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Influence of the potential energy landscape on the fission dynamics

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Abstract. A state-of-the-art three-dimensional Langevin approach is used to explore the influence of the potential-energy surface on the dynamical evolution of a system along its path to fission. Two macroscopic models have been used to parametrize the energy landscape: the Finite Range Liquid Drop Model (FRLDM) [1] and the Lublin-Strasbourg Drop (LSD) model [2]. The former is commonly used for the description of the fission of heavy nuclei. The latter, developed recently, is expected to be more realistic for describing the shapes experienced by fissioning medium-mass nuclei.

1 Introduction

In the present contribution the FRLDM and the LSD models are used to study the influence of the Potential-Energy Surface (PES) on the dynamical evolution of a fissioning nucleus at high temperature and/or angular momentum. In particular we will study the dependence of the fission-fragment mass and charge distributions, prescission and evaporation particle multiplicities on the PES parametrization. The two potential energy prescriptions used here, are observed to give similar results for heavy nuclei, whereas we observe striking differences in their prediction for the mass, charge and the total kinetic energy distributions of the fragments produced in the fission of lighter systems. Our calculations permit to define optimal experimental conditions for constraining the potential energy surface used in the dynamical description of fission.

2 Dynamical model

The Langevin equations have been solved in a three - dimensional deformation space for the collective coordinates $\{q_1, q_2, q_3\}$ based on the well-known "funny-hills" [3] parameters (c, h, α). These coordinates are connected to the elongation, neck constriction and left-right mass-asymmetry of the nucleus, respectively. The de-excitation of the nucleus by particle evaporation along its way to scission is taken into account in a Monte Carlo approach. For futher details on the model see Ref. [4–6]. The presently used code, developped by Adeev and collaborators, has shown powerful to describe many fission observables over a wide mass range.

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3 Potential-Energy Landscapes

The macroscopic potential energy is calculated for every point of the three dimensional $\{q_1, q_2, q_3\}$ mesh. Two - dimensional maps are presented for spin $L = 0\,\hbar$ (Fig. 1 and 2) and spin $L = 70\,\hbar$ (Fig. 3) for which the contribution to fission is the largest.

Figure 1 shows the energy landscape in the (q_1, q_2) plane assuming $q_3 = 0$ (symmetric fission) for the ^{132}Ce compound nucleus. The potential-energy surfaces for the FRLDM and LSD models are observed to be very different for this medium-mass system. On the contrary they are found rather similar for heavy nuclei (not shown here) [7]. The equilibrium deformation and the scission point are very close in both models, but the barrier is about 5 MeV higher with the LSD parametrization. In addition, the stiffer energy landscape in the LSD model is expected to sizeable affect the time evolution of the compound nucleus in its way to fission.

The evolution of the PES along the bottom of the fission valley (red dashed lines in the Fig. 1) is presented in Fig. 2 in the plane $\{q_1, q_3\}$. Mass-asymmetric shapes correspond to $q_3 \neq 0$. The fission barrier for the FRLDM model for necked-in shapes is smaller by more than 2 MeV than for LSD. For the mass-symmetric fission (along the red dashed lines) the height of the barrier is also larger with the LSD approach.

With increasing spin, the PES changes smoothly, see Fig. 3 where is displayed the energy landscapes at $L \approx 70\,\hbar$. Comparing Fig. 2 and 3 one notices that the valley leading to asymmetric fission disappears with icreasing L and a lower barrier is observed for the symmetric fission.

4 Charge and energy distributions

Dynamical Langevin calculations for the decay of excited ^{132}Ce nuclei ($E^\star = 122\ MeV$), produced in the reaction

