CPC(HEP & NP), 2009, **33**(Suppl. I): 43—45 **Chinese Physics C** Vol. 33, Suppl. I , Mar., 2009

Chiral doublet bands and energy-level crossing*

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Abstract Different definitions for chiral doublet bands based on excitation energies, $B(\mathrm{E2})$ and $B(\mathrm{M1})$ respectively are discussed in the triaxial particle rotor model. For the ideal chiral geometry, the selection rules of the electromagnetic transitions in different band definitions are illustrated. It is also shown that the energy-level crossings between chiral doublet bands may occur.

Key words chiral doublet bands, band definition, electromagnetic transition, energy-level crossing, triaxial particle rotor model

PACS 21.60.Ev, 21.10.Re, 23.20.Lv

1 Introduction

Since the pioneering work on chirality in atomic nuclei of Frauendorf and Meng[1], the phenomenon of chiral rotation has attracted significant attention. Lots of experimental efforts have been devoted to search for the chiral doublet bands in the $A\sim130$, $A\sim100$, and $A\sim190$ mass regions[2—11]. On the theoretical side, numerous efforts have been devoted to the development of the particle-rotor model (PRM)[12—19] and tilted axis cranking (TAC) approach[20—22] to study the chiral doublet bands.

Originally the observation of two almost degenerate ΔI=1 rotational bands is considered as the fingerprint of chiral doublet bands. Later the selection rules of the electromagnetic transitions for the doublet bands are regarded to be further critical criteria to identify the chiral doublet bands. So far, although candidate chiral doublet bands have been proposed in a number of nuclei, their identification is still an open question[9—11, 23, 24].

When we discuss the chiral doublet bands, a primary question is: “How to define the chiral doublet bands?” Obviously in different band definitions, although the near-degenerate energy relation between two partner bands still maintains, the characteristics of the intra- or inter- band electromagnetic transitions for these partner bands might be quite different. However, this question has been seldom discussed up to now. In this paper, we will study the different definitions for chiral doublet bands and look for a reasonable band definition which makes the properties of the chiral doublet bands more explicit.

2 Bands in the ideal chiral geometry

We adopt the same model as Refs. [1, 15], i.e. an $h_{11/2}$ proton particle and an $h_{11/2}$ neutron hole coupled with a $\gamma=-30°$ triaxial rotor model. The special condition corresponds to an ideal chiral geometry, namely the angular momentum vectors of valence proton, valence neutron and the even-even core are mutually perpendicular to each other[1, 15]. The cases deviated from such ideal chiral geometry will be discussed in Ref. [25].

When particle rotor model is performed, a series

Received 3 September 2008

* Supported by National Natural Science Foundation of China (10505002, 10435010, 10605001, 10221003) and Postdoctoral Science Foundation of China (20060390371)

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of discrete energy levels are obtained by diagonalizing the PRM Hamiltonian. Then how to define these discrete energy levels as chiral doublet bands? A convenient way to define the doublet bands is based on the obtained excitation energies, i.e, the lowest-energy states are defined as one band and the first excited-energy states as the partner band. The second definition of the doublet bands is based on M1 transition probabilities, i.e., the bands are considered to be linked by M1 transition; The third definition of the doublet bands is based on E2 transitions, i.e., the bands are considered to be linked by E2 transition. In Ref. [15], the authors have considered arranging the ideal chiral bands based on B(E2) at the degenerate spin region.

We calculate the energy spectra $E(I)$ and electromagnetic transition probabilities B(E2), B(M1) for the lowest pair of $\Delta I = 1$ bands with an $h_{11/2}$ proton particle and an $h_{11/2}$ neutron hole coupled with a $\gamma = -30°$ triaxial rotor model. The calculated results are plotted in Fig. 1, where the left, middle and right panels are respectively corresponding to the results of band definitions based on excitation energies, B(M1) and B(E2).

