Assessment of saddle-point-mass predictions for astrophysical applications

Aleksandra Kelić and Karl-Heinz Schmidt, GSI, Darmstadt, Germany

In the r-process, fission has the decisive influence on the termination of the r-process as well as on the yields of transuranium elements and, consequently, on the determination of the age of the Galaxy and the Universe. Fission can also influence the abundances of nuclei in the region $A \sim 90$ and 130 due to the fission cycling. One of the common conclusions from extensive investigations on the beta-delayed, neutron- and neutrino-induced fission is that the role of fission in the r-process is very sensitive to the fission-barrier heights of heavy nuclei with A>190 and Z>84. Unfortunately, experimental information on the height of the fission barrier is only available for nuclei in a limited region of the nuclide chart, and for heavy r-process nuclei one has to rely on theoretically calculated barriers. Due to the limited number of available experimental barriers, in any model the constraint on the parameters defining the dependence of the fission barrier on neutron excess is rather weak. This leads to large uncertainties in estimating the fission-barrier heights of heavy nuclei involved in the r-process as can be seen in Fig. 1.

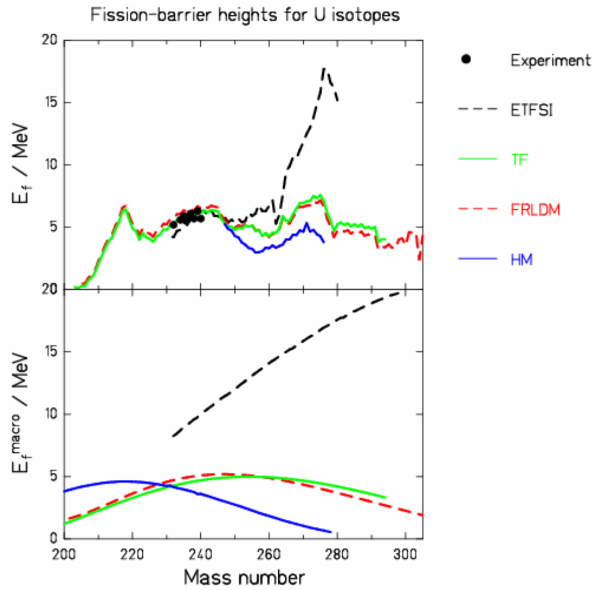

Figure 1: Full macroscopic-microscopic (upper part) and macroscopic part (lower part) of the fission barrier calculated for different uranium isotopes using the models mentioned in the text.

From the lower part of the figure it is evident that the largest discrepancies originate from the macroscopic part. Therefore, we have recently [1] examined the predictions of several macroscopic models by means of a detailed analysis of the isotopic trends of ground-state and saddle-point masses. We consider the macroscopic saddle-point masses given by the following models: Droplet model (DM) [2], Finite-range liquid drop model (FRLDM) [3], Thomas-Fermi model (TF) [4], Extended Thomas-Fermi model (ETF) [5]. In order to test the consistency of these models, we study the difference between the experimental saddle-point mass and the macroscopic part of the saddle-point mass given by models:

$$\delta U_{sadd} = E_f^{\exp} + M^{\exp} - (E_f^{macro} + M^{macro}) \qquad (1)$$

with E_f being the height of fission barrier and M the ground-state mass. This quantity corresponds to the empirical shell-correction energy at the saddle point. At the saddle point configuration, due to the topographic theorem [5], the shell-correction energy is very small. Any general trend (e.g. increase or decrease) in δU_{sad} as a function of the neutron number would thus indicate severe shortcomings of a given macroscopic model in extrapolating to nuclei far from stability. The extracted slopes (A_1) of δU_{sad} as function of the neutron excess are shown in Fig. 2 for the different elements.

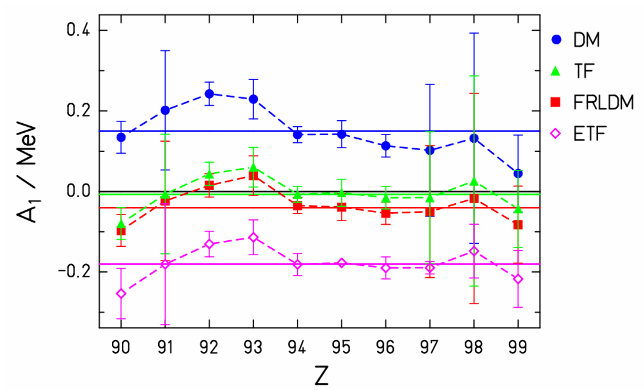

Figure 2: Slopes of δU_{sad} as a function of the neutron excess are shown as a function of the nuclear charge number Z.

The results of this study show that the most realistic predictions are expected from the Thomas-Fermi model and the finite-range liquid-drop model while inconsistencies in the saddle-point mass predictions of the droplet model and the extended Thomas-Fermi model were seen. Understanding the "extrapolatibility" of global nuclear-structure models is extremely important, and much attention has been paid to this test for ground-state masses. This work presents an important extension of these types of analyses to the question of reliably predicting fission-barrier heights for nuclei along the r-process path.

References

[1] A. Kelić and K.-H. Schmidt, accep. by Phys. Lett. B
[2] W.D. Myers, 1977 IFI/Plenum, ISBN 0-306-65170-X
[3] A. Sierk, Phys. Rev. C33 (1986) 2039
[4] W.D. Myers and W.J. Swiatecki, Phys.Rev.C60 (1999) 014606-1
[5] A. Mamdouh et al, Nucl. Phys. A 679 (2001) 337