Study of the dynamics of fusion-fission reactions by neutron multiplicity measurements

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Much interest has aroused to study the stability of heavy nuclei formed in heavy ion induced fusion-fission (FF) reactions in recent years. The main reason for this interest is the possibility of synthesizing super-heavy elements (SHE), which are predicted to be stable due to shell effects. Quasi fission (QF) is the main hurdle that hinders the synthesis of SHE [1]. It has been observed that measurements of fission fragment angular distribution, mass-distribution(MD) and mass-total kinetic energy (TKE) distribution helps in distinguishing FF and QF processes. But these measurements are not sufficient to distinguish the above two components in the fission path of heavy element as mass symmetric region may be populated both by fission process and the QF process. Neutron emission is one of the useful probes for the measurements of the time-scales of these processes and the understanding the mechanism of energy dissipation in heavy-ion reactions. It has been observed that the neutron multiplicity is found to be lower in the QF region as compared to the neutron multiplicity in FF region. So, measurement of neutron multiplicities resulting from different mass splits can be a useful probe to disentangle these two processes.

The present thesis work mainly focused to study the fission dynamics of ^{192,202}Po compound nuclei populated by ^{48}Ti+^{144,154}Sm reactions at excitation energy range of 50-95 MeV. In this regard, we have measured the average neutron multiplicity, mass-gated neutron multiplicity, MD, mass-energy distribution (MED) and the angular distribution for neutrons using National array of neutron detectors (NAND) facility. The systems ^{12}C+^{194}Pt and ^{18}O+^{192}Os were also included in the present work for which experimental data for neutron multiplicity are already available. Main idea behind this study is to have a clear picture of the contribution of QF in actinide region by considering Po compound nuclei populated through different reaction channels. The chosen systems span the neutron deficient ^{192}Po (N_{CN}=108) to neutron rich ^{210}Po (N_{CN}=126) compound nuclei. We also perform a detailed statistical model (SM) analysis for the four systems to see the role of shell effects on nuclear dissipation [2]. The experiment required for this thesis work was performed using 15UD Pelletron + LINAC accelerator facility at IUAC, New Delhi and the enriched ^{144,154}Sm targets used in this experiment were fabricated using thermal evaporation technique [3].

The conventional two-body kinematics based on the conservation laws of mass and linear momentum followed by an iterative procedure is used to determine the masses and energies of the fission fragments from their measured velocities and angles. The extracted width of the MD for ^{48}Ti+^{144}Sm system are 30 and 26 a.m.u at $E^* = 72$ and 50 MeV respectively. For ^{48}Ti+^{154}Sm the extracted width of the MD at $E^* = 72$ and 95 MeV are 26 and 29 a.m.u respectively. The <TKE> values as a function of fragment masses are also compared with the Viola systematics. These measurements confirms the mixed contribution of fFF as well as QF processes for the system under study. These studies were extended further to check the dependence of MD on TKE. TKE cuts are varied in the interval of 20 MeV and MD is checked at each energy point corresponding to the intermediate mass region. These distributions point towards the conclusion that the region with the highest TKE cut value receives the dom-

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*Electronic address: `ruchimahajan4@gmail.com` inant contribution from FF while the other three regions (with lower TKE cut values) receive mixed contribution from the FF and QF processes. The extracted mass-width (σ_M) have been compared with the already existing data for symmetric reaction (^{48}Ca+^{154}Sm) to very asymmetric reaction ^{16}O+^{186}W forming nearby same compound nucleus (CN) (Z_{CN}=82). The dependence of σ_M on parameters like excitation energy, fissility, E_{CM}/V_B and quasi-fission probability (P_{QF}) has been studied. Calculations assuming scission-point model have also been performed to interpret the experimental results. The results strongly suggest the entrance channel dependence of QF in heavy ion collisions [4].

In neutron multiplicity measurements, neutrons were detected in coincidence with the fission fragments and the contributions from the pre-scission and post-scission neutrons have been determined using multiple source least square fitting procedure based on Watt's expression. The experimentally extracted values of average neutron multiplicities M_{pre}, $2M_{post}$ and M_{total} are 1.92±0.18 , 2.80±0.12 and 4.72±0.19 for ^{48}Ti+^{154}Sm system at 72 MeV of excitation energy [5]. For ^{48}Ti+^{154}Sm system, extracted values of M_{pre}, $2M_{post}$ and M_{total} are 2.90±0.18, 3.28±0.12 and 6.18±0.19, respectively. In order to check the consistency of experimental data, SM analysis has been performed for ^{48}Ti+^{144,154}Sm along with already existing data for ^{12}C+^{194}Pt and ^{18}O+^{192}Os covering compound nuclei of Po (^{192,202,206,210}Po) with neutron number N_C=108, 118, 122 and 126 respectively. These calculations have been performed using Bohr-Wheeler and Kramer's fission widths, with shell correction in level density and fission barrier. The dissipation strength (β) values in the range (10-20)$\times 10^{21}$s^{-1} can reproduce the experimental multiplicities for the ^{18}O+^{192}Os and ^{48}Ti+^{154}Sm systems forming compound nuclei ^{210}Po and ^{202}Po respectively, a smaller value of β is required for the ^{12}C+^{194}Pt system leading to the CN ^{206}Po. However, for the ^{48}Ti+^{144}Sm reaction forming the CN ^{192}Po, number of pre-scission neutrons falls much short of the experimental value even with a strong dissipation of β=20$\times 10^{21}$s^{-1}. Though a large fraction of M_{pre} is saddle-to-scission neutrons ($M_{pre}{}^{ss}$) for β=20$\times 10^{21}$s^{-1} (M_{pre}=1.27 including $M_{pre}{}^{ss}$=0.44), it is not large enough to explain the experimental multiplicity of 1.92±0.18 [6].

These studies were further extended to see the variation of neutron multiplicities on the fission fragment masses for ^{48}Ti+^{144,154}Sm system at 72 MeV of excitation energy. It is noticed that M_{total} increases from 1.59±0.04 to 5.09±0.07 for ^{48}Ti+^{144}Sm and 1.73±0.04 to 7.04±0.22 for ^{48}Ti+^{154}Sm while transition from projectile like mass cut to symmetric mass cut. Similarly, M_{pre} is also found to increase from 0.65±0.04 to 1.49±0.06 for ^{48}Ti+^{144}Sm and 0.67±0.04 to 2.22±0.18 for ^{48}Ti+^{154}Sm while moving from projectile like mass cut to symmetric mass cut which can be justified on the basis of expected increase in the available excitation energy if one moves from projectile like mass cut to symmetric mass cut [4]. We have also extracted the neutron angular distribution by integrating the differential neutron energy spectra over the neutron energy from 0-6 MeV. It is inferred that the contribution for different sources depends significantly on the correlation angle between the fission fragment and the direction of emitted neutron.

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