Investigation of the role of break-up processes in heavy ion reactions below 7 MeV/nucleon

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Introduction

For many years, the study of heavy ion (HI) induced reactions has been used to understand the reaction dynamics and the decay characteristics of compound nuclei at energies near and above the Coulomb barrier (CB). Recently, large-scale efforts in the field have been made to understand the multitude of in-complete fusion (ICF) processes at energies as low as ≈4-7 MeV/nucleon, where only complete fusion (CF) is expected to be dominant. It is now experimentally established that both the complete and incomplete fusion processes are the dominating modes of reaction at these energies. The evidence of ICF reaction dynamics was found from initial experiments on different projectile-target combinations at energies ≥10 MeV/n[1]. The results of these experiments suggested that the main process involved in the production of fast-α-particles is the projectile break-up, in the nuclear field of target nucleus. Recently, it has been observed that ICF is a dominant mode of reaction even at energies ≤7 MeV/n. Though, several models have been proposed to explain the ICF reaction dynamics, however, none of these models are able to explain the experimental data satisfactorily at energies below 7 MeV/n or so. For the better understanding of ICF reaction dynamics, excitation functions (EFs) and recoil range distributions (RRDs) for a large number of reaction products have been measured in different projectile-target combinations.

Experimental details

The experiments have been performed, employing energetic $^{16}O^{7+}$ beam[2], from the 15UD-Pelletron accelerator, of the IUAC, New Delhi, India. For the EF measurements, isotopically pure targets of ^{181}Ta, ^{103}Rh and ^{27}Al 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. For the forward recoil range distribution (FRRD) measurements, thin samples of ^{181}Ta deposited on Al foils have been used. The irradiations have been performed in the General Purpose Scattering Chamber having in-vacuum transfer facility. The irradiations have been carried out for the duration of ≈8-12 h, with a beam current ≈5-7 pnA. Off-line γ-ray spectroscopy using a pre-calibrated high purity germanium (HPGe) spectrometer has been employed. The residues have been identified on the basis of their characteristic γ-ray energies and measured half-lives. The intensities of the γ-lines have been used to determine the production cross-sections of the residues populated via different reaction channels.

Results and discussion

EFs for twenty eight residues produced in the interaction of ^{16}O with ^{181}Ta, ^{103}Rh and ^{27}Al have been measured. The cross-sections for the population of $^{193-x}$Au (x= 1-3) isotopes via αxn channels in ^{16}O + ^{181}Ta have been measured. In case of αxn channels, the residues may be formed in two ways; (i) by CF of ^{16}O followed by the formation of an excited CN from which evaporation of neutrons and α-particles may takes place, (ii) by ICF i.e., if it is assumed that the ^{16}O breaks into α+^{12}C and ^{12}C fuses with the target nucleus leaving α particle as spectator. The α-emission

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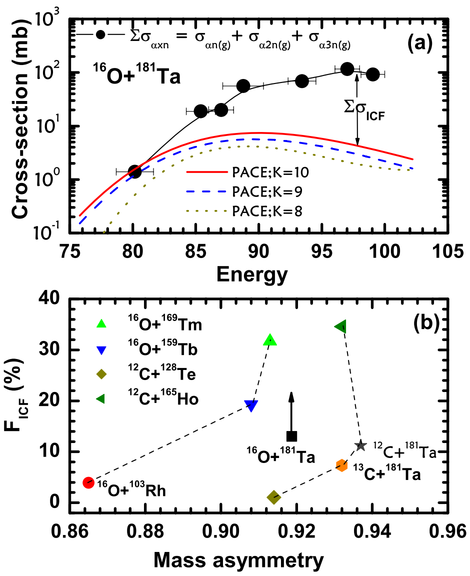

FIG. 1: The sum of measured cross-sections for αxn (x = 1, 2 & 3) channels as well as calculated using PACE4 for K = 8, 9, 10 (b) The percentage ICF fraction as a function of mass asymmetry at a constant normalised projectile energy.

channels identified in the present work are expected to have significant contribution from ICF processes. In order to determine the contribution from ICF processes to the αxn channels, the measured $\Sigma\sigma_{\alpha xn}$(exp) has been compared with the corresponding values calculated using the theoretical model code PACE4, which is based on statistical compound nucleus theory. Since, the code does not take ICF into account, the calculated cross-sections for $\Sigma\sigma_{\alpha xn}$ with code PACE4 will have predictions based on CF model only. In Fig.1(a) a comparison of $\Sigma\sigma_{\alpha xn}$(exp) has been made with $\Sigma\sigma_{\alpha xn}$(Th) calculated using CF model, for three different values of physically acceptable level density parameters (K=8,9&10). As can be seen from this figure, the $\Sigma\sigma_{\alpha xn}$(Th), with any of these parameters could not reproduce $\Sigma\sigma_{\alpha xn}$(exp) above 80 MeV or so. The difference between the experimental and the theoretical values of $\Sigma\sigma_{\alpha xn}$ may be assigned to ICF. Further, the difference between $\Sigma\sigma_{\alpha xn}$(exp) and $\Sigma\sigma_{\alpha xn}$(Th) is found to increase with energy above 80 MeV, indicating the dominance of ICF processes at relatively higher energies. Further, to study the dependence of ICF contribution on mass-asymmetry for presently studied systems, the percentage fraction of ICF cross-sections (F_{ICF}) has been plotted in Fig. 1(b) as a function of mass-asymmetry at a constant value of normalised beam energy. As can be seen from this figure, the F_{ICF} increases with the mass-asymmetry individually for different beams. Further, the value of F_{ICF} for one of the presently studied system ^{16}O+^{181}Ta is not following the expected trend shown for the other systems involving ^{16}O beam. The present F_{ICF} for ^{16}O+^{181}Ta is found to be significantly small. It may be because of the fact that in the present measurements several other α-emission channels could not be observed as the residue populated via these channels were either stable or short lived and/or had very low γ-ray intensity. In a complementary experiment[3], recoil ranges for the same residues have been determined in order to get information about the degree of linear momentum transfer and the relative contribution of CF and ICF channels in ^{16}O + ^{181}Ta system at ≈81, 90 and 96 MeV projectile energies. Significant ICF contributions have been observed in several α-emiting channels. Further, details of the measurement and analysis for all the systems and reaction channels will be presented.

References

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