Nuclear Fission: The "Onset of Dissipation" from a Microscopic Point of View

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It is of considerable interest to understand the temperature dependence of transport properties associated with slow collective motion of large scale, for which fission is a prime example. One often tries to characterize this feature by one parameter, the effective damping rate η which is related to the equation of average motion for a locally defined damped oscillator $M\ddot{q} + \gamma\dot{q} + Cq(t) = 0$ through $\eta = \gamma/(2\sqrt{M \mid C \mid})$. The $q = Q - Q_0$ measures the deviation of the collective variable Q from some fixed value Q_0.

To understand the dynamics in phase space one also needs the diffusion coefficients. Here we assume the classic Einstein relation, although there may be deviations at small temperatures (see [1]). For such a situation the fission decay rate is commonly calculated within Kramers' "high viscosity" limit [2], for which the dependence on friction is given by

$$\frac{R_K^{h.v.}(\eta_b)}{R_K^{h.v.}(\eta_b = 0)} = \sqrt{1 + \eta_b^2} - \eta_b \,. \tag{1}$$

Here, the index "b" refers to the fact that the transport coefficients are to be calculated at the barrier. This formula has been used to analyze experimental data [3,4], and the following functional form for $\eta_b(T)$ has been suggested in [3]:

$$\eta(T) = 0.2 + 3T^2 \tag{2}$$

Such a behavior with T is in qualitative agreement with microscopic calculations of the transport coefficients within linear response theory, although it must be said that there is no good reason for a finite friction at zero temperature [1,5]. In the following we report on a comparison based on microscopic values of the transport coefficients [6]. In order to keep the situation as transparent as possible, the simple picture of a one-dimensional potential has been used, with only one minimum and one barrier. But even for such a case it is not permissible to entirely parameterize the transport process by the single quantity η. Rather, other combinations of M, γ and C are needed for more realistic descriptions. Indeed, a careful analysis shows that for variable inertia Kramers' [2] classic formula for the decay rate has to be extended to

$$R_K^{h.v.}(\eta_b) = \frac{\varpi_a}{2\pi} \sqrt{\frac{M_a}{M_b}} \exp(-E_b/T) \left(\sqrt{1 + \eta_b^2} - \eta_b \right) . \tag{3}$$

The indices "a" and "b" refer to the minimum and maximum of the potential, located at Q_a and Q_b, respectively. The E_b stands for the height of the barrier. The factor $\sqrt{M_a/M_b}$, not contained in Kramers' original work, is meant to account for the modification one gets for variable inertia [7]. It is easily verified that for overdamped motion, for which no trace of the inertia must be left over, (3) turns into that of the Smoluchowski equation *only* if this factor is taken into account. It may be noted that the inertia M does not only vary with the collective coordinate, but with temperature as well: With increasing T the M gets close to the liquid drop value [1], which only varies smoothly with Q and which is quite small. Simultaneously the friction strength increases, so that one may quickly reach the situation of overdamped motion, indeed. Such features have been seen within the linear response approach (see [1]), but to the best of our knowledge no other transport model has so far addressed this question.

Using microscopic input for the T-dependence of the parameters we compare in Fig.1 the result with the one of a macroscopic picture, together with that suggested in [3,4]. By the macroscopic model we mean to use the wall formula for friction, the liquid drop model for inertia (irrotational flow) as well as for the stiffness.

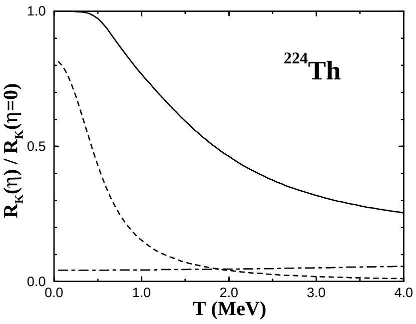

Fig. 1: Temperature dependence of the decay rate in high viscosity limit: Fully drawn curve: temperature dependence through a microscopic $\eta = \eta(T)$; dashed curve: η_b given by (2); dashed-dotted curve: wall friction and liquid drop values for stiffness and inertia.

It is seen that for such a T-dependence the onset of dissipation occurs quite abruptly and at rather small temperatures. The reason seems obvious: In (2) *the dissipation rate η is much too large at small T* — at least too large as compared to our microscopic results where at small temperatures *pairing correlations require dissipation to vanish.*

References

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