Statistical and dynamical models of fission fragment mass distribution

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Accurate theoretical modeling of fission fragment mass distribution (FFMD) is an important step towards a better understanding of fission dynamics of highly excited compound nuclei which are typically formed in heavy-ion induced fusion-fission reactions. Statistical model calculations have been applied successfully in the past [1] to calculate the FFMD of thermal neutron induced fission. For heavy-ion induced fusion-fission reactions,dynamical models are however more appropriate because nuclear dissipation plays an important role in fission of highly excited compound nuclei. In the present work, we compare the variance of FFMD from Langevin dynamical calculation with statistical model predictions. For this purpose, mass variance at saddle is obtained for the first time from dynamical model calculation.

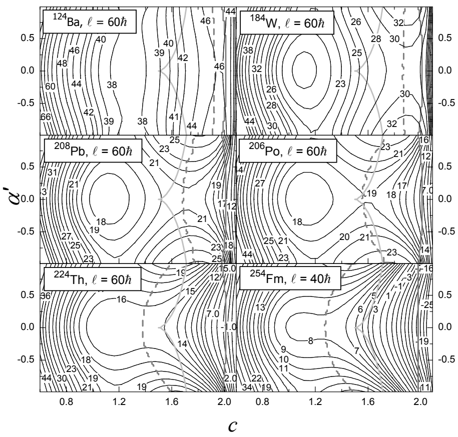

FIG. 1: $V(c, \alpha')$ contours in MeV. The saddle-ridge and the scission line are shown by dashed and solid gray-colored lines. The neck formation is indicated by light-gray lines.

We use the two-dimensional Langevin equation in (c, α') coordinates [2] where c is the elongation and α' is the mass asymmetry parameter which determines the mass ratio of the future fragments. The Langevin equations are solved using the liquid-drop model potential, irrotational-fluid inertia and one-body dissipation [3–5]. The potential energy contours are shown in Fig.1 for six rotating nuclei. The locii of the saddle ridge and that of the scission line are also shown in this figure for each nucleus. The above nuclei and their spin values are so chosen such that they represent a broad range of saddle-to-scission distances and also a reasonable range of fission barriers where Langevin dynamical calculation with good statistics can be performed. Table I gives the values of Z^2/A, the distance (c_{SS}in R_0 unit) between the saddle ridge and the scission line along the c-axis for $\alpha' = 0$, and the fission barrier of these nuclei. In a Langevin dynamical calculation, a fission trajectory crosses the saddle ridge many times in a to-and-fro motion before it reaches the scission line. We obtain the mass asymmetry distributions along the saddle ridge for the following cases. First, we calculate the asymmetry distribution by considering only those mass asymmetries which correspond to the first crossing of the saddle ridge by the fission trajectories. In a similar fashion, mass asymmtry distribution due to the last crossing is also obtained. Keeping track of all the successive crossings of the saddle ridge by a fission trajectory, we further calculate the asymmetry distribution considering the asymmetry coordinates of all such crossings.

According to the statistical model [6], the

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TABLE I:

	^{124}Ba l=60ħ	^{184}W l=60ħ	^{208}Pb l=60ħ	^{206}Po l=60ħ	^{224}Th l=60ħ	^{254}Fm l=40ħ
Z^2/A	25.29	29.76	32.33	34.25	36.16	39.37
c_{SS}	0.08	0.14	0.32	0.46	0.63	0.74
V_B	8.61	8.63	3.41	1.76	0.38	0.10

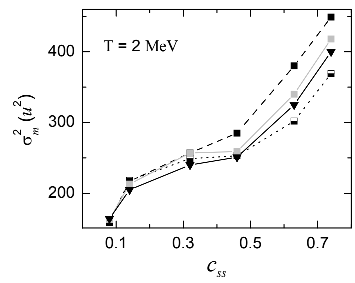

FIG. 2: The mass variances σ_m^2 at saddle from Eq. 1 (downward triangle) and dynamical calculations corresponding to the first crossing (half-filled square), last crossing (filled square) and the average distribution (gray colored square) on saddle. Lines are drawn to guide the eyes.

yield of fragments with mass asymmetry α' is given as

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

where $U(\alpha')$ is the potential profile along the saddle ridge and N is a normalization constant. The mass variances according to the statistical model are directly obtained from Eq.(1) and are compared with those obtained at the saddle from the dynamical calculations in Fig. 2. Statistical model predictions at saddle has been compared earlier with dynamical model results at scission [7]. The present comparisons are however made when both are calculated at saddle. We find that the statistical model predictions lie in between the distributions corresponding to the first crossing and last crossing of the saddle ridge. However, statistical model predictions are very close to the dynamical distributions when all the successive crossings of the saddle ridge are considered. This, in fact, shows that statistical equilibration

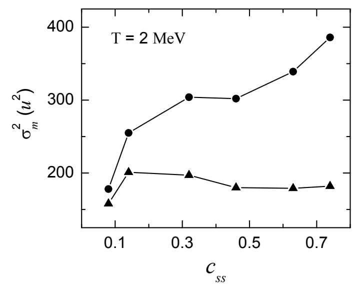

FIG. 3: The mass variances σ_m^2 at scission from statistical model (upward triangle) and dynamical model (circle) for different systems. Lines are drawn to guide the eyes.

is almost reached at the saddle region in dynamical calculations. We next compare the mass distributions calculated at scission by the statistical and dynamical models in Fig. 3. The statistical model values are obtained from a yield distribution as given by Eq.(1) where the potential profile along the scission line is used. The statistical model substantially underestimates the mass variance at scission. This also shows that no statistical equilibration is reached at scission in dynamical model calculations.

In conclusion, it is ahown from dynamical model calculations that while statistical equilibrium is very nearly established in the saddle region in fission of hot nuclei, no equilibration is reached in the scission configuration.

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