Generation of angular momentum in weakly deformed nuclei in mass ∼ 140 region

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Introduction

Curiosity about the nuclear structure enkindles us to investigate the interaction and excitation mechanism of its constituent, both experimentally and theoretically. Over the decades, with the invent of advanced heavy ion accelerators and detection techniques, different types of exotic phenomena viz. superdeformation, shape coexistence, chirality and shears mechanism have been observed for the nuclei in different region of periodic table. In this respect, the generation of angular momentum for nuclei in the shell closure region always draws our special attention as rotation is forbidden quantum mechanically in these nuclei. Therefore, the observation of band-like spectrum in the weakly deformed nuclei can only be explained by the angular momentum coupling of the different orbitals.

Investigations of the aforesaid mechanism in weakly deformed nuclei in $A \sim 140$ mass region are the key subject of the thesis. For these nuclei, the excited nucleons may occupy different orbitals and due to the opposite shape-driving forces of the protons and neutrons and different excitation mechanisms responsible for the generation of angular momentum are expected. Indeed, in the present work, two nuclei viz ^{143}Eu and ^{142}Sm ($N = 80$), studied using the technique of in-beam γ spectroscopy, manifested different excitation modes of shears mechanism. Magnetic and antimagnetic rotational (MR and AMR) bands were observed in ^{143}Eu nucleus [1, 2] which demonstrate the shears mechanism as a viable mode of generation of angular momentum in weakly deformed systems. Triaxial bands were observed in ^{142}Sm [3] in addition to axially symmetric deformation, depict the existence of shape co-existence. Multiple MR bands due to proton alignment were also observed in ^{143}Eu nucleus. The observed band structures were interpreted in the frame work of different theoretical models.

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Results and Discussion

The thesis reports the results of the spectroscopic investigations of $N = 80$ ^{142}Sm and ^{143}Eu nuclei populated through the fusion-evaporation reaction ^{31}P (^{116}Cd, p4n and 4n). The de-exciting γ rays were detected using the Indian National Gamma Array (INGA) of nineteen Compton-suppressed clover detector. The various characteristics of the excitation scheme were extracted from the time stamped data using the coincidence relationship, relative intensity, evaluation of directional correlation orientation ratio and polarization measurements. The level lifetimes of states in the bands have been measured using the DSAM technique.

The previously known level scheme of the ^{142}Sm nucleus has been extended substantially, both in the low and high spin regions. Several new rotational bands have been established. The irregular structures in the low excitation energy in ^{142}Sm have been well understood in the light of the shell model calculations. The deduced $B(M1)$ values for the dipole band have been compared with the semiclassical shears mechanism with the principal axis cranking (SPAC) model, and has been interpreted as a MR band. Comparisons between the experimental characteristics and cranked Nilsson-Strutinsky (CNS) calculations for the observed quadrupole bands indicate that they are formed on the triaxial deformed shape of ^{142}Sm. Thus, two different nuclear shapes exist in the ^{142}Sm nucleus for the dipole band and quadrupole bands which occurs almost same excitation energy of the excited spectrum. The existence of the two stable nuclear shapes at the same excitation energy reveals that the shape coexistence exists in ^{142}Sm.

The earlier studies in ^{143}Eu have established two band like structures with bandhead spins of 35/2 and 41/2 connected by dipole transitions and a quadrupole structure above 27/2 state. In the present investigation, lifetimes of the states in dipole and quadrupole structures have been determined using the DSAM and the parity of the states has been confirmed from polarization measurements. Deduced decrease nature of the experimental $B(M1)$ values for the dipole bands have been compared with the SPAC model calculations with the configurations $\pi h^2_{11/2} \otimes \nu h^{-2}_{11/2}\ \pi g^{-1}_{7/2}$ and $\pi h^3_{11/2} \otimes \nu h^{-2}_{11/2}\ \pi g^{-2}_{7/2}$, respectively. The experimental $B(M1)$ values as well as rotational frequencies ($\hbar\omega$) have been well reproduced with the SPAC model calculations. These calculations demonstrate the origin of the dipole bands as magnetic rotation. The large change in the $B(M1)$ values [$\sim 2.5\ \mu_N^2$] between the dipole bands is due 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 [1].

The deduced $B(E2)$ values for the quadrupole band in ^{143}Eu show a rapid decrease up to the state with spin-parity $59/2^+$ [marked as (I) in Fig. 1]. For the next higher lying state at $63/2^+$ it shows a sudden increase and again continues to decrease along the band [marked as (II) in Fig. 1]. The rapid increase of the $J^{(2)}/B(E2)$ ratios with increasing spins before the band crossing clearly excludes the possibility of structure I having a smoothly terminating origin. The trend of the $B(E2)$ values and the $J^{(2)}/B(E2)$ ratios are the definitive experimental signatures for the AMR phenomenon as far as structure I is concerned. The experimental results were reproduced well within the semi-classical model calculations with configuration $\nu h^{-2}_{11/2}$ $\pi(d_{5/2}/g_{7/2})^{-3} \otimes \pi h^2_{11/2}$. This can be viewed

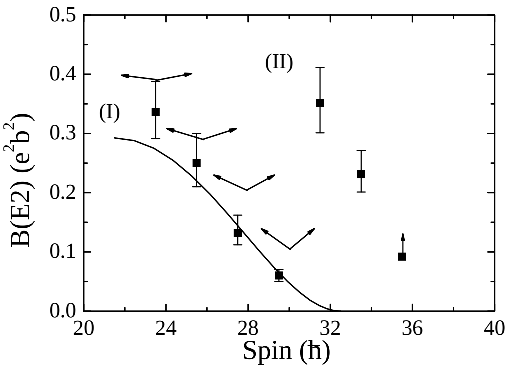

FIG. 1: Experimental $B(E2)$ values with spin ($\hbar$) for the quadrupole bands in ^{143}Eu. Arrows depict the relative orientation of the $h_{11/2}$ proton blades for structure I.

as conclusive evidence for an AMR interpretation of structure I and places it on equal footing with observations in the A $\sim$ 100 region. 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 but the possibility of smooth band termination cannot be ruled out [2]. Thus, no firm interpretation could be given to structure II from the present measurements.

In summary, The present measurements conclusively establish the shape coexistence exists in ^{142}Sm and shears mechanism ^{143}Eu in the $A \sim 140$ region. The observation of shears mechanism in a single nucleus outside the $A \sim$ 100 region establishes the shears mechanism as an alternative mechanism for generation of high angular momentum states in weakly-deformed nuclei.

References

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