IMPORTANCE OF SUFFICIENTLY LARGE DEFORMATION SPACE ADMITTED IN THE ANALYSIS OF SPONTANEOUS FISSION

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ABSTRACT

Role of the dimension of the deformation space admitted in the analysis of the spontaneous fission half-life is studied for the example of even-even heavy nucleus $^{260}106$. Importance of taking sufficiently large dimension is demonstrated.

1. INTRODUCTION

Spontaneous fission is one of the main decay modes of heavy nuclei, limiting the extension of the nuclear chart. The heaviest nuclei synthesized up to now [1] and also those planned to be synthesized in the nearest future are expected to be deformed (e.g. [2]). Thus, the quality of theoretical description of their properties strongly depends on how well is the deformation of these nuclei described, or in other words, how large is the deformation space admitted in the analysis of these properties [2].

In the studies of the spontaneous-fission half-lives performed up to now (e.g. [3]), only two dimensional spaces have been usually used. The objective of the present paper is to discuss the role of using larger spaces in the analysis of this quantity.

2. IMPORTANCE OF SHELL EFFECTS

Shell effects play an important role in the properties of heavy nuclei. Fig.1 shows shell effects in the spontaneous-fission half-life T_{sf} [4]. Here, T_{sf}^{exp} is the experimental half-life and $\tilde{T}_{sf}$ is the half-life calculated within a macroscopic model, as is described in detail in [4]. The macroscopic model, with rather well established parameters, does not include any shell effects. Thus, the deviation of the ratio $T_{sf}^{exp}/\tilde{T}_{sf}$ from unity may be attributed to shell effects.

One can see in fig.1 that the effects delay the fission process in all heavy nuclei, except only few lightest ones (isotopes of uranium). The delay increases from few orders (Pu isotopes) to about 15 orders of magnitude for the heaviest even-even nucleus with measured T_{sf} ($^{260}106$). For such a heavy nucleus like $^{260}106$, with T_{sf} of the order of few miliseconds, this delay makes up practically the whole half-life of these nuclei. In other words, they would not exist without shell effects. The reason is that only shell effects create the fission barrier for them. No barrier is obtained within a model without shell effects [4].

3. METHOD OF THE CALCULATIONS

The spontaneous-fission half-life T_{sf} is calculated dynamically (cf. e.g. [5]), by finding the fission trajectory which minimizes the action integral, i.e. which gives the largest probability of the penetration of a nucleus through the fission barrier. The potential energy E, appearing in the action integral and describing the fission barrier, is obtained in the macroscopic-microscopic approach with the Yukawa-plus-exponential model [6] taken for the macroscopic part of the energy. The Strutinski shell correction, used for the microscopic part, is based on the Woods-Saxon single-particle potential [7]. The

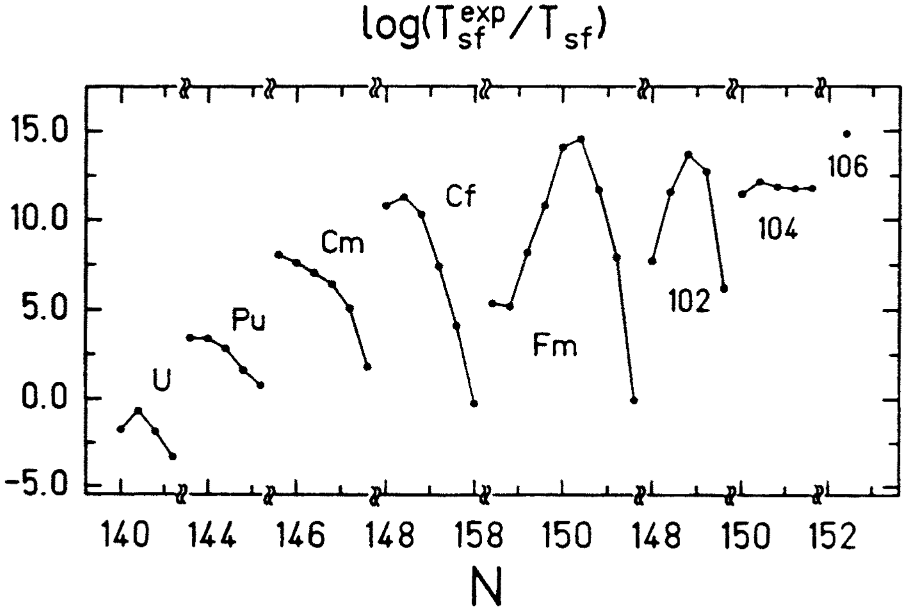

Fig.1. Shell effects in the spontaneous-fission half-lives.

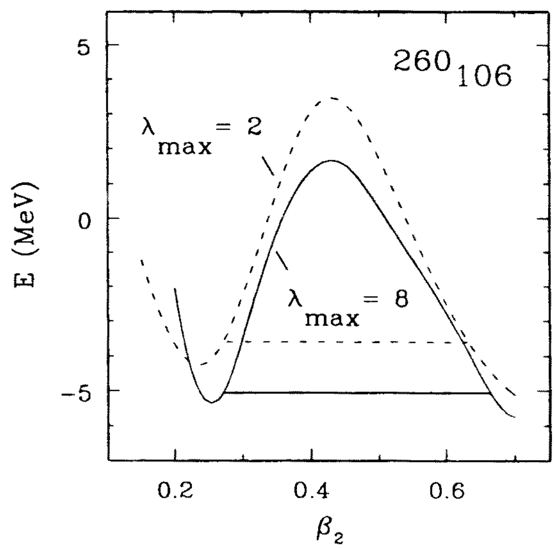

Fig.2. Fission barrier of the nucleus $^{260}106$ obtained in one- (λ_{max}=2) and four-dimensional (λ_{max}=8) deformation spaces.

inertia tensor $B_{\beta_\lambda \beta_\mu}$, describing the inertia of a nucleus with respect to the process of deforming it, is calculated in the cranking approximation. The pairing correlations are treated in the usual BCS approach. Deformation of a nucleus is described by the commonly used deformation parameters β_λ appearing in the expression for nuclear radius in terms of spherical harmonics.

