Nature of chiral symmetry in ^{134}Pr nucleus

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Introduction

We call any geometrical figure, or group of points, chiral, and say it has chirality, if its image in a plane mirror, ideally realized, cannot be brought to coincide with itself. Thus, a system is chiral if it is not symmetric with respect to mirror-reflection, $\hat{S}$, in any plane. However, the chirality of nuclear rotation does not concern the position vector, but rather the axial pseudo-vector of angular momentum. Therefore, it is represented by the operator $\kappa = \hat{T}\hat{R}^{\pi}$, where $\hat{T}$ time reversal operator and $\hat{R}^{\pi}$ is the rotation by 180^0. When chiral symmetry is broken in the body-fixed frame, the restoration of the symmetry in the lab frame is manifest as degenerate doublet $\Delta I = 1$ bands from the doubling of states. These structures arise from configurations in which the angular momenta of the valence proton, the valence neutron, and the core are mutually perpendicular [1]. The non zero components of the total angular momentum on all the three axes can form either a left-handed or a right-handed set and therefore, the system manifests chirality [2]. Pairs of bands possibly due to the breaking of the chiral symmetry have been found in a wide region of masses, namely A $\sim$ 105, A $\sim$ 130, A $\sim$ 190 experimentally. The majority of candidate chiral bands are reported in odd-odd nuclei, which have the configuration of one valence proton (neutron) particle and one valence neutron (proton) hole, such as Cs, Pr, La, Pm with $\pi h_{11/2} \otimes \nu h^{-1}_{11/2}$ configuration in $\sim$ 130 mass region. Among these nuclei, ^{134}Pr [3, 4] provides so far the best example of level degeneracy for selected states of the same spin and parity in the doublet bands being separated by energies smaller than 60 keV and has been so far taken as a sign of chiral bands[1, 2, 5]. It is quit evident that electromagnetic transition probabilities carry more stringent information on the intrinsic structure, including the chiral geometry, than excitation energies. Therefore, for an ideal chiral pair bands all corresponding properties such as energies, spin alignments, shapes, electromagnetic transition probabilities, etc. must be identical or, in practice, very similar. The observation of the identity is the necessary condition for claiming chiral bands.

To our knowledge, in only a few nuclei the electromagnetic transition probabilities of the nearly degenerate bands were measured: ^{134}Pr, ^{128}Cs, and ^{132}La. The reported BE2 $(I \rightarrow I-2)_{in}$ values for the two bands are clearly different in all three nuclei and, therefore, a condition necessary for identifying chiral pair bands is not fulfilled.

The purpose of the present study is to shed light on nature of the nuclear chirility on ^{134}Pr using the microscopic triaxial projected shell model (TPSM) approach [6]. It has been demonstrated that TPSM provides an accurate description of the high-spin properties of triaxial rotating nuclei. In a recent study, TPSM model has been generalized to study odd-odd ^{128}Cs nucleus in the mass $\sim$ 130 region [7].

TPSM Results

The basis space of the TPSM approach for odd-odd nuclei is composed of one-neutron

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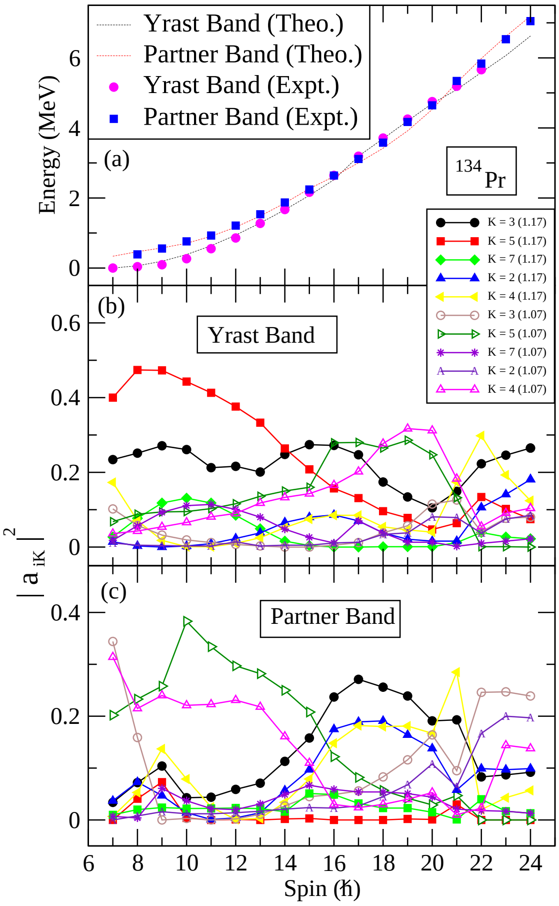

FIG. 1: Comparison of the measured energy levels of positive parity yrast and partner band for ^{134}Pr in panal (a). Wavefunction amplitudes for yrast band in panal (b) and partner band in panal (c).

and one-proton quasiparticle configurations : $\{|\phi_\kappa = a_\nu{}^\dagger a_\pi{}^\dagger|0\rangle\}$. The triaxial Nilsson Hamiltonian used in the present work is

$$\hat{H}_N = \hat{H}_0 - \frac{2}{3}\hbar\omega\left\{\epsilon\hat{Q}_0 + \epsilon'\frac{\hat{Q}_{+2}+\hat{Q}_{-2}}{\sqrt{2}}\right\}, \tag{1}$$

where $\hat{H}_0$ is the spherical single-particle shell model Hamiltonian, which contains the spin-orbit force. 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 present work, ϵ = 0.210 and ϵ'= 0.110.

The projected energies, obtained after shell model diagonalization, for the doublet bands in ^{134}Pr nucleus are depicted and compared with the corresponding experimental data in Fig. 1 it is evident from the figure that overall agreement between the calculated and the measured energies is quite remarkable. It is noted from Fig. 1 that the yrast-band is crossed by partner-band between I = 15 and 16; and again crossing is observed at I = 19. To infer the structure of the bands, the amplitudes of the wavefunctions for the dipole bands are displayed in Fig. 1(b) and (c). The structure of the dipole bands, as inferred from this figure, is some what surprising. It is noted that the yrast band is composed of K=3, 5 and 7 projected configurations originating from the same quasi-particle state (1.17). The partner band, on the other hand, is dominated by a K=4 and 5 configuration resulting from a different quasi particle state (1.07) as compared to the yrast band. Therefore, the present TPSM study demonstrates that the observed crossing of the yrast and the partner bands in ^{134}Pr is due to the crossing of the two-quasiparticle states having different intrinsic configuration. In conclusion, although the two bands are nearly degenerate ($13 < I < 19$) but they do not agree with what is expected for chiral bands.

References

[1] S. Frauendorf and J. Meng, Nucl. Phys. **A 617**, 131 (1997).
[2] V. I. Dimitrov et al.,, Phys. Rev. Lett. **84**, 5732 (2000).
[3] C. M. Petrache et al., Nucl. Phys. **A 597**, 106 (1996).
[4] K. Starosta et al., Phys. Rev. Lett. **86**, 971 (2001).
[5] S. Brant et al., Phys. Rev. **C 69**, (2004) 017304.
[6] J. A. Sheikh and K. Hara, Phys. Rev. Lett. **82**, 3968 (1999).
[7] G. H. Bhat et al., Phys. Lett. **B 707**, 250 (2012).