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Study of the Identical Bands of Odd-A and Odd-Odd Nuclei in the $A\sim190$ Mass Region *

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Abstract The microscopic mechanism of the identical bands in odd-odd nucleus ^{194}Tl and its neighbor odd-A nucleus ^{193}Tl are investigated using the particle-number conserving (PNC) method with monopole and quadrupole pairing interaction. It is found that the blocking effect plays an important role in the variation in moments of inertia ($J^{(1)}$ and $J^{(2)}$) with rotational frequency for the SD bands and identical bands. And the angular momentum alignment $i(\omega)$ of the six SD bands in ^{194}Tl relative to the ^{193}Tl(1) also is discussed.

Key words particle-number conserving method, superdeformed band, identical bands, dynamic and kinematic moments of inertia

1 Introduction

The first case of the identical bands (IB's) was discovered [1] in ^{151}Tb and ^{152}Dy about a decade ago. Shortly afterwards, IB's also were observed[2] in ^{192}Hg and ^{194}Hg. From then on, many example have been reported in both $A\sim150$ and $A\sim190$ mass region and many people using different method studied this interesting phenomenon. But the physics behind the IB's is still a open problem now. Some studies (for example Refs. [3,4]) show that there is some special physics or symmetry behind IB's while others (for example Refs. [5,6]) suggested the same γ-ray transition energy and the identical moment of inertia (MoI) is due to the competition among the shell effect (stretching effect[7]), pairing interaction, blocking effect, rotation alignment[8] and Coriolis anti-pairing effect[9].

In the $A\sim190$ mass region, for the abundant experimental date, much study of the SD band and the identical bands have been done in even-even nuclei and their neighbor odd-A nuclei. For example, by the cranked Hartree-Fock method[10,11] and strutinsky Lipkin-Nogami approach [12], the single particle configurations and the dynamical moment of inertia of the SD bands in Hg and Pb isotopes have been investigated. In the cranked shell model (CSM), the quadrupole pairing and the downturn of the moment of inertia of the Hg isotopes have been studied[5,13]. In the projected shell model (PSM)[6] and the approach based on the interacting boson model (IBM)[14], the yrast SD bands in even-even nuclei have been systematic descripted [15,16]. But the SD bands and the identical bands in the odd-odd nuclei and their neighbor odd-A nuclei are seldom studied.

We accept the particle-number conserving (PNC) method for treating the cranked shell model with monopole and quadrupole pairing interaction to investigate the identical bands in the odd-odd nuclei ^{194}Tl and their neighbor odd-A nuclei ^{193}Tl. The quantized alignment of six ^{194}Tl bands with respect to the ^{193}Tl(1a) band used as a reference also discussed in this paper.

2 Formalism

In the PNC calculation, the particle number is con-

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served from the beginning to the end, and the blocking effects are taken into account strictly. Detailed PNC calculation see Ref.[17]. The formulae needed to discuss the moment of inertia are briefly sketched as follows.

The cranked shell model Hamiltonian is:

$$H_{\mathrm{CSM}} = H_{\mathrm{SP}} - \omega J_x + H_{\mathrm{P}} = H_0 + H_{\mathrm{P}}, \qquad (1)$$

where $H_0 = H_{\mathrm{SP}} - \omega J_x$ is the one-body part of H_{CSM}, H_{SP} is the Nilsson Hamiltonian, $-\omega J_x$ is the Coriolis interaction, and H_{P} is the pairing interaction including both monopole and qudrupole pairing interactions. First we diagonalize $H_0(\omega) = \sum_i h_0(\omega)_i$, $h_0(\omega) = h_{\mathrm{Nilsson}} - \omega j_x$, to obtain the cranked Nilsson orbitals. Then, we diagonalize H_{CSM} in a sufficiently large cranked many-particle configuration (CMPC) space to extract accurate PNC solutions of the yrast and low-lying excited eigenstates of H_{CSM}.