4. RESULTS

For our discussion, we choose the nucleus $^{260}106$. As already mentioned above, this is the heaviest even-even nucleus for which the spontaneous-fission half-life has been measured.

Fig.2 shows the fission barrier of this nucleus obtained in two deformation spaces. One is the one-dimensional space, when only the quadrupole deformation β_2 is admitted (the largest multipolarity degree is: $\lambda_{max}=2$). The other is the four-dimensional space $\{\beta_\lambda\}$, $\lambda=2,4,6,8$ ($\lambda_{max}=8$). (For this heavy nucleus analyzed here, with a rather thin barrier, the odd-multipolarity deformations do not contribute to the barrier.) The barriers obtained in the two- ($\lambda_{max}=4$) and the three-dimensional ($\lambda_{max}=6$) spaces are not shown here, not to obscure the picture. The barrier is calculated along the dynamic trajectory obtained in respective space. One can see that the barrier obtained with $\lambda_{max}=8$ is thicker than that with $\lambda_{max}=2$.

Fig.3 shows the effective inertia parameter B calculated along the fission trajectory in the cases of $\lambda_{max}=2$ and 8. One can see that the inertia B is larger in the case of $\lambda_{max}=8$ than in the one-dimensional case $\lambda_{max}=2$. The reason is that in the four-dimensional case, $\lambda_{max}=8$, the deformations β_4, β_6 and β_8, in addition to β_2, are changing along the trajectory, requiring a fast reconstruction of the nucleus. This causes a resistance of the nucleus to these large changes, expressed by the large values of the

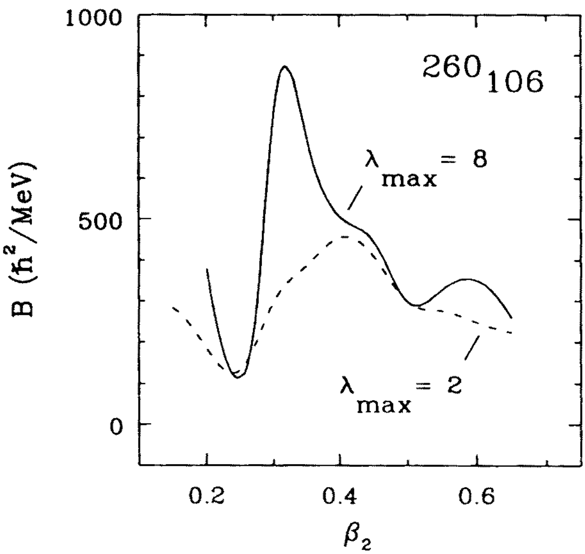

Fig.3. Same as in fig.2, but for the effective inertia B.

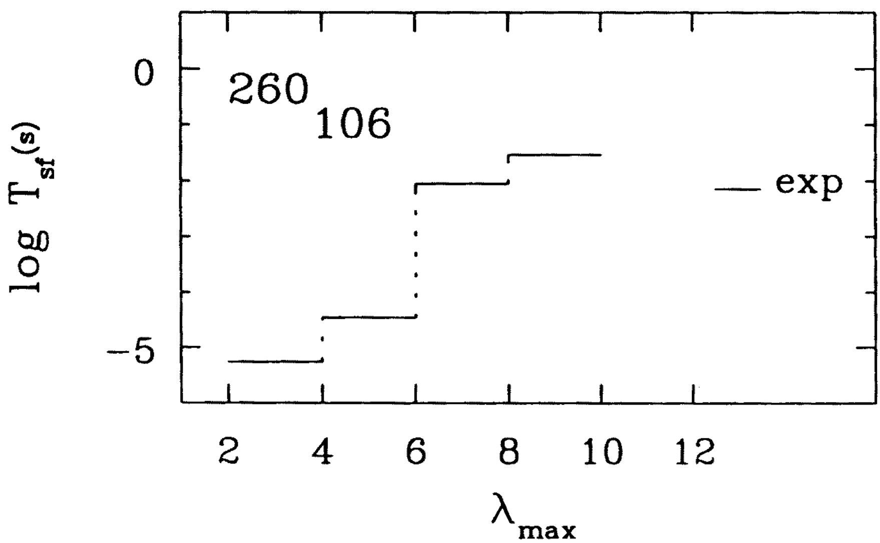

Fig.4. Dependence of logarithm of the spontaneous fission half-life T_{sf} (given in seconds) on the largest multipolarity degree λ_{max} of the deformation space used. Experimental value of T_{sf} is also shown.

inertia B.

Finally, fig.4 gives the dependence of the spontaneous-fission half-life T_{sf} on the largest multipolarity degree of the deformation space λ_{max}. One can see that the half-life systematically increases with the increasing dimension. In particular, the inclusion of the deformation β_6 increases the half-life by about two and half orders of magnitude, for the analyzed nucleus.

Concluding, one can say that the dimension of the deformation space plays important role in the analyzed spontaneous-fission half-life. The half-life increases with the increasing dimension. The contribution to this increase comes through both the fission barrier and the effective inertia of a nucleus.

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