has been justified as the consequence of high input angular momenta imparted into the system due to non-central interactions [3]. It has been observed that excess input angular momenta above the fusion limit (ℓ_{crit}) leads to projectile breakup to provide sustainable input angular momenta to the system to fuse. In this case only a part of projectile fuses with target nucleus, while the remnant flows at forward angles with projectile velocity. Apart from the well documented existence of low energy ICF, we observed a strong contradiction on mass-asymmetry systematics presented by Morgenstern *et al.,* [4]. As per Morgenstern's systematics, the fraction of ICF is expected to be more for more mass-asymmetric systems. However, in a recent systematic study of ICF based on six projectile-target combinations [1], it has been found that mass-asymmetry systematics is valid only for individual projectiles. The Morgenstern's systematic doesn't explain experimental data of six projectile-target combinations as a whole. It may, however, be pointed out that all the data presented in ref. [1] is based on alpha-cluster structure beams. In addition to our recent findings, it's important to understand how does projectile structure affect ICF? As such, we have undertaken a program to carry out conclusive experiments using ^{13}C, ^{14}N, and ^{18}O beams on ^{169}Tm target (same as in ref.[1]), which will provide us a rich data set to settle the understanding of underlying dynamics. Present work is the first experiment in this series, where ICF strength function has been deduced for non-alpha cluster structure ^{14}N beam with ^{169}Tm target from near barrier energies (V_B = 64.18 MeV) to well above it.

These experiments have been performed at the IUAC using activation technique. The targets of ^{169}Tm (100%) of thickness ≈ 1.2-2.5 mg/cm^2 were prepared by rolling . In order to trap recoiling products, each target was backed by an Al-catcher of appropriate thickness (measured by α-transmission). The experimental setup used in this experiment was same as in ref. [1]. In the present experiment 12 energy points were obtained using energy degradation technique. To record the half-lives of interest, around 10-12 hrs of irradiations were carried out with beam current ≈30 nA. The activities produced after irradiation were recorded by a pre-calibrated HPGe detector coupled to a CAMAC based data acquisition system CANDLE. The reaction residues have been identified by their characteristic decay γ-lines followed by decay curve analysis. The cross sections of different reaction residues have been computed using the standard formulation [2]. The excitation functions (EFs) for 4n, p3n, p4n, α2n, α3n, α4n and α5n channels have been measured and compared with the predictions of theoretical model code PACE4[5] to check whether they follow the equilibrated CN decay pattern. As PACE4 does not take ICF into account, any enhancement of the experimental EFs from the theoretically estimated ones may be attributed to the contribution from ICF process. Fig.1 shows the experimental EFs for 4n, p3n, and α2n channels. Here, solid curves represent PACE4 predictions using systematically justified level density parameter (a = A/K MeV^{-1}) and a good agreement of theoretical predictions with experimental data in case of 4n and p3n channels indicates the population of these residues via CF of ^{14}N with ^{169}Tm.

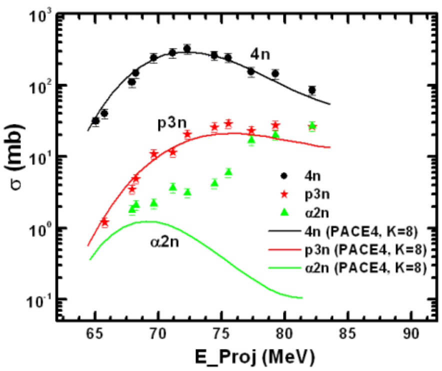

Fig.1. Experimentally measured and theoretically calculated EFs of 4n, p3n, and α2n-channels.

Further, in case of alpha-emitting channels (such as α2n-channel), PACE4 under predicts experimental EFs, which indicates the onset of ICF. The alpha-emitting channels may be formed via; *(a)* CF of ^{14}N with ^{169}Tm, and/or *(b)* partial fusion of ^{14}N. In the later case, only a fraction of projectile i.e., ^{10}Be fuses with target nucleus to form an incompletely fused composite nucleus. While, the remnant alpha-cluster flows in forward cone as a spectator. In order to understand how ICF show up with projectile energy and entrance channel mass-asymmetry, the ICF strength function has been deduced using same data reduction procedure as adopted in refs.[1-2]. Fig.2 (a) shows percentage fraction of ICF as a function of projectile energy for the presently studied $^{14}N+^{169}Tm$ system. This figure shows; *(i)* the presence of ICF at around barrier energies, and *(ii)* smooth increasing trend of ICF with projectile energies, as expected. In Fig.2 (b) the ICF strength function for the presently studied system is plotted along with several other projectile target combinations, at the same relative velocity (v_{rel}=0.053).

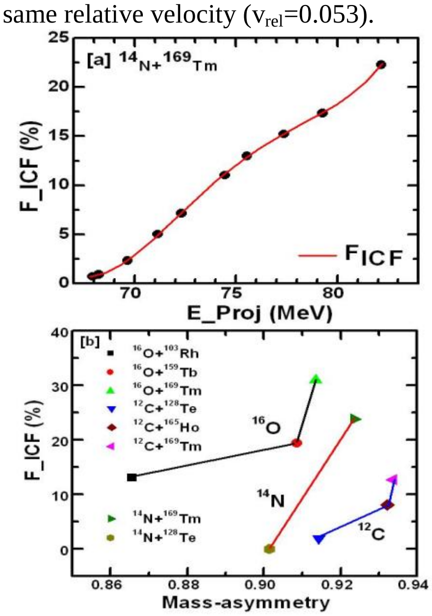

Fig.2. Experimentally measured percentage fraction of ICF as a function of (a) projectile energy and (b) entrance channel mass-asymmetry at the same v_{rel}.

From the given systematic study using data of eight projectile-target combinations, it can be inferred that the Morgenstern's systematic does not explain the experimental data achieved for different projectiles as a whole. However, the ICF fraction is found to increase with mass-asymmetry separately for each projectile. A strong projectile dependence of ICF has been revealed even in case of non-α-cluster structure beam. The details of this work will be presented during the symposium.

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