Measurement of Nuclear Fusion-Fission Time Scale using Neutron Multiplicity

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Introduction

Heavy ion induced fusion-fission (HIFF) dynamics is an area of current research due to prominent signatures of entrance channel effects in fission-fragment mass distributions and particle multiplicities [1–5]. One of the major puzzles of HIFF reactions is the fission hindrance. The fission hindrance can be understood in terms of dissipation and fission delay time which are responsible for the increased survival probability of the compound nucleus (CN) which in turn increases the emission of light charged particles, γ-rays and neutrons from the excited CN. The measured prescission neutron multiplicities were observed to be higher as compared to the statistical model predictions indicating the dynamical effect of nuclear fission. The cause for the excess emission of pre-scission neutrons arising from three distinct origins in FF dynamics can be qualitatively understood as follows. First, due to nuclear de-excitation an excess number of neutrons will be emitted from temperature equilibrated intermediate dinuclear system during its evolution towards the formation of CN which is termed as formation delay (τ_{fr}). Second, dissipation will delay the onset of fission event due to the occurrence of finite transition time as the equilibrium configuration diffuses over the saddle point causing an excess emission of neutrons. This delay is termed as transient delay (τ_{tr}). Third, in the post-saddle phase, dissipation causes excess emission of neutrons during the dynamical evolution of the system from saddle point to scission point (τ_{ssc}).

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The present thesis work, focuses on the study of reaction time scales involved in the different stages of heavy ion fusion-fission dynamics by measuring the observables like fission fragments mass distributions, average neutron neutron multiplicity, mass-gated neutron multiplicity, mass-energy distribution etc in reactions involving heavy ion beams aiming to understand some of the anomalies in fusion-fission observables. In this way, we have carried out three experiments using Pelletron LINAC Accelerator: (a) Measurement of Fusion-Fission time scale in ^{216}Th and ^{250}Cf nuclei using BARC-TIFR Pelletron LINAC Accelerator, Mumbai and (b) Measurement of Fusion-Fission time scale in ^{262}Rf nucleus using Pelletron LINAC Accelerator, IUAC , New Delhi. These three experiments have been carried out with increasing fissility of the CN system to study in detail the fusion-fission dynamics as a function of fissility.

The present work on ^{32}S + ^{184}W reaction describes the fragment-fragment-neutron correlation measurement in the collisions of ^{32}S projectile on ^{184}W target at 180 MeV bombarding energy. Pre-scission neutron multiplicity = 2.68±0.48 and post-scission neutron multiplicity = 3.3±0.20 have been deduced from multi-source fits to the observed neutron energy spectra. Dynamical model HICOL code predictions have shown $\tau_{fr} \simeq 19 \times 10^{-21}$ s for the present system and $\tau_{fr} \simeq 9 \times 10^{-21}$ s for the ^{16}O+^{208}Pb system at the similar excitation energy as in case of former reaction [1]. The HICOL code analyses have predicted a higher value of τ_{fr} for the present symmetric system in comparison to the asymmetric ^{16}O+^{208}Pb system for the case where both systems are lying lower side of α_{BG}. For the present reaction, the HICOL predicts fusion trajectory up to ℓ=49, beyond 49 upto 58 ℓ-values, quasi-fission/fast fission trajectories are observed. Beyond ℓ=58, the trajectory re-separates as projectile-like and target-like. The HICOL code does not distinguish between quasi-fission and fast fission rather group them together from time evolution of trajectories. The HICOL predicts 20% of quasi-fission/fast fission for the present system studied, which is in good agreement with the DNS model predictions of around 28% quasi-fission and 4% fast fission for the present system [1].

For the ^{32}S+^{184}W reaction we have simultaneously reproduced both measured ν_{pre} and available ER cross section at an E* $\simeq$ 71.3 MeV within the framework of statistical model JOANNE2 code by considering fission delay, deformation dependent particle binding energies, charged particle transmission coefficients and level densities. The excess ν_{pre} = 2.06±0.48 were converted into τ_{tot} of 66^{+20}_{-20} $\times$ 10^{-21} s. The JOANNE2 code analyses have shown that the τ_{tr}= 10 $\times$ 10^{-21} s is required to account the ER cross section and τ_{ssc} = 37^{+20}_{-20} $\times$ 10^{-21} s is required to account the excess ν_{pre} for the present system. A comparative study of fission delay for the $^{16}O + ^{208}Pb$ system has shown $\tau_{tot} = 60^{+23}_{-23} \times 10^{-21}$ s and τ_{ssc}= $41^{+23}_{-23} \times 10^{-21}$ s for the excess ν_{pre} = 2.27±0.50. A slightly lower value of τ_{ssc} for $^{32}S + ^{184}W$ system in comparison to $^{16}O + ^{208}Pb$ system can be understood by higher quasi-fission percentage prediction by HICOL code for former system in comparison to latter system. These analyses illustrate that fission delay for both systems can be understood by considering different τ_{fr} values as predicted by HICOL code.

The JOANNE2 code analysis has shown, $Z_{ssc} = 2.45$ is required to account the observed τ_{ssc} and ν_{pre} for the present reaction and Z_{ssc} = 2.32 is required for $^{16}O + ^{208}Pb$ reaction. The difference of Z_{ssc} observed in above two reactions can be understood in terms of elongated fission configuration of ^{32}S+^{184}W system in comparison to relatively compact fission configuration of $^{16}O + ^{208}Pb$ system.

In case of ^{12}C + ^{238}U reaction, correlations between mass distributions of the binary fragments, total kinetic energy (TKE), and neutron multiplicity have been investigated at 45.6 MeV excitation energy. In this work, average neutron multiplicities were extracted as a function of different fragment mass splits and TKE windows. A weak decrease of the pre-scission neutron multiplicity is observed going from asymmetric to symmetric mass splits. The detailed study will be presented during the talk. In case of ^{30}Si + ^{232}Th reaction, neutron multiplicity measurement in-coincidence with fission fragments has been carried out to understand the reaction mechanism of fusion-fission and quasi-fission in the near super heavy nucleus ^{262}Rf in the beam energy range 165-210 MeV and pre-and post-scission neutron multiplicities at highest energy 210 MeV have been extracted by analyzing angular correlation of the neutron energy spectra using moving source fitting procedure. Statistical Model code analysis have shown the presence of quasi-fission events [2]. The detailed analysis of the data is being carried out to obtain the conclusions on the experiment.

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References

[1] Prashant N. Patil et al., Phys. Rev. C **102**, 034618 (2020).

[2] Prashant N. Patil et al., Wutan Huatan Jisuan Jishu **XVII**, 134-147, (2021).

[3] Prashant N. Patil et al., Proceedings of the DAE Symp. on Nucl. Phys. **62** 484-485 (2017).

[4] Prashant N. Patil et al., Proceedings of the DAE Symp. on Nucl. Phys. **63** 720-721 (2018).

[5] Prashant N. Patil et al., Proceedings of the DAE Symp. on Nucl. Phys. **64** 401-402 (2019).