# Signature Pattern of 2QP Rotational Bands in Deformed Nuclei

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## Introduction:

The energy spectrum of two- quasiparticle (2QP) rotational bands of deformed nuclei exhibit many interesting features. The anomalous features like large odd–even staggering [1, 2], signature inversion [3 - 5] and signature reversal [6, 7] have been observed. Signature effects in deformed nuclei have been in limelight for quite time. Attempts have been made to understand these features using several models such as cranked shell model [8], the particle –rotor model and the interacting boson – fermion model [9]. The term signature effect is used to denote the behavior of the odd and even spin sequences of the rotational band. The wavefunction is invariant for rotation about an axis perpendicular to the symmetry axis and gives rise to signature quantum number 'α'. For odd –I and even –I levels different properties of rotational bands can be described in terms of signature quantum number and it is known as signature dependent phenomenon. We have studied many interesting features and explained them in terms of coupling between the bands. Similar types of features are observed in almost all deformed nuclei. In the present paper we have presented summary and a few examples of anomalous features observed in 2QP rotational bands of deformed nuclei.

## Discussion:

The energy pattern for 2QP rotational bands should show smooth behavior with spin. But the most common effect is a perturbation in the energy spacing which leads to the odd–even staggering. The odd–even staggering has been observed in Gallagher-Moszkowski doublet ($K_+$ and $K_-$ bands) for almost all deformed nuclei. It is expected that $K_-$ bands should show an odd-even staggering in energy whereas $K_+$ bands show a very smooth conduct. It is clearly shown in Figure 1 that $K_-$ bands are more staggered than $K_+$ bands however the $K_+$ bands composed of high–j configuration exhibit surprising feature of odd–even effect in their rotational energy spacing.

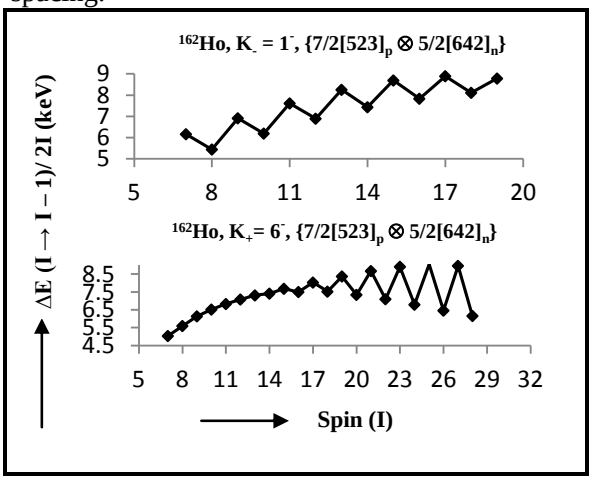


**Figure 1:** The plots between ΔE (I→I-1)/ 2I (keV) and spin (I) showing odd-even staggering in Gallagher doublet.

In deformed nuclei, the change of phase in the level staggering is one of the interesting features. This abnormal phase change in the level staggering is termed as signature inversion. The favored signature for 2QP rotational bands in doubly odd nuclei is represented as-

$$\alpha_f = \frac{1}{2}[(-1)^{j_p - (1/2)} + (-1)^{j_n - (1/2)}] \quad \ldots. (1)$$

where $j_p$ and $j_n$ are angular momentum quantum numbers of proton and neutron respectively. For $\alpha_f = 0$, even spins are favored and for $\alpha_f = 1$, odd spins are favored. In some of the cases, this rule is violated i.e. the favored signature branch lies higher in energy and becomes unfavored up to a particular spin called critical spin ($I_c$). After the critical spin the normal signature splitting is restored and causes signature inversion. It has been noticed that after restoring the normal feature, the abnormal feature appears once again and it is termed as second point of signature inversion $I_c(2)$. In few bands, a very interesting behavior has been observed that the favored

signature branch lies higher in energy all through the staggering pattern and results in abnormal odd–even staggering feature. The plots in terms of ΔE (I→I-1)/ 2I (keV) versus spin (I) are presented in Figure 2 to show the anomalous feature of signature inversion.

