Effects of dissipation and simultaneous break-up on fission at high excitation energies

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The time a nucleus needs to populate its deformation space is ruled by dissipation, that is, the transfer of energy between intrinsic and collective degrees of freedom. The study of fission allows for gaining information on the strength of dissipation within a broad range of deformation. For small deformations, the hindrance of fission caused by dissipation starts to be remarkable only at high nuclear temperatures, when the statistical decay time is shorter than the dynamical delay. On the other hand, as shown in [1], thermal instabilities arise when nuclear temperatures larger than 5 MeV are reached. The aim of this work is to investigate the effects of dissipation and thermal instabilities on fission at high temperatures.

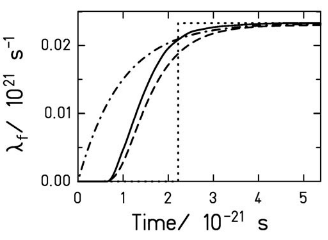

Figure 1: Time-dependent fission rate $\lambda_f(t) = \Gamma_f(t)/\hbar$ for $A = 248$, $T = 3$ MeV, and $\beta = 5\cdot10^{21}$ s^{-1}. The full line is the numerical solution of the FPE [3]. The dashed line is the result of including eq. (1) and (2) in eq. (3). The dotted line represents the step function and the dashed-dotted line the exponential-like function [2].

To obtain reliable conclusions, a realistic description of the effects of dissipation in fission by means of a time-dependent fission width $\Gamma_f(t)$ is mandatory. In our previous contributions [2], we have discussed the two most widely used approximations for $\Gamma_f(t)$, a step function and an exponential-like in-growth function. Comparing to the numerical solution of the FPE obtained in reference [3] for the fission rate, full line in figure 1, these two approximations appear to be considerably crude. For this reason, we have implemented in our model a highly realistic description based on the analytical solution of the Fokker-Planck equation (FPE) when the nuclear potential is approximated by a parabola [4]. Solving the FPE under these conditions gives the time dependence of the probability distribution W at the saddle point deformation x_b

$$W(x_b,t)=\frac{1}{\sqrt{2\pi}\sigma}\cdot\exp\left(-\frac{x_b^2}{2\sigma^2}\right) \quad (1)$$

where σ^2 is a time-dependent function of the form: $\sigma^2 =$

$$\frac{kT}{\mu\omega_1^2}\left\{1-e^{(-\beta\cdot t)}\left[\frac{2\beta^2}{\beta_1^2}\sinh^2\left(\frac{1}{2}\beta_1 t\right)+\frac{\beta}{\beta_1}\sinh(\beta_1 t)+1\right]\right\} \quad (2)$$

where k is Boltzmann´s constant, T is the nuclear temperature, μ is the reduced mass associated to the deformation degree of freedom, ω_1 describes the curvature of the potential at the ground state, and $\beta_1 = (\beta^2-4\omega_1^2)^{1/2}$.

In the overdamped regime ($\beta > 2\omega_1$) and for the case of a parabolic potential, the fission width can be approximated by

$$\Gamma_f(t)=\hbar\lambda_f\approx\frac{W(x_b,t)}{W(x_b,t\rightarrow\infty)}\cdot\Gamma_f^K \quad (3)$$

Implementing equations (1) and (2) in equation (3), we find an analytical expression that represents a very adequate description of $\Gamma_f(t)$, see dashed line in figure 1, especially at the onset of the fission rate, which is particularly important.

Two calculations with this new description of Γ_f(t) have been performed in order to study the reaction of ^{238}U at 1 A GeV on lead. In one case, the simultaneous break-up stage, explained in [1], that results from the thermal instabilities at high temperatures has been considered and in the other case not. The simultaneous break-up has an influence on the deduced value of the dissipation coefficient β. In fact, to reproduce the total nuclear cross section of ^{238}U at 1 A GeV + Pb when the model without break-up is used a value of $\beta = 3.5\cdot10^{21}$ s^{-1} is needed, while for the calculation with the break-up stage the value of β has to be decreased to $\beta = 2\cdot10^{21}$ s^{-1}. In figure 2 the excitation energy at fission is plotted against the initial excitation energy for the two calculations with and without the break-up stage and $\beta = 2\cdot10^{21}$ s^{-1}. The 45-degree straight lines depicted in these spectra represent the upper limit for the excitation energy at fission. This line starts to be depopulated at initial excitation energies of around 150 MeV, indicating that above these excitation energies the transient time is longer than the decay time for particle emission. On the other extreme, comparing figure 2a) and 2b) one realises that the break-up process suppresses fission of nuclei produced with initial excitation energies E^*_0 over 800 MeV. Consequently, the data investigated in the present work are sensitive to the value of β at initial excitation energies E^*_0 between 150 MeV and about 800 MeV.

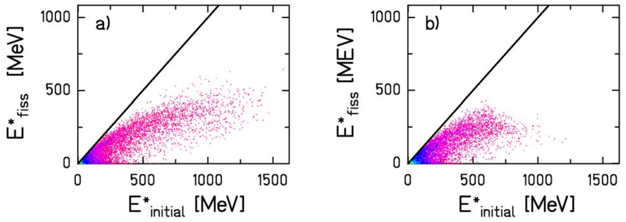

Figure 2: Calculations performed with $\beta = 2\cdot10^{21}$ s^{-1} and $\hbar\omega_1$ = 1MeV without including the break-up stage a) and including it b). They represent the excitation energy at fission versus the excitation energy of the prefragment for the fission events obtained in the reaction of 1·A GeV ^{238}U on a lead target.

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References

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