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$\pi g_{9/2}\otimes\nu h_{11/2}$ doublet bands in $A\sim 100$ mass region*

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Abstract Using the model with one particle and one hole coupled with a triaxial rotor, the $\pi g^{-1}_{9/2}\otimes\nu h_{11/2}$ doublet bands in the $A\sim 100$ mass region are studied, and compared with the $\pi h_{11/2}\otimes\nu h^{-1}_{11/2}$ doublet bands. It is found that the calculated results for the configuration of $\pi g^{-1}_{9/2}\otimes\nu h_{11/2}$ are very similar the results for a pure $h_{11/2}$ proton particle and a neutron quasiparticle with $\lambda_{\rm n}=\varepsilon_5$. After including the pair correlation, the model describes the candidate chiral doublet bands in ^{106}Rh successfully, which supports the interpretation of chirality geometry.

Key words chiral doublet bands, electromagnetic transition, triaxial particle rotor model

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1 Introduction

Symmetries play a key role in the understanding of nuclear physics phenomena. Nuclear chirality is a novel manifestation of spontaneous symmetry breaking resulting from an orthogonal coupling of angular momentum vectors in triaxial nuclei.[1] Chiral rotation in atomic nuclei has attracted significant attention. Lot of experimental effort has been devoted to search for this new phenomenon. So far, a number of pairs of bands have been identified in nuclei in the $A\sim 130$ and $A\sim 100$ mass regions of the nuclear chart and have been suggested as candidates for chiral partners.[2—6]

Originally, most candidate chiral bands were suggested only on the basis of similar energy spectra and identical parities of two bands. Compared with the energy spectra, the electromagnetic transition probabilities carry more information on the intrinsic structure. For the identification of chiral bands, lifetime measurements of doublet bands were done for ^{128}Cs[7], ^{134}Pr[8] and ^{135}Nd[9], where ^{134}Pr was often considered to be the best example of a chiral nucleus in the $A\sim 130$ mass region. However, the results of lifetime measurements for ^{134}Pr give different E2 transition values for the two bands, which contradict the static chiral interpretation.

Thus far, the lifetime data for the doublet bands are not available in the $A\sim 100$ mass region, but the inband B(M1)/B(E2) ratios are known. In Ref.[10], the doublet bands in odd-odd nuclei ^{104,106}Rh have been examined in relation to the known energy spectra, spin alignment and B(M1)/B(E2) ratios. The results indicate that ^{106}Rh possesses better chiral geometry than ^{104}Rh, although doublet bands in ^{104}Rh possesses better energy degeneracy than ^{106}Rh. This motivated the study of chiral symmetry breaking in odd-odd nuclei in the $A\sim 100$ mass region.

2 Results and discussions

The detailed formalism and numerical techniques can be seen in Refs.[11—14] and references therein.

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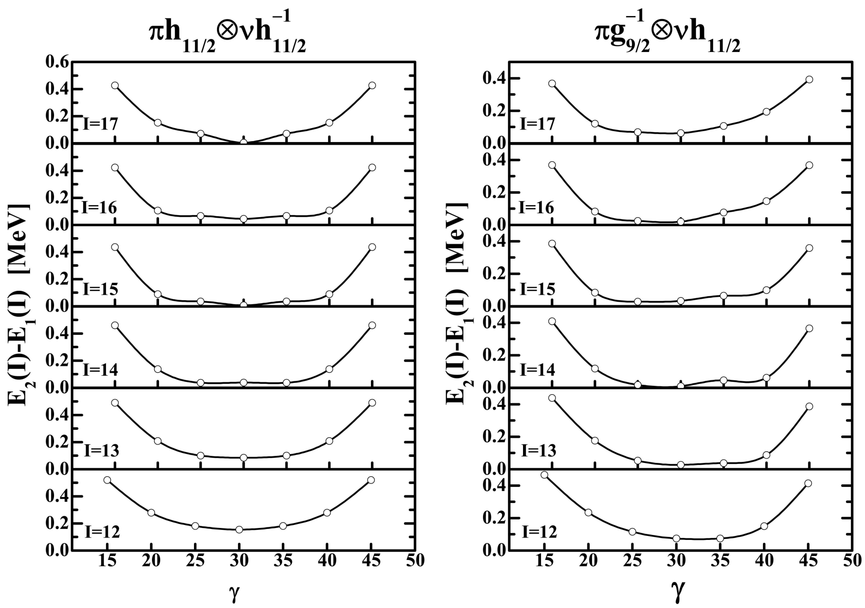

