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Tilted Axis Rotations in Covariant Density Functional Theory

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Abstract. Tilted axis rotations in nuclei have attracted a lot of attentions in the last few decades. In this contribution, the tilted axis rotational bands observed in ^{198}Pb and ^{199}Pb are discussed within the framework of covariant density functional theory. In particular, the effects of pairing correlations are discussed in details.

1 Introduction

The most common nuclear rotational bands are built on states with a substantial quadrupole deformation and connected by strong electric quadrupole ($E2$) transitions. However, since the discovery of rotational-like sequences in weakly deformed Pb isotopes in the 1990s [1], the rotation of nuclei round about a tilted axis has attracted worldwide attentions [2]. In this type of rotation, the sequences are connected by the enhanced magnetic dipole ($M1$) transitions and the rotational axis of nuclei is tilted with respect to the principal axes of the nuclear density distribution, which is caused by the fact that the nucleus is composed of a deformed core and nucleons possessing a quantized amount of angular momentum. There are several typical examples of the tilted axis rotation in nuclei including the high-K bands in axially deformed nuclei [3], the magnetic rotations in weakly deformed nuclei [2,4,5], the chiral rotations in triaxial nuclei [2,6,7], *etc.*

Theoretically, the tilted axis rotation was first suggested within the framework of tilted axis cranking (TAC) model based on a phenomenological Nilsson mean filed [8]. In the past few decades, density functional theories (DFTs) have received wide attention due to their successful descriptions for many nuclear phenomena [9–11]. Considering the achievements of these DFTs, the extended TAC approaches based on relativistic [12–14] and nonrelativistic [15, 16] DFTs have been developed. These DFT-based TAC approaches are based on more realistic two-body interactions and include all important effects, such as core polarization and nuclear currents [14, 15]. Therefore, they can be used to investigate the nuclear rotations on a more fundamental level. In particular, the tilted axis cranking covariant density functional theory (TAC-CDFT) provides a self-consistent description of nuclear currents and time-odd fields [17] and thus, gives an excellent description of nuclear rotational excitations with a high predictive power [18, 19].

Very recently, pairing correlations which are very important to describe the nuclear rotational excitations have been implemented in the TAC-CDFT by solving the relativistic Hartree-Bogoliubov (RHB) equations with a monopole [20] and finite range separable pairing force [21, 22]. It is found that the inclusion of pairing correlations improves the description of nuclear energy spectra and transition probabilities [20–22].

In this contribution, the TAC-CDFT descriptions for the observed tilted axis rotational bands in ^{198}Pb and ^{199}Pb are presented and the effects of pairing correlations are discussed in details.

2 Results and Discussion

In Figure 1, the calculated rotational excitation energies by TAC-CDFT with and without pairing correlations for bands 1 and 3 in ^{198}Pb as well as bands 1 and 2 in ^{199}Pb are shown, in comparison with the data [23, 24]. The numerical details of the TAC-CDFT calculations for these four tilted axis rotational bands can be found in Ref. [22].

As shown in Figure 1, the energy spectra of these four bands are reproduced well. In particular, the descriptions of bandhead energy differences before and after back-bending show good agreement with the experimental data after

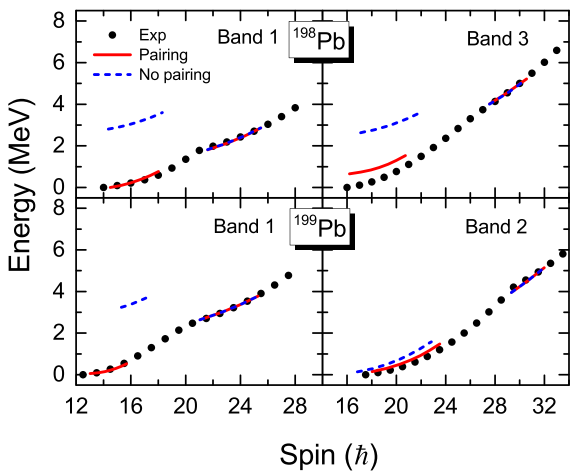

Figure 1. Rotational excitation energies obtained from TAC-CDFT for bands 1 and 3 in ^{198}Pb (upper panels) and bands 1 and 2 in ^{199}Pb (lower panels) as functions of angular momenta, in comparison with the experimental data [23, 24] (solid dots). The solid and dashed lines denote the calculated results with and without pairing correlations, respectively. Taken from Ref. [22].

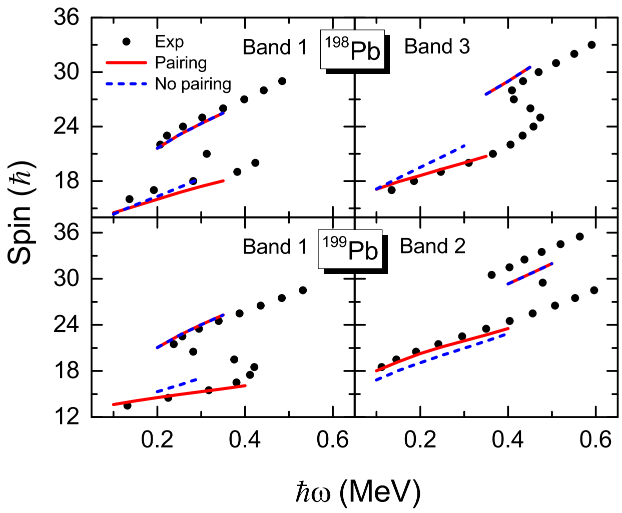

Figure 2. Total angular momenta obtained from TAC-CDFT for bands 1 and 3 in ^{198}Pb (upper panels) and bands 1 and 2 in ^{199}Pb (lower panel) as functions of rotational frequencies, in comparison with the experimental data [23, 24] (solid dots). The solid and dashed lines denote the calculated results with and without pairing correlations, respectively. Taken from Ref. [22].

the consideration of pairing correlations. The inclusion of pairing correlations mainly reduce the excitation energies of states before back-bending and have almost no influence on the energies after back-bending, in which two more aligned $i_{13/2}$ neutron holes are blocked.

