Nature of the Fission barrier heights of Trans-Uraniums

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Introduction

Several authors have carried out detailed studies of the fission and shape isomerism in heavy actinides, see the review [1].

The theories of nuclear fission are guided by the extensive calculations of the potential energy surfaces (PES) in the multi-dimensional deformation space defining the shape of a deforming nucleus on the way to fission. Many approaches have been used for this. A well established technique is the microscopic-macroscopic (mic-mac) approach in which the macroscopic part is given by the liquid drop energy and the microscopic part is given in terms of Strutinsky shell correction. This approach led to the prediction of the double-hump barrier and the existence of the secondary well for these nuclei. The second well is the home to the fission isomers. Because of the experimental difficulties, the fission isomers still remain rather poorly studied. The experimental data for the properties of fission isomers have been growing again after a long gap. Still, the spectroscopy of the second well remains an uncharted course. We propose to study the properties of the fission isomers as well as explore some possible unknown features of these isomers within the mic-mac approach.

Formalism

We have used the mic-mac approach [2] to calculate the PES by using the Cassini ovaloid shape parameterization [3] for nuclear potential. This formalism is due to Garcia et al [4]. In this formalism, the single particle energies as a function of deformation parameters are calculated from an axially deformed Woods-Saxon potential. This single particle level scheme is used to calculate the shell and pairing corrections to the liquid drop energy (smooth macroscopic part) in Strutinsky approach. The well known BCS prescription is used for the pairing calculations. Our aim is to study the double-humped fission barrier [1, 5] where nuclei captured in the second well can either tunnel through the outer barrier (isomeric fission), or decay back to the first minimum (isomeric gamma decay). Such a study is expected to yield information about the single particle energy levels in the second well as well the properties of the fission isomers like the half-life.

As the nucleus deforms, the nuclear Coulomb energy decreases due to the increased averaged distance between the protons while the nuclear Surface energy increases due to increment in the nuclear surface area. At the saddle point, the rate of change of Coulomb energy is equal to the rate of change of nuclear Surface energy. If the nucleus deforms beyond this point then the neck between the two fragments disappears and nucleus divides into two at the scission point. The Cassini parameterization allows one to move from an ellipsoidal shape to the formation of two fragments, and, finally, fission.

Cassinian ovals are taken as zero order approximation which explains the nuclear shape at saddle point for axially symmetric nuclear shapes and the deviation from these is defined in terms of Legendre Polynomials. The geometrical definition is given by [4]

$$r^2(z,\varepsilon) = \sqrt{(a^4 + 4(cz)^2)} - (c^2 + z^2 - \varepsilon^2),$$

where r and z are cylindrical coordinates; ε is a dimensionless quantity defined as

$$c = \varepsilon R_0^2 \cdot$$

Here c is the square distance from the focus of the Cassini ovaloids to the origin of the coordinates, and a is a dimensionless parameter which completely defines the shape, taking into account volume conservation.

Results and Discussion

The Fig. 1(a) to 1(d) show the energy systematic of the inner and the outer barrier heights, and the second minimum for neutron number N = 138 to 148 for Z=92(Uranium), 93(Neptunium), 94(Plutonium), and 95(Americium) respectively. Here E_{b1} and E_{b2} stand for the inner and the outer barrier heights, respectively. We have calculated the two barrier heights and the second minimum relative to the first minimum. Both, E_{b1} and E_{b2}, are seen to rise with N for all the four elements. However, the E_{b1} remains nearly similar for Z=92 to 95 whereas E_{b2} is seen to come down as a whole. Eventually, E_{b2} crosses E_{b1} for Z=95. The behavior of the second minimum remains nearly same in all the cases, decreasing slightly with Z. Odd-N neighbor is always at a higher energy than its even-N neighbor due to pairing. For Z=95, the second barrier crosses the first barrier at neutron number 141.

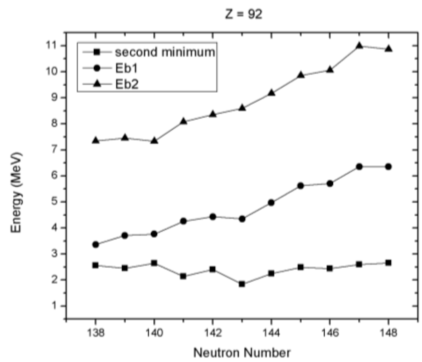

Fig. 1(a) Barrier height systematic for Z = 92 isotopes.

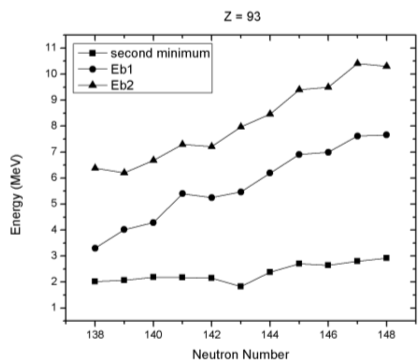

Fig. 1(b) Barrier height systematic for Z = 93 isotopes.

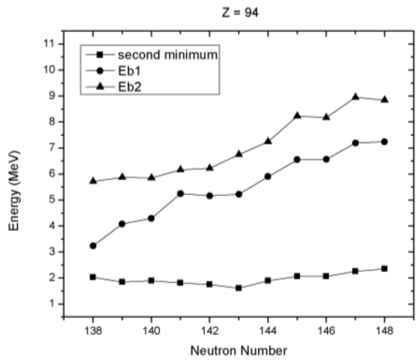

Fig. 1(c) Barrier height systematic for Z = 94 isotopes.

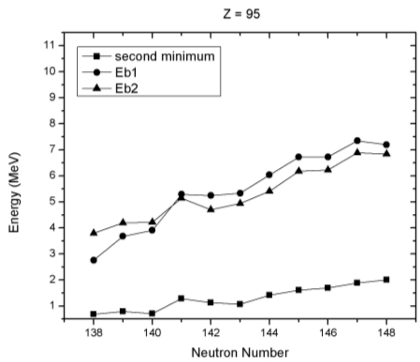

Fig. 1(d) Barrier height systematic for Z = 95 isotopes.

To conclude, the barrier heights show almost linear dependence with neutron number and an odd-even staggering due to pairing is clearly visible. Energy of the second well i.e. the isomeric state exhibits a dip at N=143 for all the cases which can be due to a magic neutron number configuration for deformed stable nuclei.

References

[1] S. Bjornholm, J.E. Lynn, Rev. Mod. Phys. **52**, 4 (1980).

[2] V.M. Strutinsky, Nucl. Phys. A **95**, 420 (1967); Nucl. Phys. A **122**, 1 (1968).

[3] V.V. Pashkevich, Nucl. Phys. A **169**, 275 (1971).

[4] F. Garcia, O. Rodriguez, J. Mesa, J.D.T. Arruda-Neto, V.P. Likhachev, E. Garrote, R. Capote, F. Guzman, CPC **120,** 57 (1999).

[5] M. Brack, J. Damgaard, A.S. Jensen, H.C. Pauli, V.M. Strutinsky, C.Y. Wong, Rev. Mod. Phys. **44**, 320 (1972).