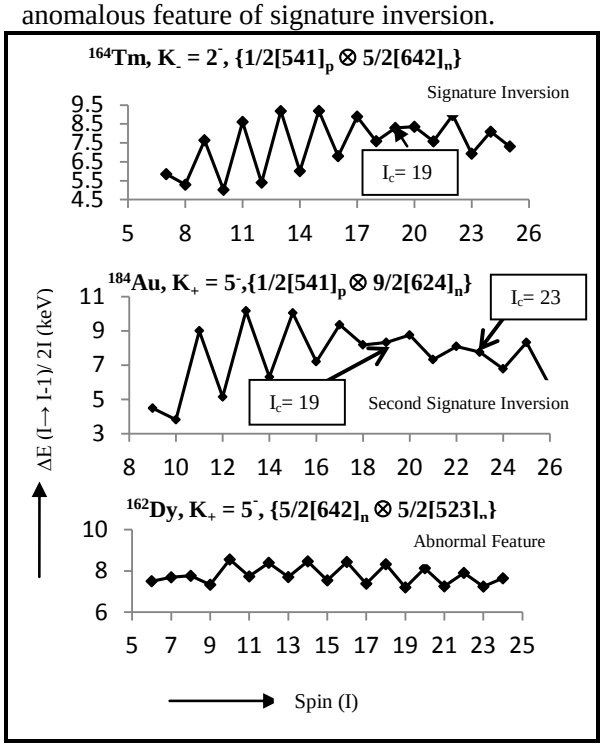


**Figure 2:** The staggering plots between ΔE (I→I-1)/ 2I (keV) and spin (I) showing feature of signature inversion. $I_c$ represents the critical spin of inversion.

In 2QP rotational bands of deformed nuclei another interesting feature like signature reversal has been observed. Normally, it would be expected that Gallagher partner bands should have the same phase of odd-even staggering but it has been noticed that both the partner exhibit a mutually opposite phase of odd-even effect. This abnormality is termed as signature reversal [7]. Figure 3 shows a particular example of 2QP rotational band structure to represent the phenomenon of signature reversal in deformed nuclei.

We have done detailed analysis for doubly odd and doubly even nuclei in rare earth region. Surprisingly such feature has been observed in transition region and actinide region too. Thus, it shows that signature effect is not confined to any particular region's nuclei. We have analyzed these phenomena within the framework of the two-quasiparticle plus symmetric rotor model [TQPRM] [1]. All the anomalous features are well explained by TQPRM without incorporating γ – deformations and hence show that our model is self sufficient to reproduce the anomalous features. The mechanism behind the reverse behavior of signature pattern is also well explained by Particle Rotor Model and is of similar nature to the signature inversion observed in deformed nuclei.

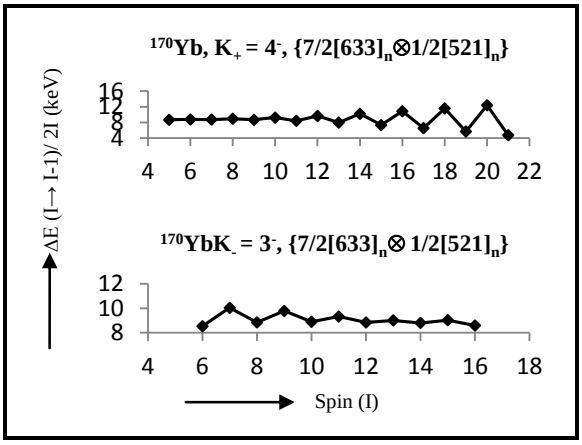


Figure 3: Signature Reversal observed in Gallagher partner of $^{170}$Yb in $K_+$= 4 & $K_-$=3 bands.

## References:


1. A.K.Jain et al. J.Kvasil, R.K.Sheline and R.W. Hoff, Phys. Lett. B 209, 19 (1988); Phys. Rev. C. 40,432 (1989).
2. K. Hara and Y. Sun, Nucl. Phys. A 531, 221 (1991).
3. A.K. Jain and Alpana Goel, Phys. Lett. B 277, 233 (1992).
4. Alpana Goel and A.K. Jain, Pramana -J. of Phys., 46, 51 (1996); Nucl. Phys. A 620,265 (1997).
5. A.K. Jain, et al. Rev. Mod. Phys. ,70, No.3, (1998).
6. Alpana Goel and A.K. Jain, Phys. Rev. C. 45, 221 (1992); Phys. Lett. B 337, 240 (1994).
7. Alpana Goel and A.K. Jain, Phys. Lett. B 337, 240 (1994).
8. R.Bengtsson et al. Nucl. Phys. A 415,189 (1984).
9. N.Yoshida et al. Nucl. Phys. A567, 17 (1994).