A comprehensive study of in-complete fusion reaction dynamics in ^{16}O + ^{181}Ta system at 4-7 MeV/nucleon

Devendra P. Singh[1*], Vijay R. Sharma[1], Abhishek Yadav[1], Pushpendra P. Singh[2], Unnati[1], M. K. Sharma[3], K. S. Golda[4], R. Kumar[4], A. K. Sinha[5], B. P. Singh[1], and R. Prasad[1]
[1] *Department of Physics, A. M. U., Aligarh (UP)-202 002, INDIA,*
[*] *Department of Engineering Physics, GIIT,Gwalior (MP)-474 015, INDIA*
[2] *INFN-Laboratori Nazionali di Legnaro, I-35020 Legnaro, ITALY*
[3] *Department of Physics, S. V. College, Aligarh (U.P.) INDIA*
[4] *Inter-University Accelerator Center, Aruna Asaf Ali Marg, New Delhi - 110 067, INDIA and*
[5] *UGC-DAE-CSR, Bidhan Nagar, Kolkata - 700 098, INDIA*

The evidence of in-complete fusion (ICF) reactions was found from initial experiments on different projectile-target combinations at energies ≥10 MeV/n[1]. In order to explain these reactions it is assumed that the projectile breaks-up into fragments as it comes near the field of the target nucleus, one of the fragments fuses with the target forming in-completely fused composite system, while remnant goes on moving in the forward cone. Recently, it has been observed that ICF is a dominant mode of reaction even at energies ≈ 4-7 MeV/n. It is now well established experimentally that both the complete and in-complete fusion processes are the dominating and competing modes of reaction at these energies. In one of our recent studies [2], it has been observed that the value of mean input angular momentum increases with α-multiplicity, which indicates the competition from successively opened ICF channels for each l-value above l_{crit} for complete fusion (CF) even at energies ≈ 5 MeV/n. This clearly indicates that ICF predominantly occurs due to the centrifugal potential at higher values of impact parameter. Though, several models have been proposed to explain the ICF reaction dynamics, however, none of these models is able to explain the data satisfactorily at ≈ 4-7 MeV/n. For the better understanding of ICF reaction dynamics, system ^{16}O + ^{181}Ta has been studied where, excitation functions (EFs) and recoil range distributions (RRDs) for a large number of reaction products have been measured, thus having a complementry as well as comprehensive study of this system.

Energetic $^{16}O^{7+}$ beam obtained from the 15UD-Pelletron accelerator, of the IUAC, New Delhi, India, has been used to in the present experiments. The isotopically pure targets of ^{181}Ta of thicknesses ≈1.5-2.0 mg/cm^2 have been used. After each target an Al-foil of suitable thickness was used as catcher foil. The irradiations have been performed in the General Purpose Scattering Chamber having in-vacuum transfer facility. The irradiations time was ≈8-12 h, with a beam current ≈5-7 pnA. Off-line γ-ray spectroscopy using a pre-calibrated high purity germanium (HPGe) detector coupled to a CAMAC based system has been used. The residues have been identified on the basis of their characteristic γ-ray energies and measured half-lives. Further details of the experiments are given elsewhere[3].

The excitation functions for the reactions; ^{181}Ta(O,3n)^{194}Tl^{g,m}, ^{181}Ta(O,4n)^{193g}Tl, ^{181}Ta(O,5n)^{192}Tl^{g,m}, ^{181}Ta(O,p3n)^{193}Hg^{g,m}, ^{181}Ta(O,p4n)^{192}Hg, ^{181}Ta(O,p5n)^{191}Hg^{g,m}, ^{181}Ta(O,αn)^{192}Au^{g}, ^{181}Ta(O,α2n)^{191}Au^{g} and ^{181}Ta(O,α3n)^{190}Au^{g} have been measured in the energy range ≈ 76-100 MeV. The measured EFs have been compared with the calculations made by theoretical model code PACE4 based on CF model. The measured cross-sections for xn and pxn (x = 3, 4, 5) channels are found to be satisfactorily

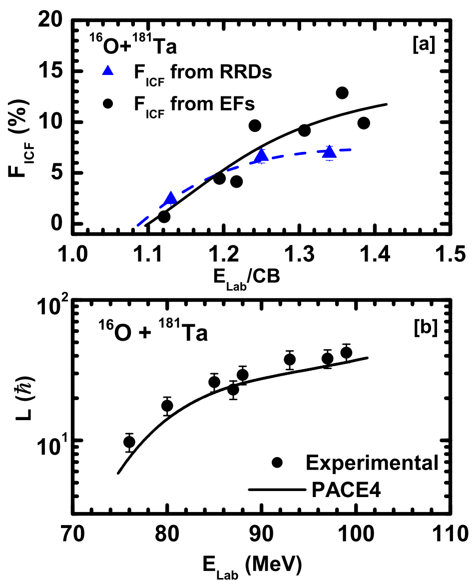

FIG. 1: (a) The percentage F_{ICF} value deduced from the analysis of EFs and RRD measurements, and (b) ℓ-values extracted from the measured fusion cross-section data and calculated using PACE4.

reproduced with the theoretical calculations done using code PACE4 using a suitable set of parameters[3]. However, in case of α-emitting channels, measured cross-sections were found to be significantly enhanced over their theoretical predictions. The enhancement in the measured cross-sections over the PACE4 calculations has been assigned to the contribution from ICF. In order to further decipher the contribution of ICF channels from CF, a complementary experiment for measuring the RRDs, for all the channels for which EFs have been measured, at three widely different energies viz, 81, 90 & 96 MeV, has also been performed. The measured RRDs were found to have a single peak in case of residues populated via CF (xn and pxn) channels. However, in case of α-emitting channels the measured RRDs could be resolved in to two or three Guassian peak profiles indicating various linear momentum transfer components due to partial fusion of projectile. The peaks in the RRDs may be attributed to the complete linear momentun transfer events involved in the CF of ^{16}O and the partial linear momentum transfer events due to the fusion of a part (^{12}C or ^{8}Be) of the projectile (ICF), if it breaks-up into its α-cluster fragments. The percentage ICF contributions deduced from the measured EFs as well as from the measured RRDs have been compared in Fig.1(a). As can be seen from this figure that the data obtained from two complementary experiments give nearly same values of ICF fraction within experimental errors and indicate the dominance of ICF processes at relatively higher enegies. The measured cross-sections for CF channels have also been used to deduce the angular momentum involved in the fusion reactions using the prescription given in Ref. (4), and is plotted in Fig.1(b). The values of angular momentum obtained from PACE4 are also shown in this figure. For the system under consideration the ℓ-values first increase rapidly with energy but soon appears to saturate at the critical value 40 $\hbar$, as expected, which is close to the ℓ_{crit} for fusion ($\approx 41 \pm 0.5\ \hbar$), in agreement with the studies made by Cavinato et al.,[4]. It may, therefore, be concluded that the results obtained from two complementary experiments agree well within experimental errors. Further, the angular momentum values obtained from the measured cross-section data is found to be in good agreement with the theoretical as well as literature values. Further details will be presented.

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