The eigenstate of H_{SCM} can be expressed in terms of the CMPC $|i\rangle$: $|\psi\rangle = \sum_i c_i |i\rangle$, (2)

where $|i\rangle$ denotes an occupation of particle in the cranked orbitals and c_i is the corresponding probability amplitude. The angular momentum alignment of $|\psi\rangle$ is:

$$\langle\psi|J_x|\psi\rangle = \sum_i |c_i|^2\langle i|J_x|i\rangle + 2\sum_{i<j} c_i^* c_j \langle i|J_x|j\rangle \qquad (3)$$

Then, the kinematic moment of inertia of $|\psi\rangle$ is:

$$J^{(1)} = \langle\psi|J_x|\psi\rangle/\omega = \sum_\mu j^{(1)}(\mu) + \sum_{\mu<\nu} j^{(1)}(\mu\nu), \qquad (4)$$

$$j^{(1)}(\mu) = \langle\mu|j_x|\mu\rangle n_\mu/\omega, \qquad (5)$$

$$j^{(1)}(\mu\nu) = \frac{2}{\omega}\langle\mu|j_x|\nu\rangle\sum_{i<j}(-)^{M_{i\mu}+M_{j\nu}} c_j^* c_j, (\mu\neq\nu), \qquad (6)$$

where $n_\mu = \sum_i |c_i|^2 P_{i\mu}$ is the occupation probability of the cracked orbital μ, $P_{i\mu}=1$ if μ is occupied in $|i\rangle$, and $P_{i\mu}=0$ otherwise. A similar expression for the dynamical moment of inertia $J^{(2)} = \mathrm{d}(\langle\psi|J_x|\psi\rangle)/\mathrm{d}\omega$ also can be obtained.

3 Calculated result and discussions

3.1 Moment of inertia of SD band in ^{194}Tl and ^{193}Tl

In our calculation, the Nilsson parameters (κ, μ) are taken from Ref.[18] (for neutron $N=6$ shell, their value are sifted slightly), the deformation parameter $\varepsilon_2 = 0.46$ and $\varepsilon_4 = 0.03$. The effective pairing interaction strengths (G_0 for monopole pairing and G_2 for quadrupole pairing) in unite of MeV are given as follow,

^{193}Tl: $G_{0p}=0.3$, $G_{0n}=0.2$, $G_{2p}=0.01$, $G_{2n}=0.011$

^{194}Tl: $G_{0p}=0.3$, $G_{0n}=0.2$, $G_{2p}=0.01$, $G_{2n}=0.009$

The truncated CMPC's energy E_c is set about $0.65\,\hbar\omega_0$ (the corresponding CMPC's space dimensions are about 700) and $0.45\,\hbar\omega_0$ (the corresponding CMPC's space dimensions are about 1000) for proton and neutron respectively. The cranked Nilsson proton and neutron orbitals near the Fermi surface for the SD bands in $A\sim190$ mass region is shown in Fig.1.

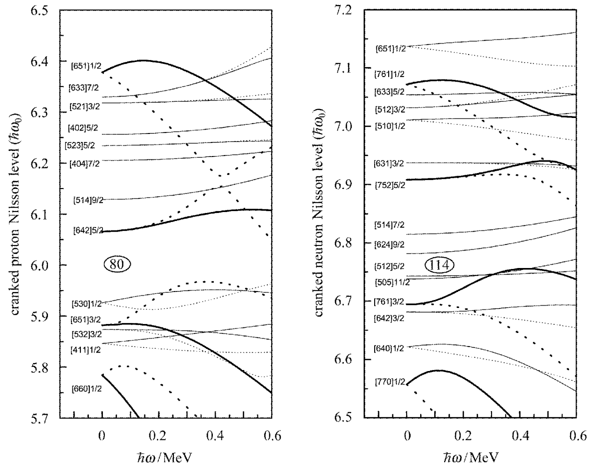

Fig.1. The cranked proton and neutron Nilsson orbitals near the Fermi surface for $A\sim190$ region. $-$ ($\cdots$) for $\alpha=+1/2$ ($\alpha=-1/2$), and the intruder high-N are denoted by bold line.

