CAN A CHIRAL SYSTEM BE BUILT ON A STRONGLY ASYMMETRIC NUCLEON CONFIGURATION?*

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The multi-particle-plus-triaxial-rotor (MPR) model calculations were performed for several nuclei in the 100, 130 and 190 mass regions. It was found that chiral geometry can form even for very asymmetric nucleon configurations. However, the near-degeneracy of the partner bands may not be as good as the one observed for symmetric or slightly asymmetric configurations.

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1. Introduction

A 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 has predominantly particle, and the other one has predominantly 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. Apart from these doubly-odd nuclei, chiral partner bands associated

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with $\pi g^{-1}_{9/2} \otimes \nu h^2_{11/2}$ and $\pi h^2_{11/2} \otimes \nu h^{-1}_{11/2}$ three-quasiparticle configurations have also been found in some odd-mass nuclei in $A \approx 100$ and 130 mass regions respectively (*i.e.* ^{103,105}Rh [2–4] and ^{135}Nd [5]). Recently, a pair of four-quasiparticle $\pi h_{9/2} \otimes \nu i^{-3}_{13/2}$ chiral partner bands was discovered in the odd–odd ^{194}Tl nucleus at iThemba LABS, South Africa [6]. Most importantly, the near-degeneracy in those bands is the best observed up to date. A particle rotor model which couples an axial or triaxial rotor to multi-particle configurations has been developed by Carlsson and Ragnarsson [7].

Previous studies of chiral systems built on two-quasiparticle configurations indicate that optimal conditions for chiral symmetry occur when the magnitude of the projections of the total angular momenta along the three nuclear axes is similar. For strongly asymmetric configurations, in particular for an asymmetric four-quasiparticle configuration, Coriolis effects are considerably stronger due to the large particle angular momenta. In this work, we examined whether stable chiral geometry may persist for strongly asymmetric configurations.

2. The MPR calculations

We have used the multi-particle-plus-triaxial rotor (MPR) [7] model of Carlsson and Ragnarsson to calculate properties of the chiral geometry systems with strongly asymmetric configurations 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. The quadrupole deformation was set to $\varepsilon_2 = 0.15$, while values of the triaxiality parameter γ around 30° were considered. This nucleus was chosen since 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 [8] 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 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. Thus it is expected that a 3-dimensional chiral geometry is formed. It is important to note that for such strongly asymmetric configurations the near-degeneracy remains reasonably good, *e.g.* for $\gamma = 24^\circ$, 30° and 36° the partner bands approach each other in excitation energy and reach $\Delta E \approx 200$ keV (see Fig. 1).

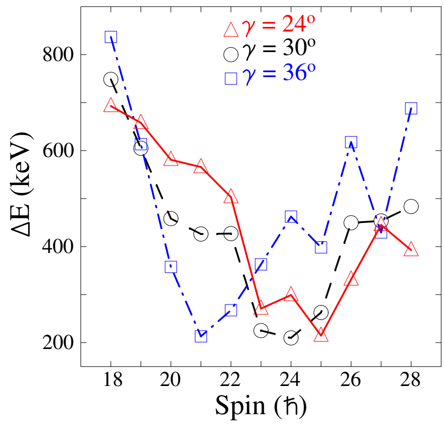

Fig. 1. Calculated relative excitation energy, $\Delta E = E_{\rm side} - E_{\rm yrast}$, *versus* spin for the $\pi h_{9/2} \otimes \nu i^{-3}_{13/2}$ partner bands at $\gamma = 24°$, $30°$, $36°$ and $\varepsilon_2 = 0.15$ in the 190 mass region.