Fig. 1. Calculated energy difference $\mathrm{E}_2(I)-\mathrm{E}_1(I)$ between yrare and yrast bands at $I=12,13,\cdots,17$ as a function of γ deformation. In the calculations, the odd proton and neutron are fixed to be the pure $h_{11/2}$ particle and $h_{11/2}$ hole, respectively (Left panel), the odd proton and neutron are fixed to be the pure $g_{9/2}$ hole and $h_{11/2}$ particle, respectively (Right panel).

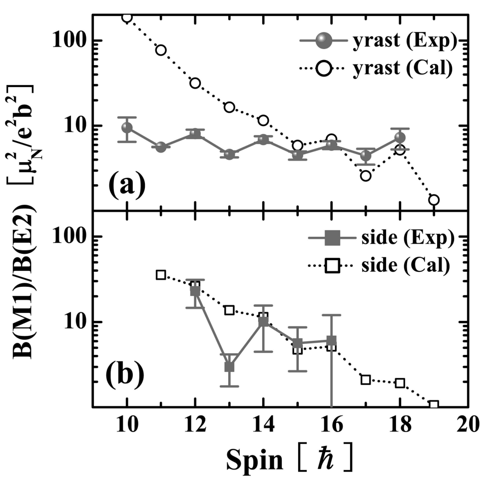

Fig. 2. Comparisons between the calculated $B(\mathrm{M1})/B(\mathrm{E2})$ ratios and experimental values[4] for the doublet bands in ^{106}Rh.

First we investigate the behavior of doublet bands for a nucleus based on the configuration of $\pi g_{9/2}^{-1}\otimes\nu h_{11/2}$ and compared with the $\pi h_{11/2}\otimes\nu h_{11/2}^{-1}$ doublet bands.

The calculated energy difference $\mathrm{E}_2(I)-\mathrm{E}_1(I)$ between yrare and yrast bands at spins $I=12,13,\cdots,17$ as a function of γ deformation is plotted in Fig.1. The left panel displays the results for a pure $h_{11/2}$ proton particle and a pure $h_{11/2}$ neutron hole configuration. A symmetric $\mathrm{E}_2(I)-\mathrm{E}_1(I)$ curve about $\gamma=30°$ can be seen, which in turn is associated with the symmetries of Hamiltonians with respect to $\gamma=30°$. The smallest energy difference takes place at $\gamma=30°$ for all the shown spins, and particularly at spins $I=15,17$, very good degeneracy is obtained, namely the energy differences are 7.2 keV and 4.1 keV, respectively. This corresponds to so-called ideal chiral doublet bands in the $A\sim130$ mass region. The energy difference increases when the γ degree deviates from 30°, and presents a parabola-like curve. In the right panel of Fig.1, the results for a pure $g_{9/2}$ proton hole and a $h_{11/2}$ neutron particle are shown. The $\mathrm{E}_2(I)$–$\mathrm{E}_1(I)$ curves are still parabola-like, while their minima change with the spin I. The tendency is that the γ deformation with the minimum energy difference decreases with spin. For example, the smallest energy difference takes place at $\gamma\sim35°$ and $\gamma\sim30°$ at spins $I=12$ and $I=13$, respectively. For spins $14\leqslant I\leqslant17$, the smallest energy difference takes place at $\gamma\sim27°$. It is noted that this calculated results are very similar the results for a pure $h_{11/2}$ proton particle and a neutron quasiparticle with $\lambda_n=\varepsilon_5$ and Δ=1 MeV[14]. A near-constant energy difference may be observed for $20°\leqslant\gamma\leqslant35°$.