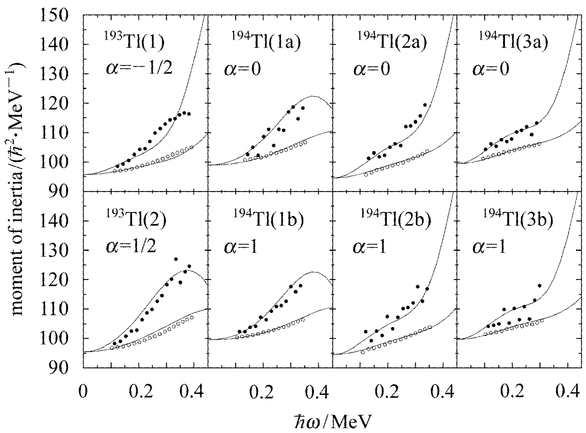

Fig.2. Comparison between the experimental and calculated $J^{(1)}$ and $J^{(2)}$ for ^{193,194}Tl. ∘ (•) and-for experimental and calculated $J^{(1)}$ ($J^{(2)}$) respectively.

The comparison between the calculation and experimental $J^{(1)}$ and $J^{(2)}$ for two SD bands in ^{193}Tl and the six SD bands in ^{194}Tl are displayed in Fig.2. It is see that the observed variation in kinematic moment of inertia with rotational frequency of all the eight SD bands is reproduced quite satisfactorily, and the dynamical moment of inertia, however, is reproduced qualitatively since the experimental data are rather dispersed. An intrinsic single-proton configuration $\pi[642]5/2$ was assigned to the signature partner SD bands of ^{193}Tl(1, 2). It confirms the assignment of the experimental study of their magnetic properties[19].

3.2 The identical bands of ^{193}Tl(1) and ^{194}Tl(2a,2b)

In experiment, the transition energy of bands ^{194}Tl(2a, 2b) display "striking similarities" to the negative-signature SD band ^{193}Tl(1). We plot the comparison between the experimental and calculated identical bands of ^{193}Tl(1) and ^{194}Tl(2a,2b) in Fig.3. The calculations agree very well with data.

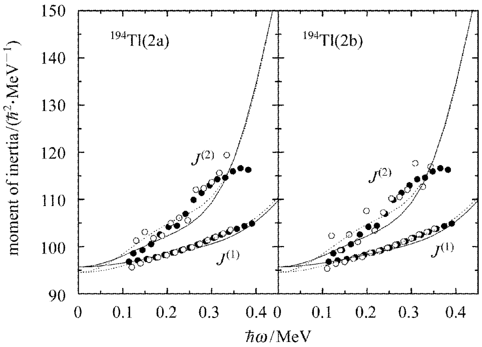

Fig.3. Experimental and calculated $J^{(1)}$ and $J^{(2)}$ of the SD bands in ^{194}Tl(2a,2b) with ^{193}Tl(1) as reference band. • (◦) and – (⋯) stand for experimental ^{193}Tl(1) (^{194}Tl(2a,2b)) and calculated $J^{(1)}$ and $J^{(2)}$ respectively. —•— denote the case where high-j low-ω neutron intruder orbital ([752]5/2) is blocked in ^{194}Tl(2a,2b)

The calculated occupation probability n_μ of each cranked Nilsson orbital versus rotational frequency in ^{193}Tl(1) and ^{194}Tl(2a,2b) is given in Fig.4 (the orbital with $n_\mu = 0$ or $n_\mu = 2$ is not shown here).

As shown in Fig.4, the blocking of individual proton high-j intrude orbital [642]5/2($\alpha = -1/2$) is clear and pure due to the comparatively large energy gap blow the Fermi surface (see in Fig.1), and there is no blocked neutron orbital for ^{193}Tl(1). For ^{194}Tl(1a,1b), the assigned configurations ($\pi[642]5/2\nu[624]9/2$) are taken from the previous letter[20]. The blocked neutron orbital[624]9/2 is a low-j high-Ω orbital, the corresponding Coriolis response is very small, thus the occupation probability of these orbitals keep

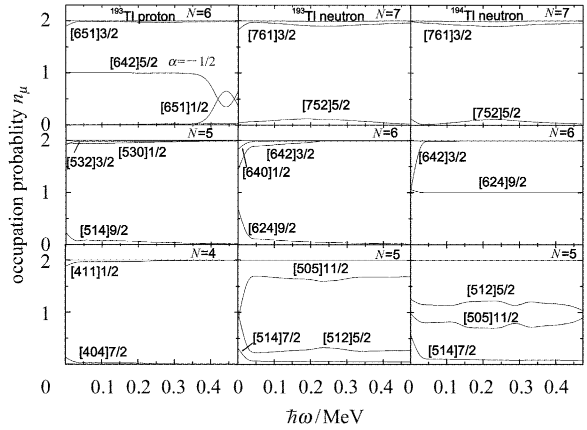

Fig.4. Occupation probability n_μ of each proton and neutron cranked orbital μ near the Fermi surface in ^{193}Tl(1) and ^{194}Tl(2a,2b).

