MULTIPLE CHIRAL BANDS ASSOCIATED WITH THE SAME STRONGLY ASYMMETRIC MANY-PARTICLE NUCLEON CONFIGURATION*

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Multi-particle-plus-triaxial-rotor (MPR) model calculations were performed for chiral partner bands associated with strongly asymmetric many-particle nucleon configuration in the 190 mass region. Multiple chiral systems were found, but they may not necessarily form well defined pairs of near-degenerate bands.

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1. Introduction

Nuclear chiral system is formed when the total angular momentum of the nucleus is aplanar, *i.e.* when it has significant projections along all three nuclear axes [1]. It is revealed by the observation of degenerate $\Delta I = 1$ partner bands [1]. The simplest chiral system is built on a two-quasiparticle configuration, where one quasiparticle is predominantly of the nature of particle, and the other one predominantly of hole nature, coupled to the rotation of a triaxial core. Up to date, chiral candidates showing two-quasiparticle partner bands have been observed in odd–odd nuclei in $A \approx 80$, 100, 130 and 190 mass regions. Chiral partner bands associated with multi-quasiparticle configurations have been found in some odd-mass and odd–odd nuclei, *i.e.* the $\pi g^{-1}_{9/2} \otimes \nu h^2_{11/2}$ bands in ^{103,105}Rh [2–4], the $\pi h^2_{11/2} \otimes \nu h^{-1}_{11/2}$ bands in ^{135}Nd [5], and the $\pi h_{9/2} \otimes \nu i^{-3}_{13/2}$ bands in ^{194}Tl [6, 7]. The existence of

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muti-chiral partner bands (MχD) with different particle-hole nucleon configuration were proposed in a single nucleus [8], and experimentally confirmed in ^{133}Ce [9], where two chiral systems, built on different nucleon configurations were found. Each was associated with a pair of partner bands.

Contrary to MχD, where the multiple chiral systems differ from each other in their nucleon configurations and correspond to different triaxial deformations, previous calculations performed with a single shell particle-rotor model (*i.e.* without pairing, residual proton–neutron interaction and considering only single shell) found that more than one pair of chiral bands can exist in a single nucleus with the same particle-hole configuration [1, 10]. The only multiplet of chiral bands built on the same nucleon configuration was discovered very recently in ^{105}Rh [11].

In the present work, we used multi-particle-plus-triaxial rotor (MPR) model [12] of Carlsson and Ragnarsson to study the existence and properties of multiple chiral bands built on the same many-particle nucleon configuration. To highlight the difference, we compared these results with two-quasiparticle-plus-triaxial-rotor model (TQPRM) [13]. The latter calculations were performed for a multi-chiral system in ^{198}Tl built on the two-quasiparticle $\pi h_{9/2} \otimes \nu i^{-1}_{13/2}$ configuration. The TQPRM calculations are more realistic with respect to the single shell particle-rotor model, because they include the monpole pairing interaction, describe the proton and the neutron configuration spaces as involving one or more orbitals each, and also include the residual proton–neuton interaction. The TQPRM calculations were performed with an ideal (*i.e.* restricted) and realistic (*i.e.* non-restricted) configurations and $\gamma = 30°$. The ideal configuration involves a configuration space with the valence proton and neutron being confined to one orbital each, at the lowest- and highest-energy orbitals of the $h_{9/2}$ and $i_{13/2}$ shells respectively. A realistic configuration is a configuration where the valence proton and neutron span large configuration space (for instance, five orbitals with $\pi h_{9/2}$ and seven orbitals with $\nu i_{13/2}$ nature), while the Fermi surfaces are located at the lowest- and highest-energy orbitals of the corresponding high-j shells. The detailed description of an ideal and realistic configurations can be found in Refs. [14–16].