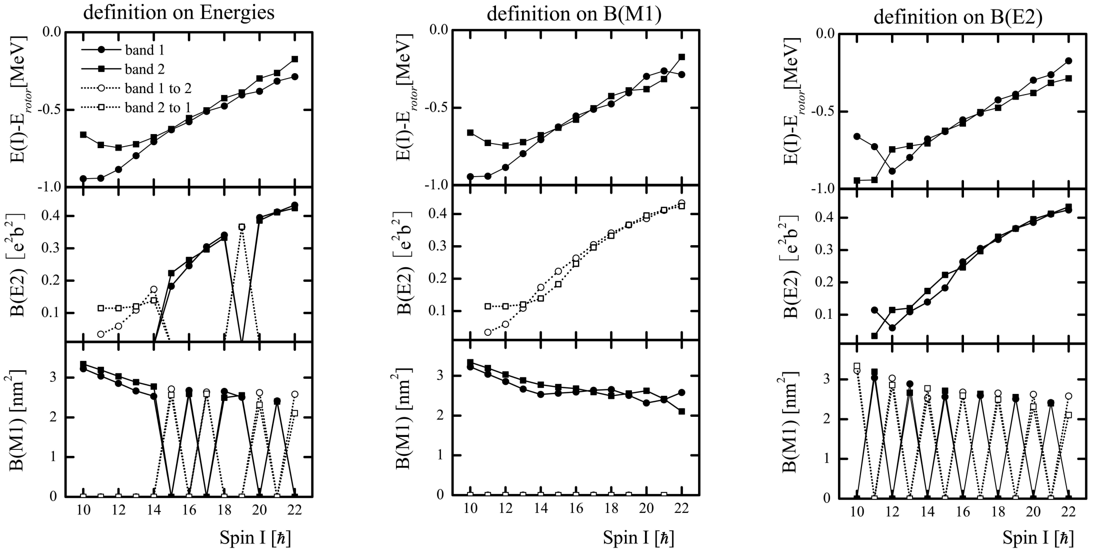

Fig. 1. The energy spectra $E(I)$, B(E2), B(M1) values for the lowest pair of $\Delta I = 1$ bands with the configuration $\pi h_{11/2} \otimes \nu h^{-1}_{11/2}$ calculated by PRM with triaxial deformation $\gamma = -30°$. To show the detail of energy difference between the doublet bands, the excitation energy is plotted relative to a rigid rotor $E_{\text{rotor}} = 0.01I(I+1)$. For the calculated B(E2) and B(M1), the solid symbols express the intraband transition values and the empty symbols express the interband transition ones. In the calculations, the parameters $\beta = 0.3$, $\mathcal{J} = 30$ MeV$^{-1}\hbar^2$, $g_{\text{p}} - g_{\text{R}} = 0.71$, $g_{\text{n}} - g_{\text{R}} = -0.70$, and $Q_0 = 3.5$ eb are adopted. The chiral doublet bands are defined respectively based on excitation energies (left panels), B(M1) (middle panels) and B(E2) (right panels).

As shown in Fig. 1, the selection rules of the electromagnetic transition in different definitions of the ideal chiral doublet bands can be summarized as the following.

When the chiral doublet bands are defined based on excitation energies, the B(E2) and B(M1) values change irregularly at certain spins (here refers to $14\hbar$ and $19\hbar$).

When the chiral doublet bands are defined based on M1 transition probabilities, the intraband B(E2) are forbidden, whereas the interband B(E2) increase smoothly as functions of spin; The intraband B(M1) decrease smoothly as functions of spin whereas interband B(M1) are forbidden. Thus the chiral doublet bands are linked by the intraband M1 transitions and interband E2 transitions.

When the chiral doublet bands are based on E2 transition probabilities, the intraband B(E2) increase smoothly as functions of spin, whereas the interband B(E2) are forbidden; the intraband B(M1) show a odd-even spin staggering with an unique phase; and the interband B(M1) also show a staggering, but the phase is opposite to that of intraband ones.

Let us consider the energy spectra of the ideal chiral doublet bands in different definitions. As shown in Fig. 1, when the doublet bands are defined based on

B(E2) or B(M1), the energy-levels of the two bands cross each other at certain spins. It indicates a new mechanism of band crossing, which occurs in the chiral geometry.

3 Comparison between experiment and theory

On the experimental side, the placement of the observed gamma transitions to establish a level scheme is based mainly upon their relative intensities I_γ, energy sums, coincidence relationships and multipolarities. Recently, the absolute B(E2) and B(M1) values for candidate chiral bands are extracted from the lifetime measurement, which also provides an opportunity to discuss the different band definitions for candidate chiral bands .

The first lifetime measurement for candidate chiral bands was performed for ^{134}Pr[10], which seems not to support the presence of static chirality in this nucleus. Subsequently with the lifetime data, the doublet bands in ^{128}Cs are regarded as the best known examples revealing the chiral symmetry breaking phenomenon in Ref. [9].

We have examined the experimental data of candidate chiral bands of ^{128}Cs and ^{134}Pr in different band definitions, and compared them with the PRM calculations[25]. It is found that the candidate chiral bands in ^{128}Cs show similar characters with ideal chiral bands for band definition based on B(E2) or B(M1). Considering the different band definitions, the energy-level crossing and electromagnetic transitions of candidate chiral bands in ^{134}Pr can also be understood qualitatively in the calculations with the conditions deviated from the ideal chiral geometry[25].

4 Summary

Different definitions for chiral doublet bands based on excitation energies, B(E2) and B(M1) respectively are discussed in the triaxial particle rotor model. For the ideal chiral geometry, the selection rules of the electromagnetic transitions in different band definitions are illustrated. It is also shown that the energy-level crossings between chiral doublet bands may occur.

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