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Structural Investigation of ^{101}Pd and Systematic in Neighboring Even-Z and Odd-N nuclei

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Abstract. Structural investigation of ^{101}Pd by E-GOS (E-Gamma Over Spin) method and systematic of $\nu h_{11/2}$ bands in neighboring even-Z and odd-N nuclei has been studied by plotting the ratio of Gamma Ray Energy divided by spin against that spin. Afterwards, we arranged the plots in order of increasing nucleon number. The concept of the E-Gamma Over Spin or E-GOS prescription has been applied to a number of even-even nuclei in vicinity of the A=110 mass region with the conclusion that many of these nuclei exhibit a decay sequence consistent with quasi-vibrational bands. Plotting the E-GOS curves in this manner shows a clear transition from vibrational to rotational motion like character in some bands.The concept of the E-Gamma Over Spin or E-GOS prescription has been applied to a number of even-even nuclei around the ~ 110 mass region. The level scheme of the ^{101}Pd has been studied within the framework of E-GOS approach. The results are interpreted using the E-GOS prescription, modified for use with odd-A nuclei. Both of these analyses highlight the role of the low-Ω intruder orbital in stabilizing the quadruple deformation in this region. The $\nu h_{11/2}$ bands in some neighboring even-Z and odd-N nuclei exhibit vibrational to rotational character.

KEY WORDS: Shapes coexistence, E-GOS calculations, Nuclear models

1 Introduction

The weakly deformed nuclei can be probed using nuclei with proton numbers that are between those of semi-closed $Z = 40$ and closed $Z = 50$ shells and neutron numbers that are near to that of shell closure at $N = 50$. New deformation-generating mechanisms have been discovered by theoretical interpretation of level structures from recent spectroscopic studies in these nuclei [1–4]. The presence of spherical and deformed geometries in this mass region primarily leads to complicated level structure, and the proton-neutron ($\pi\nu$) residual interaction predominates in odd-odd nuclei. The Pd ($Z = 46$) isotopes with the proton Fermi surface in the middle of the $g_{9/2}$ proton shell, serve as a platform for a number of fascinating occurrences. Changes in neutron number have an impact on these nuclei's structure, particularly in the neutron valence space with respect to the $N = 50$ core, which consisting of the $\nu d_{5/2}$, $\nu g_{7/2}$, $\nu d_{3/2}$ and $\nu s_{1/2}$ orbitals. When the neutron number of a Pd isotope is above N = 54, the prolate-driving low-Ω $\nu h_{11/2}$ intruder orbital begins to fill up, and configuration-dependent triaxiality based phenomena are produced as a result of the competing shape-driving ability of the $\nu h_{11/2}$ and $\pi g_{9/2}$ orbitals [5–7]. There are a number of novel phenomena that have been discovered, including magnetic rotation (MR), smooth band termination (ST), and antimagnetic rotation (AMR), wherein angular momentum is generated by the gradual alignment of the angular momenta of the valence proton hole and the neutron particle, which have different initial geometrical compositions. These phenomena exhibit band structures with different magnitude and the trends of dynamic moment of inertia and the transition rates as a function of angular momentum. The angular momentum contributions of the particles and holes in open shells, are able to compete energetically with weakly deformed collective structures in mass A $\sim$ 100 region. Further, it reaches a maximum value for a given single-particle configuration where the band terminates. Such terminating phenomenon is fruitful to study the disappearance of quantum many-body collectivity. Rotational interpretations for collective structure such as cranked shell model (CSM) [8] are mainly tools in the analysis of yrast states. One of the new approaches called E-GOS (E-Gamma over spin) curves has been introduced by P.H. Regan et al. [9, 10]. Regan et al. have suggested a simple approach, namely the E-gamma over spin (E-GOS), which can be used to limit the shape and phase evolution between vibrational and rotational modes in nuclei as a function of spin. The E-GOS (E-Gamma Over Spin) approach enables us to compare to the ideal limitations of perfect harmonic vibrator and axially symmetric rotor in order to experimentally establish the structure of a nucleus as a function of its angular momentum. Moreover, new approach for E-GOS curves, which invoke no structural presumptions and allow vibrational and rotational behavior, and the transition between the two can be conversed in the low-lying states in A$\sim$110 mass region nuclei. By analyzing structure evolution as a function of angular momentum rather than as a function of nucleon number, this method varies from other widely used models. In present paper we reported Structural investigation of ^{101}Pd by E-GOS method and systematic of $\nu h_{11/2}$ bands in neighboring even-Z and odd-N nuclei. Even though it has been noted in the literature that the electric quadruple transition rate in the purportedly rotational and vibrational bands of the decay schemes are quite comparable, it is still challenging to directly discern between bands that are vibrational and those that are rotational [11].

