Structural evolution and symmetry breaking features of exotic nuclei

T. Trivedi*

Department of Pure & Applied Physics, Guru Ghasidas Vishwavidyalaya, Bilaspur- 495009, INDIA

Atomic nucleus exhibits a fascinating variety of shapes and phenomena due to nucleon-nucleon interactions inside the nucleus. Particularly, nuclei with mass A $\approx$ 70, are known to display strong shape competitions and rapid shape changes with Z, N, and spin. The present high-spin spectroscopic data on these nuclei will highlight different aspects of shape evolution, shape coexistence and γ-vibrational bands. The observed high spin structure of these nuclei will be described by cranked Nilsson-Strutinsky model and total Routhian surface calculations.

1. Introduction

Nuclei in the mass A=70 region provide a unique and rich testing ground for the study of exotic shapes and structural phenomena associated with fundamental symmetries. Nuclei in this region of the nuclear chart are known to exhibit rapid changes in the structure with the number of protons and the number of neutrons. This has been attributed due to the availability of valence proton and neutrons in the unique parity $g_{9/2}$ intruder orbital and existing large shell gap in the Nilsson single-particle spectrum at different deformations and particle numbers. An important aspect of nuclear studies is to perform investigations at extreme of angular momentum, excitation energy and other nuclei lying far away from beta stability. The spectroscopic studies of nuclei under these extreme conditions lead to the discovery of various nuclear phenomena like shape co-existence, identical bands, band termination, magnetic rotation, super deformation and hyper deformation etc[1].

In the present talk, systematic will be discussed for the high spin structure of A $\sim$ 70 nuclei in Ge-Br region including some of the nuclei, viz., ^{68}Ge, ^{72}Se and ^{73}Br, studied with Indian National Gamma Array (INGA) at TIFR, Mumbai and IUAC, New Delhi. The spectroscopic studies of these nuclei offer valuable insight into several nuclear structure aspects that shed light on various exotic phenomena like shape coexistence, shape evolution, octupole correlations and existence of multiple gamma bands. Further, lifetime measurements of high spin states give appreciated information about the B(E2)s which can provide deeper insight into these issues.

2. Shape coexistence and shape evolution in ^{73}Br nucleus

Shape coexistence is a manifestation of delicate interplay between single particle and collective excitation in such a way that nearly degenerate states with different shapes are observed in a single nucleus. This kind of competition of shape is of particular importance in characterizing the evolution of nuclear shapes near the shell closure. However, due to the lack of experimental data, it is a challenging task for nuclear models to explain this phenomenon. Motivated by these considerations, the detailed spectroscopy of ^{73}Br has been carried out by S. Bhattacharya *et al.,* in a recent publication [2]. The lifetime of high spin states have been measured using Doppler shift attenuation method. In ^{73}Br nucleus, two strongly coupled bands have been identified with rotational positive parity band at $9/2^+$ state. We have also identified interconnecting transitions between these positive parity bands. The R_{DCO}, R_{ADO} and IPDCO measurements confirm the mixed nature of these E2 and M1 transitions. These characteristic measurements shows the shape-coexistence at the $17/2^+$ state in positive parity band. Further, from lifetime measurements, the transitional quadrupole moment has been extracted. The variation of transitional quadrupole moment as a function of spin/frequency shows clear reduction which confirms the loss of collectivity for this band. The experimental results have been interpreted in terms of the cranked Nilsson-Strutinsky model and total Routhian surface calculations. A good agreement has been ob-

*Electronic address: ttrivedi1@gmail.com

served between experimental data and calculations which clearly indicate possible band termination at higher spin.

3. Octupole correlations in ^{72}Se

Compared to the A∼ 200 and 150 mass regions, the nuclei in the vicinity of A∼ 70 region are relatively less studied for octupole correlations. The octupole correlations occur mainly due to availability of angular momentum Δj=3, and presence of Fermi level between an intruder orbital and a normal parity orbital. The presence of $p_{3/2}$ and $g_{9/2}$ intruder orbital in this mass region makes it an ideal platform to search for octupole correlations. The average value of B(E1)/B(E2) ratio in ^{125}Ba [3] nucleus is found to be $\approx 0.035{\times}10^{-6} fm^2$, whereas in ^{73}Br the values are $\approx$ $0.01{\times}10^{-6} fm^2$ respectively [2]. Similarly, for ^{72}Se it is found to be $\approx$ $0.03{\times}10^{-6} fm^2$. Further the strength of the enhanced B(E1) transition is also found to be similar in these nuclei having the values of $\approx$ $1.1{\times}10^{-4}$ W.u. These characteristics confirm the existence of octupole correlations in ^{72}Se nucleus.

4. Evidence for Z(4) symmetry in ^{68}Ge

An atomic nucleus is a fundamental and unique laboratory of nature for investigating the relationships among the fundamental symmetries. The nuclei can undergo a phase transition between different shapes which is a challenging problem for nuclear models to describe the properties of the nucleus in the phase transition region due to lack of experimental data [4]. The collective motion of a deformed nucleus creates rotation as well as vibration, which is described by deformation parameter β and γ. The most common low-lying collective vibrational band structure are known as β- band and γ- vibration band. The collective one phonon vibration with no component of angular momentum along the symmetry axis is known as β- vibration (K = 0). Whereas, the vibration of one phonon with a component of angular momentum along the symmetry axis (K = 2) is known as γ- vibration. The energy level of quasi γ- band have been identified as clear distinct patterns of angular momentum for different γ dependencies symmetry structure of nuclei. One of the important symmetry is Z(4), which lies very near to the second critical point E(5) symmetry structure. The Z(4) symmetry have been characterized by $R_{4^+/2^+}$ and $R_{2^+_\gamma/2^+}$. The calculated values of $R_{4^+/2^+}$ and $R_{2^+_\gamma/2^+}$ ratios have been found 2.23 and 1.77, respectively for ^{68}Ge nucleus. Another feature of Z(4) symmetry is the variation of staggering parameter S(J) as a function of spin for quasi-γ -bands. In ^{70}Ge and ^{108}Ru nuclei the E(5) symmetry is already predicted and has been compared with ^{68}Ge nucleus. We have also observed the fluctuations of quadrupole deformation parameter β and high fluctuations in the triaxiality parameter γ. These features predicts the existence of Z(4) symmetry in ^{68}Ge nucleus. Further, the experimental results have been compared with the total Routhian surface calculations within the framework of cranked shell model with Strutinsky shell correction.

5. Summary

The availability of clover detector array provides an opportunity to investigate high spin states to probe a wide variety of phenomena like shape coexistence, shape evolution and critical point symmetries in different nuclei throughout the nuclear chart. The variation of collective phenomena with both proton and neutron number has been investigated. The experimental results are well explained within the framework of cranked Nilsson-Strutinsky model and total Routhian surface calculations.

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