Study of nuclear dissipation in heavy ion fusion-fission dynamics

N. K. Rai*
Department of Physics, Banaras Hindu University, Varanasi-221005, India†

Introduction

The nuclear dissipation is now a well known phenomenon inside the nucleus in heavy-ion reactions. The efforts have been made to investigate the factors affecting the strength of this dissipation. The threshold for excitation energy had been determined and it was found that up to certain excitation energy the experimental results are well produced by the statistical model [1], but the experimental results are over predicted with respect to the statistical model predictions with an increasing excitation energy. The pre-scission neutron multiplicity is measured and the effect of N/Z on the nuclear dissipation is investigated and it does not show any appreciable effect on the strength of nuclear dissipation [2]. Shell closure effect on the nuclear dissipation is also investigated and it is found that the dissipation strength is weaker in the nucleus having shell closure as compared to the adjacent nuclei away from the shell closure. However, it is evident that the entrance channel mass asymmetry also influences the nuclear dissipation.

Experiments

The experiment was carried out using the National Array of Neutron Detectors (NAND) facility of the Inter University Accelerator Center (IUAC), New Delhi. Pulsed beam of ^{18}O having a repetition rate of 250 ns delivered from the 15UD Pelletron accelerator was bombarded on a ^{184}W target of thickness 770 µg/cm^2. The target was prepared by using the ultra-high vacuum evaporation technique with a carbon backing of 40 µg/cm^2. The target was placed at the center of a spherical chamber of 100 cm diameter. A pair of multiwire proportional counters (MWPCs) of active area 11 × 16 cm^2 each were used to detect the fission fragments. Following the folding angle between the fragments, the MWPCs were mounted at 35^o and 126^o with respect to the beam direction and at distances of 26 cm and 21 cm, respectively, from the target. These were operated with isobutane gas of 4 mbar gas pressure. The time of flight (TOF) spectra of the fission fragments were generated using the fast timing signal of the MWPCs with reference to the beam arrival time. Fission events were separated from the other competing channels by analyzing the TOF signal. Two silicon surface barrier detectors (SSBD) were also placed inside the chamber at angles $\pm 12.5^o$ with respect to the beam direction to monitor the beam. The neutrons emitted from the compound nucleus and subsequently from the fragments were detected by using an array of organic liquid scintillator (BC501) detectors. We placed 50 neutron detectors at different polar (θ) and azimuthal (ϕ) angles in a semi-spherical configuration of radius 175 cm. The pulse-shape discrimination (PSD) method, based on the zero crossing technique, was combined with the TOF technique to discriminate neutrons from different sources. Neutron energy spectra were obtained by converting the TOF spectra, considering the prompt γ peak as the reference line.

Results and Discussion

We have observed that the angular momentum calculated by the statistical model calculation (CASCADE) and the dynamical model calculation (HICOL) suggest the different value of angular momentum contribution in the higher energy region compared to

*Electronic address: nkrai233231@gmail.com
†Present address: Institute for Plasma Research, Gandhinagar-382428, India.

the lower energy region for both the symmetric and asymmetric systems. The angular momentum hindrance (Δl_{max}) increases with the incident energy of the projectile for both the symmetric and asymmetric systems, which concludes that the dissipation in the entrance channel increases with the projectile energy and causes the angular momentum hindrance in both the symmetric and asymmetric systems at the higher energy. Moreover, the dissipative behavior of the fusing nuclei is also compared with respect to the entrance channel parameters like, mass asymmetry α and the Coulomb interaction term $Z_P Z_T$ at constant excitation energy and observed that with increasing value of mass asymmetry it decreases almost linearly and it increases almost linearly when the Coulomb interaction term $Z_P Z_T$ increases [3]. So, it is desired to do more such kind of experiments to verify the above mentioned results for both symmetric and asymmetric systems.

We have measured the pre- and post-scission neutron multiplicity for the reaction ^{18}O+^{186}W. We have compared our results with the system ^{16}O+^{181}Ta, existing in the literature. It was found that for the similar value of the entrance channel mass asymmetry at the same excitation energy, populating the compound nucleus in same mass region, almost similar value of the dissipation parameter is required. Moreover, we have chosen the different systems from the literature with different mass asymmetry, populating the compound nucleus with near value of mass number and excitation energy. The required value of the dissipation parameter to match the statistical model predicted value of the pre-scission neutron multiplicity M_{pre} with the experimental value is higher for the lower value of the entrance channel mass asymmetry. It concludes that in the fusion-fission process, nuclear dissipation decreases with the increasing value of the entrance channel mass asymmetry. In the present case, it was also verified that nuclear dissipation increases with the increasing value of the Coulomb factor $Z_P Z_T$ [4].

Pre- and post-scission neutron multiplicities have been also measured for the reaction ^{18}O+^{184}W. The statistical model calculation was performed and dissipation parameter β was used as an adjustable parameter to reproduce the experimental M_{pre} value. Statistical model was unable to reproduce the experimental value of the M_{pre} with $\beta = 0\ s^{-1}$. We have also seen the effect of N/Z, fissility, for the Pb isotopes including our earlier measurement of ^{204}Pb and the data from literature for the isotopes ^{200}Pb,^{198}Pb, and ^{192}Pb. The experimental value of the M_{pre} increases with the increasing value of the N/Z and decreases with the increasing value of the fissility. The entrance channel effect was also studied using the delay time (τ_{delay}) in the saddle-to-scission transition, which depends on the entrance channel mass asymmetry[5]. It was also observed that the systems with the higher value of the entrance channel mass asymmetry have a lower value of the nuclear dissipation.

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