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PAPER

Novel semi-empirical formula and examination for fission barriers of super-heavy nuclei with $Z \geqslant 100$

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Abstract

In this study, we developed a semi-empirical formula for predicting fission barriers of super-heavy nuclei (SHN), which have fissilities $\chi > 48.5428$, based on a former formula proposed by Myers and Swiatecki [1999 *Phys. Rev.* C **60**, 014 606]. We calculated fission barriers for isotopes with $Z = 100$–135 using our formula and the Lublin-Strasbourg Drop model. It was found that the macroscopic component of the fission barrier is less than 0.2 MeV, which is large enough to be considered with microscopic part for many SHN. These results were compared to each other and to those estimated using other approaches. Through evaluations of theoretical fission barriers, we found that there is a significant difference, up to a few MeV, between the results obtained from different models. In other words, recent fission barrier predictions are very uncertain. Finally, the results of this study are useful for estimating the spontaneous-fission lifetime and production cross sections of unknown super-heavy nuclei.

1. Introduction

The fission barrier is one of the most important factors in estimating the production cross sections and fission lifetimes of super-heavy nuclei (SHN). This enables evaluation of the competition between the α decay and fission processes. Indeed, calculations of the cross sections and the spontaneous fission lifetime strongly depend on the fission width of a formed compound nucleus [1–6]. Because the fission decay width is exponentially proportional to the fission barrier [7, 8], the cross sections and the fission lifetime are highly sensitive to this barrier. It has been reported that an uncertainty of 1MeV in the fission barrier can result in a difference of one order of magnitude in calculated the cross sections [4, 9, 10]. This can lead to major difficulties in conducting experiments; that is, the beamtime of accelerator facilities may change from a few months to years.

Presently, measuring the fission barrier remains a challenge for experimentalists. In practice, this quantity is often determined based on the survival probability of an excited compound nucleus in a fusion reaction. Hence, SHN synthesis cross sections must be measured to extract the probability. The procedures for determining the fission barrier also present a theoretical problem because of the differences in both theoretical models and intermediate parameters (i.e., level density, compound nucleus formation probability, friction coefficient, shell correction, etc.), which generate unavoidable uncertainties [11–14]. For instance, the shell damping energy (E_d), to which the level parameter is exponentially proportional [15, 16], can be varied from 13MeV to 25 MeV [13], leading to a change of up to a few orders of magnitude in the evaporation residue cross sections [4, 17] of SHN production cross sections. Another factor that affects the determination of the fission barrier is the viscosity coefficient, which has a value in the range of 1×10^{-21}–$30 \times 10^{-21}\ \mathrm{s}^{-1}$ [1] (and therein). Note that a variation of only 2×10^{-21}–$8 \times 10^{-21}\ \mathrm{s}^{-1}$ in this coefficient can change the cross sections by one order of magnitude [13]. Additionally, experimental data for SHN are very limited because of the small synthesis cross sections and short lifetimes of SHN. Therefore, it is difficult to experimentally obtain the fission barrier.

Since there are no experimental data for unknown SHN, estimations of the fission barrier are mainly based on theoretical calculations. The fission barrier can be described in terms of two components: macroscopic energy (B_{LD})