Study of in-complete fusion dynamics: Measurement and analysis of forward recoil range distributions at≈ 5-6 MeV/nucleon

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Introduction

The study of reaction dynamics in heavy ion (HI) interactions involving asymmetric nuclei at energies around the Coulomb barrier (CB) has been a topic of current interest. Recent literature[1, 2] indicates the observation of residues in HI reactions due to (i) complete fusion (CF) with full momentum transfer followed by particle and/or γ-emission and (ii) in-complete fusion (ICF) with partial momentum transfer, where only a part of the projectile fuses with the target nucleus. Each of these processes leads to the characteristic velocity distribution of the reaction products. As such, the measured yield of a particular isotope as a function of velocity or rather the range of residues helps to identify the origin of the observed reaction products. Further, the in-complete momentum transfer events referred to as in-complete fusion (ICF) reactions, may be understood on the basis of disappearance of pocket in the one-dimensional inter-nuclear potential energy as the angular momentum increases. In order to reduce the effective angular momentum of the composite nucleus (CN) and to restore a pocket in the inter-nuclear potential energy, as the entrance channel angular momentum is increased, an increasing part of the projectile escapes and carries away some of the angular momentum. Since, a portion of the projectile is not captured by the target, there is a deficit in the linear momentum of CN, when compared with the projectile momentum. An in-complete linear momentum transfer (LMT) event may be observed directly from the measurement of velocity/range distribution of evaporation residues. Several models have been reported in literature to explain the mechanism of ICF processes but no clear picture of the reaction dynamics has emerged. The ICF reactions have been extensively studied, however, the energy dependence of ICF reactions is still not well explored. In order to obtain detailed information regarding the ICF reaction dynamics and to study its energy dependence, the forward recoil range distributions (FRRDs) of the CF and ICF products in $^{16}O+^{181}Ta$ system at incident beam energies ≈81, 90 and 96 MeV have been measured using recoil catcher technique.

Experimental details

The experiments have been performed, using energetic $^{16}O^{7+}$ ion beam obtained from the 15UD-Pelletron accelerator, at the Inter-University Accelerator Center (IUAC), New Delhi, India. The isotopically pure ^{181}Ta (abundance =100%) of thickness ≈150 μg/cm^2 has been deposited by the electro-deposition technique on Al-foils of thickness ≈1.5 mg/cm^2. The irradiations have been performed in the General Purpose Scattering Chamber, which has an invacuum transfer facility. In each irradiation, stacks of thin Al-catcher foils (with the total thickness sufficient to stop CN formed via full LMT) have been placed just after the target, so that

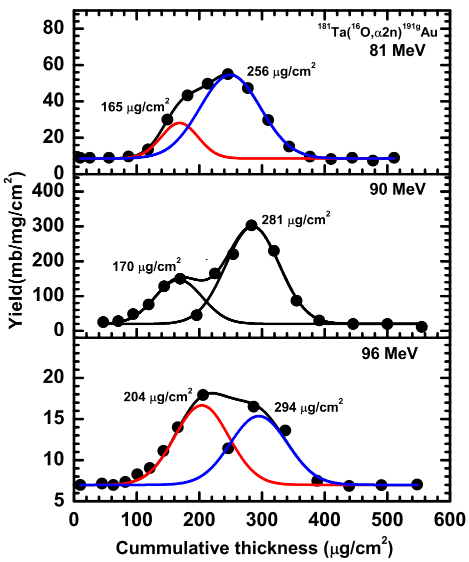

FIG. 1: Experimentally measured RRDs for ^{191g}Au(α2n) at projectile energies $\approx$ 81, 90 & 96 MeV. The lines joining data points are the result of best fit to the experimental data points.

the heavy residues populated via CF and/or ICF could be trapped at various Al-catcher foil thicknesses. The beam energies in three separate irradiations were $\approx$81, 90 & 94 MeV. The irradiations have been carried out for the duration of $\approx$12 h, with a beam current $\approx$7 pnA. After each irradiation, the activities of the recoiling heavy residues trapped in each Al foil of the catcher stacks were counted separately using a pre-calibrated high purity germanium (HPGe) spectrometer of 100 c.c. active volume coupled to a CAMAC-based FREEDOM software. The production yield of different reaction products have been deduced by normalizing the experimentally measured production cross-sections with the respective catcher foil thicknesses. In order to generate FRRDs, the normalized yield of a individual reaction products has been plotted as a function of cumulative catcher foil thicknesses.

Results and discussion

The FRRDs for thirteen residues viz., ^{194}Tl, ^{193g}Tl, ^{192}Tl, ^{193}Hg^g, ^{193}Hg^m, ^{192}Hg, ^{191}Hg^g, ^{191}Hg^m, ^{193}Au^g, ^{192}Au^g, ^{191}Au^g, ^{190}Au^g and ^{186}Ir^g produced in ^{16}O+^{181}Ta system have been measured at three incident beam energies. As a representative case, the recoil range distributions for the residues ^{191}Au^g populated via α2n channel, shown in Fig. 1, are found to have two peak structure at all the three energies, one corresponding to the complete momentum transfer events i.e., fusion of ^{16}O and other corresponding to the fusion of ^{12}C (if ^{16}O breaks into ^{12}C + α) with ^{181}Ta. Further, from Fig.1, it may be observed that for the residues ^{191}Au^g, there are two linear momentum transfer components one having mean ranges at 256$\pm$38, 281$\pm$43 & 294$\pm$45 μg/cm^2 at $\approx$ 81, 90 & 96 MeV beam energies (indicating fusion of ^{16}O) and the other at 165$\pm$26, 170$\pm$25 & 204$\pm$30 μg/cm^2 (indicating fusion of ^{12}C) at the respective three energies. It may also be observed from the Fig.1, that the peak value of the ranges i.e., $R_{p(exp)}$ shifts towards higher cumulative catcher thickness as the beam energy increases, as expected, and are consistent with the calculations based on range energy relations. The results are also found to be consistent with our recent work on the same system[3]. An attempt has also been made to obtain the relative contribution of CF and/or ICF components. In the case of ^{192}Au^g, ^{191}Au^g, ^{190}Au^g and ^{186}Ir^g residues, the RRDs data clearly indicate that the ICF reaction mechanism is dominant at the energies of interest in the present work. Further, details of the measurement, analysis and the energy dependence of ICF reaction dynamics will be presented.

References

[1] Pushpendra P. Singh et. al., Phys. Lett. B 671, 20(2009).

[2] Manoj Kumar Sharma et. al., Nucl. Phys. A **776**, 83(2006).

[3] Devendra. P. Singh et. al., Phys. Rev. C **80**, 014601(2009).