Fission fragment mass distribution from combined dynamical and statistical model of fission including evaporation

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An appropriate theoretical model for fission fragment mass distribution (FFMD) of a highly excited heavy nucleus involves multi-dimensional Langevin dynamical calculations [1]. Though a full Langevin simulation provides a more accurate description of fission dynamics, it is often replaced by a combined dynamical and statistical model (CDSM)[2]. This is essentially done because the demand on computer time for a full Langevin calculation is very large. In CDSM, the Langevin dynamical computation is pursued for a time interval during which the initial transients are settled and the fission width has reached a stationary value. The decay of the compound nucleus in subsequent times is followed treating fission at par with other decay channels, such as partcle and γ emission channels which are already included in the calculation from the beginning, and using statistical methods. Evidently, CDSM takes less computer time than full dynamical model simulation.

One of the underlying assumptions of CDSM is that, in the statistical branch of calculation, the various decay channels, including fission, are independent statistical processes represented by respective dacay widths. The Kramers' expression[3] is usually taken as the fission decay width which was obtained by considering fission channel alone at a constant temperature. The validity of using Kramers' width in the presence of evaporation channels has not been tested so far. In the present work, we intend to address this issue. To this end, we first perform dynamical model calculations for a sufficiently long time interval (taken as $2000\hbar/MeV$ here for illustration purpose) which we will subsequently compare with CDSM results. For the dynamical calculation, we use two-dimensional Langevin equation in (c, α') coordinates [1] where c is elongation and the mass asymmetry parameter α' determines the ratio of masses of the future fragments. The Langevin equations are solved using the liquid-drop model potential, irrotational-fluid inertia and one-body dissipation [4–6] for $^{16}O+^{208}Pb$ system at three projectile energies. From the distribution of asymmetry coordinate on the scission line, the fragment mass distributions are obtained. The number of pre-scission neutrons are also obtained from the dynamical calculation.

We next perform CDSM calculations where the dynamical calculation is performed for an initial interval of $t_{dyn} = 80\hbar/MeV$ during which fission rate reaches a stationary value. The calculation then switches over to statistical mode and continues till $t_{max} = 2000\hbar/MeV$. In the statistical mode, fission width is calculated using the two-dimensional Kramers' formula. The fragment mass distribution in the statistical branch is calculated as follows. As soon as an event is identified as fission, the fragment yield with mass asymmetry α' is obtained from the statistical model distribution [7] given by

$$Y(\alpha') = N \exp\left(-U(\alpha')/T\right). \qquad (1)$$

Here, U(α') is the potential profile along the saddle ridge and N is a normalization constant. We have included neutron, proton, α and γ evaporation channels in competition

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with fission in both the calculations.

We first compare the fragment mass distributions from dynamical model and CDSM calculations in Fig. 1.

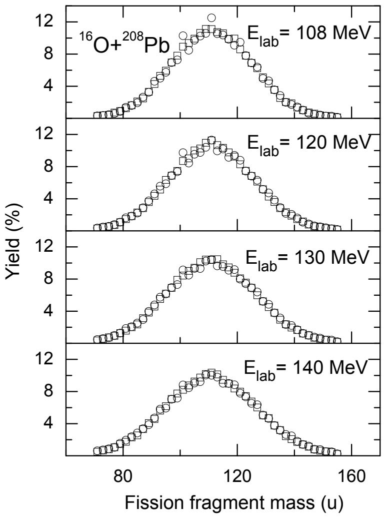

FIG. 1: FFMD of ^{224}Th calculated with the CDSM (open squares) and with full dynamical calculation (open circles).

It is evident from Fig. 1 that the FFMD calculated with these two different methods are in good agreement.

In order to make further comparisons between the two approaches, we next show in Fig. 2 the variances of FFMD and the multiplicity of prescission neutrons obtained from the dynamical and CDSM calculations. We find that the results are in agreement with 5% though CDSM marginally underestimates the neutron multiplicity and overestimates the variance of fission fragment mass distribution. The experimental values[1] of σ_m^2 and n_{pre} for O+Th system at excitation energy of E^* =53.8MeV are 213u^2 and 2.5 respectively.The present calculation for fission fragment mass distribution thus agrees reasonably well with the experimental distribution though it underestimates substantially the prescission neutron multiplicity. This feature has been noted earlier

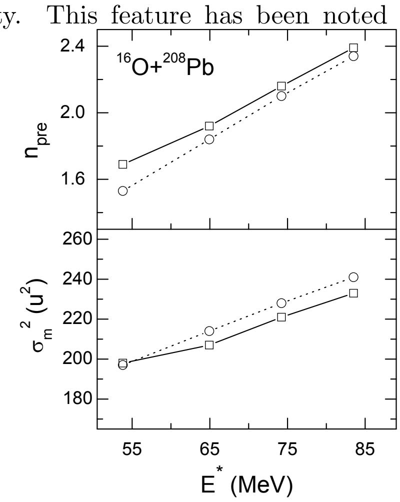

FIG. 2: Prescission neutron multiplicity n_{pre} (upper panel) and σ_m^2 (lower panel) plotted as a function of excitation energy E^*. Symbols have the same meaning as in Fig. 1.

in other dynamical model calculations [1] and requires further attention in future works.

In summary, we conclude that CDSM is a reasonable approximation to a full dynamical model calculation.

References

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