constant ($n_\mu = 1$) up to rather high ω. As we known the blocking effect is very important when the blocked high-j orbital near Fermi surface. The contribution to the moment of inertia from the blocked low-j high-Ω orbital [624]9/2($\alpha = \pm 1/2$) is negligible. Otherwise, if the blocked neutron orbital is a high-j low-ω intruder orbital, for example, [752]5/2(It is also plotted in Fig.3), they can not be the identical bands. From this one can understand why there is the identical moment of inertia in ^{194}Tl(2a,2b) and ^{193}Tl(1).

3.3 The alignment of the six SD bands in ^{194}Tl

In addition to identical transition energy and moment of inertia, IB's also possess the "quantized" alignments. The alignment i is the difference in spin with respect to a chosen reference band at a fixed rotational frequency.

$$i(\omega) = \langle J_x \rangle(\text{SDband}) - \langle J_x \rangle(\text{referenceband}). \quad (7)$$

The ω variation of the angular momentum alignment $i(\omega)$ of the six SD bands in ^{194}Tl relative to the ^{193}Tl(1) are shown in Fig.5. In general, our calculation show reasonable agreement with data, at leat at the low rotation frequency. However, as

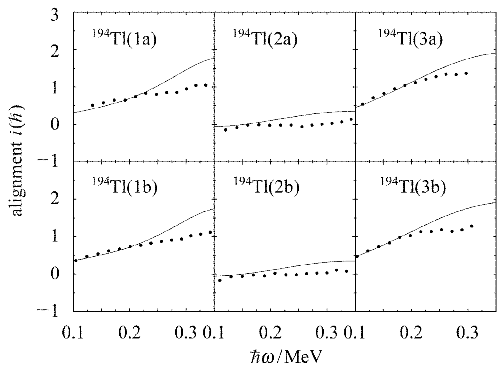

Fig.5. The angular momentum alignment $i(\omega)$ of the six SD bands in ^{194}Tl relative to the ^{193}Tl(1). – (⋯) stand for calculated and experimental $i(\omega)$ respectively.

for the identical bands ^{193}Tl(1) and ^{194}Tl(2a,2b), the calculation can give the quantized alignment of $\sim 0\hbar$ shown by the experiment data. But for other case, the experiment alignment does not have an integer value over the whole observed frequency, nor do they give "striking" identical bands.

4 Summary

In summary, the particle-number conserving (PNC) method for treating the cranked shell model with monopole and quadrupole pairing interaction has been used to provide the microscopic mechanism of the identical bands in odd-odd nuclei ^{194}Tl and their neighbor odd-A nuclei ^{193}Tl. It is found that the blocking effect is important both in the variation in moments of inertia ($J^{(1)}$ and $J^{(2)}$) with rotational frequency for the SD bands and identical bands, and the influence of blocking effects on moments of inertia depends on the energy location and in particular on the Coriolis response of the blocking levels. Furthermore, the blocking of the high-j orbital near Fermi surface often play a important role while the influence of the low-j high-Ω orbital is negligible.

The angular momentum alignment $i(\omega)$ of the six SD bands in ^{194}Tl relative to the ^{193}Tl(1) also discussed in this paper. The integer value, $\sim 0\hbar$, of the bands in ^{194}Tl(2a, 2b) can be reproduced in a reasonable degree. And the "strict" quantized alignment seems not universal in $A\sim190$ region.

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$A\sim190$ 区奇-A 及奇奇核全同带的研究*

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摘要　应用包含单极对力及四极对力的粒子数守恒方法对 $A\sim190$ 区的奇奇核^{194}Tl 和奇 A 核^{193}Tl 中的全同带进行了研究. 结果发现堵塞效应对全同带的形成及转动惯量随角频率变化的微观机制都起着非常重要的作用. 同时文中对^{194}Tl 的 6 条超形变转动带相对于^{193}Tl(1)的角动量顺排 $i(\omega)$的量子化也做了研究.

关键词　粒子数守恒方法　超形变转动带　全同带　动力学和运动学转动惯量

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