Backbending phenomena in deformed even-even nuclei at A∼160 mass region

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Investigations of the ground state bands of nuclei at A ∼ 160 mass region have become a particularly interesting research in nuclear structure studies. These nuclei exhibit a range of interesting features, including oblate and prolate deformations as well as rapid variations in shape as a function of both spin and particle number. The effect of the backbending occurs due to the rapid increase of the moment of inertia with rotational frequency towards the rigid value. When the rotational energy exceeds the energy needed to break a pair of nucleon, the unpaired nucleon goes into different orbits, which result in change of the moment of inertia. An explanation of this effect is due to a disappearance of the pairing correlation by the action of Coriols forces, where the nucleus then undergoes a phase transition from a superfluid state to a state of independent particle motion. The above physical picture of the band crossing can be clearly seen in the Triaxial Projected Shell Model (TPSM) [1], which has been applied successfully to the description of the energy spectra and electromagnetic transitions in deformed nuclei. In the past few years, TPSM approach has been used quite extensively to shed light on some of the outstanding issues related to the triaxility in atomic nuclei and in the present abstract we shall provide the importance of triaxiality on the band crossings in both low spin and high spin region interms of backbending.

A diagram in which 2Θ is plotted as a function of ω^2 is called backbending plot, which is known to disclose the finer feature of the yrast levels. The band energy of some low-lying two-quasiparticle bands decreases with spin in the low-spin region. The reason is that due to the rotational alignment of a decoupled state and the amount of spin alignment is given by spin value at which the band energy takes the minimum value. Among such a 2-qp bands, the one that crosses first to the g-band is the so-called s-band. It becomes the yrast band after crossing. This leads to the S-shaped (backbending) diagram. In the low-spin region ($I < 10$ or $\omega^2 < 0.08$) in which the g-band is dominant band (g-dominant). It is clear from the Fig. 1 that in lighter Er isotopes the slope of the experimental backbending plot (open circles) is steeper than that of the theoretical one (filled circles) although the agreement between theory and experiment improves rapidly as the neutron number increases. The horizontal (vertical) line in the backbending plot represents the rotational (vibrational) limit, therefore, the experimental results slants slightly towards the vibrational side in comparison with the theoretical prediction. On the other hand the yrast spectrum of triaxial rotor is known to change from the (purely) rotational spectrum to a (more) vibration-like spectrum as the triaxiality parameter γ increases from 0 to 30^0. Therefore, the present (g-band) problem can be be resolved by introducing triaxiality in the Nilsson basis and using three dimensional angular momentum projection as is done in TPSM. The results using TPSM model are presented in Fig. 1 where I_c is the spin at crossing point.

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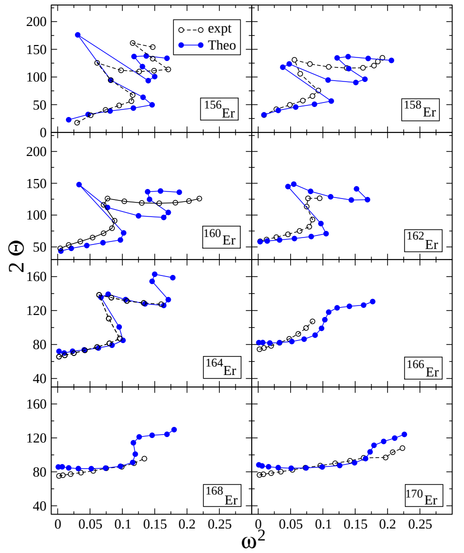

FIG. 1: (Color online) Back-bending plots for Er isotopes ($A = 156 - 170$). Solid/dashed lines represent theory/experimental.

At this point, we comment on the role of the quadrupole pairing force. If this force is absent, the g-s crossing occurs around $I_c = 8$ which is too early since we find $I_c \simeq 12 - 16$ experimentally. This is due to the well-known fact that theoretical g-band moment of inertia becomes 10 to 15% smaller than the experimental value if the monopole pairing force is adjusted to observed energy gap. The quadrupole pairing force corrects this mishap and increase the moment of inertial to proper value. The smaller the g-band moment of inertia (i.e. the smaller deformation), the larger the g-s crossing angle. This explains the reason why (sharply) backbending nuclei are found at the beginning and at the end of the deformed region while nuclei in the middle show upbending rather than backbending. The evidences for this can be found from Fig. 1. Namely, the moments of inertia of the backbending nuclei start from $2\Theta \simeq 40$ while those of upbending nuclei start from $2\Theta \simeq 70$.

Finally, we discuss the spin region beyond the first band crossing. The s-band, which crossed the g-band at the (first) band crossing remains to be yrast band (s-dominant) until it is crossed by another band (usually a $2\nu \otimes 2\pi$ 4-qp band). As we can see in Fig. 1, the nuclei $^{156-164}$Er exhibits both the first and second backbending while the $^{(166-170)}$Er shows what is usually called upbending as well as a beautiful plateau for the moment of inertia (a horizontal line in the backbending plot) which already starts to develop at a moderate spin. This feature is also clear from their band diagrams. In the nucleus ^{156}Er, the second backbending is due to the crossing between 2-qp and 4-qp bands. However, in neutron rich nuclei the band crossing takes place one after the other with very small crossing angle. This leads to the upbending and, in the higher spin region, to a plateau of moment of inertia. Actually when one sees such a plateau in the backbending plot, one might conclude that the system reached the classical rotation limit having very large deformation (because of the large moment of inertia), but this is not correct. In first place, as mentioned above, the plateau is produced by the successive band crossings which take place one after the other as the spin increases. In fact, the theoretical moment of inertia will decrease if this does not happen since the rotational spectrum of a (single) band in general develops faster than I^2 (i.e. a stretches rotational spectrum) for the high spin region. This can be seen from the decrease in the moment of inertia immediately after the first band crossing in a strongly backbending nucleus (e.g, ^{156}Er) in which the s-band continues to be the yrast for a wide range of spin. Secondly, even if the moment of inertia becomes very large in the plateau region, one should not conclude that the deformation is very large. This interpretation contradicts with the fact that the measured BE2 values are not much larger than those of the g-band. On the contrary, they are usually smaller and even decrease with spin, which may indicate the occurrence of successive band crossings.

References

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