Transverse Wobbling: A New Collective Motion in Nuclei

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Deformed nuclei usually have an axial shape but may be triaxial in certain circumstances. There are two unique fingerprints of a triaxial nuclear shape: wobbling and chirality. Chirality has been reported in many regions of nuclear chart but wobbling has been observed rather sparingly.

The wobbling bands have been extensively identified in the triaxial strongly deformed region around N = 94, such as in ^{161,163,165,167}Lu, ^{167}Ta and ^{135}Pr [1–3], which are built on configurations that contain an odd $i_{\frac{13}{2}}$ proton. The highly aligned odd proton plays a pivotal role in generating the wobbling excitations. The presence of an odd $i_{\frac{13}{2}}$ proton drives the nuclear shape towards large deformation there by stabilizing atriaxial strongly deformed shape. In addition it causes a general lowering of the wobbling frequency. This decrease made it possible to observe the one- and two-phonon wobbling excitations as individual bands, because it prevented them from being immersed among the numerous particle-hole excitations. The triaxial shape of the rotor determines the orientation of quasiparticle with respect to its principal axes. However, it also determines the ratios between the three Moment of inertia (MoI). The MoI of the medium (m) axis is always the largest. This can be inferred from a simple argument that holds for any quantal system. The MoI is zero for rotation abouta symmetry axis and increases with the deviation from axial symmetry of the axis. The triaxial shape deviates most strongly from axial symmetry with respect to the m-axis,which results in the largest MoI. Therefore, for systems with angular-momentum of the odd-particle aligned along the m-axis of the core, which has largest moment of inertia, referred to as transverse mode, the wobbling frequency decreases with spin. This frequency increases if angular-momentum of the last particle is anti-parallel to the m-axis and has been called as the longitudinal mode. Different theoretical models like standard cranking model combined with the quasiparticle plus triaxial rotor model was proposed to describe the chirality and wobbling motion. This approach goes beyond the mean-filed approximation and could microscopically describe not only the yrast sequence but also the highly excited bands. However, this model could not provide better explaination for the sequence of transverse-longitudinal-transverse motion [4]. Recently, Triax- ial projected shell model (TPSM) [6], on the other hand, was able to explain the transition from transverse wobbling in ^{135}Pr to longitudinal wobbling in ^{135}La. This TPSM model has been successful in describing the γ-band, chiral symmetry breaking and wobbling motion in transitional nuclei with varying degree of success .

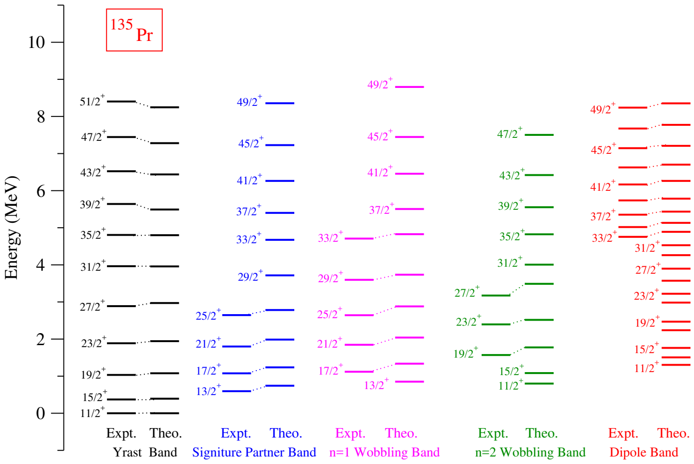

FIG. 1: Energy Spectra of ^{135}Pr nucleus.

In this work we have provided theoretical explination for the "transverse wobbling" in the ^{135}Pr nucleus. In the case of ^{135}Pr the one proton + two neutron quasi-

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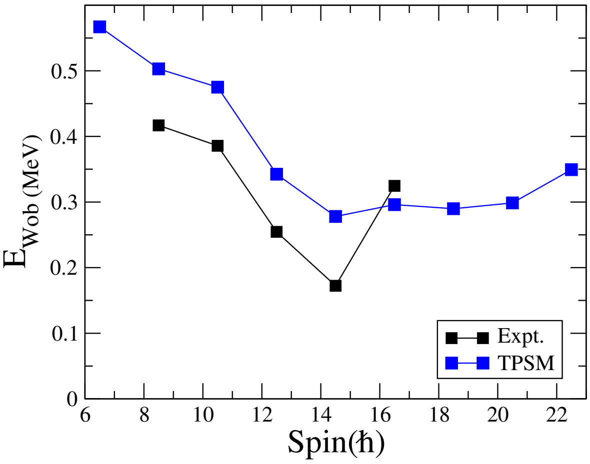

FIG. 2: Excitation energies of the wobbling band in ^{135}Pr.

particle states were generated by the solving the triaxial Nilsson and pairing (monopole and quadrupole terms) Hamiltonian in the BCS approximation [6]. The Nilsson potential with the deformation parameters $\varepsilon = 0.16$ and $\varepsilon' = 0.11$ have been used for ^{135}Pr which are consistent with the previous TRS calculation and observed systematic of Pr-isotopes. In the present TPSM calculation, the configuration space consisted of N$= 3,4,5$ major shells for neutrons and N$= 2,3,4$ for protons. The lowest 20 K-bands were obtained through angular momentum projection within the energy window of 2.5 MeV. The projected bands (basis states) were employed to diagonalise the shell model Hamiltonian consisting of pairing and quadrupole-quadrupole interaction terms. The interaction strengths used in the present calculations were the same as those used in the previous studies. The energies for the three bands after the diagonalisation are shown in Fig. 1. It is quite evident from the figure that calculated values are in good agreement with the experimental data.

The wobbling energies, E_{wob}, defined as:

$$\begin{aligned} E_{wob} &= E(I,n_\omega = 1) \\ &- [E(I-1,n_\omega = 0) + E(I+1,n_\omega = 0)]/2 \end{aligned} \tag{1}$$

were calculated from the level energies and were plotted in Fig. 2 as a function of spin. The wobbling energy is decreasing with angular momentum which along with the mixing ratio of interconnecting transitions suggests tranverve wobbling in ^{135}Pr. The general trend of the decreasing wobbling frequency is reproduced in our calculations with the TPSM. At $I \leq 14.5$, both the theoretical and experimental wobbling frequencies decrease with spin, which provides the evidence of transverse wobbling motion. The theoretical calculations overestimate the data at $I \leq 10.5$. The reason might be attributed to the fact that the angular momentum projection is not general approximation method. At the high spin region $I \leq 14.5$, the experimental wobbling frequency shows an increasing trend, indicating the wobbling mode transition from transverse to longitudinal type.

In summary, the nature of the wobbling mode in ^{135}Pr has been studied and excellent agreement is shown between TPSM and experimental data. Further, it is evident that a characteristic signature of the rotational spectrum for a wobbling nucleus is the observation of $DI = 1, E2$ interband transitions between the first wobbling band $(n_w = 1)$ and the yrast band $(n_w = 0)$, which is supported by the TPSM results. Further, it is confirmed that the wobbling mode in ^{135}Pr changes from the transverse to longitudinal one with the increase of rotational frequency. This transition is understandable by analyzing the effective MOIs of the three principal axes. It is pointed out that the effective MOI caused by the valence particle is of importance for forming different type of wobbling mode, and the softness and shapes of the collective potential determine the variation trends of the wobbling frequency.

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