Description of the Chiral Doublet Bands in ^{135}Nd nucleus

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Introduction

The interesting phenomenon that is associated with the triaxial deformation is the chirality in nuclei. It was proposed that the spontaneously broken chiral symmetry may take place in triaxially deformed nuclei when a particular angular momentum coupling scheme appears, where three angular momenta of the valence neutrons, the valence protons and the core are mutually perpendicular so that a left- and a right- handed systems can be formed [1]. Some of the experimental evidences for the doublet bands of chirality were reported in the mass region A $\sim$ 130, where the proton Fermi level lies in the lower part and the neutron Fermi level in the higher part of the $h_{11/2}$ subshell.

Since the first experimental evidence for chiral doublet bands was found in the odd-Z N = 75 isotones [2], more than 20 experimental candidates have been reported in the A $\sim$ 100, 130, and 190 mass regions, including odd- odd, odd-A and even-even nuclei [3]. On the theoretical side, many attempts have been made to describe the bands and to investigate the underling physics. These models include one-particle-one-hole-rotor model (PRM), tilted axis cranking (TAC) approximation, realistic TAC approaches, the Strutinsky shell correction method with a hybrid Woods-Saxon and Nilsson potential, the Skyrme Hartree-Fock model and the relativistic mean field model. These models have been developed to investigate this new phenomena with varying degree of success. Within the TAC mean field approximation, the left-handed and right-handed solutions are exactly degenerate. It is not possible to calculate the energy difference between the bands, which is the consequence of quantum tunneling between the two solutions. These chiral vibrations have been also studied in the framework of the random phase approximation (RPA) based on the TAC mean field. However, TAC + RPA is not able to describe the smooth transition from a slow vibration to quantum tunneling between the left- and right-handed mean field solutions. Particle rotor model (PRM) has been shown to provide a reasonable description of the most of the characteristics of the chiral bands, it is known to depict discrepancies with the observed data [4]. For instance, the measured B(E2) values for the yrast band in ^{128}Cs drop with spin and PRM calculations display opposite trend of increasing B(E2) with spin. Recently triaxial projected shell model (TPSM) gives a slightly better description of the observed data as compared to the PRM approach for ^{128}Cs [5]. In particular, it was shown that TPSM correctly reproduces the observed trend in the measured $B(E2)$ transitions as a function of spin. Quite recently, pair of degenerate bands in ^{108}Ag is studied using the microscopic TPSM. It is shown that the partner band has a different quasiparticle structure as compared to the yrast band [6].

TPSM Results

The basis space of the TPSM approach for odd-neutron nuclei is composed of one-neutron and two-proton quasiparticle configurations : $\{|\phi_\kappa = a_\nu{}^\dagger a_\pi{}^\dagger a_\pi{}^\dagger|0\rangle\}$. The Hamilto-

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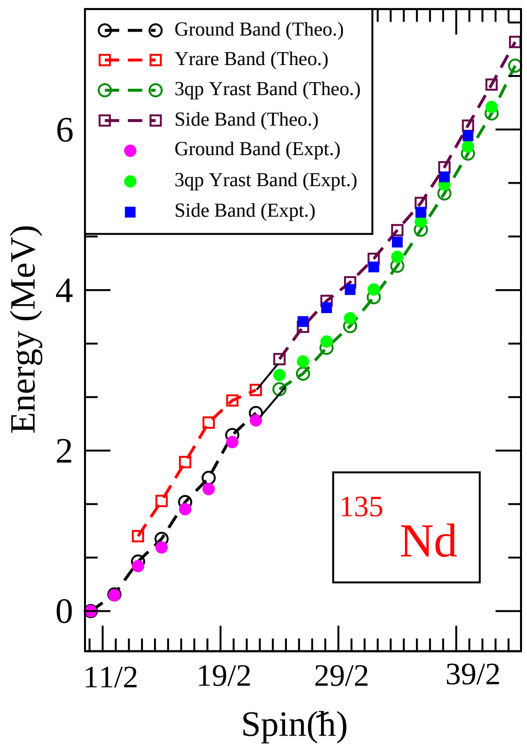

FIG. 1: Comparison of the measured energy levels for ^{135}Nd nucleus.

nian used in the present work is

$$\hat{H} = \hat{H}_0 - \frac{1}{2}\chi \sum_{\mu} \hat{Q}^{\dagger}_{\mu}\hat{Q}_{\mu} - G_M \hat{P}^{\dagger}\hat{P} - G_Q \sum_{\mu} \hat{P}^{\dagger}_{\mu}\hat{P}_{\mu}, \quad (1)$$

where $\hat{H}_0$ is the spherical single-particle shell model Hamiltonian, which contains the spin-orbit force. The second, third and fourth terms in Eq. (1) represent quadrupole-quadrupole, monopole-pairing, and quadrupole-pairing interactions, respectively. In the first stage of TPSM study, the triaxial basis space is constructed by solving three-dimensional Nilsson potential with deformation parameters of ϵ and ϵ'. In the TPSM calculations for the doublet bands in ^{135}Nd, the configuration $\pi h_{11/2} \otimes \nu h^{-1}_{11/2}$ is adopted. The deformation parameters ϵ = 0.223 and ϵ'= 0.100 for ^{135}Nd are obtained from the microscopic self-consistent triaxial relativistic mean field calculation [7].

The calculated excitation energy spectra Energy(MeV)) for the ground-, yrare and doublet bands for ^{135}Nd are presented in Fig. 1, together with the corresponding data [8]. The experimental energy spectra are excellently reproduced by the TPSM calculation. In more detail, the calculated energy spectra well reproduce the experimental results that show a energy separation from 400 keV at I = $29/2\hbar$ decreasing with spin to 100 keV at I = $39/2\hbar$. In this Letter, we want to touch another point. As an odd- nucleus, the chiral bands in ^{135}Nd are not built on the low-lying one-quasiparticle state, but on an excited three-quasiparticle state. In fact, it has been observed that the chiral bands would decay to the ground-state band based on $\nu h^{-1}_{11/2}$. The ground-state band together with the main partner of chiral bands composes the yrast band in ^{135}Nd. In conclusion the observed energies are excellently reproduced by 1-qp TPSM calculations in the lower spin region ($I < 23/2\hbar$) and by 3-qp TPSM calculations in the higher spin region ($I > 23/2\hbar$). Based on the analysis of the angular momentum components, it is illustrated that the yrast band changes from the electric rotation to chiral mode, which is supported meanwhile by the performance of electromagnetic transitions.

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