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BIMODAL FISSION IN THE SHELL-CORRECTION APPROACH

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It is shown that in the theoretical description of the fission process in the nucleus ^{264}Fm there turn out to be two valleys on the potential-energy surface in the region of the scission point. One valley corresponds to the compact configuration of two nearly spherical fragments; and the other, to more separated strongly alongated fragments. Only mirror-symmetric shapes were considered.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

Бимодальное деление в рамках метода оболочечной поправки

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Показано, что при теоретическом описании деления ядра ^{264}Fm вблизи точки разрыва имеются две долины, ведущие к делению. Одна соответствует близко расположенным почти сферическим осколкам, другая - более удаленным друг от друга вытянутым осколкам. Рассмотрение ограничено зеркально симметричными формами.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

The recently observed bimodal fission/1/, i.e., two symmetrical modes, one of which has a broad and the other a narrow fragment mass distribution, was described by the authors as liquid-drop and shell-fragment-directed modes, respectively. Our aim is to show that both modes can be described in a unified manner by the Strutinsky shell-correction method/2,3/. We consider the simplest, for the theory, case of the hitherto not observed fission of ^{264}Fm, in which the influence of the shell of the two magic fragments of ^{132}Sn is apparently the strongest one. The dramatic manifestation of the role of the nearly spherical magic fragments has recently been demonstrated in the strongly asymmetric fission of a series of nuclei/4-7/.

As will be shown later, on the surface of the potential energy for ^{264}Fm there exist two valleys leading to fission. One of them corresponds to a compact configuration with closely located spherical fragments, and the other to more separated strongly deformed shapes. For simplicity we restrict ourselves to mirror-symmetric shapes. Asymmetric variations of the shapes are also of great interest because they permit describing, for example, two close spherical fragments of different volumes or one near spherical and the other strongly deformed fragments[4]. They also allow one to estimate the width of the fragment mass distribution. However, the asymmetric shapes will be considered elsewhere.

For the description of the expected shapes of nuclei it is important to choose a rather unrestricted parametrization of the nuclear-surface shape. From this point of view the description of the nuclear surface appears to be most appropriate in the coordinate system, connected with Cassinian ovals[8]. Denoting the respective coordinates by (R, x), we present the equation of the curve that describes the cut of the surface of an axially-symmetric nucleus by the meridional plane in the form

$$R = R(x), \qquad -1 \le x \le 1. \tag{1}$$

As a particular case, the Cassinian ovals are described by the equation

$$R = \text{const}, \tag{2}$$

and a small deviation from the Cassinian ovals can be expanded in a series in the Legendre polynomials

$$R = \frac{R_0}{c}(1 + \sum_m \alpha_m P_m(x)), \tag{3}$$

where R_0 is the radius of a spherical nucleus of the same volume and the constant c is chosen to satisfy the volume conservation condition during the deformation.

If the distance between the foci of the Cassinian ovals is equal to zero, then (R, x) turn out to be the spherical radius and the cosine of the polar angle, respectively. The connection of (R, x) with cylindrical coordinates is given in ref.[8] (see also ref.[9]).

The coefficients α_m are the parameters that specify the shape of the nucleus. Another parameter, α, is used which is connected with the distance between the foci of the Cassinian ovals and specifies the general elongation of the nucleus[8].

The method of calculating the potential energy surface used here is described in detail in ref.[8]. Here we only note that the deformation energy, E, is the sum of the two terms, the liquid-drop component, E_{LD}, and the shell correction, δE,

$$E = E_{LD} + \delta E. \tag{4}$$

The phenomenological expression for E_{LD} from refs.[10,11] was used and the shell component δE was calculated on the basis of the single-particle spectrum in a Woods-Saxon-type potential[12-14] which parameters taken from ref.[15]. However, for qualitative effects discussed here the exact values of the parameters are unimportant.

In the approach used here it is possible to uniformly describe the shapes of a nucleus in the fission process from the ground state through the scission point, and for our purpose it is sufficient to consider only the cross section of the potential energy surface at a fixed value of the parameter α equal to 0.98 which, in the liquid drop approach, corresponds, according to the neck thickness, to the shapes for which scission takes place[16]. For the parametrization chosen here the thickness of the neck equals zero at $\alpha = 1$ for any values of all the other parameters α_m[8].

