Study of entrance channel effects in fusion reactions at energies around the Coulomb barrier

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Heavy ion induced fusion-fission reaction at near barrier energies has been a topic for extensive theoretical as well as experimental research for the past few decades. The composite system after capture follows a long dynamical path and equilibrates in all degrees of freedom or re-separates before complete equilibration. Fusion process is found to be very much sensitive to various entrance channel parameters such as deformation of the reaction partners, entrance channel mass asymmetry, mean fissility etc. The enhancement of fusion cross sections at near and sub-barrier energies over the predictions of one dimensional-barrier penetration models, due to the coupling of various internal degrees of freedom [1] was known long back. However, the effects of inelastic and transfer couplings are not fully understood till date. It is also reported that the experimental fusion cross sections in ∼200 mass region are significantly reduced [2] even for very asymmetric reactions, due to the onset of other non-compound nucleus (NCN) processes. Hence, heavy-ion fusion process has to be considered on a better platform, beyond the convetional barrier passing models, as it is clear that merely overcoming the barrier may not ensure the formation of the compound nucleus (CN).

In this context we present our measurements on ^{16}O+^{194}Pt and ^{24}Mg + ^{186}W reactions, populating the compound system ^{210}Rn. The entrance channel mass asymmetry (α) of ^{16}O + ^{194}Pt reaction is very near to the Businaro-Gallone critical mass asymmetry (α_{BG}), while that of ^{24}Mg + ^{186}W reaction is much lower.

Dynamical models proposed in early eighties predicted the onset of NCN process for systems with $Z_P Z_T > 1600$. However, recent reports on the onset of NCN processes in asymmetric reactions evoked considerable interest in this topic. In order to investigate this matter, mass-angle and mass ratio distributions of the fission fragments from the two reactions mentioned above were measured using the 15-UD Pelletron accelerator facility at IUAC, New Delhi. Strong mass-angle correlation and larger mass widths were considered to be the possible experimental signatures of non-equilibrium processes such as quasifission. Experiments were performed in the scattering chamber and fragments were detected using two MWPC detectors. Fragment mass ratio distrubtions were obtained using the time-difference method. Though fission fragments from both the reactions did not show any mass-angle correlation, at similar CN excitation energies, the fragments from ^{24}Mg + ^{186}W showed [3, 4] larger mass widths. The deviations from compound nucleus behavior were dominant at near barrier energies. The angular momentum dependence of the fragment mass variance could not explain the observed difference in the two reactions. This dramatic deviation from CN behavior, especially at near barrier energies, is a clear experimental signature of onset of quasifission process in ^{24}Mg + ^{186}W reaction. Though $Z_P Z_T$ for this reaction is much lower than 1600 (888 in this case) and mean fissility less than 0.723, the onset of NCN process indicate the role of mass asymmetry and deformation in reaction dynamics at near barrier energies.

Systematic study of fusion-fission reaction in ∼200 mass region also revealed the effect of nuclear dissipation in the reaction dynamics. It was observed that the fission decay widths

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were reduced over the predictions of statistical models. Considerable enhancement in ER cross sections were also observed in these systems. Although neutron, GDR gamma-ray multiplicities etc were used as experimental probes, ERs are the most sensitive probe to explore the role of dissipation. ERs are the unambiguous signatures of CN formation and can provide valuable information about the role of dissipation as well as the onset of NCN process in reaction dynamics. We measured the ER cross sections [5] in ^{16}O + ^{194}Pt reaction using the gas filled recoil mass spectrometer HYRA at IUAC [6]. The excitation function measurements were performed in the energy range 10% below to 25% above the Coulomb barrier. Standard statistical model calculations using Bohr-Wheeler fission widths [7] underpredicted the ER cross sections at higher energies. In these calculations, the effects of nuclear dissipation were not incorporated. However, calculations using Kramers' [8, 9] formula for fission width with dissipation coefficient $\beta = 5{\times}10^{-21}\text{sec}^{-1}$ reproduced the experimental cross sections at all energies. The present measurement provides further evidence for the effect of nuclear dissipation in 200 mass region.

The angular distributions of the fission fragmets in heavy ion induced fission is an effective probe to understand the dynamics of fusion-fission process. The angular distributions were found to be anomalous even with a slight admixture of NCN process. It was found that the entrance channel mass asymmetry plays a decisive role in the dynamics and hence on the angular distributions. Effect of shell closure on angular anisotropies were also reported in literature. Angular distributions of the fission fragments in ^{16}O + ^{194}Pt reaction were measured using the 14 UD Pelletron accelerator facilty at TIFR, Mumbai [10]. The fragments were measured using silicon detector telescopes mounted inside the scattering chamber. SSPM calculations assuming average values of angular momentum and excitation energy could not explain the fragment angular anisotropies at all energies satisfactorily. Statistical model calculations were performed incorporating shell corrections at saddle point deformations and equilibrium deformations. In ∼200 mass region, fission barrier and neutron separation energies are comparable which assist the multichance fission decay to be a dominant decay channel. The distributions of the fissioning nuclei in different chances were included in the statistical calculations. The effective moment of inertia $\Im_{eff}$ was scaled to fit the anisotropy values. It was observed that $\Im_{eff}$ scaled by 1.10 ±0.04 reproduced the experimental anisotropies.

In summary, fission fragment mass distributions, fragment angular distributions and ER cross sections were measured for reactions forming the composite system ^{210}Rn. Experimental signatures of onset of quasifission process and its strong entrance channel dependence were observed in mass distribution studies. ER cross section measurements revealed the effect of nuclear dissipation in 200 mass region. The role of shell correction at saddle point and multichance nature of fission on reaction dyamics were observed in the angular distribution studies.

Acknowledgments

The author is thankful to Prof. K. M. Varier (Supervisor), all the collaborators and the Pelletron staff of IUAC, New Delhi and TIFR/BARC, Mumbai.

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