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Fission of transactinide elements described in terms of generalized Cassinian ovals: Fragment mass and total kinetic energy distributions

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Abstract

The total deformation energy at scission for $Z = 100$, 102, 104 and 106 isotopes is calculated using the Strutinsky's procedure and nuclear shapes described in terms of Cassinian ovals generalized by the inclusion of three additional shape parameters: α_1, α_4 and α_6. The corresponding fragment-mass distributions are estimated supposing they are due to thermal fluctuations in the mass asymmetry degree of freedom. For these four series of isotopes the experimentally observed transition from asymmetric to symmetric fission, that happens with increasing mass number A, is qualitatively reproduced. In lighter isotopes (e.g. ^{254}Fm and ^{254}Rf) two mass-asymmetric fission modes are predicted to occur with comparable yields: one having relatively compact and the other relatively elongated scission configurations. On the other hand, in heavier isotopes (e.g. ^{264}Fm and ^{264}Rf) the fragment-mass distributions are predicted to be narrow single-peaked around $A/2$ corresponding to essentially one mass-symmetric fission mode. The mass distributions are estimated separately for each fission mode, in the case of Fm and Rf isotopes, in order to display their inversion when A increases. Finally the distributions of the total kinetic energy of the fragments are calculated, for the same isotopes, in the point-charge approximation. Non-Gaussian shapes are obtained. With increasing mass number A, a transition from a distribution tailing towards higher energies to a distribution tailing towards lower energies and an increase of the difference in the peak positions of the two modes were observed; again in qualitative agreement with experimental data.

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1. Introduction

The systematics of the fragment-mass distributions in low-energy fission (defined as spontaneous or sub-barrier) is quite complex and up to now not fully understood. The old rule: "as a function of the mass number A of the system undergoing fission, the distribution has two peaks for $A > 226$ and one peak for $A < 226$" was meanwhile invalidated at both ends; it is narrow double humped in ^{180}Hg [1] and narrow single humped in ^{258}Fm [2].

In typical actinides (e.g., isotopes of U, Pu and Cf) the fission fragment mass distribution has two peaks (i.e., the fission is asymmetric) with a remarkable stability of the most probable heavy masses [3]. The role of double magic ^{132}Sn in the explanation of this experimental fact has been over-emphasized. The heavy mass plateau starts indeed at 132 but has an average value 140 (for U and Pu) and even 142 (for Cf). "Two fission modes" is a more plausible explanation: in the major mode the H-fragment is born deformed (in a relatively elongated scission configuration) and in the minor mode it is born spherical (in a relatively compact configuration). Only in the latter mode ^{132}Sn is predominant. Even the pre-actinide nuclei that mainly fission symmetrically seem to have a small asymmetric component [4].

In Fm ($Z = 100$) and No ($Z = 102$) isotopes, with increasing mass number, there is a known sharp transition from asymmetric at $A = 256$ to symmetric fission at $A = 258$ [5]. This transition is less sharp but present also in Rf ($Z = 104$) isotopes [6]. It doesn't seem to occur at a fix N or Z but at a fix $A = N + Z$ which makes again the explanation in terms of two double-magic fragments less obvious.

Finally, the expectation that ^{180}Hg fissions into two ^{90}Zr (magic $N = 50$ and semi-magic $Z = 40$) was not met [1].

Since the mass distribution is a central observable for the process of nuclear fission, fully understanding the reason why fission is sometimes symmetric and sometimes asymmetric is of crucial importance. More experimental and theoretical studies in less explored regions of the nuclear chart are therefore necessary [7].

In this paper we tackle the heaviest elements ($Z = 100$, 102, 104 and 106) that fission spontaneously with a scission-point model and analyze their configurations just-before their separation into two fragments. For this we use a family of nuclear shapes, presented in Section 2, quite suitable to describe the last mono-nucleus configuration of a fissioning system. Section 3 contains the potential energy surfaces at scission as a function of two shape parameters: the mass asymmetry and the elongation of the nascent fission fragments. The mass distributions derived from these surfaces are presented in Section 4 for several isotopes of Fm, No, Rf and Sg. The total kinetic energy (TKE) distributions are presented in Section 5 for the same fissioning nuclei. The conclusions are in Section 6.