2. The MPR calculations

We have used MPR model [12] to calculate chiral bands associated with strongly asymmetric many-particle nucleon configuratios in $A \approx 100$, 130 and 190 mass regions. We will present here results for the most asymmetric configuration that was considered, $\pi h_{9/2} \otimes \nu i^{-3}_{13/2}$ in ^{198}Tl. In this nucleus, a candidate chiral pair was observed [17]. Calculations for this 2-quasiparticle $\pi h_{9/2} \otimes \nu i^{-1}_{13/2}$ configuration based on the TQPRM showed that in order to reproduce the observed nearly constant energy difference between the two partners, one needs to assume that the nuclear shape has a considerable triaxiality of $\gamma = 40°$ [17]. Furthermore, the Cranked Nilsson–Strutinsky calculations for ^{194}Tl predicted a similar γ-deformation of $\gamma = 40°$ for this nucleus [6]. Therefore, for our calculations in $A \approx 190$, the quadrupole deformation was set to $\varepsilon_2 = 0.15$, while values of the triaxiality parameter $\gamma = 30°$ and $40°$ were considered. The ^{198}Tl nucleus was chosen so that the Fermi levels for the valence odd proton and the odd neutrons were situated at the lowest-energy $\pi h_{9/2}$ and the highest-energy $\nu i_{13/2}$ orbitals respectively. Standard parameters for the Nilsson potential [18] and irrotational moments of inertia for the core were used. A configuration space containing realistically large number of orbitals close to the corresponding Fermi levels was considered. The nucleon configuration included one proton in the $h_{9/2}$ shell and eleven neutrons in the $i_{13/2}$ shell.

3. Results and discussion

The calculations yielded several bands associated with the configuration of interest. To test for a possible chiral symmetry, the orientation of the total angular momenta for the calculated four lowest-energy bands was examined. It was found that the calculated total angular momentum has major contributions from the proton angular momentum on the short axis, from the neutrons angular momentum on the long axis, and from the angular momentum of the core on the intermediate axis. Furthermore, the expectation values for the angles between the angular momenta of the odd proton (p), odd neutrons (n) and the collective rotation (R), see Fig. 1, are large, suggesting that the vectors form a 3-dimensional chiral geometry.

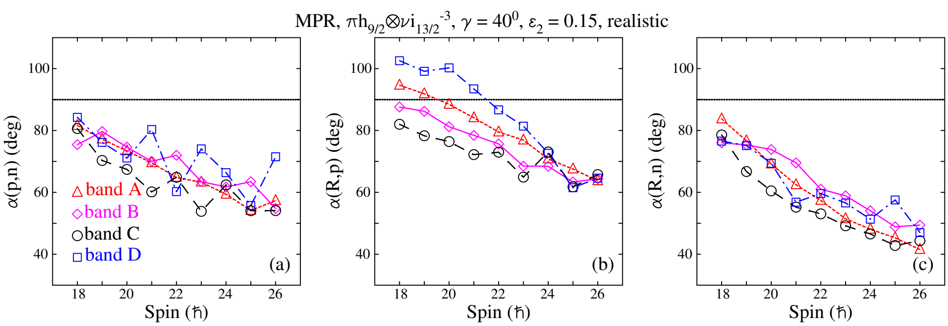

Fig. 1. Calculated expectation values for the angles (in degree) between the angular momenta of the proton (p), neutron (n), and collective rotation (R) for the four lowest lying bands for realistic configuration description and for the $\pi h_{9/2} \otimes \nu i_{13/2}^{-3}$ chiral partner bands at $\gamma = 40°$ and $\varepsilon_2 = 0.15$.

Figure 2 compares the relative excitation energies for multiple chiral bands built on a two-quasiparticle $\pi h_{9/2} \otimes \nu i_{13/2}^{-1}$ configuration ((a) and (b)), and on a four-quasiparticle $\pi h_{9/2} \otimes \nu i_{13/2}^{-3}$ configuration ((c) and (d)). Figure 2 (b) is similar to previous results [1, 10]. Based on such results, the general expectation that multiple chiral systems show distinct pairs of near-degenerate bands is created. The two two-quasiparticle chiral pairs remain easily distinguishable even when a realistic configuration is used (see Fig. 2 (a)).