2 Results and Discussion

Numerous even-even nuclei in the vicinity of the $A \sim 110$ mass region [9, 10] have been studied using the E-Gamma Over Spin (E-GOS) prescription; it was found that many of these nuclei exhibit a decay sequence that is consistent with quasi-vibrational excitations at lower spins, which gives way to more statically (weakly) deformed sequences above spins of $10\hbar$. The population of $\nu h_{11/2}$ neutron orbitals, which are found low in the shell, are generally thought to be responsible for this change in structure due to their prolate-shape-polarizing influence or stiffening of the nuclear mean field. When we plotted the theoretical limitations, you can see that the curvatures of the vibrator and rotor functions are noticeably different. Limits predictions show a distinct hallmark of a vibrating nucleus as a hyperbolic reduction in R with spin, and for a rotor, R actually rises at low spins [9, 10]. We, thus, propose plots of $R = E_\gamma(I \longrightarrow I-2)/I$ versus I as a simple prescription for distinguishing rotational and vibrational ranges of spin. We call the trajectories in such plots E-GOS curves are very well explained in the recent work [9, 10]. Note, R is an experimentally determined quantity based on well-defined observables, and includes no rotational ansatz or the model-based concepts of rotational frequency and moment of inertia [9,10]. Moreover, in the framework of E-GOS, the phenomena of a vibration-to-rotational crossing appear to be prevalent in many nuclei in A∼110 mass region [9, 10]. The low-lying states in nuclei with A∼110 have long been proposed as among the best examples of quadrupole vibrational structures in the nuclear chart. The higher-spin yrast states of many of these nominally vibrational nuclei often demonstrate a weakly deformed behavior, with sequences of stretched E2 transitions which can be described as rotational bands [9, 10]. Although the predicted small quadrupole deformations in these systems give rise to very large Coriolis effects, which in turn lead to the observation of what are described in the CSM as rotational alignments. To investigate the observed bands (band head spin ($j \neq 0$)) for the rotational and vibrational character, the renormalized E-Gamma Over Spin (E-GOS) approach described by P. H. Regan et al. [9, 10] was used, where the renormalized RE-GOS for odd-A nuclei is given by, $R_{\text{E-GOS}}(I-j) = (E_\gamma - jR_{j+2})/(I-j)$, where $R_{j+2} = R(I = K+2) = [E_\gamma(I = j+2 \rightarrow j)]/[I(j+2)]$. The E-GOS curve which is an empirical approach to distinguish vibrational from rotational regime is provided in Figure 1 for various positive and negative-parity bands, respectively, in ^{101}Pd [12,13]. Here for the discussion, we kept the bands B1-B7 as presented in previous work [12]. The E-GOS curve for bands B1 and B2 exhibit a decreasing trend and attain a nearly constant value after spin $(I-j) = 8\hbar$, which indicate that both the bands based on $\nu d_{5/2}$ and $\nu g_{7/2}$ orbitals transit from

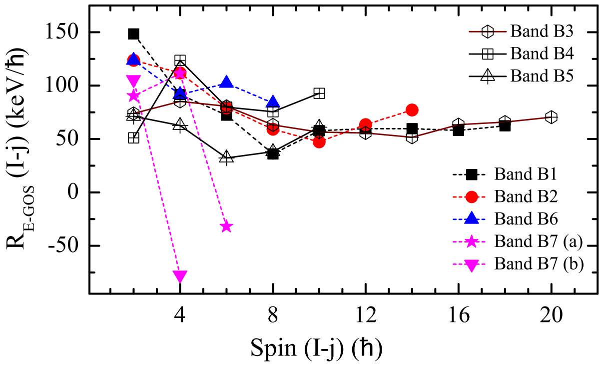

Figure 1. E-GOS plot for the positive-parity bands B1, B2, B6 and B7 and the negative-parity bands B3, B4, and B5 in ^{101}Pd [12].

vibrational to rotational character. The EGOS trajectory for band B6 is not that sharp as observed for bands B1 and B2 which indicate the presence of mainly rotational character. The rotational character of band B3 based on $\nu h_{11/2}$ is nicely depicted by E-GOS curve. The band B4 is also rotationally evolved band whereas E-GOS curve for band B5 indicate the slightly vibrational character at lower spin values which evolve into rotational band. These data come from our recent experiment performed by the Pelletron- LINAC facility at TIFR, Mumbai and published [12]. In present work only the E-GOS curve for $\nu h_{11/2}$ bands systematic in neighboring even-Z and odd-N nuclei is presented.

