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Effects of Pairing Correlations on the Antimagnetic Rotation

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Abstract: The antimagnetic rotation bands in ^{105,106}Cd are investigated by the cranked shell model with pairing correlations treated by a particle-number conserving method, in which the blocking effects are taken into account exactly. The experimental moments of inertia, $I-\Omega$ relation and the reduced B(E2) transition probabilities are well reproduced. The two-shears-like mechanism for the antimagnetic rotation is investigated by examining the shears angle, *i.e.*, the closing of the two proton hole angular momenta. The sensitive dependence of the shears angle on the nuclear pairing correlations is revealed.

Key words: antimagnetic rotation; pairing correlation; particle-number conserving method

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1 Introduction

Magnetic rotation (MR)[1] and antimagnetic rotation (AMR)[2] are interesting exotic rotational phenomena existing in weakly deformed or nearly spherical nuclei[3]. In the MR bands, the energy and angular momentum are generated due to the so-called “shears mechanism”. This type of rotational bands have been discovered experimentally in $A\sim 60, 80, 110, 130$, and 190 mass regions[3–6]. In analogy to the antiferromagnetism in condensed matter physics, a similar phenomenon known as “antimagnetic rotation” is predicted in nuclei by Frauendorf[2, 3]. In AMR bands, the energy and angular momentum are increased by the so-called “two-shears-like mechanism”. The physical reason behind the establishment of such rotational bands built on these weakly deformed or nearly spherical nuclei is the violation of the rotational symmetry by the nucleon currents.

AMR is expected to be observed in the same mass regions as MR[3]. Since AMR was proposed[3], it has been investigated both experimentally and theoretically. To date, experimental evidence of AMR has been reported in ^{105}Cd[7], ^{106}Cd[8], ^{108}Cd[9, 10], ^{110}Cd[11], ^{107}Cd[12], and ^{101}Pd[13, 14]. In addition, the occurrence of AMR still needs further investigation by lifetime measurements in ^{109}Cd[15], ^{100}Pd[16], ^{144}Dy[17], and ^{112}In[18].

Theoretically, AMR has been discussed by simple geometry in the classical particle rotor model[4], and the tilted axis cranking (TAC) model[19–22]. Based on the TAC model, many applications have been carried out in the framework of microscopic-macroscopic model[8, 9, 16], pairing plus quadrupole model[3, 15], and the covariant density functional theory[23–26].

In this work, the cranked shell model (CSM) with the pairing correlations treated by a particle-number conserving (PNC) method[27, 28] is used to investigate the AMR bands in ^{105,106}Cd. In contrary to the conventional Bardeen-Cooper-Schrieffer or Hartree-Fock-Bogolyubov approach, the Hamiltonian is solved directly in a truncated Fock-space in the PNC method[29]. Therefore, the particle-number is conserved and the Pauli blocking effects are taken into account exactly. The PNC scheme has also been used both in relativistic and nonrelativistic mean field models[30, 31] and the total-Routhian-surface method with the Woods-Saxon potential[32, 33]. Very recently, the particle-number conserving method based on the cranking Skyrme-Hartree-Fock model has been developed[34]. The PNC-CSM has also been employed successfully for describing various phenomenon concerning on the rotating nuclei, *e.g.*, the odd-even differences in moments of inertia (MOI’s)[35], the identical bands[36, 37], the nonadditivity in MOI’s[38–40], the nuclear pairing phase transition[41], the rotational

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bands and high-K isomers in the rare-earth[42–49], the actinide nuclei[50–54], *etc.*

2 AMR bands in ^{105}Cd and ^{106}Cd

Fig. 1 (taken from Ref. [55]) shows the experimental (solid circles) and calculated kinematic MOI's $J^{(1)}$ with (solid black lines) and without (dashed red lines) pairing correlations for ^{105}Cd and ^{106}Cd. The pairing correlations are very important in reproducing the experimental MOI's, especially the upbending. It can be seen that the MOI's of ^{105,106}Cd are overestimated when the pairing interaction is switched off, while they are well reproduced after the pairing interaction is included. The first backbending in ^{105}Cd at $\hbar\omega \approx 0.4$ MeV is caused by the alignment of one pair of $\nu g_{7/2}$ neutrons. The configuration after backbending in ^{105}Cd is thus $\nu h_{11/2}(g_{7/2})^2$ coupled to one pair of $\pi g_{9/2}$ proton holes, which is consistent with the previous calculations[7, 23]. The first backbending in ^{106}Cd at $\hbar\omega \approx 0.4$ MeV is caused by one pair of neutrons jumping from $\nu g_{7/2}$ to $\nu h_{11/2}$.

