Backbending region study in ^{160}Dy nuclues using triaxial projected shell model

G. H. Bhat[1,2],* S. Jahangir[3], J. A. Sheikh[2], and R. Palit[4]
[1]*Department of Physics, SP College, Cluster University, Srinagar 190 001, India*
[2]*Cluster University Srinagar, Jammu and Kashmir, 190 001, India*
[3]*Department of Physics, National Institute of Technology, Srinagar, 190 006, India and*
[4]*Department of Nuclear and Atomic Physics,*
Tata Institute of Fundamental Research, Colaba, Mumbai, 400 005,India

Investigations of the ground state bands of nuclei at A $\sim$ 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.

A dramatic increase in apparent moment of inertia was first discovered [1] in ^{160}Dy at an angular momentum of I $\sim$ 16$\hbar$, and is now well established as a general feature of nuclear rotation. In well deformed, axially symmetric nuclei, backbending has been understood [2] to be due to the alignment of the angular momentum of a pair of high-j nucleons along the rotation axis, so that the mean angular-momentum component along the symmetry axis (perpendicular to the rotation axis) is K=0. The aligned structure (s-band) becomes favored in energy at high spin and crosses the nonaligned structure (g band). In the A$\sim$ 160 mass region, where backbending is due to a pair of i$_{11/2}$ neutrons, it has been demonstrated that a new structure arises due to the Fermi-aligned coupling scheme which is active in the middle of the neutron shell (N $\sim$ 104). In this scheme the nucleon angular-momentum precesses about an axis lying between the rotation and symmetry axes. The projections of the angular momentum onto the symmetry axis, K, and the rotation axis, i, are both localized at a nonzero value. This differs from the strong-coupling scheme in which the nucleon angular-momentum precesses about

*Electronic address: gwhr.bhat@gmail.com

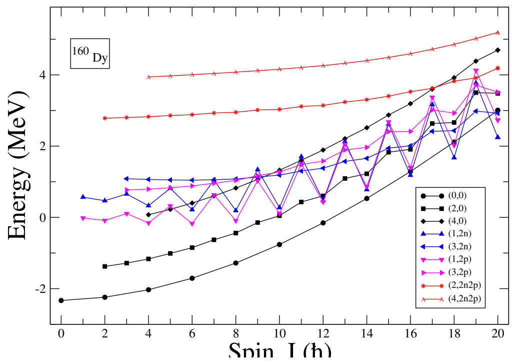

FIG. 1: Band diagram for ^{160}Dy nucleus. The labels (0,0), (2,0), (4,0), (1,2n), (3,2n), (1,2p), (3,2p), (2,2n2p) and (4,2n2p) correspond to ground, γ, 2γ, two neutron-aligned, γ-band on this two neutron-aligned state, two proton-aligned, γ-band on two this proton-aligned state, two-neutron plus two-proton aligned, $\gamma-$ and $\gamma\gamma-$ band built on this four-quasiparticle state.

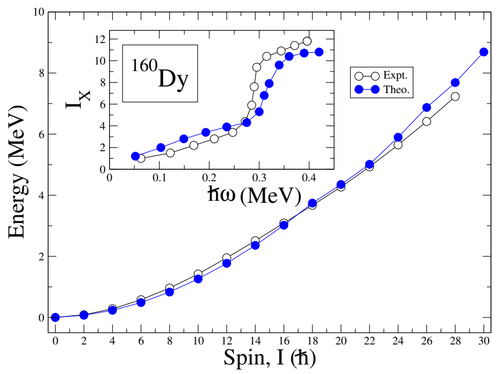

FIG. 2: Comparison of Experimental energies of the positive parity bands in ^{160}Dy as reported in Fig. 6 of Ref. [3] compared with the TPSM calculations. In the Fig. $I_{ref} = \omega\mathcal{J}_0 + \omega^3\mathcal{J}_1$ is subtracted with $\mathcal{J}_0 = 23\hbar^2\text{MeV}^{-1}$ and $\mathcal{J}_1 = 90\hbar^4\text{MeV}^{-3}$.

the nuclear symmetry axis resulting in good K, with $< i >= 0$. States formed from a pair of Fermi-aligned nucleons have $K = |K_1 \pm K_2|$ and $i = |i_1 \pm i_2|$, resulting in the usual s-states, having K $\sim$ 0. The s-band compete for "yrast" status corresponding to nuclear rotation. The clear nature of this competition is not yet clear and needs explination.

Several theoretical approaches have been developed to describe the backbending phenamena in a microscopic way that include quasiparticle phonon, multi-phonon, dynamic deformation, the quasiparticle random phase approximation (QRPA) based on the rotating mean-field. Recently, the microscopic approach of the triaxial projected shell model (TPSM) has been developed to describe the high-spin band structures in transitional nuclei. In this approach, the three-dimensional projection method is applied to project out the good angular-momentum states from the triaxial intrinsic states. From the symmetry requirement, the projection from the self-conjugate vacuum state leads to even-K states with K=0,2, 4,... The K=0, 2, 4 states represent the main components of the ground-state, γ- , and $\gamma\gamma$-bands at low spin. Fig. 1 illustrates how the non-rotating quasiparticle basis states of the TPSM become entangled with increasing angular-momentum. The ground-state band is crossed by the $(1, 2n)$ band, which is a two-quasineutron aligned configuration having K=1, at I=16. Further, the two-quasiproton aligned band, (1,2p), with K=1 also crosses the ground-state band at I=18. From wavefunction analysis it is demonstrated that the yrast band is dominated by (1,2n) configurations. In Fig. . 2 we present the comparison between the theoretical results and the experimental data for the positive parity bands. For the yrast band of ^{160}Dy, the agreement with experiment is very good, only in the upbending region a slight deviation is observed. To examine further the quasiparticle structures of the observed band structures, we have analyzed the alignments of the bands as a function of the rotational frequency and the results are presented in Fig. 2 (inset). The observed ground-state band has a gradual increase in the alignment at a rotational frequency of $\hbar\omega = 0.3$ MeV. This increase is also noted in the TPSM calculated alignment, although it is slower than in the experimental data. This increase can be traced to the alignment of four-quasiparticle (2n2p) having K=2. This configuration crosses the ground-state band at I=20-22 and becomes the dominant component in the ground-state band above this spin value as is evident from wavefunction analysis.

In conclusion the yrare band in ^{160}Dy up to high spin, namely, the I$\sim$30$\hbar$, which allowed to accurately determine the interaction strength between the ground state band and the s-band i.e., the backbending. This is the strongest interaction firmly established for a nucleus in the rare earth region.

References

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