Convergence of Stochastic Models in Nuclear Fission: Analysis of Langevin and Random Walk Approaches

T. Cap[1], A. Augustyn[1], M. Kowal[1], and K. Pomorski[1]
[1]*National Centre for Nuclear Research, Pasteura 7, 02-093 Warsaw, Poland*

We present a comparative analysis of two distinct stochastic approaches for modeling nuclear fission: Langevin dynamics [1] and a density-of-states-based random walk methodology [2]. The study focuses on fragment mass distributions in neutron-induced fission of several actinide nuclei (^{229,232}Th, ^{235}U, ^{239}Pu, ^{245}Cm, and ^{249}Cf). To ensure methodological consistency, both approaches are implemented within an identical four-dimensional deformation space using the Fourier-over-Spheroid (FoS) parametrization [3], with potential energy surfaces derived from the macroscopic-microscopic model.

Our investigation reveals that Langevin dynamics converges to the random walk model in the limit of low friction, with the two approaches exhibiting similar predictions for positions of asymmetric fission peaks across the studied actinides. The random walk model, guided solely by the potential energy surface, strictly predicts zero symmetric fission yield at low excitation energies - a feature consistent with experimental trends. In contrast, the Langevin model, which incorporates fluctuations, allows for minimal symmetric yield even at low energies, reflecting the physical possibility of barrier crossing driven by statistical fluctuations.

A systematic discrepancy emerges in the widths of mass distributions: Langevin dynamics typically produces slightly narrower peaks compared to experimental data, while the random walk methodology yields significantly narrower distributions. This disparity highlights the critical importance of dynamical effects like inertia and friction, which are explicitly included only in the Langevin formalism. For higher excitation energies (14 MeV neutrons), the Langevin model tends to overestimate symmetric fission contributions for several nuclei, while reduced-friction Langevin simulations and the random walk model provide better qualitative agreement with experimental observations.

This study offers insight into the theoretical relationship between these complementary stochastic approaches and demonstrates how their convergence in the low-friction limit connects fundamental physical principles of nuclear dynamics with statistical descriptions of fission processes. Our findings suggest that while both methods capture essential features of fragment mass distributions, a comprehensive understanding of nuclear fission requires accounting for the complex interplay between potential energy landscape, statistical exploration, and dynamical effects. The detailed results of this work have been submitted to Physical Review C.

[1] K. Pomorski *et al.*, Phys. Rev. C 110, 034607 (2024).
[2] T. Cap *et al.*, Phys. Rev. C 109, L061603 (2024).
[3] K. Pomorski *et al.*, Phys. Rev. C 107, 054616 (2023).