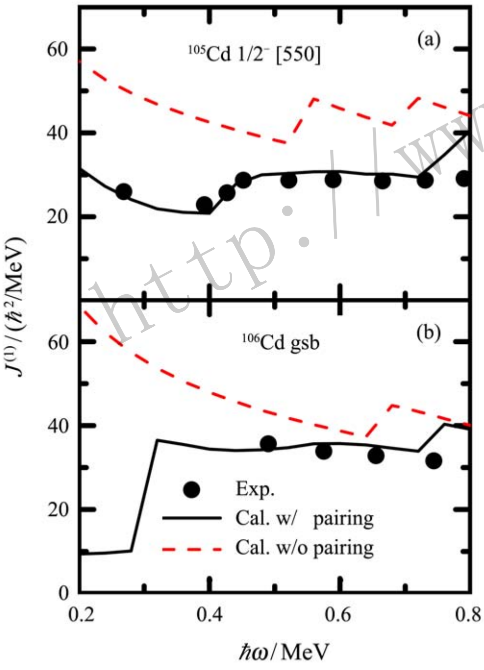

Fig. 1 (color online) The experimental (solid circles) and calculated kinematic MOI's with (solid black lines) and without (dashed red lines) pairing correlations for (a) ^{105}Cd and (b) ^{106}Cd. This figure is taken from Ref. [55].

The $I-\Omega$ relations with (solid black lines) and without (dashed red lines) pairing correlations for ^{105}Cd and ^{106}Cd are shown in Fig. 2. By considering the quantal corrections[3], the total angular momentum J calculated in the PNC-CSM corresponds to the quantum number of the angular momentum $I+1/2$ since $\sqrt{I(I+1)} \approx I+1/2$. It can be seen clearly that, the total angular momentum I increase almost linearly with increasing rotational frequency, and agree very well with the data after considering the pairing interaction.

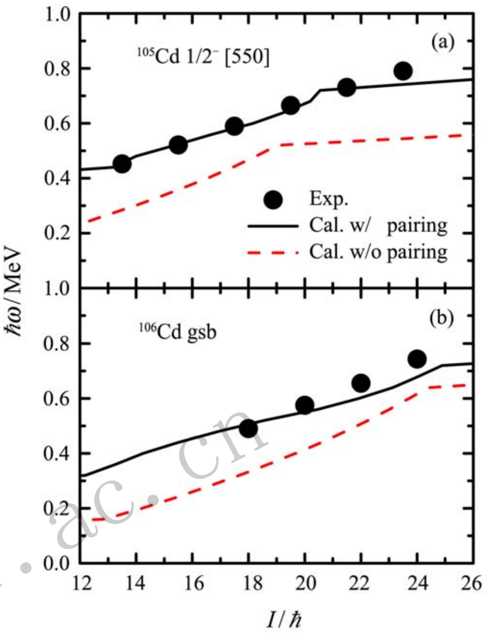

Fig. 2 (color online) The experimental (solid circles) and calculated $I-\Omega$ relation with (solid black lines) and without (dashed red lines) pairing correlations for (a) ^{105}Cd and (b) ^{106}Cd.

One of the typical features of AMR is the weak E2 transitions. Moreover, the corresponding B(E2) values decrease rapidly with increasing angular momentum, which is connected with the interpretation of the two-shears-like mechanism. Fig. 3 (taken from Ref. [55]) shows the experimental (solid circles) and calculated B(E2) values with (solid black lines) and without (dashed red lines) pairing correlations for ^{105}Cd and ^{106}Cd. It can be seen that the decreasing tendency of the B(E2) values with the cranking frequency can be obtained no matter the pairing interaction is considered or not. However, the agreement between the data and the calculated results is further improved by taking the pairing correlations into account, especially for the higher rotational frequency region. For ^{106}Cd, it is difficult to reproduce the B(E2) behavior with a frozen deformation parameter. This may be due to the deformation change with increasing rotational frequency for ^{106}Cd. In fact, as shown in the blue dotted line in Fig. 3(b), in order to reproduce the B(E2) behavior from $\hbar\omega = 0.45$ to $\hbar\omega = 0.75$ MeV, a corresponding deformation change from $\varepsilon_2 = 0.14$ to $\varepsilon_2 = 0.12$ is needed.