3 Description of doublet bands in ^{106}Rh

In order to describe the $\pi g_{9/2}\otimes\nu h_{11/2}$ doublet bands in ^{106}Rh, the calculations proceed in two steps. First, the configuration-fixed constrained triaxial relativistic mean field (RMF) approach is applied to determine the quadrupole deformations β and γ[15]. In the second step, using these self-consistent deformation parameters as inputs for the PRM, energy spectra and electromagnetic transition ratios are calculated based on our model of a triaxial rotor coupled with two quasi-particles (QPRM)[16].

In Figs. 2(a) and (b), the calculated B(M1)/B(E2) ratios for the doublet bands are compared with experiment data[4]. The calculated B(M1)/B(E2) values decrease rapidly with increasing spin in the whole spin region. Except for the low spin, the calculated B(M1)/B(E2) ratios for yrast band are close to the experimental data, and reproduce the staggering phase of the experimental B(M1)/B(E2) ratios, i.e., the value at even spin is larger than the one at odd spin. The staggering phase is opposite to that observed in the $A\sim130$ mass region[6] since the proton orbital changes from $h_{11/2}$ to $g_{9/2}$. In comparison with the core-quasiparticle coupling model used in Ref. [4], the present calculations provide an improved description of the data.

To compare with future lifetime data, the reduced B(M1) and B(E2) transition probabilities are calculated and presented in Fig.3. The upper panel shows the B(E2) transition probabilities, and the lower panel corresponds to the B(M1) transition probabilities. At low spins, the intraband and interband B(E2) transition probabilities are close to each other. After $I=12\hbar$, the intraband B(E2) values increase linearly with spin, whereas interband B(E2) values steeply decrease and vanish. It is noteworthy that similar intraband B(E2) values and small intreband B(E2) values are obtained for the partner bands. These are consistent with suggested ideal chiral criteria. The calculated B(M1) values in the lower panel of the Fig.3 show prominent odd-even staggering for $I\geqslant14\hbar$. The intraband B(M1) values at even spin are larger than the values at odd spin. The staggering phase is consistent with the staggering phase of experimental B(M1)/B(E2) ratios in ^{106}Rh. In addition, from Fig.3, the staggering amplitude of B(M1) transitions in yrast states are seen to be larger than those in the side band.

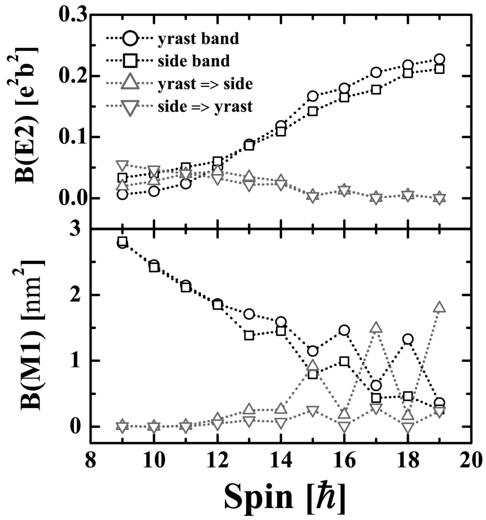

Fig. 3. The calculated B(E2) and B(M1) values as functions of the spin in ^{106}Rh.

4 Conclusions

Using the model with one particle and one hole coupled with a triaxial rotor, the $\pi g_{9/2}^{-1}\otimes\nu h_{11/2}$ doublet bands in the $A\sim100$ mass region are studied, and compared with the $\pi h_{11/2}\otimes\nu h_{11/2}^{-1}$ doublet bands. It is found that the calculated results for the configuration of $\pi g_{9/2}^{-1}\otimes\nu h_{11/2}$ are very similar the results for a pure $h_{11/2}$ proton particle and a neutron quasiparticle with $\lambda_n=\varepsilon_5$. After including the pair correlation, The present calculated results well reproduce the electromagnetic transition ratios of the doublet bands, thus supporting the chiral interpretation of these doublet bands in ^{106}Rh.

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