An alternative explanation of nuclear fission mass asymmetry

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The asymmetric distribution of fragment masses from the spontaneous or low excitation energy induced fission can't be explained within a liquid drop model (LDM). P. Möller and S. G. Nilsson in 1970 as well as V. V. Pashkevich in 1971 gave the first explanation of the mass asymmetry by showing that the outer fission barrier for reflection-asymmetric shapes is lower than for symmetric ones when shell corrections are added to the LDM deformation energy. J. A. Maruhn and W. Greiner successfully used in 1972 the two center shell model for this purpose.

The shapes during a fission process from one parent nucleus to the two final fragments, have been studied either statically (looking for the minimimum of potential energy), or dynamically (by choosing a path with the smallest value of action integral).

In a static approach, the equilibrium nuclear shapes are determined by minimizing the energy functional on a class of trial functions representing the surface equation. The required number of independent shape parameters may be as high as nine values. We derived a method allowing to obtain a very general reflection asymmetric saddle point shape as a solution of an integro-differential equation without a shape parametrization *apriori* introduced [1, 2]. This method [3] allows to obtain straightforwardly the axially symmetric surface shape for which the liquid drop energy, $E_{LDM} = E_s + E_C$, is minimum. By taking into account the shell corrections, δE, it was possible to obtain minima at a finite value of the mass asymmetry parameter [2].

The deformation energy increases with the mass-asymmetry parameter $\eta = (A_1 - A_2)/(A_1 + A_2)$, as is illustrated in Fig. 1, where η is replaced by an almost linear dependent quantity $(d_L - d_R)$ expressed in units of R_0 — the radius of a spherical nucleus with the same volume. In this way the well known fission fragment mass asymmetry can not be explained. By adding the shell corrections δE, $E_{def} = E_{LDM} + \delta E$, one can obtain the minima shown in Fig. 2.

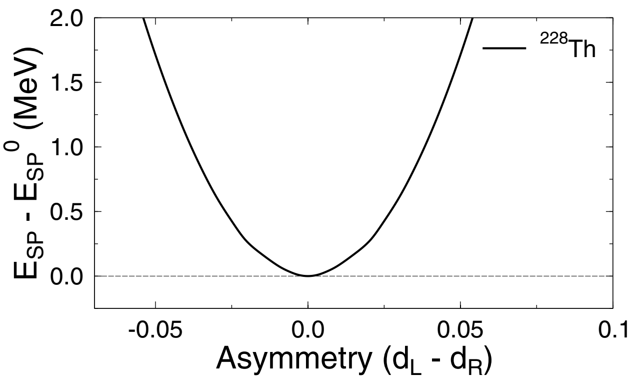

Figure 1: Saddle-point deformation energy versus mass asymmetry parameter for the binary fission of ^{228}Th within Myers-Swiatecki's liquid drop model.

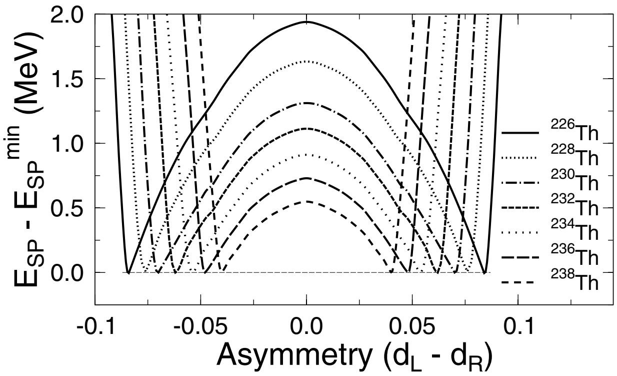

Figure 2: Saddle-point deformation energy versus mass asymmetry parameter for the binary fission of even-mass Thorium isotopes in the presence of shell corrections. The minima at a finite value of mass asymmetry are clearly seen.

The surface equation of an axially symmetric nucleus is a solution of an integro-differential equation with d as an input parameter (d_L and d_R for the left-hand side and right-hand side of the shape, respectively) which determines the deformation and the mass asymmetry (when $d_L \neq d_R$). We included in the deformation energy $E(R) = E_{LDM}(R) + \delta E(R) - \delta E^0$ a phenomenological shell corrections δE inspired from [4]. In this way the minima of deformation energy illustrated in Fig. 2 for $^{226-238}$Th nuclides are showing up at a finite mass asymmetry.

The saddle point shapes and the corresponding energy barrier heights (E_b) for ^{170}Yb ($X = 0.6$), ^{204}Pb ($X = 0.7$), ^{210}Po ($X = 0.71$), ^{226}Th ($X = 0.76$), and ^{230}U ($X = 0.78$) are in good agreement with those tabulated By Cohen and Swiatecki in 1963.

The variations of the saddle point energy with the mass asymmetry parameter $d_L - d_R$ (which is almost linear function of the mass asymmetry η) for some even-mass isotopes of Th are plotted in figure 2. The minima of the saddle-point energy occur at nonzero mass asymmetry parameters $d_L - d_R$ between about 0.04 and 0.085 for these nuclei. When the mass number of an isotope increases, the value of the mass asymmetry corresponding to the minimum of the saddle point energy decreases.

References

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