Formation Probabilities for Super-Heavy Elements with Microscopic Transport Coefficients

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The description of fusion of heavy ions is commonly performed by studying separately the entrance phase and the formation of the compound nucleus [1]. Typically, for the latter process the system has to overcome a barrier and in this sense resembles nuclear fission. Both processes may be described by transport models involving Fokker-Planck or Langevin equations. One essential difference of both is found in different initial and boundary conditions.

For thermal fission the influence of microscopic transport coefficients which in one way or other are governed by quantum effects has been shown to modify the decay rate considerably [2,3]. In [4] the importance of microscopic transport coefficients for a description of fusion processes has been examined. To this end calculations with such coefficients have been compared with those using the common macroscopic pictures of the liquid drop model and wall friction. Another issue of our studies was to examine the relevance of the initial conditions for the phase space distribution. Whenever the whole process of fusion is split into parts where the entrance phase is treated differently from the formation of the compound nucleus uncertainties for the initial conditions of the formation process are more or less inherent.

In Fig. 1 we show for certain initial conditions (see [4]) the formation probability

$$\Pi_\infty = \frac{1}{2}\,\mathrm{erf}\left(-\frac{q_\infty}{\sqrt{2\Sigma_{qq}^\infty}}\right) . \tag{1}$$

as a function of the ratio of the initial kinetic energy E_0^{kin} over the height of an effective barrier defined as $B_{eff} = \left(\sqrt{1+\eta_b^2}+\eta_b\right)^2 E_b \geq E_b$. It accounts for the energy loss seen in the average trajectory due to the damping rate η_b. The q_∞ and Σ_{qq}^∞ represent the long time limits of the average value of the coordinate and its fluctuation, respectively.

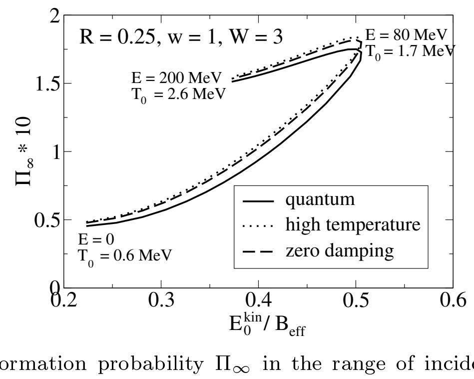

Fig. 1: Formation probability Π_∞ in the range of incident energy above the barrier $E = 0 \ldots 200$ MeV as a function of the ratio E_0^{kin}/B_{eff}. Microscopic transport coefficients are used as input. Concerning the diffusion coefficients a quantum calculation (comp. [5]) and the limits of high temperature and zero damping are compared.

As a remarkable feature we observe in Fig. 1 a back-bending of the curves at $E_0^{kin}/B_{eff} \approx 0.5$. The reason can be found in the fact that the microscopic transport coefficients significantly depend on the temperature associated to the incident energy E by $E + E_b = E_0^{kin} + aT^2$. The back-bending occurs slightly below the temperature where collective motion turns from under-damped to over-damped motion ($\eta_b = 1$ at $T \approx 1.9$ MeV). The final formation probability also exhibits a shallow maximum near the turning point. This behavior might have some influence on reasonable choices of incident energies in an experimental setup for heavy ion collisions. The survival probability decreases with increasing excitation energy E^* and therefore a smaller E is more favorable for survival.

The same calculation has also been made using macroscopic transport coefficients (see Fig. 2). Two features become obvious: (i) Π_∞ gets smaller than for the microscopic transport coefficients by *orders of magnitude*, and (ii) back-bending is absent. Both differences can be traced back to the fact that for macroscopic transport coefficients collective motion is strongly damped, even at small temperatures: The η_b is larger by about one order of magnitude as compared to the microscopic case.

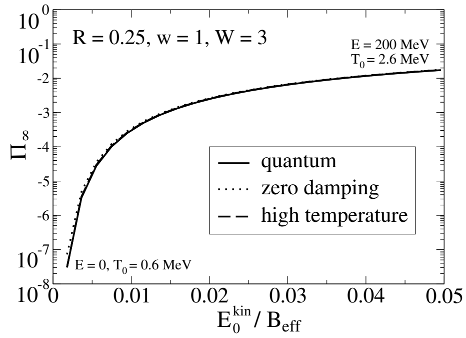

Fig. 2: Same quantities as in Fig. 1 but for macroscopic transport coefficients. Note the logarithmic scale.

Also shown in the figures are quantum effects of collective motion which are hidden in diffusion coefficients defined through the quantal fluctuation dissipation theorem. They are compared with calculations in the limits of high temperature and zero damping (see [5]). It is seen that these differences have much less impact on Π_∞ than the quantum effects in the transport coefficients. This finding is in accord with results obtained before for the case of fission [2].

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