

WOBBLING MOTION IN THE MULTI-BANDS CROSSING REGION: DYNAMICAL COUPLING MODE BETWEEN HIGH- AND LOW- K STATES*

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We analyze a mechanism of coupling of high- and low- K bands in terms of a dynamical treatment for nuclear rotations, *i.e.*, wobbling motion. The wobbling states are produced through the Generator Coordinate Method after Angular Momentum Projection (*GCM-after-AMP*), in which the intrinsic states are constructed through fully self-consistent calculations by the 2d-cranked (or tilted-axis-cranked) HFB method. In particular, the phenomena of “signature inversion” and “signature splitting” in the t-band (tilted rotational band) are explained in terms of the wobbling model. Our calculations will be compared with new data for in-band E2 transition rates in ^{182}Os , which may shed light on the mechanism of the anomalous $K = 25$ isomer decay, directly to the yrast band.

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1. Introduction

In the $A \simeq 180$ region of the rare-earth nuclei, three bands are observed to interact with each other at $I \simeq 14\hbar$. The bands are g-, s- and t-bands. The g- and s-bands are well-known rotational bands of the ground state and rotation-aligned configurations, respectively. On the other hand, the t-band means “tilted-rotating” band which was proposed by Frauendorf [1]. In ^{184}Os , the t-band has a $K^\pi = 10^+$ band head, while ^{182}Os has $K^\pi = 8^+$. These high- K states are assigned to two quasi-particle excitations in the neutron $i_{13/2}$ orbits. Because the neutron Fermi levels in these nuclei are in

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the high- Ω orbits in the $i_{13/2}$, it is expected that high- K states are excited favourably and appear near the yrast line.

These three bands, *i.e.*, g- and s-bands (low- K) and t-band (high- K), seem to interact with each other near $I = 14\hbar$ to cause a backbend in the yrast line. An interesting phenomenon here is that the t-bands split into two sequences: one of them consists of even- I members while the other of odd- I , which is energetically lower than the former. (See Fig. 1.) Therefore, it seems that so-called “signature splitting” and “signature inversion” are induced by these multi-band crossings. These phenomena are observed systematically for even–even nuclei in the $A \simeq 180$ region such as $^{180-184}\text{W}$ and $^{182-186}\text{Os}$.

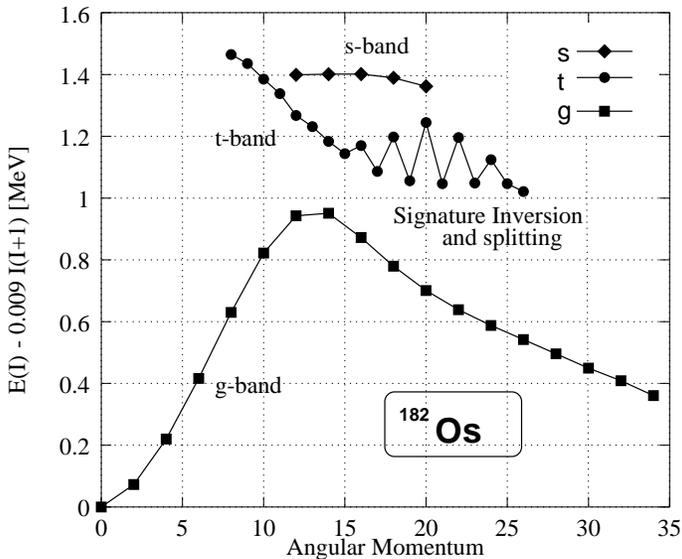


Fig. 1. Multi-bands crossing in ^{182}Os .

2. Wobbling model

To explain these phenomena, *i.e.*, a coupling between high- and low- K states (in other words, break-down of the K -selection rule), we propose the *wobbling model*. The term “wobbling motion” was originally introduced into nuclear structure physics by Bohr and Mottelson [2], in order to explain excited rotational structures of triaxial nuclei. The wobbling motion in this context is considered as the small deviation or fluctuation of angular momentum from the typical collective rotation around the x -axis. The motion is quantized and presents phonon-like structures above the ground state band.

