Measurement of fission delay time for the near super-heavy nuclei

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Introduction

Fair understanding of the reaction dynamics is a prerequisite for synthesis of the super-heavy nuclei. In collisions between two heavy nuclei, it is a well known fact that there is a considerable contribution from quasi-fission processes along with the fusion-fission processes. To disentangle these processes, a number of experimental probes like mass distribution, mass-energy and mass-angle correlations, and mass-gated neutron multiplicity measurements have been adopted. For such studies, neutron emission is one of the preferable probes as it helps in measuring timescales of these processes and in understanding the mechanism of energy dissipation in heavy-ion reactions. With this motivation in mind, we have studied the mass distribution, mass-energy and mass-angle correlations, average neutron multiplicity, mass-gated and energy-gated neutron multiplicity, and neutron angular distribution for the ^{48}Ti + ^{208}Pb reaction populating the near super-heavy nucleus ^{256}Rf at an excitation energy of 57.4 MeV. These measurements have been carried out using the 15UD Pelletron + LINAC accelerators and NAND facility at IUAC, New Delhi, India. The details of the experimental setup and analysis procedure are given in Ref. [1]. In the present paper, the experimental results for neutron multiplicity are compared with the theoretical predictions from statistical model calculations and the value of reduced dissipation strength and fission delay time for the ^{256}Rf are estimated. Along with this, these calculations are also performed for the systems ^{28}Si + ^{232}Th and ^{19}F + ^{232}Th.

Results and Discussion

We have performed theoretical calculations of average pre-scission (M_n^{pre}) neutron multiplicity for the systems ^{48}Ti + ^{208}Pb, ^{19}F + ^{232}Th and ^{28}Si + ^{232}Th populating near-super-heavy compound nuclei ^{256}Rf, ^{251}Es and ^{260}Rf respectively at an excitation energy of 57.4 MeV using a statistical model code [2]. In these calculations, the shell corrections are included in the fission barrier and nuclear level density. The experimentally extracted average M_n^{pre} is reproduced by varying the dissipation strength value (β) in the statistical model calculations for the ^{48}Ti + ^{208}Pb system. Figure 1 (a) shows the variation of M_n^{pre} with β for the three systems. This figure indicates a decrease in M_n^{pre} with increase in projectile mass (from ^{19}F to ^{48}Ti), which might be an effect of lowering of fission barrier at higher compound nuclear spin populated by heavier projectiles.

We found that the experimentally measured value of M_n^{pre} (1.68 $\pm$ 0.10) for the ^{48}Ti + ^{208}Pb system can be reproduced by the β value of (7.6 $\pm$ 0.7) $\times$ 10^{21} s^{-1}. The

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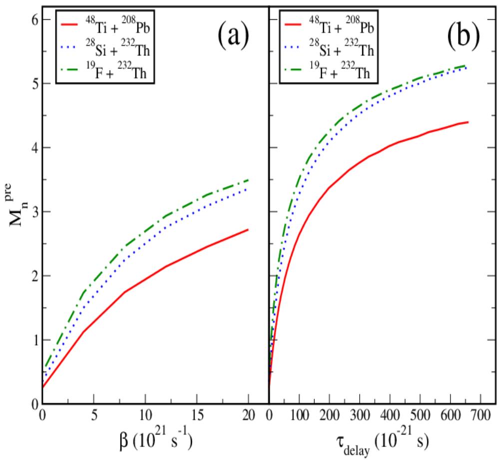

FIG. 1: Variation of the pre-scission neutron multiplicity (M_n^{pre}) with, (a) the reduced dissipation coefficient (β), and (b) delay time (τ_{delay}) for the ^{48}Ti + ^{208}Pb, ^{28}Si + ^{232}Th and ^{19}F + ^{232}Th reactions at an excitation energy of 57.4 MeV.

strength of the dissipation thus found is close to the value reported for the CN ^{260}Rf populated using the ^{20}Ne + ^{240}Pu reaction [3].

For the estimation of fission delay time needed for emission of the experimentally observed number of pre-scission neutrons, another set of calculations is performed by introducing a delay time (τ_{delay}) in the saddle-to-scission stage of fission without considering any dissipation. The variation of M_n^{pre} with τ_{delay} for the above systems is shown in Fig. 1 (b). It is observed that the a fission delay of $(39.6^{+4.6}_{-4.1}) \times 10^{-21}$ s corresponds to the experimentally observed value 1.68 ± 0.10 of M_n^{pre} for the ^{48}Ti + ^{208}Pb system. For the ^{19}F + ^{232}Th reaction, we have also reproduced the available experimental values of M_n^{pre} from Refs. [4, 5] in E^* range of 54 - 90 MeV, by varying τ_{delay}. It is observed that τ_{delay} value of 33 × 10^{-21} s is required to reproduce experimental data. Figure 2 shows M_n^{pre} at different E^* values for the best fitted value of τ_{delay}. This value is in good agreement with value reported in Refs. [4, 5] and is also comparable with our value obtained for the ^{48}Ti + ^{208}Pb system.

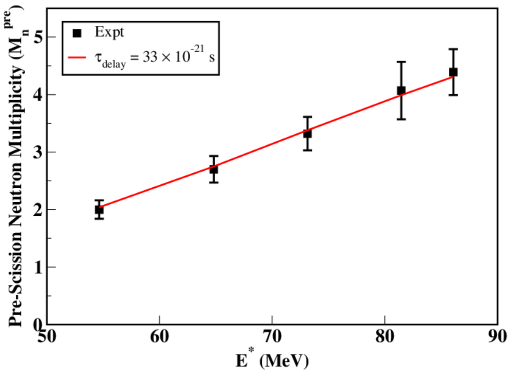

FIG. 2: Variation of M_n^{pre} with E^* for the best fitted value of τ_{delay} 33 × 10^{-21} s in the ^{19}F + ^{232}Th reaction.

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