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# MECHANISM OF A DECREASE OF THE FISSION-BARRIER HEIGHT OF A HEAVY NUCLEUS BY NON-AXIAL SHAPES*

I. Muntian and A. Sobiczewski

Soltan Institute for Nuclear Studies, Hoża 69, 00-681 Warsaw, Poland

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Mechanism of reduction of (static) fission-barrier height $B_{\rm f}^{\rm st}$ by non-axial deformations is studied for the nucleus $^{250}$Cf. Two-dimensional (quadrupole) deformation space is used. It is found that the reduction is the effect of a rather strong change of shell structure with a change of deformation of the nucleus.

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## 1. Introduction

(Static) fission-barrier height $B_{\rm f}^{\rm st}$ is usually studied in the case of axial symmetry of a nucleus (*e.g.* [1–5]). It has been shown, however, that this quantity may be strongly reduced by inclusion of non-axial shapes of a nucleus into the analysis (*e.g.* [6–9], *cf.* also the study [10]). The reduction may be even as high as about 2 MeV.

The objective of the present paper is to look at mechanism of this reduction. To this aim, we take the nucleus $^{250}$Cf, the barrier height $B_{\rm f}^{\rm st}$ of which has been recently studied in a multidimensional deformation space [9]. The study has shown that the largest contribution to the reduction of $B_{\rm f}^{\rm st}$ was coming from non-axial shapes of the lowest (quadrupole) multipolarity. Thus, for simplicity, we consider here only quadrupole deformations.

Our interest in $B_{\rm f}^{\rm st}$ comes from its importance for calculations of cross sections for synthesis of heaviest nuclei (*e.g.* [11–13]).

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## 2. Description of the calculations

Macroscopic-microscopic approach is used for description of the potential energy of a nucleus. The Yukawa-plus-exponential model is taken for the macroscopic part of the energy and the Strutinski shell correction is used for its microscopic part. The shell correction is based on the Woods-Saxon single-particle potential with the "universal" variant of its parameters [14]. Details of the approach are specified in [9,15]. Two-dimensional deformation space, specified by the following expression for the nuclear radius $R(\theta,\phi)$ (taken in the intrinsic frame of reference) in terms of spherical harmonics $\mathrm{Y}_{\lambda\mu}$

$$R(\theta,\phi) = R_0 \left\{ 1 + \beta_2 \left[ \cos\gamma \mathrm{Y}_{20} + \frac{\sin\gamma}{\sqrt{2}} (\mathrm{Y}_{22} + \mathrm{Y}_{2-2}) \right] \right\}, \tag{1}$$

is taken, where $\gamma$ is the Bohr quadrupole non-axiality parameter.

## 3. Results

Fig. 1 shows a contour map of the potential energy of the nucleus $^{250}$Cf plotted as a function of $\beta_2 \cos\gamma$ and $\beta_2 \sin\gamma$. The line $\gamma = 0°$ corresponds to the axially symmetric (with respect to $Oz$ axis) prolate shapes, and the line $\gamma = 60°$ is corresponding to the axially symmetric (with respect to the $Oy$ axis) oblate shapes of the nucleus. The line $\gamma = 30°$ corresponds to shapes with maximal non-axiality. One can see that in the case of axial symmetry the saddle point (denoted by the symbol "+") has the energy 3.8 MeV, while non-axiality shifts the saddle to the point denoted by the symbol "×" and decreases its energy to 2.0 MeV, *i.e.* by 1.8 MeV.

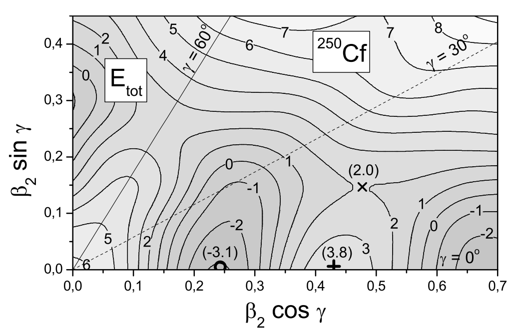


Fig. 1. Contour map of total potential energy calculated for the nucleus $^{250}$Cf. Numbers at contour lines specify the value of the energy. Position of the saddle point is marked by the symbol "+", when axial symmetry of the nucleus is assumed, and by the symbol "×", when non-axiality is taken into account. Position of the equilibrium point is denoted by the sign "∘". Numbers in parentheses give values of the energy at these points.

(The energy is normalized so, that its macroscopic part is zero at spherical shape of a nucleus). This means that the reduction of the saddle-point energy (and, thus, of the barrier height $B_{\rm f}^{\rm st}$) of this nucleus by non-axiality is quite large. Also the deformation of the saddle point is significantly changed by non-axial shapes, from $(\beta_2^{\rm s}, \gamma^{\rm s}) = (0.43, 0°)$ to $(0.50, 17°)$. Position of the equilibrium point $\beta_2^0 = 0.24$, $\gamma_0 = 0°$, denoted by "$\circ$", is not changed by the inclusion of the non-axial deformation.

Fig. 2 gives contour map of the macroscopic part, $E_{\rm macr}$, of the energy. One can see that this energy privileges prolate shapes (the $\gamma = 0°$ line) over oblate ones ($\gamma = 60°$) and the stiffness of the axially symmetric nucleus against the deformation $\gamma$ increases with increasing $\beta_2$. The positions of the saddle point of Fig. 1, in both cases of axial and non-axial shapes, are indicated, showing that non-axiality increases the macroscopic energy at the saddle point by 1.0 MeV. Thus, the decrease of the total energy by non-axiality has to come from a strong decrease of the microscopic part of the energy.

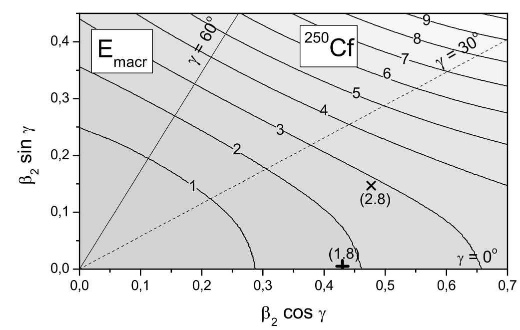


Fig. 2. Same as in Fig. 1, but only for the macroscopic part of the energy.

Contour map of the microscopic part, $E_{\rm micr}$, of the energy is shown in Fig. 3. Really, this energy at the saddle point is decreased by 2.8 MeV, *i.e.* very much, by inclusion of non-axial shapes.

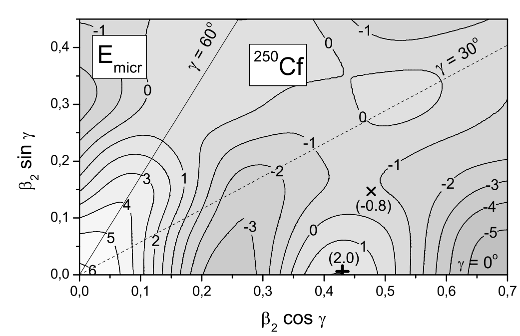


Fig. 3. Same as in Fig. 1, but only for the microscopic part of the energy.

Concluding, one can say that reduction of the barrier height $B_{\rm f}^{\rm st}$ by inclusion of non-axial shapes is the effect of the shell structure of a nucleus. Decrease of the microscopic part (coming from the shell structure) of the potential energy at the saddle point, due to this effect, overcomes the increase of the macroscopic part of the energy, resulting in the decrease of the total potential energy of a nucleus at this point.

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