Role of transport coefficients in fission dynamics

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The Langevin approach has been widely used in the study of fission. In this approach, the fission process is described as the time evolution of the shape deformation of the nucleus, and the fragment mass and kinetic energy distributions can be calculated. The physical inputs for the Langevin equation are the potential energy of deformation and two transport coefficients: the inertia and the friction tensor. The inertia tensor represents the geometric structure of the coordinates, while the friction tensor represents the coupling between collective and thermal nucleonic degrees of freedom. The fission process is mainly governed by the potential energy, such as the saddle points and the fission valleys. In the range from the ground state to the fission barrier, nuclear deformation can be roughly understood as a thermal equilibrium distribution due to the potential. On the other hand, the process from the saddle to scission is a dynamical motion governed by both the potential and the transport coefficients.

To elucidate the role of the transport coefficients, we have adopted two alternative methods: the Smoluchowski limit and the Metropolis walk [1, 2]. The Smoluchowski limit corresponds to the strong friction limit of the Langevin equation, which does not include the inertia tensor but depends on the friction tensor and the potential. The Metropolis walk is a method to simulate a random walk on the potential. This method chooses to stay or to move to the next point depending on the thermal probability based on the Boltzmann factor. With this method, the fission process can be calculated using only the potential. It should be noted that the Metropolis walk provides the evolution of the shape, but it is not the time evolution.

In this study, we compare the results calculated with the three methods in the actinide region. First, we focus on ^{264}Fm which can be divided into a pair of stable double magic nuclei $(Z, N) = (50, 82)$ and hence strongly induces 132+132 symmetric fission. To simplify the comparison, the temperature is fixed at 1 MeV and shell damping is neglected. As collective coordinates, we adopt three deformation parameters $\{\alpha, \alpha_1, \alpha_4\}$ corresponding to elongation, mass asymmetry, and quadrupole deformation of fragments, respectively, in Cassini shape parameterization [3]. Figure 1 shows the fragment mass distribution calculated with the three methods. In the Metropolis walk, the yield of symmetric fission is much large than that of asymmetric fission. In contrast, in the Langevin equation and the Smoluchowski limit, the yields of symmetric and asymmetric fission are almost the same.

To understand the origin of this different behavior, we analyze the fission paths along the fission valleys. The deformation energy is calculated with the microscopic-macroscopic method [4]. In the three-dimensional deformation space, we obtain the symmetric and the asymmetric saddle points which have almost the same height for ^{264}Fm. These points are connected to the symmetric and the asymmetric fission valleys, respectively. Near scission, the symmetric fission valley is deeper than the asymmetric one. In the Metropolis walk, it is found that the trajectories move from the asymmetric valley to the symmetric one. On the other hand, in the Langevin equation and the Smoluchowski limit, the change in the mass-asymmetric degree of freedom is suppressed by the friction tensor when the neck becomes thin. It should be noted that the friction tensor is calculated using the completed wall-and-window formula which is a sum of the one-body wall-and-window friction and the friction regarding the mass transfer between the fragments [5]. From this analysis, we conclude that the Metropolis walk needs to be used with caution, in particular, when the distribution near the saddle region is different from that near scission.

The comparison between the Langevin equation and the Smoluchowski limit shows only a small difference. This indicates that the driving and friction force strongly contribute to the fission dynamics. On the other hand, around the saddle point where those forces are weak, it is found that the distribution of the trajectories is wider for the Langevin equation than for the Smoluchowski limit. This can be due to the effect of the inertia tensor.

As another example, we examined ^{236}U and we found the asymmetric fragment mass distributions in the three models. When the potential is examined, the saddle point of the elongated symmetric fission is higher than that of the compact asymmetric fission and the asymmetric fission valley is more pronounced. The peak position of the mass distribution essentially coincides with the bottom of the valley. In such a case, Metropolis walk may give a similar result with that of the Langevin equation and the Smoluchowski limit.

The yield of the symmetric fission in ^{264}Fm was smaller than expected. We have performed the four-dimensional Langevin calculation by adding a new parameter α_6 corresponding to the octupole deformation of the fragments. In our study of the Fm isotope, it was found that the four-dimensional calculation better describes the saddle point and the valley of the symmetric fission. We found that the symmetric fission is dominant for ^{264}Fm.

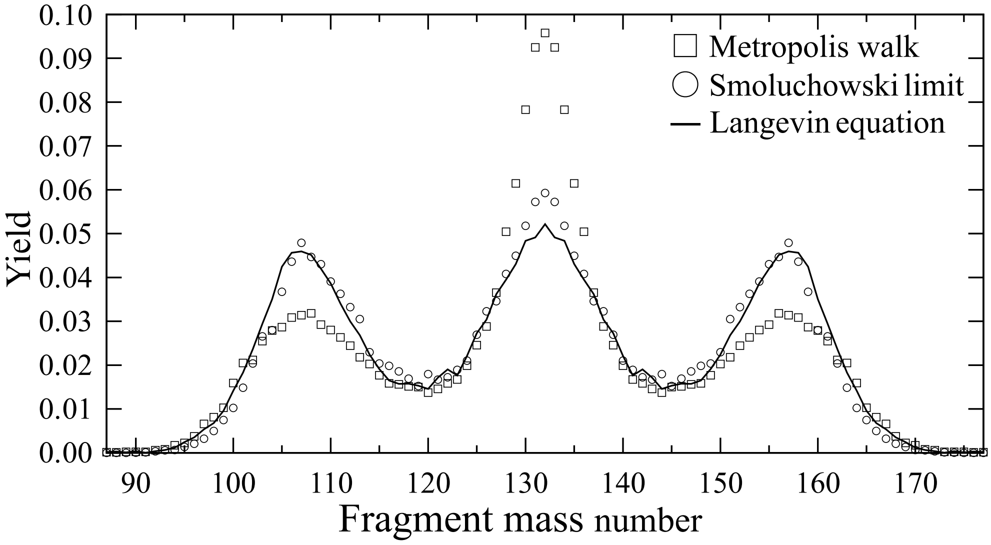

Figure 1. Calculated fragment mass distributions for fission of ^{264}Fm. Squares give the results using the Metropolis walk and circles give the results using the Smoluchowski limit. For clarity of the graph, the results using the Langevin equation are shown as a solid line.

References

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