On the other hand, our wobbling motion is based on the theory by Kerman and Onishi [3]. It is based on the Time-Dependent Variational Model (TDVM) and attempts to handle general three-dimensional nuclear rotations. In our present model, we describe the wobbling state, $|\text{Wbll}\rangle$, as a superposition of different tilted-axis-cranked HFB states, $|\text{HFB}(\theta, J)\rangle$, where θ and J are defined in the constraints of angular momentum. $J_x = \langle \hat{I}_x \rangle = J \cos \theta$; $J_y = \langle \hat{I}_y \rangle = 0$; $J_z = \langle \hat{I}_z \rangle = J \sin \theta$. (Note that the tilt angle θ is measured from the x -axis to see the deviation of the rotation axis from the x -axis.)

The wobbling states are written,

$$|\text{Wbll}_M^I\rangle = \sum_K \int d\theta f_K^I(\theta) \hat{P}_{MK}^I |\text{HFB}(\theta, J)\rangle, \quad (1)$$

where $f_K^I(\theta)$ is the GCM wave function and the variation is made with respect to this function. The pairing-plus- Q force is employed as an residual interaction for the spherical parts (from the Nilsson model) in the Hamiltonian. Quantization is made through the angular momentum projection technique (\hat{P}_{MK}^I).

As a result, our wobbling motion can describe not only small but also large amplitude wobbling motion around any types of rotations (with any kinds of deformations). In other words, this model describes a dynamical picture of nuclear excited modes such as rotations and vibrations.

Fig. 2 shows schematically how the wobbling motion occurs. As a nucleus rotates rapidly, the rotation-alignment occurs, in both of the g- and t-bands. As a result, the yrast band takes on the s-band character (left panel) and the t-band has some amount of fluctuations in K -distribution as well (center

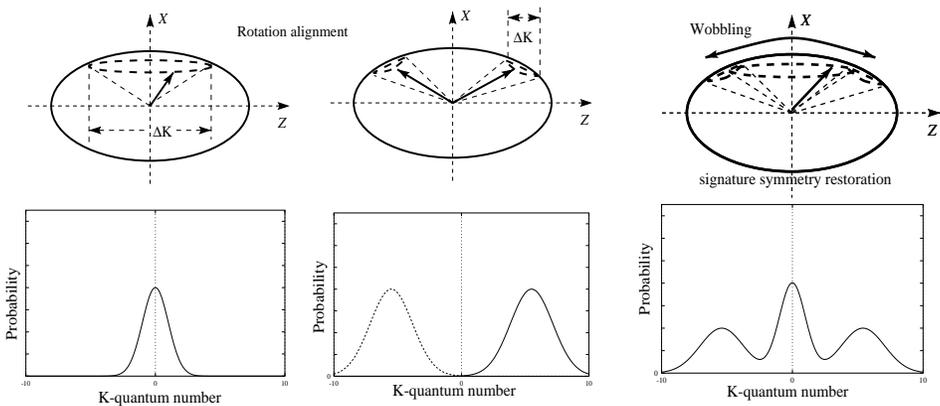


Fig. 2. Schematic explanation of the wobbling motion.

panel). As the nucleus rotates more rapidly, the K fluctuation around high- and low- K components spreads and finally there is an overlap between them (right panel). As a result, the corresponding state has very large fluctuation in K . Semi-classically, this state coupling low- K states with high- K can be pictured as the wobbling motion.

We performed numerical calculations and confirmed that the wobbling model can describe the main features of the multi-bands crossing phenomena. Particularly, our calculations can reproduce the coupling of low- and high- K components in the yrast and excited bands through the crossing. (See Fig. 3.) Then, we propose an interpretation for the mechanism of the signature inversion through the wobbling model: first, as a result of the rotation-alignment, the yrast line takes on the s-band character; then, the t-band approaches the yrast line and inter-band interactions start between even- I members of the t-band and members in the s-band, while odd- I members in the t-band are unperturbed because there are no counterparts in the yrast band. Thus, the even- I members are pushed up from the original t-band sequence while the odd- I s keep staying in the sequence. This mechanism can explain the signature inversion (and splitting) phenomena. At the same time, the yrast line is pushed down through the inter-band interaction, and as a consequence backbending can be enhanced. The detailed results and discussions are presented in our previous paper [4].

