Shape evolution and coexistence in neutron-rich Yb, Hf, W, Os and Pt nuclei

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Abstract

We have investigated the shape evolution and shape coexistence in the even-even neutron-rich isotopes of Yb, Hf, W, Os and Pt and the isotones N = 110-122 in the A~190 within the microscopic-macroscopic Cranked Nilsson-Strutinsky framework. Here, we have focused on the potential energy surface (PES) calculations to detect shape variations with N and Z. The PESs in the ground state for low-lying energy show the presence of collective and non-collective bands. The results are comparable to the studies of others where the pairing correlation was also included. It is evident deformation changes in the isotopic and isotonic chains with increasing the neutron and proton number and the filling of closed shells. The qualitative consistence of our calculations without pairing correlations, especially on the position of the PES's minima, shows that the pairing force has no a considerable effect on the nuclear shape at least in the mass region A~190.

Keywords: Cranked Nilsson-Strutinsky method, PES calculations, deformation parameters, shape coexistence, shape evolution

Introduction

In nuclear physics, nuclear shapes and their evolution plays an important role to understanding nuclear phenomena and describing their structure. During last decades one active and attractive field research is the shape coexistence phenomena in the $A \sim 190$ mass region [1, 2]. Several works have been caried out in Pt, Os, W, Hf and Yb isotopes chains [3] such as Skyrme-functional, the Gogny-interaction or by using a relativistic mean-field approach or interacting boson model (IBM). We aim to use the macroscopic-microscopic Cranked Nilson-Strutinsky (CNS) model [4,5] to describe the shape evolution shape coexistence in the chains of even-even Pt, Os, W, Yb, Hf isotopes in the neutron number range N=110-122. In the CNS method, a deformed mean field is considered as a modified harmonic oscillator, and then the total energy obtained is minimized relative to the deformation parameters [6].

Our calculation:

In this work, the energy is minimized in a three-dimensional deformation space $(\varepsilon, \gamma, \varepsilon_4)$. The three-dimensional space is as follows:

$$x = 0.00(0.04)0.64$$

$$y = -0.28(0.04)0.32$$

$$\varepsilon_4 = -0.09(0.03)0.09$$

The standard parameters [1,6] is used for heavy nuclei. Figure 1 shows the PESs in even-even Yb, Hf, W, Os, and Pt isotopes with neutron numbers (110 ≤ N ≤ 120) using the CNS method. In these diagrams, one can see an increase in the number of neutrons from left to right, and an increase in the number of protons from top to bottom.

Results and discussion

In this study, we can see interesting results that are comparable to the studies of others [3]. In the all PESs in the ground state, shape coexistence is considered for low-lying energies in all isotopes, except in some Pt isotopes where the simultaneous presence of collective and non-collective bands is quite visible. In these nuclei, with increase Z, the transition from prolate to oblate can be seen that is similar in the first three Yb-W nuclei. While the result is different for Os and Pt. In the study of Yb isotopes, we see that this transition takes place at N = 118, i.e from N = 110 to N = 118, the Prolate shape is observed. It also appears the triaxial minimums at higher energy levels and at shallower depths. One can see a prolate-oblate shape coexistence, only prolate minimums at shallower energies. These shape evolution occur with the appearance of triaxial minima from ${}^{186}_{72}Hf_{114}$ to ${}^{190}_{72}Hf_{118}$ .In some studies [3], triaxial minima with the same energy can be seen in all three regions $-120 < \gamma < -60$, $-60 < \gamma < 0$ and $0 < \gamma < 60$, Of course, it is seen that these minima appear in its two neighboring nuclei, but at higher energies. If we look at the column total, we see in nuclei with N=110-118 (except in Pt which are only prolate at N=116,118) a collective and non-collective prolate shape. It should be noted that with increasing the number of protons in all isotones, there is a decrease in the quadrupole deformation parameter. For a better comparison of these PES diagrams, we can refer to diagram from the reference [3] calculated with Gogny D1S interaction.

Conclusions

In the present research, we have carried out systematic mean-field exploration of the Potential Energy Surfaces (PESs) in various isotopic chains where nuclear shape transitions occur, and in addition we have explored the shape evolution and shape coexistence in Yb, Hf, W, Os and Pt isotopic chains with neutron number (N=110-122) by using the microscopic-macroscopic unpaired Cranked Nilsson-Strutinsky (CNS). Interesting results are observed in five isotopic chains $70 \le Z \le 78$. For all considered nuclei except Os at N=118 there is a prolate to oblate shape transition. Of course, in the paired calculations, this transition was created at N = 116 [9].

