Influence of proton and neutron alignment on shears mechanism: A case in mass ∼ 140 region

A. Goswami*
Nuclear Physics Division, Saha Institute of Nuclear Kolkata - 700064, INDIA

Shears mechanism [1] has been observed more than a decade ago, and represents a mechanism for the generation of angular momentum in nuclei which are almost spherical or weakly deformed. It leads to rotation-like band structures in the excitation spectra. The experimental signature of this mechanism is the gradual reduction in the reduced transition strength with spin along the bands.

In the shears mode of excitation, the coupling of angular momentum vectors produced by the nucleons is the basic process for generating the total spin of the nuclei. For the weakly deformed nuclei, few proton quasi-particles occupy the high-j particle-like orbitals while the neutron quasi-particles fill up the high-j hole-like orbitals, or vice versa. A perpendicular coupling of their angular momenta is energetically favored because it maximizes the overlap of spatial density distribution. This coupling results in a substantial transverse component of the magnetic dipole moment vector and gives rise to large magnetic dipole transition probabilities. As the magnetic dipole moment rotates about the axis of the total angular momentum, this mode is called Magnetic Rotation (MR). An alternative arrangement of the proton and neutron angular momentum vectors exists which also breaks the symmetry about the total angular momentum vector, termed as Antimagnetic Rotation (AMR). In this description the angular momentum is generated by the closing of the two blades of conjugate shears, produced by the valence particles (holes). These valence particles (holes) are initially aligned in time reversed orbits at the band head. There is no net perpendicular component of the magnetic dipole moment for this configuration and it is symmetric with respect to a rotation by π about the total angular momentum axis (rotational axis). The resulting quadrupole transition strength will decrease with the increase in spin along the band due to the gradual closing of the angular momentum blades. Thus shears mechanism, manifested in both MR and AMR band, has been predicted [1] as a general mechanism for the generation of angular momentum for weakly deformed systems.

The gradual closing of the angular momentum blades will ultimately lead to the termination of the band (both MR and AMR) generating maximum spin due to the complete superposition of the angular momentum vectors. But it was observed in the case of MR bands only, that the angular momentum is generated much beyond the predicted maximum value. This was interpreted as the re-opening of the shear structure due to the crossing of a two different configurations resulting from particle alignment. In $A \sim 140$ region, multiple MR bands have been observed in the Eu and the Gd isotopes [2, 3]. Configurations were assigned to these bands to reproduce the $B(M1)$ values from different model calculations. It has been observed that these MR bands have identical proton configurations but differ with respect to the neutron alignments. No such band crossing was observed in the case of AMR band till date.

In the present work, observation of multiple MR bands due to the alignment of protons in ^{143}Eu is reported and compared its characteristics with the neighboring nuclei. Also the observation of an AMR band is reported for the same nucleus. The AMR phenomenon in the present case has been established on the basis of the decreasing $B(E2)$ values with in-

*Electronic address: `asimananda.goswami@saha.ac.in`

creasing spin for the band of interest. Furthermore, a sudden increase of the $B(E2)$ value, at higher spins, followed by another rapid decrease has been observed. This is the first nucleus to exhibit such a behavior and is a novel feature in the context of the AMR band and discussed in the light of band-crossing due to proton alignment.

High-spin dipole and qudrupole structures in ^{143}Eu have been populated using the reaction ^{116}Cd (^{31}P, 4n) and the de-excitation γ rays were detected using INGA stationed at TIFR. The two dipole bands with opposite parity have been firmly identified from the γ -ray anisotropy and linear polarization measurements. The level lifetimes of both the bands have been measured using the DSAM technique. The deduced experimental $B(M1)$ values for the two dipole bands have been compared with the SPAC model calculations [4]. These calculations demonstrate the origin of the two dipole bands as MR. The large change in the $B(M1)$ values between the two dipole bands is attributable to the alignment of an additional proton, excited across the $Z = 64$ subshell closure into the $h_{11/2}$ orbital. This is the first such observation in this mass region.

The deduced $B(E2)$ values from the lifetime measurements of the states in the qudrupole band decrease with increasing spin, indicating the bands to be of AMR origin. The sudden rise of the $B(E2)$ value at $63/2^+$ may be due to crossing of the two AMR bands. It may possibly be associated with the emergence of a new double shear structure. This possibility is also supported by the fact that the original AMR structure can generate spin only upto $63/2^+$ and the observed states with higher angular momentum must have a different single particle configuration, resulting in a re-opening of the shear structure. This new structure can be visualize as two additional $h_{11/2}$ protons in time reversed orbits start to align at the spin $63/2^+$. This is in addition to the rotation aligned spin (59/2) due to the initial structure. The present measurements conclusively establish AMR in the $A \sim 140$ region. This observation outside the $A \sim 100$ region establishes the AMR phenomenon as an alternative mechanism for generation of high angular momentum states in weakly-deformed nuclei.

References

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