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Pre-scission model predictions of fission fragment mass distributions for super-heavy elements

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Abstract

The total deformation energy just before the moment of neck rupture for the heaviest nuclei for which spontaneous fission has been detected ($^{279-281}$Ds, ^{281}Rg and $^{282-284}$Cn) is calculated. The Strutinsky's prescription is used and nuclear shapes just before scission are described in terms of Cassinian ovals defined for the fixed value of elongation parameter $\alpha = 0.98$ and generalized by the inclusion of four additional shape parameters: α_1, α_3, α_4, and α_6. Supposing that the probability of each point in the deformation space is given by Boltzmann factor, the distribution of the fission-fragment masses is estimated. The octupole deformation α_3 at scission is found to play a decisive role in determining the main feature of the mass distribution: symmetric or asymmetric. Only the inclusion of α_3 leads to an asymmetric division. Finally, the calculations are extended to an unexplored region of super-heavy nuclei: the even–even Fl (Z = 114), Lv (Z = 116), Og (Z = 118) and (Z = 126) isotopes. For these nuclei, the most probable mass of the light fragment has an almost constant value (≈136) like in the case of the most probable mass of the heavy fragment in the actinide region. It is the neutron shell at 82 that makes this light fragment so stable. Naturally, for very neutron-deficient isotopes, the mass division becomes symmetric when N = 2 × 82.

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1. Introduction

Spontaneous fission (SF) and super-heavy elements (SHE) have an intriguing relation. On one hand, SHE should not exist because of SF; their macroscopic fission barriers are zero. On the other hand, they rarely fission. Their ground states are so much reduced by microscopic corrections that even a zero macroscopic barrier becomes difficult to cross. Instead they undergo α decay. For this reason most studies in the field of nuclear fission of SHE are theoretical: either in the frame of the macroscopic-microscopic model [1–4] or self-consistent mean field [5–8]. In these studies the accent was put on the spontaneous fission barriers and half-lives. Therefore the potential energy surfaces (PES) were calculated in the vicinity of ground states and saddle points. In the present study the accent is put on the fission-fragment properties and therefore the PES are calculated in the vicinity of the scission point.

The scission-point model [9] was recently improved and used to calculate the fission-fragment mass and total kinetic energy distributions for Fm, No, Rf and Sg isotopes [10,11]. These are the heaviest nuclei for which such distributions have been measured in spontaneous fission.

The scission process (from the beginning of the neck rupture at finite radius, $r_{neck} \approx 2.0$ fm, till the total absorption of the neck stubs by the fragments) is extremely fast [12]. During this transition the number of nucleons to the left and right from the neck and the distance D_{cm} between fragments centers of mass stays practically unchanged. It is, therefore, at a configuration "just-before scission" that the above mentioned fission-fragment properties have to be estimated (and not when the fragments are already separated).

This is the first improvement brought to the traditional scission point approach.

The second improvement is the description of the corresponding pre-scission shapes in the lemniscate coordinate system $\{R, x\}$ [13]. The cylindrical co-ordinates $\{\bar{\rho}, \bar{z}\}$ are related to the lemniscate co-ordinates $\{R, x\}$ by the equations

$$\begin{aligned}
\bar{\rho} &= \frac{1}{\sqrt{2}}\sqrt{p(x) - R^2(2x^2-1) - s}\,, \\
\bar{z} &= \frac{\mathrm{sign}(x)}{\sqrt{2}}\sqrt{p(x) + R^2(2x^2-1) + s}, \\
p^2(x) &\equiv R^4 + 2sR^2(2x^2-1) + s^2, 0 \le R \le \infty, -1 \le x \le 1. \qquad (1)
\end{aligned}$$

The relation between $\{\bar{\rho}, \bar{z}\}$ and $\{R, x\}$ depends on the parameter $\varepsilon \equiv s/R_0^2$, where s is the squared distance between the focus of Cassinian ovals and the origin of coordinates.

The shape of the nuclear surface in lemniscate coordinate system is given by some function $R = R(x)$. The basic lines $R = \text{const}$ (defined for a fixed elongation parameter ϵ) represent the sequence of shapes (Cassinian ovals) that are surprisingly close to the sequence of shapes of a fissioning nucleus. At $\epsilon \approx 1.0$ these ovals represent the two nascent fragments. The expansion of such particular ovals in series of Legendre polynomials is used to generate the nuclear shapes along the scission line. Apart from the elongation parameter ϵ, two other relevant shape parameters are included: α_1 (the mass asymmetry) and α_3 (the octupole deformation). In addition minimization with respect to α_4 and α_6 is performed.

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