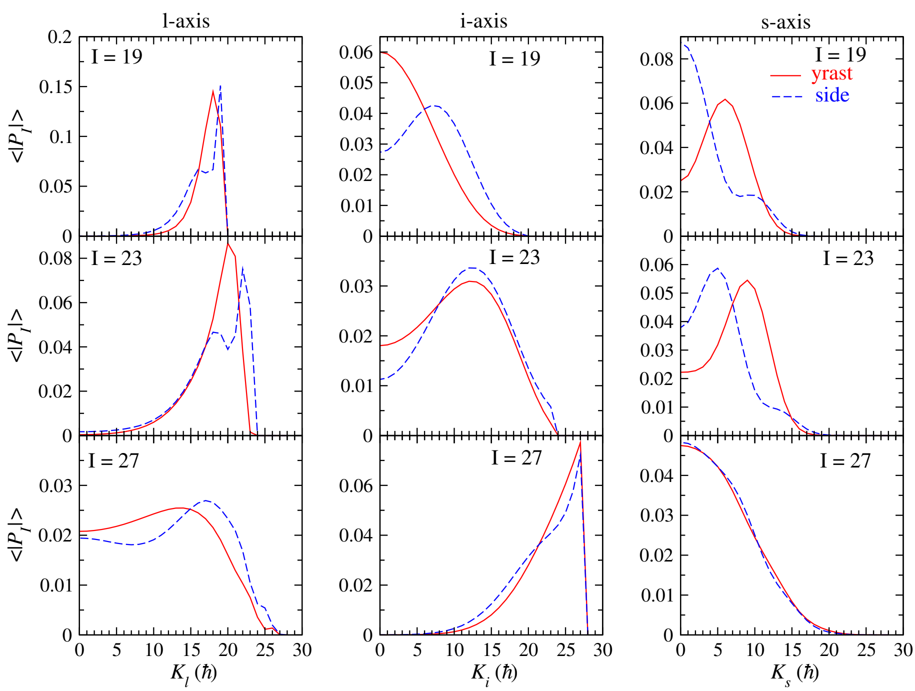

Fig. 2. Calculated probability distributions for the projections of the total angular momentum on the short (s), intermediate (i), and long (l) nuclear axes, for the yrast and the side $\pi h_{9/2} \otimes \nu i^{-3}_{13/2}$ partner bands and at $\gamma = 30°$ and $\varepsilon_2 = 0.15$ in the 190 mass region.

For this $\pi h_{9/2} \otimes \nu i^{-3}_{13/2}$ configuration the magnitude of the angular momenta of the particle ($j_p = 9/2$) and holes ($j_h = 33/2$) differ considerably. Furthermore, since large angular momenta are involved, the Coriolis effects are also considerably stronger than in the case of two-quasiparticle configurations. It is well known that at high spins the Coriolis effects tend to change the orientation of the angular momenta of the particles and holes, increasing the probability for planar contributions, and making the formation of chiral geometry less probable. One can better evaluate the magnitude of the possible non-chiral (*i.e.* planar) contributions to the wave functions by looking at the distributions of the projections of the total angular momentum along the three nuclear axes, shown in Fig. 2. Each distribution peaks at the most likely projection of the total angular momentum. The figure shows that the optimal conditions for forming a 3-dimensional system occur at intermediate spins, $I \approx 23$, where all three distributions have maxima at non-zero projections. Therefore, we conclude that 3-dimensional chiral geometry can form even for very asymmetric nucleon configurations, although the near degeneracy of the partner bands is not as good as the one observed for symmetric or slightly asymmetric two-quasiparticle configurations (*e.g.* see references [9, 10]). This result further emphasises the surprising observation that the best found so far near-degeneracy in candidate chiral bands is observed in ^{194}Tl for the most asymmetric four-quasiparticle configuration.

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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] B.G. Carlsson I. Ragnarsson, *Phys. Rev.* **C74**, 044310 (2006).
[8] T. Bengtsson, I. Ragnarsson, *Nucl. Phys.* **A436**, 14 (1985).
[9] E.A. Lawrie, O. Shirinda, *Phys. Lett.* **B689**, 66 (2010).
[10] O. Shirinda, E.A. Lawrie, *Int. J. Mod. Phys.* **E20**, 358 (2011).