Shape evolution in nuclei with Z in A ~ 180 – 190 region

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Introduction

A systematic investigation of the shape evolution of nuclei in A ~ 180 ï 190 region with proton number from Z = 72 ï 82 has been performed in the frame work of cranking model. For the nuclei below Z = 82 and near A~180, the active proton and neutron orbitals are $\pi g_{7/2}$, $\pi d_{5/2}$, $\pi h_{11/2}$, $\pi d_{3/2}$ and $\nu h_{9/2}$, $\nu i_{13/2}$ respectively that is both high- and low-j orbitals. The Hf (Z = 72) nuclei are known to possess axially prolate deformation up to neutron rich isotope ^{182}Hf (N = 110) with several known K-isomers [1]. On the other hand, the neutron deficient Hg and Pb nuclei in A ~ 190 region show shape co-existence and oblate shape. Therefore, it is interesting to study if the shape evolution of these nuclei from prolate to oblate is through intermediate non-axial shapes. Experimental indication of such non-axial shapes has been reported in the W and Os nuclei in relation to K-isomerism [2,3].

In the present work, the Total Routhian surfaces (TRS) have been calculated near the ground state for the N = 110 even-even isotones from Hf to Pb. The variation of the active single particle orbitals, near the proton Fermi levels in these nuclei, with the deformation parameter γ have also been studied for microscopic understanding of nuclear shape evolution.

Theoretical basis

In the calculations, performed in the present work, a Woods-Saxon potential was used with BCS pairing to calculate the single particle energies. The TRSs were calculated using the Strutinsky shell correction method for several values of the deformation parameters β_2, γ and β_4 at different rotational frequencies (<ω). The β_2 and γ values corresponding to the minimum of the TRS have been taken as the deformation parameters of a nucleus at a fixed rotational frequency. The TRS code of Nazarewicz et al., [4, 5] was used for this calculations and the procedure has been given in Ref. [6]. In these calculations the Lund convention was followed, according to which, $\gamma=0^o$ ($\gamma=\pm60^o$) corresponds to prolate (oblate) shape and any intermediate γ values correspond to the triaxial shape.

Results and Discussions

The results of the TRS calculations are shown in Table 1 and Fig.1. The calculated β_2 and γ values corresponding to the minimum of the TRS at ǩω = 0.1 MeV for ^{182}Hf, ^{184}W, ^{186}Os, and ^{188}Pt, ^{190}Hg and ^{192}Pb isotones (N=110) are shown in Table 1.

Table 1: Calculated β_2 and γ values from TRS.

Nucleus	β_2	γ
^{182}Hf	0.237	-1.2^o
^{184}W	0.213	-5.1^o
^{186}Os	0.196	-14.1^o
^{188}Pt	0.165	-30.1^o
^{190}Hg	0.151	-52.8^o
^{192}Pb	0.04	13.4^o

Fig. 1 shows the corresponding TRS plots in the β_2–γ deformation mesh. It is evident from Table 1 that the deformation (β_2) decreases as the proton number approaches the Z = 82 shell closure with a drastic drop in β_2 for ^{192}Pb. Interestingly, the non-axiality (γ) in the nuclear shape increases with the increase in Z, attaining the maximum triaxiality (γ ~ -30^o) at Z = 78 for ^{188}Pt.The surfaces also become more and more γ-soft with increasing proton number, as can be seen from Fig.1. In case of ^{190}Hg, the minimum of the TRS shifts to near collective oblate deformation while for ^{192}Pb, the shape becomes near-spherical.

The TRS energies (E_{TRS}) for these nuclei (except ^{192}Pb, as it has near spherical shape as seen in Fig. 1) are plotted as a function of γ in Fig. 2. The β_2 values in these plots correspond to the TRS minima for each nucleus. The shape evolution in γ degrees of freedom for these nuclei is clearly seen in this plot.

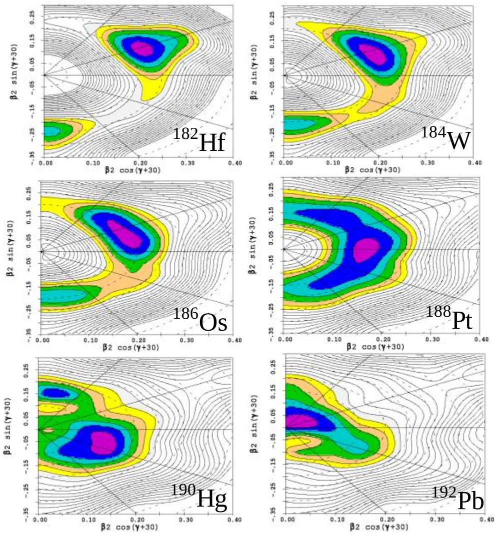

Fig. 1: TRS plot in the β_2-γ plane for Z = 72 – 82 at ħω = 0.1 MeV. The contours are 250 keV apart.

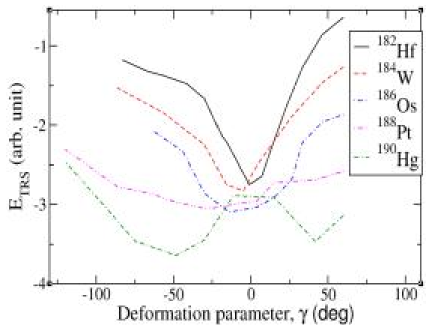

Fig. 2: TRS energy (E_{TRS}) as a function of γ

The variation of energy of the active proton single particle orbitals in this mass region have been plotted with γ in Fig. 3. These are plotted for β_2 = 0.2 and $\check{k}\omega$ = 0.0 MeV. It can be seen that the positive parity orbitals of $7/2^+$[404] and $5/2^+$[402], originated from $g_{7/2}$ and $d_{5/2}$ parentage, respectively, have maximum at prolate (γ=0°) and minimum at oblate (γ=±60°) deformation, while $1/2^+$[411] orbital, originated from $d_{3/2}$ parentage, has minimum at prolate deformation.

On the other hand, the negative parity orbitals of $7/2^-$[523] and $9/2^-$[514], originated from the $h_{11/2}$ parentage show nearly flat minima around γ=0° and γ=±40° respectively. The flat minima can give rise gamma softness in nuclear shape. The other high-Ω negative parity proton orbital shows minima near γ=±60° (oblate).

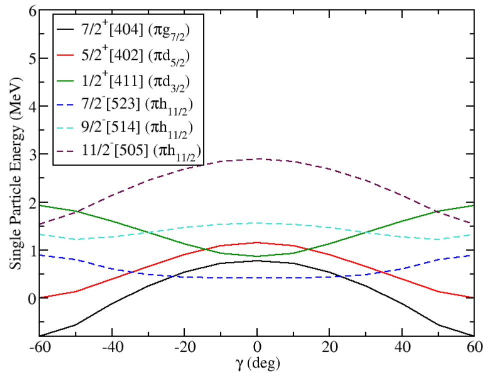

Fig. 3: Plot of proton single particle energies with γ

Summary

A systematic study of the evolution of the near-ground-state shape for the even-even, N = 110 isotones from Z = 72 to Z = 82 has been performed from TRS calculations. It clearly shows that the deformed prolate shape in Hf gradually transforms to a less deformed axially symmetric oblate shape in Hg, before the shape becomes near-spherical in Pb, through gamma-soft and triaxial shapes with maximum triaxiality in Pt. The calculated proton single particle energies of different active positive and negative parity orbitals have different γ dependence. The shape driving effect of these orbitals, particularly on the γ-soft even-even core, may be investigated in more detail in the odd-proton nuclei, both theoretically and experimentally.

References

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