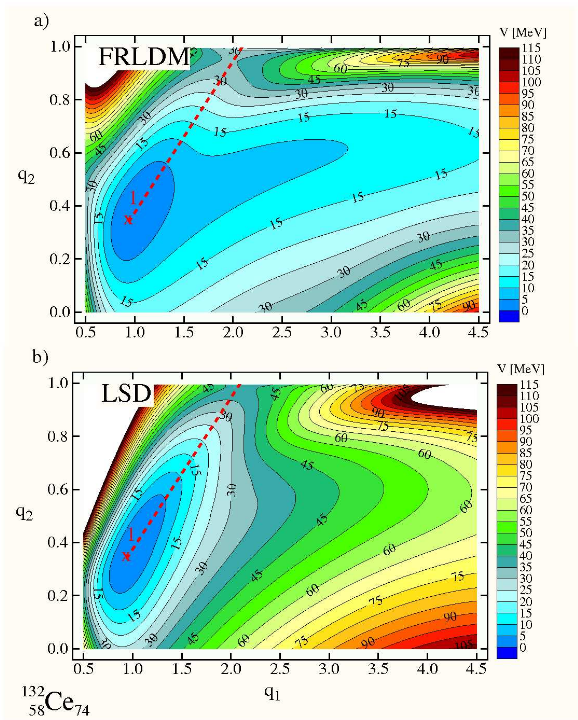

Fig. 1. Two-dimensional $\{q_1, q_2\}$ potential energy surfaces with $q_3 = 0$ for ^{132}Ce calculated with the FRLDM (a) and LSD (b) parametrizations for $L = 0\ \hbar$. Red dashed lines guide the eye along mean fission paths.

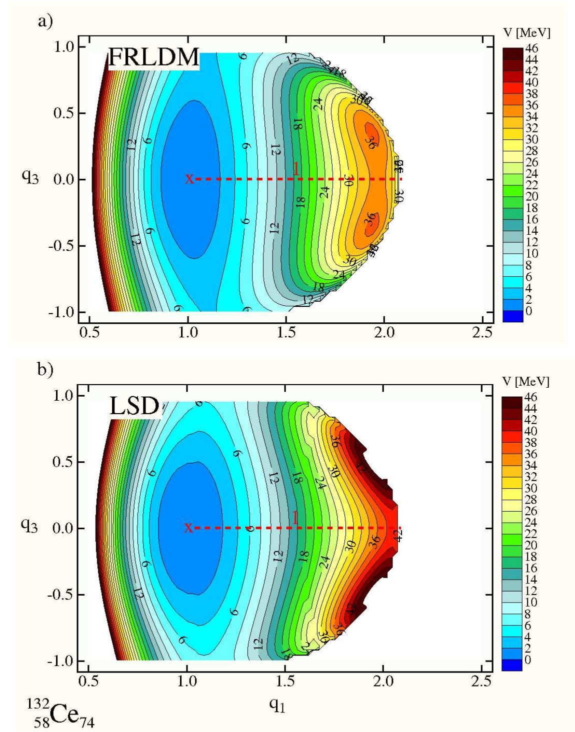

Fig. 2. Two-dimensional $\{q_1, q_3\}$ potential energy surfaces with $h = 0$ for ^{132}Ce calculated with the FRLDM (a) and LSD (b) parametrization for $L = 0\,\hbar$. Red dashed lines guide the eye along mean symmetric fission paths.

$^{32}S(200\ MeV)+\ ^{100}Mo$, have been performed in [8] and compared to available experimental data. The emphasis was put there on the influence of the viscosity and level - density parameters which have been varied, while the FRLDM was assumed for the potential-energy landscape. Presently we focus on another important input of the model, i.e. the PES parametrization. Figure 4 shows some results of the dynamical calculations using either of two aforementioned parametrizations of the potential energy. The fission-fragment Z distributions obtained for the FRLDM and the LSD models are observed to be very different.

Various choices of the viscosity and level-density parameters, set to a friction reduction factor $k_s = 1.0$ and $a = A/6$ presently, do not affect this observation. The narrow Z-distribution predicted by the LSD model, as well as the larger fission probability [7], is due to the stiffer profile of the LSD landscape as compared to the FRLDM one. The absence of mass-asymmetric fission fragments in the Z-distribution for the calculation with the LSD model can be explained by the PES profile shown in Fig. 3.