The energies E and E_{LD} (see eq.(4)) are depicted in fig.1 as functions of the hexadecapole deformation α_4. The α_2 parameter remains fixed, $\alpha_2 = 0$, because its small variations are strongly correlated with those of α.

It is seen that E has two minima, which stand for the two fission valleys. The deeper one corresponds to near spherical fragments and the shallow one to strongly deformed fragments. The shape of the nucleus in both minima is drawn in fig.2. Accordingly, a larger total kinetic energy of the fragments is expected to be released in the former case and a noticeably lower one in the latter. The depth and position of the deep minimum remains almost unchanged after taking into account the higher deformations α_m, while minimization with respect to α_6, α_8 and α_{10} leads to a shift of the position and a strong deepening of the shallow minimum (see the open points connected by a solid curve in fig.1). The two valleys are separated by a 5.6 MeV ridge over the higher valley, so that one can speak about a good separation of the valleys near the scission point. The stability of both minima against asymmetric variations of the shape was not considered in the present paper.

Thus, the existence of two well separated valleys in the region of the scission point of ^{264}Fm was demonstrated in a unified approach. The shape of the nucleus near the bottom of the valley corresponding to a compact configuration is well approximated by two spherical fragments, which to some extent justifies the model of two spherical fragments used, in particular, in ref.[17]. for describing that mode of fission.

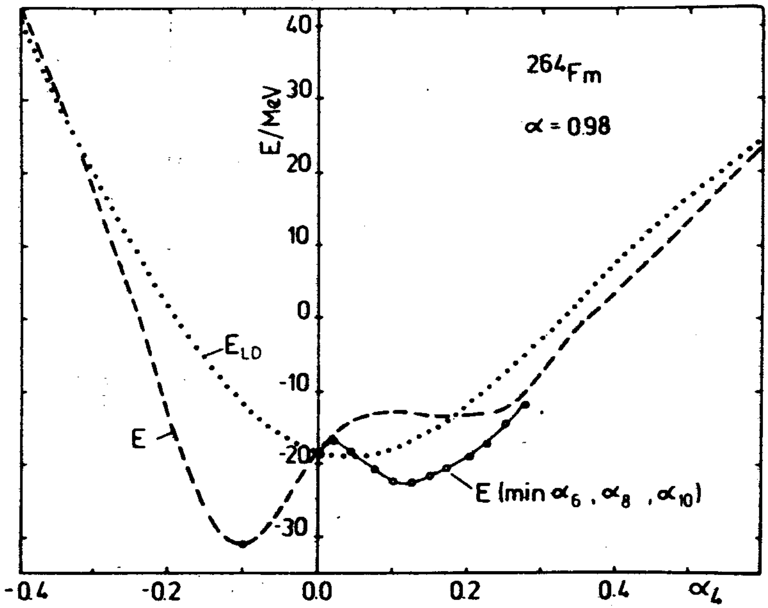

Fig.1. The deformation energy (in MeV) in the liquid-drop model, E_{LD}, (dots) and taking into account the shell correction, E, (dashed and solid curves) as a function of the hexadecapole deformation a_4 at the fixed deformation a = 0.98. The solid curve with open points corresponds to the minimum of E with respect to a_6 , a_8 and a_{10}. The definition of the parameters is given in the text (see. expr.(1)).

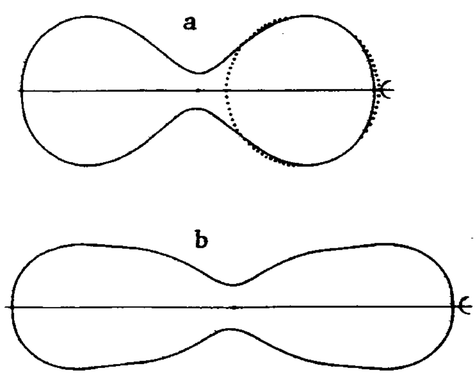

Fig.2. The nuclear shape in the minimum with respect to a_6 , a_8 and a_{10} at a = 0.98 and a_4 = −0.093 (a) and a_4 = = 0.1 (b). A half-volume sphere is shown by dots for comparison.

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