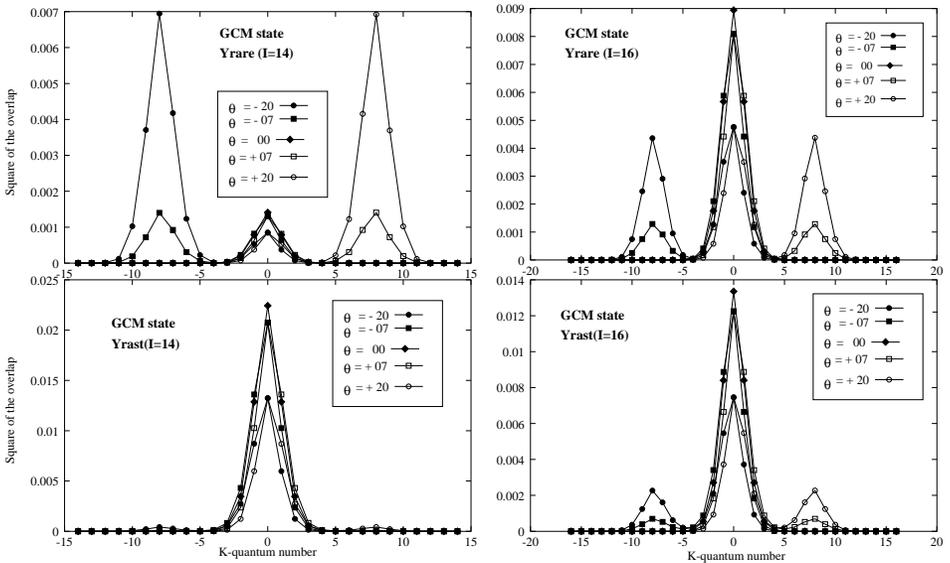


Fig. 3. Overlap $\langle \text{HFB}(\theta, J) | \hat{P}_{KK}^{I\dagger} | \text{Wbbl}_M^I \rangle$ for $I = 14\hbar$ (before crossing) and $I = 16\hbar$ (after crossing). See Ref. [4] for details.

3. Experimental investigations of the wobbling motion

In ^{182}Os , there is an isomer with $K^\pi = 8^-$, and its rotational band seems to be isolated. Thus, it is expected to have a pure high- K ($K = 8\hbar$) structure (at least, no low- K component). Podolyák *et al.* [5] have measured the effect of low- K components in the t-band ($K^\pi = 8^+$) by the comparison of the transition rates between these two high- K bands (*i.e.*, $K^\pi = 8^+$ and 8^-).

Furthermore, it is hoped to identify the effect of high- K components ($K \simeq 8\hbar$) in the yrast line at high spin ($I \simeq 24\hbar$), which influences the transition probability from the $K^\pi = 25^+$ isomer (having a very short half life, $T_{1/2} = 130$ ns) to the yrast line. (See Fig. 4.)

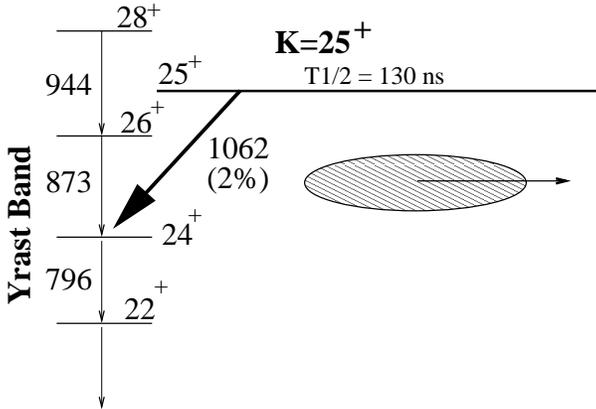


Fig. 4. Transition from $K^\pi = 25^+$ to the yrast line [6].

4. Summary

We have investigated a mechanism of signature inversion and splitting in the $A \simeq 180$ region by means of *GCM-after-AMP* on the tilted-axis- cranked HFB states. With this method, we have qualitatively reproduced the main features of the excited level structure in the high- K t-band. We interpret this result from the point of view of an inter-band interaction between the low- K (s-) and high- K (t-) bands. We have shown that the perturbed states have the character of wobbling motion, that is, a dynamical mode coupling low- K PAR (Principal-Axis Rotation) and high- K TAR (Tilted-Axis-Rotation) states. In terms of this wobbling model, we have discussed an enhancement of backbending in the $A \simeq 180$ region, in which the typical rotation-alignment is somewhat suppressed due to the location of the neutron Fermi level.

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