The corresponding mean Total Kinetic Energy distributions (TKE) are shown Fig. 5. Both distributions have similar shapes but the mean TKE for LSD is smaller by around 5 MeV in the $20 < Z < 40$ range. The difference between these two TKE distributions can be explained by looking at Fig. 3 where the mean potential energy is higher for the LSD landscape.

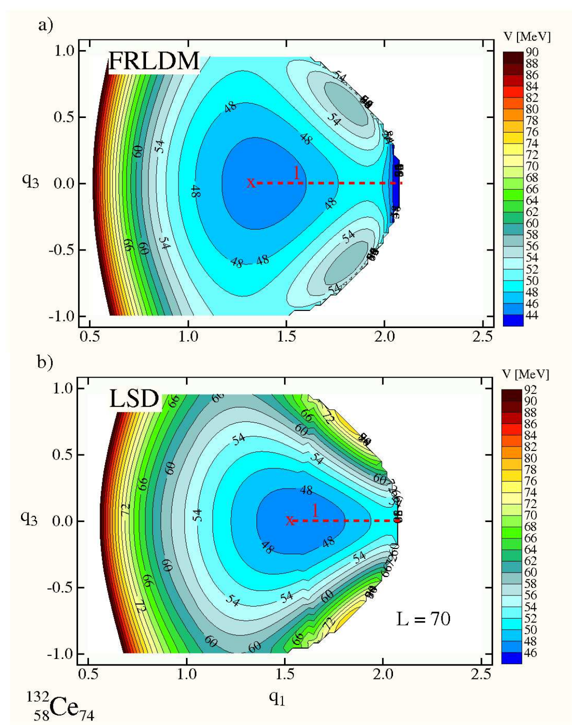

Fig. 3. The same as Fig. 2 for spin $L = 70\ \hbar$.

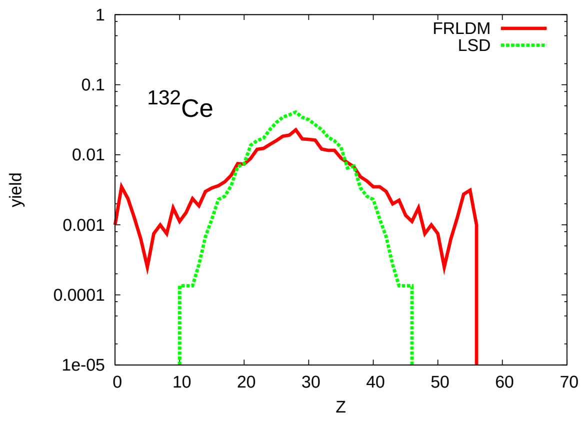

Fig. 4. Fission-fragment charge distributions obtained with the FRLDM (red, full line) and the LSD models (green, dotted line) for fissioning ^{132}Ce nuclei.

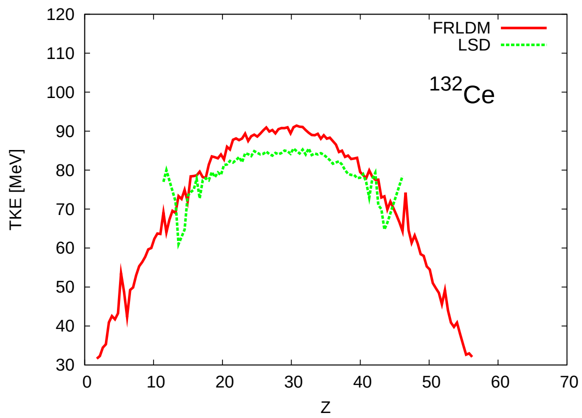

Fig. 5. Total Kinetic Energy (TKE) distributions obtained with the FRLDM (red,full line) and the LSD models (green, dotted line) for fissioning ^{132}Ce nuclei.

Other dynamical observables such as neutron, proton, and α multiplicities have also been investigated and found less sensitive to the change of the PES for the present medium mass system.

The results of the present work demonstrate the critical role played by the potential-energy landscape used in dynamical calculations. The choice of the potential energy parametrization may sizeable influence the conclusion extracted for other ingredients of the calculation, namely the nuclear viscosity and level-density parameters.

Acknowledgements

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