Collective rotation in ^{90}Zr beyond shell model excitations

Nidhi Goel[1],* Somnath Nag[1], P. Dey[2], and R. Palit[2]
[1]*Dept. of Physics, Indian Institute of Technology (BHU), Varanasi (U.P.), India and*
[2]*Department of Nuclear and Atomic Physics,*
Tata Institute of Fundamental Research, Mumbai 400005, India

Introduction

The nuclei near the closed shells become subject of considerable interest owing to emergence of high-spin rotational collectivity due to occupancy of high-j orbitals whereas the low-spin states are dictated by shell model like excitations. According to the principal axis cranking calculations, the nucleus can rotate around any of the three principal axes corresponding to three different minima for the total energy in the (ε, γ) plane. The rotation around the shortest axis is stabilized at $\gamma \sim 20°$ and $\gamma \sim$ -30° corresponds to the rotation around the intermediate axis. The classically forbidden rotation around the longest principal axis with minimum moment of inertia drives the nucleus towards $\gamma \sim$ -75°. Such rotations are manifested by the alignment of holes along the equator of the nucleus thereby generating the smallest J_{rig}. Such a phenomenon was observed for $E2$ cascade band in ^{142}Gd [1] where dominance of unpaired holes in $\pi(gd)$ and $\nu(ds, h_{11/2})$ can be clearly observed. Owing to striking similarity in proton and neutron valence Fermi level in $A \sim 150$ and 90 regions, it is expected to observe similar phenomenon in $A \sim 90$. With this motivation the nucleus ^{89}Zr was probed in at high angular momentum and rotation around the longest principal axis could be established [2]. However, unlike the $A \sim 150$ region, $A \sim 90$ region is mostly dominated by presence of dipole bands [3]. With the above motivations, it is interesting to understand the evolution of nuclear shapes in ^{90}Zr through cranked Nilsson Strutinsky model calculations [4].

Model Calculations

In the CNS model, the configurations are designated by the number of particles (holes) in orbitals labeled by N oscillator shell, which is further subdivided into high- and low- j shells. The breaking of rotational symmetry makes the signature quantum number $\alpha = 1/2$ or -1/2 a good quantum number for a nuclear state. The calculations are performed with κ and μ parameters fitted for the A = 80 region [4]. The static liquid drop reference used is the Lublin-Strasbourg drop (LSD) [8]. The calculations minimize the total energy for the different configurations with respect to the axial and triaxial deformation parameters, ε_2, ε_4, and γ respectively. The minimization is performed at different angular momenta. The configurations are labeled as per the nomenclature : $[p_1, n_1]$, where, p_1 and n_1 are the numbers of protons and neutrons in high-j $g_{9/2}$ orbital respectively.

Discussions

Stable minima in potential energy surface minimized with respect to ε_2, ε_4 and γ are followed as a function of spin ($12\hbar$ to $30\hbar$), see Fig. 1. At $I = 12\hbar$, the energy minimum is centered at non-collective oblate shape with very small ε_2 parameter, which is a common behavior in semi magic nuclei. With the increase in spin, the minimum does not deviate much from $\gamma \sim 60°$ though ε_2 increases to 0.1. Beyond $I = 20\hbar$, the nucleus coexists in two different minima. One is the non-collective oblate with approximately zero-deformation while the latter is also situated at non-collective $\gamma \sim 60°$ and $\varepsilon_2 \sim 0.1$. Beyond $I = 24\hbar$, evolution of three minima is ob-

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*Electronic address: `nidhi.goel.rs.phy18@itbhu.ac.in`

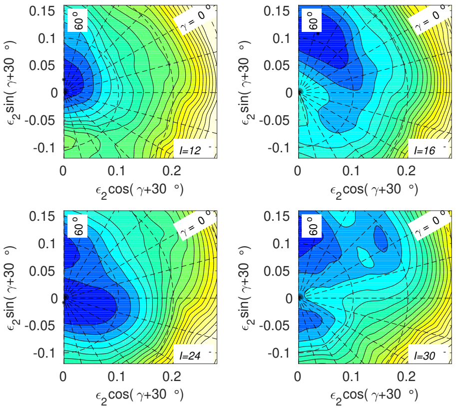

FIG. 1: Total energy surfaces for general scan run for spins $12\hbar$ to $30\hbar$. The contour line separation is 0.25 MeV.

served. One of the minima is around $\gamma \sim 60°$ whereas a second minimum converges around prolate deformation with $\gamma \sim 0°$. The third minimum corresponds to the triaxial shape. The nucleus ^{90}Zr, being a semi magic nucleus with 40 protons and 50 neutrons is expected to show shell model type of excitations up to high spin range [7], though deformation sets in at a cost of higher angular momentum and excitation energy. It will be interesting to probe the high-spin region experimentally as well as to explore the evolution of above said minima.

It is observed that the positive parity configuration $\pi(g^2_{9/2}) \otimes \nu(g^8_{9/2}(gds)^2)$ [2, 8] remains energetically favorable up to spin $20\hbar$. On the other hand, two signature partner degenerate bands [30, 9] $\pi(g^3_{9/2}) \otimes \nu(g^9_{9/2}(gds)^1)$ overtake the [2, 8] around $12\hbar$ and becomes favorable but the degeneracy is broken soon after $I = 16\hbar$.

The ground state band is compared with the positive parity [2, 8] configurations. Two negative parity bands 4 and 5 are observed experimentally which are characterised by intra band dipole transitions. If compared with the neighboring ^{89}Zr, these two bands should be potential candidate for rotation around the longest axis. The band 4 can be explained by contribution from $\pi(g^3_{9/2}) \otimes \nu(g^8_{9/2}(gds)^2)$. Band 5 also agrees well with configurations [30, 9] and [3, 8] respectively. The energy contours for [30, 9] configuration shows interesting behavior of semi magic nucleus. For lower spins up to 16 $\hbar$ the shape is stabilized with $\gamma \sim 60°$ and $\varepsilon_2 \sim 0.1$. The shape further collapses to non-collective oblate for higher spin states up to $I \sim 22\hbar$. Beyond $22\hbar$, the energy minimum shifts towards $\gamma \sim$ -45° which signifies probable rotation of the nucleus around the intermediate axis. Therefore, it should be quite possible that up to spin $22\hbar$ the configurations of the bands can very well be reproduced by large scale shell model calculations. However, experimental results are awaited to observe the high-spin phenomena as predicted by the model calculation.

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