The total angular momenta as functions of rotational frequencies calculated by TAC-CDFT and their comparisons with the experimental data [23, 24] are shown in Figure 2. Good agreements with the experimental data have been achieved for all of these four tilted axis rotational bands after the inclusion of pairing correlations. In addition, for the spin regions before back-bending of bands 1 and 3 in ^{198}Pb as well as band 1 in ^{199}Pb, the contributions of pairing correlations to the angular momenta are visible only in the high rotational frequencies. The calculated angular momenta for band 2 in ^{199}Pb with pairing correlations are even larger than the ones without pairing. As demonstrated in Refs. [20, 22], this is caused by the fact that for tilted axis rotations, pairing correlations have two competitive consequences, namely, reducing the amplitudes of proton and neutron angular momenta and expediting the close of the angles between them.

The calculated transition probabilities $B(M1)$ of these four tilted axis rotational bands in ^{198}Pb and ^{199}Pb and their comparisons with available data are shown in Figure 3. The experimental $B(M1)$ values are reproduced well by the TAC-CDFT calculations. The pairing correlations play a role for the spin

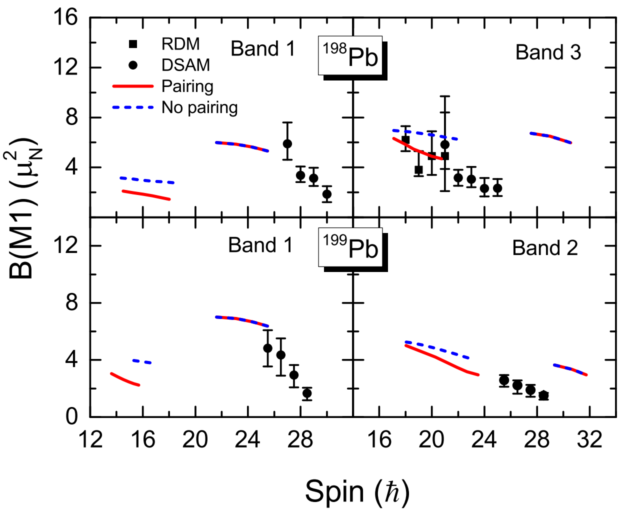

Figure 3. The calculated $B(M1)$ values for bands 1 and 3 in ^{198}Pb (upper panel) and bands 1 and 2 in ^{199}Pb (lower panel) as functions of total angular momenta, in comparison with the data. Solid dots and squares denote experimental data taken from DSAM [26] and FDM [27], respectively. Taken from Ref. [22].

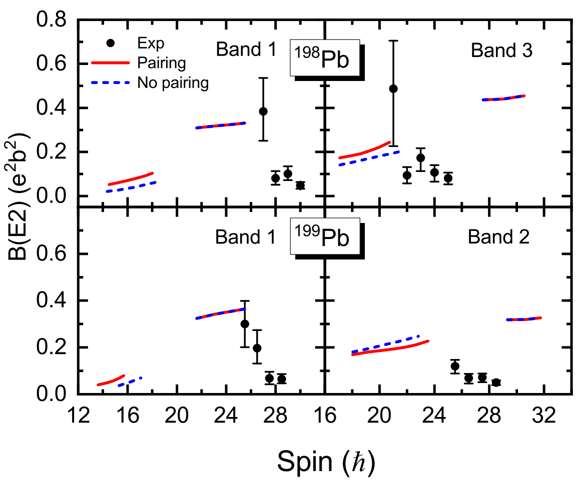

Figure 4. The calculated $B(E2)$ values for bands 1 and 3 in ^{198}Pb (upper panel) and bands 1 and 2 in ^{199}Pb (lower panel) as functions of total angular momenta, in comparison with the data [26]. The solid and dashed lines denote the calculated results with and without pairing correlations, respectively. Taken from Ref. [22].

regions before back-bending and can reduce the strength of $B(M1)$ transition probabilities compared with the results without pairing.

For the $B(E2)$ transition probabilities, as shown in Figure 4, the calculated results are in reasonable agreement with the experimental data. Meanwhile, the $B(E2)$ values keep roughly a constant with the total angular momenta, which is associated with the nearly unchanged quadrupole deformation for each configuration. Different from the cases in $M1$ transitions, pairing correlations have marginal effects on the $E2$ transitions.

3 Conclusion

In summary, four tilted axis rotational bands observed in ^{198}Pb and ^{199}Pb are discussed with in the framework of tilted axis cranking covariant density functional theory. The experimental energy spectra, total angular momenta and the transition probabilities are reproduced well after the consideration of pairing correlations. In particular, the descriptions of bandhead energies before and after back-bending are improved significantly after including the pairing correlations. Meanwhile, pairing correlations reduce the strength of $M1$ transition probabilities and have marginal effects on the $E2$ transitions.

Acknowledgements

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