The fission rate in multi-dimensional Langevin calculations

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Experimental indications of fission as a slow and highly dissipative process have come from the multiplicities of prescission particles [1] and γ-rays [2]. As the quantitative estimations of nuclear dissipation found from different theoretical models differ substantially [3], it becomes important to understand the reasons, which lead to different predictions of theoretical models. One would like to conclude on the validity of the physics considered in these models by comparing these predictions with experimental data. For this purpose, however, one should be sure that technical restrictions of the model calculations do not have any significant influence on the results. One of these restrictions is the dimensionality of the model space, which is the subject of the present work. Experimental data on nuclear dissipation have often been interpreted using one-dimensional Langevin models, where only one parameter is used for the description of the possible shapes of the fissioning nucleus. However, almost all the problems of collective nuclear dynamics are essentially multi-dimensional. Therefore, such an important characteristic as the fission rate is investigated in the present work using Langevin calculations with different numbers of collective coordinates involved in the dynamical consideration for the two most frequently used dissipation mechanisms: one-body and two-body. In order to investigate only the influence of the dimensionality of the model on the calculated results, we carry out one-dimensional, two-dimensional, and three-dimensional Langevin calculations with some simplifications. We started modelling the fission process from the compound nucleus in spherical shape. The calculations have been done for zero angular momentum. The evaporation of the prescission light particles was not considered in the present analysis. Shell corrections have also been neglected. Of course, all these effects have important influence on the fission process, but in the present study we are particularly interested in the importance of the dimensionality of problem, and, therefore, we want to keep all other effects as simple as possible. Technical details on the calculations can be found in ref. [4]. The results of the calculations for the nucleus ^{248}Cf at two excitation energies are presented in Fig. 1 for the case of the one-body dissipation. One can see from this figure that the transient time depends on the number of collective coordinates involved in the Langevin calculations. The lowest transient time is obtained in one-dimensional calculations, and this tendency is independent on excitation energy. One can also see in Fig. 1 that the stationary value of the fission rate increases after introducing new collective coordinates in the dynamical consideration: The stationary value of the fission rate in the one-dimensional case is lower than in the two-dimensional and three-dimensional cases. This effect is more pronounced at high excitation energy. The same qualitative conclusions were obtained in case of two-body dissipation.

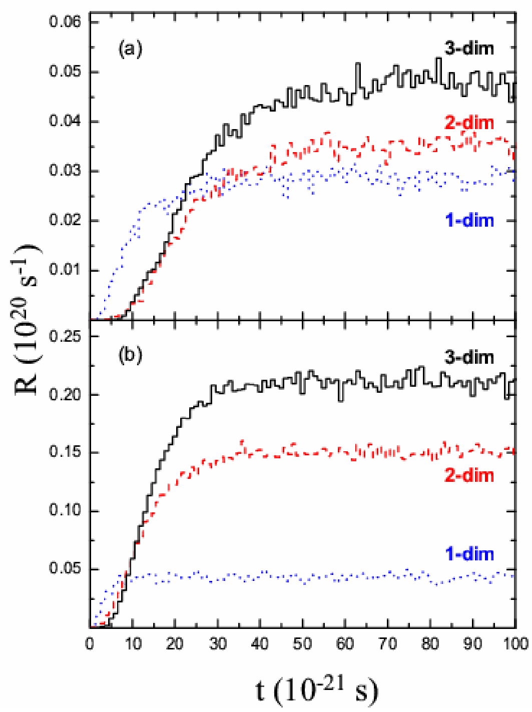

Figure 1: The fission rate calculated for the nucleus ^{248}Cf in the case of one-body dissipation for excitation energy E=30 MeV (a) and E=150 MeV (b). The solid, dashed, and dotted curves correspond to the three-, two-, and one-dimensional Langevin calculations, correspondingly.

These results are particularly important for the conclusions about nuclear dissipation, deduced from the comparison of experimental results with model calculations, which are performed in restricted deformation space. One may suppose that qualitatively the same conclusion is valid for other problems in statistical physics and chemistry on the decay of metastable states of multi-dimensional systems, which might be revisited with the powerful modern tools of Langevin calculations.

Acknowledgment

One of us (P.N.N.) is grateful to the Humboldt foundation for the financing of the stay at GSI, Darmstadt.

References:

[1] D.J. Hinde et al., Nucl. Phys. A 502 (1989) 497c.
[2] M. Thoennessen et al., Phys. Rev. Lett. 59 (1987) 2860.
[3] D. Hilscher and H. Rossner, Ann. Phys. 17 (1992) 471.
[4] P. N. Nadtochy and G. D. Adeev, Phys. Rev. C 72 054608 (2005).