3 EGOS Systematic of $\nu h_{11/2}$ Bands in Neighboring Even-Z and Odd-N Nuclei

The systematics of the neighboring even-Z, $N = 55$ and 57, and $\nu h_{11/2}$ bands are shown in Figures 2 and 3, respectively, together with their E-GOS systematics. In lower spins, the $\nu h_{11/2}$ bands in ^{97}Ru ($N = 53$), ^{99}Pd ($N = 53$), and ^{103}Cd ($N = 55$) are vibrational in nature, and as spin increases, they take on a rotational nature. The $\nu h_{11/2}$ bands in ^{99}Ru ($N = 55$), ^{101}Pd ($N = 55$); ^{101}Ru ($N = 57$), ^{103}Pd ($N = 57$), and ^{105}Cd ($N = 57$) exhibit rotational character. The data used to plot these $\nu h_{11/2}$ bands in Figure 2 is obtained from the previously published publications [12, 14–18]. Back bending behavior would be described as a change in the moment of inertia between two rotating phases following a Coriolis-driven pair breaking in the context of the standard rotational model, *i.e.* Cranking Shell model (CSM). However, as Figures 1 and 3 clearly depicts, the E-GOS plot for the same data allows an alternative explanation, namely, the evolution from a vibrational structure at lower spins to a rotational sequence above spins of (10-12)$\hbar$. This interpretation suggests a crossover between a deformed minimum and the (anharmonic) vibrational ground state con-

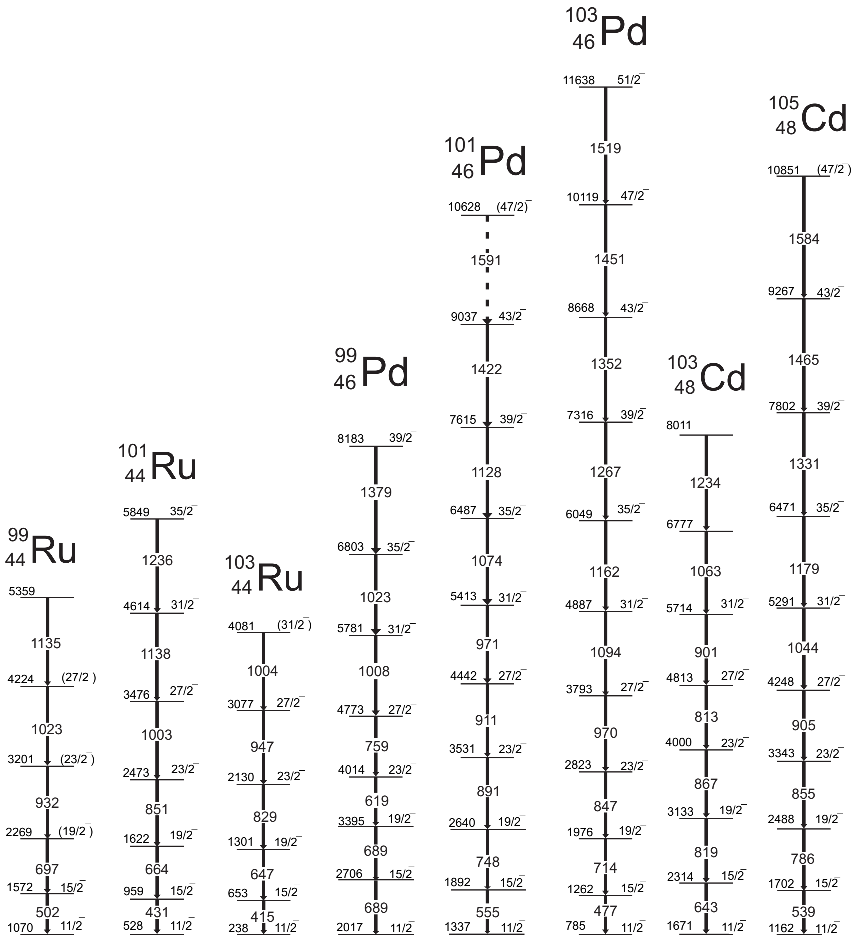

Figure 2. The $\nu h_{11/2}$ bands in neighboring even-Z and odd-N nuclei [12, 14–18].

figuration rather than requiring a rotational phase at lower spin [9, 10]. To study the rotational properties of the observed band structures, the experimental level energies and spin values have been translated into the rotating frame of reference following the prescription of Bengtsson and Frauendorf [19], and using the Harris parameters $J_0 = 8.9\hbar^2$ MeV^{-1} and $J_1 = 15.7\hbar^4$ MeV^{-3}. The alignment plots for the bands B1and B2 are shown in Figure 4. The initial band crossover in the $\nu d_{5/2}$ band (B1) is observed at $\hbar\omega = 0.32$ MeV which lies lower than that observed at $\hbar\omega \approx 0.32$ MeV for the $\nu g_{7/2}$ band (B2). The experimental alignment gain in bands B1 and B2 are high $\sim 7\hbar$ which along with the blocking arguments do not favor the $(\nu d_{5/2})^2$ or $(\nu g_{7/2})^2$ pair alignment. Therefore, the likely candidate responsible for the observed alignment gain $\sim 7\hbar$ in bands

