Triaxial projected shell model study of transition probabilities for ^{134}Pr nucleus

G. H. Bhat[1],* J. A. Sheikh[1,2], R.N. Ali[1], W. A. Dar[1], and R. Palit[3]
[1]Department of Physics, University of Kashmir, Srinagar,190 006, India
[2]Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996, USA and
[3]Department of Nuclear and Atomic Physics, Tata Institute of Fundamental Research, Colaba, Mumbai, 400 005,India

The quest to establish stable triaxial shapes in nuclei is being pursued with keen interest during the last about half-a-century. In the initial phases for it, the structures of energy levels at relatively low angular momenta were considered. Generally, the deviations from axially symmetric shape are expected at high spins [1] since the rotational effects are strong for high-j orbitals. The loss of axial symmetry affects a number of observables. For a nucleus having a stable triaxial shape, different moments of inertia are associated with each of the principal axes and the rotational motion is possible about all the three axes. Therefore, the rotational spectra are expected to be richer for stable triaxial nuclei as compared to that for axially symmetric deformed nuclei. There are several empirical observations indicating that axial symmetry is broken in transitional regions and therefore the nuclei in these regions have triaxial shapes. However, triaxial shape has been invoked to explain a number of observed phenomena in the mass A $\sim$ 100, A $\sim$ 130 and A $\sim$ 160 regions, like, signature dependence of B$(E2; I \to I-1)$ values in odd-A nuclei, anomalous signature splittings and signature inversions in odd-odd nuclei [2]. The most prominent among these observations, which has attracted a considerable attention recently, is the existence of doublet bands that may result from the breaking of the chiral symmetry. The occurrence of chirality in nuclei was first predicted in the year 1997 by Frauendorf and Meng. This effect is expected to occur in rotational motion at moderately high spins in triaxially deformed nuclei and in which there are a few high-j valence particles and a few high-j valence holes. In the mass A $\sim$ 130 region, the proton Fermi level is located in the lower part of valence proton high-j (particlelike) $h_{11/2}$ subshell and in the upper part of the valence neutron high-j (holelike) $h_{11/2}$ subshell. For a triaxial nucleus, having three mutually perpendicular principal axes, short (s), intermediate (i) and long (l), the angular momentum vector of the high-j valence proton particle, j_π is aligned along the short (s) axis because its torus-like density distribution which is perpendicular to j_π, in the l-i plane, gives a maximum overlap with the triaxial core. The high-j neutron hole tends to align its angular momentum j_ν, along the long l-axis because its dumbbell-shaped density distribution (sphere minus torus) has maximum overlap with the core if its (that of the distribution) symmetry axis is parallel to the l-axis. Such a coupling of both the valence particle and the hole with the triaxial core minimizes the interaction energy with the core. Different theoretical calculations show that the doublet band structures in triaxial nuclei arises due to the restoration of chiral symmetry breaking mechanism. Based on the theoretical calculations number of fingerprints for experimental observables have been suggested which may serve as signatures for identifying and qualifying candidate doublet bands as chiral partners in odd-odd triaxial nuclei. These are as follows: (i) near degenerate doublet $\Delta I = 1$ bands for a range of spins I; (ii) $S(I) = [E(I) - E(I-1)]/2I$ independent of spin I; (iii) chiral symmetry restoration $M1$ and $E2$ selection rules vs I. Lifetime measurements of doublet band structures in several nuclei revealed that the third criterion is not fulfilled by many nuclei and the interpretation of these bands as chiral partners is erroneous. In particular, the doublet bands in ^{134}Pr that exhibit the best overall energy degeneracy, lifetime measurements revealed that B(M1) values are, although, similar but B(E2) values of the main band are a factor of 2-3 larger than that of the partner band and, therefore, the two bands cannot arise from the chiral symmetry breaking [3].

The triaxial projected shell model (TPSM) [4] calculations proceed in several stages. In the first stage, the deformed basis are constructed from the solutions of the triaxially deformed Nilsson potential. The potential is solved for each nucleus with the axial and triaxial deformation parameters of $\varepsilon = 0.210$ and $\varepsilon = 0.110$. In the next step, good angular-momentum basis are projected out from the Nilsson + BCS states using the explicit

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*Electronic address: `gwhr.bhat@gmail.com`

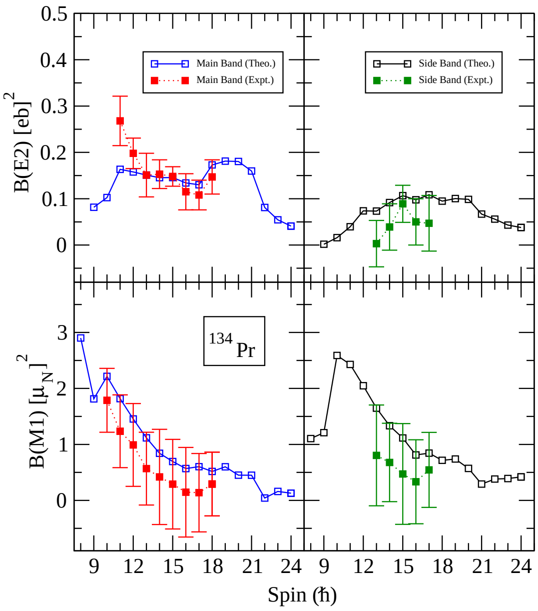

FIG. 1: Comparison of the TPSM transition probabilities doublet bands for ^{134}Pr with experimental data.

three-dimensional angular-momentum projection operator. In the third and final stage of the TPSM analysis, the projected bands constructed from the quasiparticle configurations close to the Fermi surface are used to diagonalise the shell model Hamiltonian.

The TPSM calculations are performed for the two doublet bands and are compared with the experimental data. It is to be noted that this model has been successful in describing the chiral band structure and transition rates in ^{128}Cs [5] and the level structure and branching ratios of the doublet bands in ^{108}Ag [6]. It is known that transition probabilities are very sensitive to the wavefunctions and in order to confirm the above predicted structures for the doublet bands for ^{134}Pr, it is quite important to compare the TPSM calculated transition probabilities with the observed values. The comparison is shown in Fig. 1 and it is evident that experimental transition rates for the doublet bands are in good agreement with the predicted values. It is evident from the Fig. 1 that transition probabilities for the two doublet bands, i.e., the B(M1) values in both doublet bands have similar behave. however, the B(E2) strengths for Main Band are a factor 2 to 3 larger than those of Side Band. Thus the B(E2) strengths within the two bands differ drastically. This result is incompatible with the pure chiral picture where the intraband B(E2) transition strengths must be equal. Such a fingerprints indicates that the limit of static chirality is not reached in ^{134}Pr and the nucleus stays in a very soft vibrational regime. In conclusion, on analyzing the results carefully, we obtain the B(E2) transitions for the doublet-bands to be 2-3 factor times different, which obviously is not consistent with the chiral symmetry breaking interpretation. Because in the chiral picture, the partner bands should have quite similar and smooth B(E2) transitions as they correspond to the same intrinsic structure but for ^{134}Pr nucleus the $B(E2)$ transitions are different for the two band and, therefore, are not consistent with those expected for the chiral bands.

References

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