Also, for all except Pt at N=110-114 there is collective and non-collective coexistence. At N=118, in these nuclei (even in Os, albeit at very shallow minima), the coexistence of four minimum oblate and prolate collective and non-collective is reported. In contrast to the Os isotopes, which had no transition in this mass region, in Pt, a triaxial to prolate shape transition is seen at N = 114, then an oblate-prolate shape transition at N = 118 and an oblate-prolate shape transition at N = 120. As the shell fills and approaches to the closed shell in all isotopic (isotonic) chains, the quadrupole deformation parameter decreases with increasing number of protons (neutrons). It is obvious that in the theoretical calculations of others, considering the pairing interaction, this issue has also been reported for β. However, here in the isotope in which the transition takes place, we will see an increase in the amount of axial quadrupole deformation parameter. As expected, due to the behavior of the closed shell and its alignments, as well as the results of other theories, it is observed that the intended nuclei tend to be spherical. The qualitative consistence of our calculations without pairing correlations with paired studies, especially on the position of the PES's minima, shows that the pairing force has no a considerable effect on the nuclear shape at least in the mass region A~190.

References

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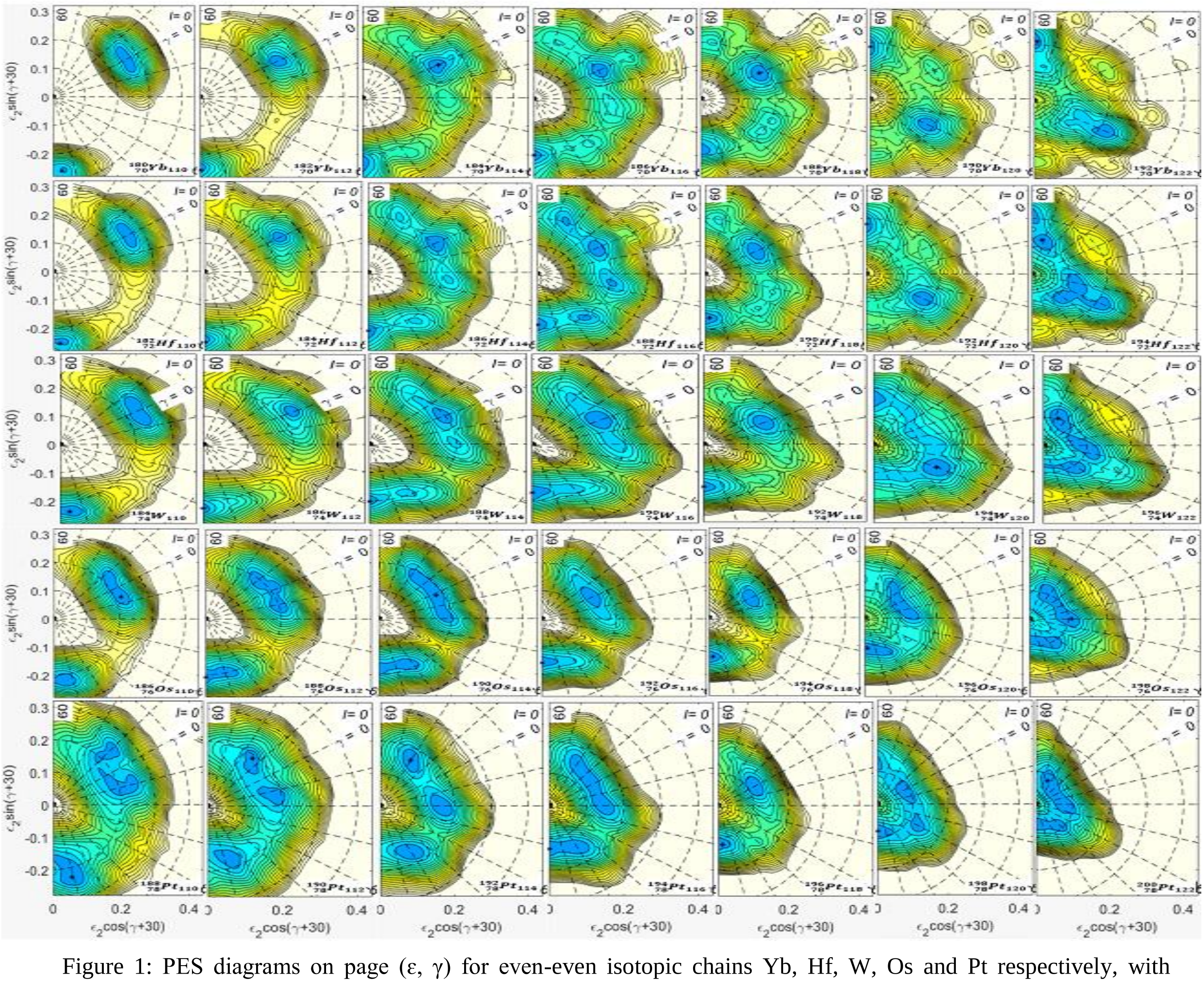

Figure 1: PES diagrams on page (ε, γ) for even-even isotopic chains Yb, Hf, W, Os and Pt respectively, with neutron number (N = 110-122), by using the microscopic-macroscopic unpaired Cranked Nilsson-Strutinsky (CNS) formalism in the ground state $(\hbar\omega = 0)$.