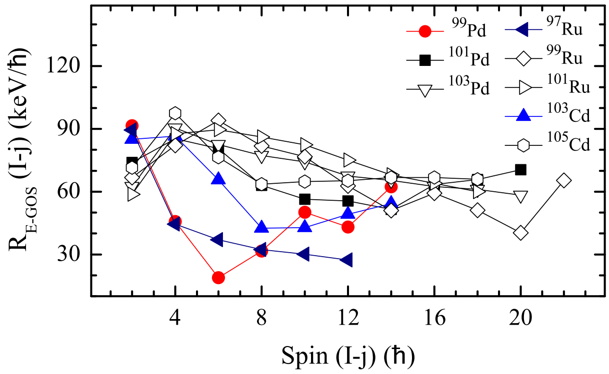

Figure 3. The $\nu h_{11/2}$ bands in neighboring even-Z and odd-N nuclei [12, 14–18]

B1 and B2 is the $(\pi g_{9/2})$ pair [12]. It's also noteworthy to observe that dipole cascade and crossover transitions are present in band B2 above the 27/2$^+$ level. Characteristic is very comparable to that seen in the level structure above the $\nu g_{7/2}$ band in ^{99}Pd [14]. The alignment plots for the $\nu d_{5/2}$ and $\nu g_{7/2}$ bands in odd-A ^{99,101,103}Pd isotopes [12, 14, 15] are shown in Figure 4. The alignment plots for the coupled level structure lying above the $\nu g_{7/2}$ band in ^{99}Pd [14] shows close similarity with that observed for the high spin coupled part of band B2 above the 27/2$^+$ level. It indicates the similar structure of these bands. The $\nu g_{7/2}$ band in ^{103}Pd [15] is not observed to evolve to such band structure. The lowest excited negative-parity band B3 consisting of $\Delta I = 2$ transitions are built on the favored signature of low-Ω orbital of $\nu h_{11/2}$ subshell [12, 13]. The first band crossing is observed at $\hbar\omega \approx 0.41$ MeV and the second band cross-

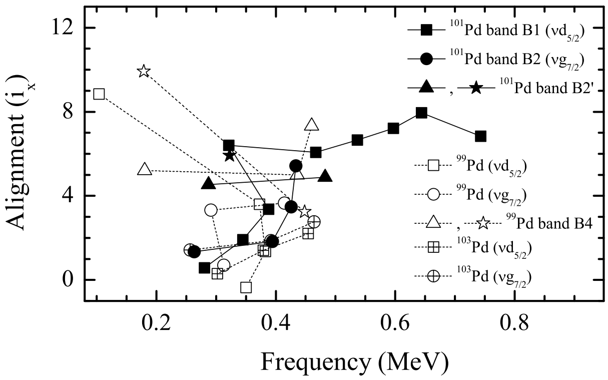

Figure 4. The $\nu d_{5/2}$ and $\nu g_{7/2}$ bands in odd-A ^{99,101,103}Pd isotopes [12, 14, 15]. The band B2' correspond to the coupled part of band B2 in ^{101}Pd [12].

ing is observed at $\hbar\omega \approx 0.53$ MeV. The $(\nu g_{7/2})^2$ and $(\pi g_{9/2})^2$ pairs are the likely candidates generating the total observed alignment gain of $\sim 7\hbar$, while the $(\nu h_{11/2})^2$ pair alignment is blocked in band B3.

4 Conclusions

The level scheme of the ^{101}Pd nucleus has been studied within the framework of E-GOS method. The results are explained using the E-GOS method, modified for use with odd-A nuclei. The quadruple deformation in this mass area is stabilized by the low-Ω intruder orbital, as shown by these two studies. The $\nu h_{11/2}$ bands in some neighboring even-Z and odd-N nuclei exhibit vibrational to rotational character at higher spins. It is evident that vibrational character at lower spin for the $\nu h_{11/2}$ bands in ^{97}Ru, ^{99}Pd and ^{103}Cd, which further evolving to a rotational character at higher spin. Instead, the predominant behavior of ^{99}Ru (N=55), ^{101}Pd ($N = 55$); ^{101}Ru ($N = 57$), ^{103}Pd ($N = 57$), and ^{105}Cd is rotating.

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