Study of non-equilibrium processes in heavy-ion induced fission

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The presence of non-equilibrium processes such as fast-fission (FF), quasifission (QF) and pre-equilibrium fission (PEF) is a major hurdle in the synthesis of heavy and superheavy elements by heavy-ion fusion reactions [1, 2]. Many factors such as entrance channel mass asymmetry (α), charge product, deformation of colliding nuclei, and fissility are known to affect the dynamics. In the present thesis work, investigation of mass relaxation in fissile systems using mass-angle distribution measurements and analysis of extraction of probability of compound nucleus formation, P_{CN}, from fission fragment anisotropy data for various systems using pre-equilibrium fission formalism are carried out and are briefly discussed as follows.

Investigation of mass relaxation in fissile systems

It has been shown that, in fission induced by several projectiles like ^{11}B, ^{12}C, ^{16}O and ^{19}F with largely deformed and fissile targets like ^{232}Th and ^{238}U, a fraction of the fission events arise from non-equilibrium fission channel, which is called the pre-equilibrium fission [3]. These PEF events occurs in a time scale comparable to characteristic relaxation time in K-degree (where K is projection of total angular momentum on to the fissioning axis) of freedom. A relaxation time of $\sim 6 \times 10^{-20}$s was deduced as the K equilibration time. However the mass relaxation in these cases were not investigated. In this context, we investigated the equilibration in mass degree of freedom by studying fission-fragments mass distribution and mass-angle correlations in the reactions using different target projectile combinations forming the same compound nucleus at same excitation energies. The systems we studied are, ^{12}C+^{238}U and ^{18}O+^{232}Th forming the compound system ^{250}Cf. The entrance channel mass asymmetry (α) of ^{18}O + ^{232}Th reaction is much lower than the Businaro-Gallone critical mass asymmetry (α_{BG}), while that for ^{12}C + ^{238}U is very close to α_{BG} value. It should be noted that the charge product of interacting nuclei for both the reactions ^{12}C+^{238}U and ^{18}O+^{232}Th are 552 and 720 respectively way below the critical limit of 1600 predicted theoretically for QF to occur. The experiment was performed at the 15UD Pelletron accelerator facility of Inter University Accelerator Centre (IUAC), New Delhi. Pulsed beams of ^{12}C and ^{18}O were bombarded on the targets of ^{238}U and ^{232}Th respectively. The experiment was performed at the 1.5 m diameter general purpose scattering chamber equipped with rotatable arms. Fission-fragments were detected using two large area position sensitive Multi Wire Proportional Counters (MWPC's) mounted on rotating arms at the respective folding angles. The fragment mass-angle distribution were obtained using time of flight method. The full momentum transfer fission events for both the system do not show any correlation of mass splits with emission angle ($\theta_{c.m.}$) at all the energies studied. But extracted width

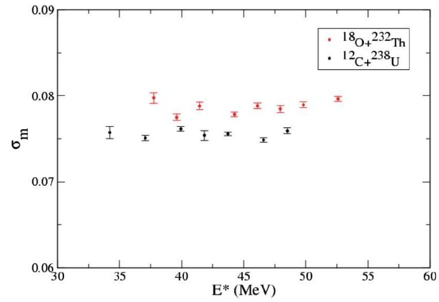

FIG. 1: Fragment mass ratio width vs compound nucleus exciation energy for two systems for the same compound nucleus ^{250}Cf.

of mass distribution of the fission-fragments in the two reactions forming the same compound nucleus at matching excitation energies shows evidence of non-compound nucleus fission in the $^{18}O+^{232}Th$ reactions. The higher width (see Fig. 1) of mass distribution in $^{18}O+^{232}Th$ reaction indicates that fission occurs before complete mass relaxation of the intermediate composite system . This indicates that in this system fission occurs before complete relaxation of both mass as well as K degrees of freedom [4].

Analysis of P_{CN} for various systems using pre-equilibrium fission formalism

The cross section (σ_{ER}) for heavy element formation via fusion-evaporation is determined by three factors, i) the capture cross section (σ_{cap}), ii) probability of compound nucleus (CN) formation (P_{CN}), and iii) the probability (P_{surv}) that the formed compound nucleus survives equilibrium fission decay through light particles evaporation leading to evaporation residue (ER). While the first and third factors are simpler to calculate, the second factor P_{CN}, is difficult to estimate due to its complex dependence on various parameters.

We have carried out the analysis of fragment anisotropy data [5] of various systems selected for cases where $Z_P Z_T$ much less than 1600 so that both quasifission and fast-fission are absent and the anomalous anisotropies are only due to PEF and also it may be noted that in such cases J_{cr} (the J above which the fusion pocket vanishes) is less than $J_{B_f=0}$ (the J at which the liquid drop fission barrier vanishes) so that all $J's$ will be contributing to PEF as well. According to PEF model, the observed angular anisotropy of fission fragments in heavy-ion induced reactions can be written as an admixture of two components: the anisotropy from compound nucleus fission (CN) and anisotropy due to non-compound nucleus fission (NCN) and is given as follows:

$$A_{exp} = A_{CN} P_{CN} + P_{NCN} A_{NCN} \qquad (1)$$

where, A_{CN} is the anisotropy corresponding to compound nucleus fission, A_{NCN} is the ansiotropy due to pre-equilibrium fission (fission

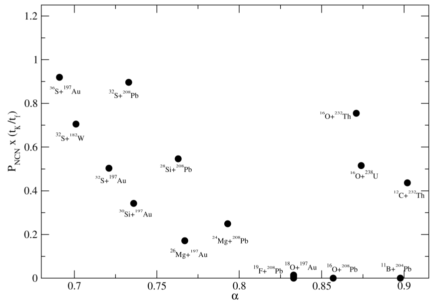

FIG. 2: Plot showing $P_{NCN}(t_K/t_f)$ versus α for various reactions.

before K equilibration) component. P_{NCN} is the probability of non-compound nucleus fission and P_{CN}(=1-P_{NCN}), the probability of compound nucleus formation. While A_{CN} is calculated using standard statistical saddle point model, A_{NCN} is obtained using pre-equilibrium fission formalism and is described in detail in [6]. The obtained expression for P_{NCN} is given as

$$P_{NCN}(t_K/t_f) = \frac{(A_{exp} - A_{CN})}{(A_{CN} - 1)} \qquad (2)$$

The obtained values of $P_{NCN}(t_K/t_f)$ for various systems are plotted with respect to mass asymmetry, α and is shown in Fig. 2. From above equation, it can be seen that unambiguous extraction of P_{CN} requires the knowledge of t_K/t_f. Based on the above analysis we conclude that reliable values of P_{CN} cannot be infered from the analysis of fission fragment anisotropies as attempted in some earlier work [5].

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