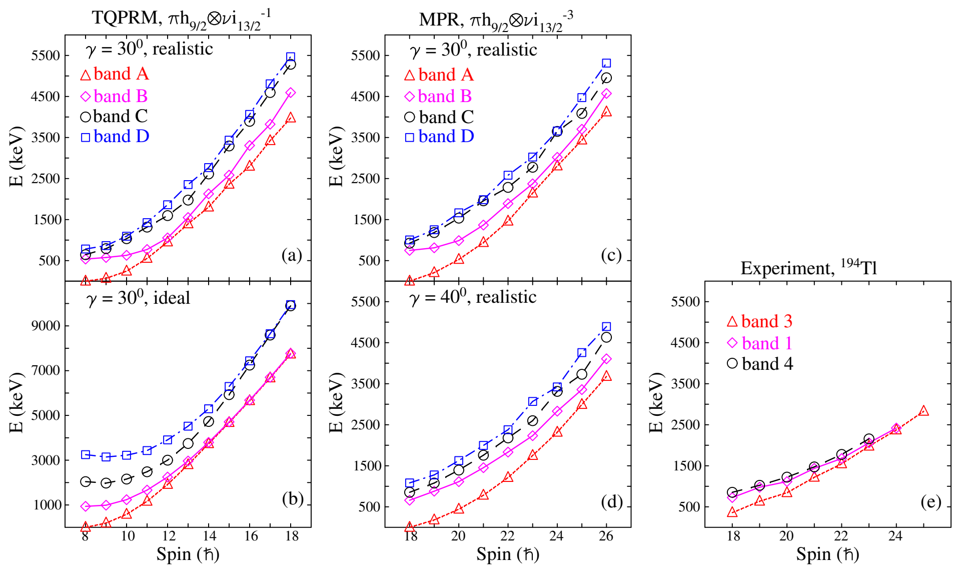

Fig. 2. Calculated excitation energies for the four lowest lying bands for ideal and realistic configuration descriptions and for the $\pi h_{9/2} \otimes \nu i_{13/2}^{-1}$ ((a), (b)) and $\pi h_{9/2} \otimes \nu i_{13/2}^{-3}$ ((c), (d)) chiral partner bands at $\gamma = 30°$, 40° and $\varepsilon_2 = 0.15$. Measured excitation energies for the $\pi h_{9/2} \otimes \nu i_{13/2}^{-3}$ bands in ^{194}Tl are shown in (e) [7].

The MPR calculations predict multiple chiral bands for both $\gamma = 30°$ and $\gamma = 40°$ with the same $\pi h_{9/2} \otimes \nu i_{13/2}^{-3}$ configuration (see Fig. 2 (c) and (d)). It should be noted how different the layout of the four bands is in comparison with that for a two-quasiparticle configuration. Instead of two well identifiable pairs of chiral bands, the four bands group differently, particularly for $\gamma = 40°$. In that case, one of the bands is well separated and lies at lower excitation energy, while the other three bands group together with similar excitation energy. This is similar to the layout of the three $\pi h_{9/2} \otimes \nu i_{13/2}^{-3}$ bands observed in ^{194}Tl [7] (see Fig. 2 (e)). These calculations indicate that the observed three $\pi h_{9/2} \otimes \nu i_{13/2}^{-3}$ bands in ^{194}Tl [7] may represent a multiplet of chiral partners.

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REFERENCES

[1] S. Frauendorf, J. Meng, *Nucl. Phys.* **A617**, 131 (1997).

[2] J. Timar *et al.*, *Phys. Rev.* **C73**, 011301(R) (2006).

[3] J. Timar *et al.*, *Phys. Lett.* **B598**, 178 (2004).

[4] J.A. Alcantara *et al.*, *Phys. Rev.* **C69**, 024317 (2004).

[5] S. Zhu *et al.*, *Phys. Rev. Lett.* **91**, 132501 (2003).

[6] P.L. Masiteng *et al.*, *Phys. Lett.* **B719**, 83 (2013).

[7] P.L. Masiteng *et al.*, *Eur. Phys. J.* **50**, 119 (2014).

[8] J. Meng *et al.*, *Phys. Rev.* **C73**, 037303 (2006).

[9] A.D. Ayangeakaa *et al.*, *Phys. Rev. Lett.* **110**, 172504 (2013).

[10] Q.B. Chen *et al.*, *Phys. Rev.* **C82**, 067302 (2010).

[11] I. Kuti *et al.*, *Phys. Rev. Lett.* **113**, 032501 (2014).

[12] B.G. Carlsson, I. Ragnarsson, *Phys. Rev.* **C74**, 044317 (2006).

[13] P.B. Semmes, I. Ragnarsson, *AIP Conf. Proc.* **259**, 566 (1992).

[14] E.A. Lawrie, O. Shirinda, *Phys. Lett.* **B689**, 66 (2010).

[15] O. Shirinda, E.A. Lawrie, *Eur. Phys. J.* **A48**, 118 (2012).

[16] O. Shirinda, E.A. Lawrie, *Int. J. Mod. Phys.* **E20**, 358 (2011).

[17] E.A. Lawrie *et al.*, *Phys. Rev.* **C78**, 021305(R) (2008).

[18] T. Bengtsson, I. Ragnarsson, *Nucl. Phys.* **A436**, 14 (1985).