Large Influence of fusion incompleteness in incomplete fusion reaction dynamics at low energies

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It is a widely accepted fact that at energies near and/or beyond the Coulomb barrier, the unambiguous reaction processes are the formation and decay of an equilibrated compound nucleus (CN) followed by the entire projectile's fusion with the target nucleus [1–3], leading to the amalgamation of all nucleonic degrees of freedom of these interacting partners. However, incomplete fusion (ICF) has been found to be competing fusion-like processes at energies even a little above the Coulomb barrier, forming a reduced excited composite system with relatively lower mass, charge, and excitation energy compared to the completely fused composite system, due to the prompt emission of forward-peaked projectile-like fragments (PLFs) at the initial stage of interaction. As the projectiles ^{12}C, ^{16}O and ^{20}Ne are clusters of α-particles, it could be assumed that it is easy to transfer α particle from these projectiles to the target. In such reactions the mass flow is always from projectile to target. In the present work, the relative contributions of incomplete fusion process to the total reaction cross section in the two systems, i.e., ^{16}O + ^{165}Ho and ^{16}O + ^{115}In have been calculated. The excitation functions of these systems were calculated earlier, which are already presented in our previous studies [4, 5].

Both the experiments were carried out at the Inter University Accelerator Centre (IUAC), New Delhi. The details of these experiments have been discussed in our previous studies [6, 7]. The overall errors in the present work have been estimated to be less than or equal to 17 %.

The analysis of the work has been carried out in the frame work of statistical model code PACE4 [8]. The details of this code are given in our earlier observation [7]. The excitation functions of the *xn* and *pxn* channels agree with the theoretical predictions. However, in case of α-emitting channels, the enhancement over the theoretical predictions can be assigned to the ICF reaction processes. As a representative case, the enhancement over the theoretical predictions is shown in Fig. 1. In this figure, cummulative as well as independent yields of ^{176}Ta residue are shown. Cummulative yield is due to the contribution of higher charge isobar precursor. As a representative case, the following equation has been used for the evaluation of independent yield of ^{176}Ta isotope.

$$\sigma_{cum}(^{176}Ta) = \sigma_{ind}(^{176}Ta) + 1.398\ \sigma_{ind}(^{176}W) + 1.415\ \sigma_{ind}(^{176}Re) \quad (1)$$

Moreover, to study the dependence of ICF on various entrance channel parameters, percentage ICF fraction (F_{ICF}) can evaluated using the relation,

$$F_{ICF} = \frac{\Sigma\sigma_{ICF}}{\Sigma\sigma_{CF} + \Sigma\sigma_{ICF}} X100. \quad (2)$$

Further, the deduced F_{ICF} from our earlier measurement [6, 7] has been plotted in Fig. 2, with respect to the normalized projectile energy. From this figure, it can be seen that the percentage ICF contribution for the system ^{16}O + ^{165}Ho [6] increases

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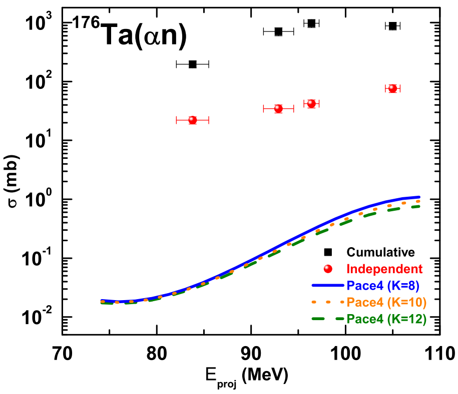

FIG. 1: Experimentally measured and theoretically calculated EFs for ^{176}Ta residue. The dark circles represent independent while solid squares represent cumulative cross sections and different lines represent the polynomial fit to the PACE4 predictions.

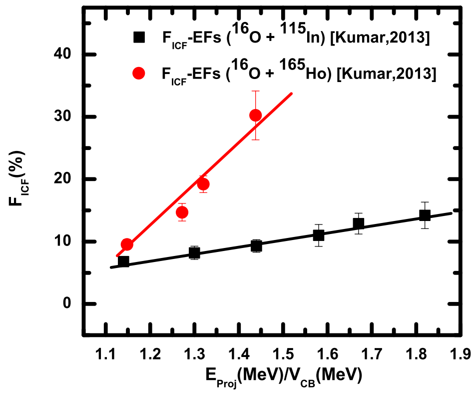

FIG. 2: The incomplete fusion fractions (F_{ICF}) deduced from Kumar's analysis of EFs [6, 7] are shown.

more rapidly than that of the system ^{16}O + ^{115}In [7], which can be understood in terms of mass-asymmetry systematics of interacting partners, introduced by Morgenstern *et al.* [9]. According to the mass-asymmetry systematics, the ICF probability should be more for more mass asymmetric system than that of mass symmetric system. The mass-asymmetry of any system can be denoted as ($M_a = A_T/(A_T + A_P)$), where A_T and A_P are the masses of the target and of the projectile, respectively. Hence, the calculated mass-asymmetries of the systems ^{16}O + ^{115}In and ^{16}O + ^{165}Ho are 0.877 and 0.911, respectively. Therefore, Fig. 2 reflects that these two systems follow the mass-asymmetry systematics even at low incident energies, while, Morgenstern *et al.* [9] observed this systematics at relatively higher energies ≈ 10 to 25 MeV/nucleon. Moreover, this rapid increase in Fig. 2, can also be explained by the systematics introduced by Gomes *et al.* [10], which shows dependence of ICF on Coloumb repulsion ($Z_P.Z_T$) of the interacting partners. Hence, the larger Coloumb repulsion in ^{16}O + ^{165}Ho system than in ^{16}O + ^{115}In system leads to a higher probability for ICF. Also, it was observed by Inamura *et al.* [11] that ICF processes are mainly due to the pheripheral interactions. This situation may also be one of the reason for the rapid increase due to the larger angular momenta associated with the system ^{16}O + ^{165}Ho than that associated with the system ^{16}O + ^{115}In.

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