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# Study of fission modes in $^{258}$Md with six-dimensional Langevin equation/6 次元 Langevin 方程式を用いた$^{258}$Md 核分裂モードの研究

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Understanding nuclear fission is critical for updating and improving the nuclear data. In particular, significant questions remain regarding fission near the mass number $A = 257$, where the dramatic changes in fragment mass distribution due to variations in neutron number are observed. These phenomena are generally attributed to shell effects, although a detailed explanation has yet to be provided. Moreover, it is important to clarify the dependence of excitation energy on the shell effects.
Recently, measurements of the fragment mass and total kinetic energy (TKE) distributions for the fission of $^{258}$Md, which is produced in the $^{4}$He + $^{254}$Es reaction and conducted at JAEA, indicate the coexistence of multiple distinct fission modes: short symmetric, asymmetric, and super-long symmetric fission [1]. To understand these observations, the analysis of fission paths obtained from dynamical calculations using high-dimensional Langevin equations plays an important role. These calculations explore the origins of the observed distributions, shedding light on the mechanisms driving each fission mode.

In this study, we calculate the fission process of $^{258}$Md with the multi-dimensional Langevin equation with the Cassini shape parameterization [2]. To describe various fission modes, we use the six Cassini shape parameters $\{\alpha, \alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5\}$, and apply them to the six-dimensional Langevin equation. The combination of these shape parameters can flexibly describe deformed nuclear shapes. This is the first attempt to calculate the Langevin dynamics in the six-dimensional collective coordinates. The resulting fragment mass and TKE distributions show the existence of three types of fission modes, consistent with the measurement data. Furthermore, by increasing the excitation energy from 15 MeV to 18 MeV, the relative contribution of each mode is changed. With higher excitation energy, the short symmetric fission mode decreases significantly, and the asymmetric fission mode becomes dominant. It is considered that the shell effect corresponding to short symmetric fission is largely damped by the increase in excitation energy. Through analysis of fission paths obtained from these six-dimensional Langevin calculations, we expect to elucidate the physical origins and mechanisms of each fission mode.

References
[1] K. Nishio \textit{et al}., “Competition between mass-symmetric and asymmetric fission modes in $^{258}$Md produced in the $^{4}He$ + $^{254}$Es reaction”, submitted to Phys. Rev. C (2024).
[2] V. V. Pashkevich, “On the asymmetric deformation of fissioning nuclei”, Nucl. Phys. A \textbf{169}, (1971), pp. 275-293.

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