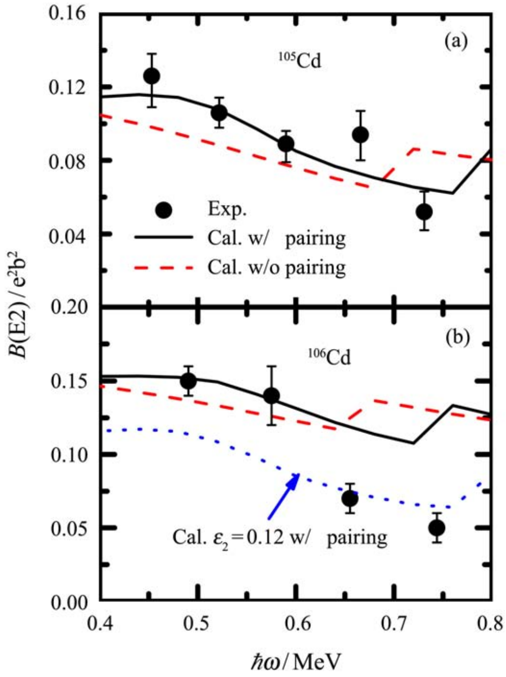

Fig. 3 (color online) The experimental (solid circles) and calculated B(E2) values with (solid black lines) and without (dashed red lines) pairing correlations for (a) ^{105}Cd and (b) ^{106}Cd. This figure is taken from Ref. [55].

In order to examine the two-shears-like mechanism for the AMR bands, the variation of the shears angle with increasing rotational frequency in ^{105}Cd is shown in Fig. 4. The insect shows the angular momentum vectors of neutrons J_ν and the two $\pi g_{9/2}$ proton holes j_π when pairing is considered. It should be noted that, in the principal axis cranking model, the expectation value of J_z vanishes due to the conservation of signature. Here, the J_z is calculated approximately in the following way according to Ref. [56]

$$J_z = \sqrt{\langle\Psi|J_z^2|\Psi\rangle}\ . \tag{1}$$

It can be seen from the insect of Fig. 4 that the two proton angular momentum vectors j_π are pointing opposite to each other and are nearly perpendicular to the vector J_ν at $\hbar\omega = 0.5$ MeV. With increasing cranking frequency, the gradual alignment of the vectors j_π of the two $\pi g_{9/2}$ proton holes toward the vector J_ν generates angular momentum, while the direction of the total angular momentum stays unchanged. This leads to the closing of the two shears. Therefore, the two-shears-like mechanism can be seen clearly. It should be noted that the shears angle decrease more quickly with increasing rotational frequency when pairing is considered, *i.e.*, closing of the two proton hole angular momenta becomes more obvious when the pairing correlations are taken into account. This indicates the important role played by the the nuclear superfluidity in AMR.

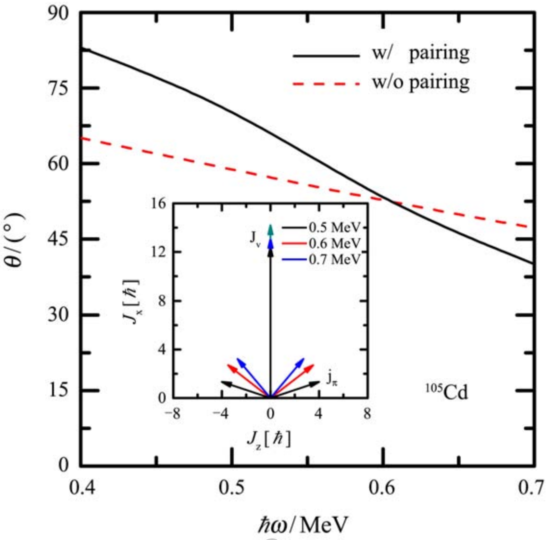

Fig. 4 (color online) The variation of the shears angle with increasing rotational frequency in ^{105}Cd. The black solid line and red dashed line show the results with and without pairing, respectively. The insect shows the angular momentum vectors of neutrons J_ν and the two $\pi g_{9/2}$ proton holes j_π when pairing is considered.

3 Conclusions

Antimagnetic rotation bands in ^{105}Cd and ^{106}Cd are investigated using the cranked shell model with the pairing correlations treated by a particle-number conserving method, in which the blocking effects are taken into account exactly. The experimental moments of inertia and $I-\Omega$ relations in ^{105}Cd and ^{106}Cd are well reproduced with the proper treatment of the pairing correlations. The calculated B(E2) values in ^{105}Cd are in good agreement with the data. In order to reproduce the B(E2) values in ^{106}Cd, a corresponding deformation change is necessary. The two-shears-like mechanism for the antimagnetic rotation is investigated and its dependence on the nuclear pairing correlations is revealed.

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对关联在反磁转动中的作用

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摘要: 采用基于推转壳模型的粒子数守恒方法对^{105}Cd和^{106}Cd中的反磁转动带进行了研究，在计算当中，粒子数严格守恒，并且堵塞效应也是严格考虑的。计算结果很好地再现了实验上观测到的$I-\Omega$关系、转动惯量以及约化跃迁几率$B(\mathrm{E2})$。通过检验双剪角，即两个质子空穴角动量的合拢，对反磁转动中的双剪刀机制进行了分析。研究表明剪刀角的合拢非常敏感地依赖于对关联。

关键词: 反磁转动；对关联；粒子数守恒方法

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