

# Proton and neutron pair correlations in $^{10}\text{B}$

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**Abstract.** We developed an extension of the antisymmetrized molecular dynamics in which we perform energy variation after the projection to isospin eigenstates. In our first application of this method to  $^{10}\text{B}$ , we found that low-lying positive-parity states ( $J^\pi T = 3_1^+0, 1_1^+0$  and  $0_1^+1$ ) have a spatially correlated  $pn$  pair and  $2\alpha$  structure.

## 1. Introduction

For a  $pn$  pair in nuclei, two types of isospin states exist; the  $T = 0$  and  $S = 1$  state like a deuteron-like pair and the  $T = 1$  and  $S = 0$  state analogous to a dineutron pair. In low-lying spectra of  $N = Z$  odd-odd nuclei,  $T = 0$  and  $T = 1$  states compete with each other. To clarify their structures, we extended the antisymmetrized molecular dynamics.[1] That is the isospin projected and  $\beta\gamma$  constraint AMD ( $T\beta\gamma$ -AMD) combined with the GCM, which is an extended method of the  $\beta\gamma$ -AMD+GCM.[2]

In our first application of the  $T\beta\gamma$ -AMD+GCM, we investigate the low-lying states of  $^{10}\text{B}$ .  $^{10}\text{B}$  has a  $2\alpha$  core and a  $pn$  pair [3], and therefore we need to consider spin dynamics and spatial dynamics of the  $pn$  pair around the  $2\alpha$  core. In the  $T\beta\gamma$ -AMD framework, we can see the structures on the energy surfaces by the first principle calculation based on nucleon degrees of freedom and take soft modes into account with the GCM.

## 2. Formulation

In the framework of the  $T\beta\gamma$ -AMD, a wavefunction is given by a Slater determinant of Gaussian packets. We performed the energy variation after the isospin and parity projections under the constraint on the quadrupole deformation parameters  $\beta$  and  $\gamma$ :

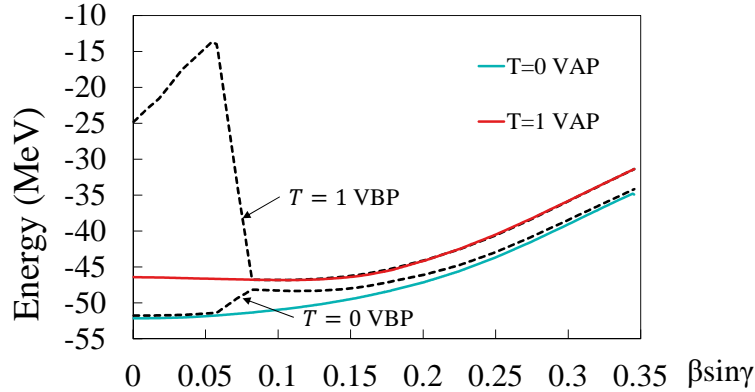
$$\delta \frac{\langle \Phi | HP_{MK}^J P^\pi P^T | \Phi \rangle}{\langle \Phi | P_{MK}^J P^\pi P^T | \Phi \rangle} = 0. \quad (1)$$

After the variation, we superposed the obtained wavefunctions on the  $\beta\gamma$  plane to calculate expectation values. Here we used the Volkov No2 force and the spin-orbit part of the G3RS force. See more details in Ref. [4]. The energy variation after the isospin projection is necessary to obtain proper  $T = 0$  and  $T = 1$  wavefunctions in the whole region of the  $\beta\gamma$  planes.

## 3. Result

In Fig. 1, we show the energy surfaces obtained by the  $T\beta\gamma$ -AMD and  $\beta\gamma$ -AMD. We obtained the smooth energy surfaces in the  $T\beta\gamma$ -AMD results, but we found the serious energy gaps at





**Figure 1.** The energy curves at  $\beta \cos \gamma = 0.40$  of  $T = 0$  and  $T = 1$  states for  $^{10}\text{B}$ . Results with isospin projection (solid lines) and those without isospin projection (dashed lines) are shown.

$\beta \sin \gamma = 0.07$  in the  $T\beta\gamma$ -AMD results. It indicates that the  $T\beta\gamma$ -AMD is suitable to describe the low-lying states of  $N = Z$  odd-odd nuclei. The energy surface is soft along the  $\beta \sin \gamma$  axis, corresponding to the  $pn$  pair motion around the  $2\alpha$  core. By superposing these wavefunctions, we can take the motion of the  $pn$  pair into account even near the core.

We calculated the energy spectra of  $^{10}\text{B}$  and show the results in Fig. 2. We can see that the level ordering and level spacings for each isospin are well reproduced. Moreover, energy gains from the single Slater determinant calculation are remarkably large for all spectra. It implies that the  $pn$  pair motion, which is efficiently taken into account by the GCM in the  $T\beta\gamma$ -AMD, is important in  $^{10}\text{B}$ .

We found that spin configuration and spin-orbit force play significant roles in the low-lying states of  $^{10}\text{B}$  (see Fig. 3). In the low-lying states, we found a  $2\alpha$  core and a  $pn$  pair. For the  $T = 0$  spectra, the lowest state ( $3_1^+0$ ) has the  $S = 1$   $pn$  pair moving in the  $D$ -wave rotation around the core.  $S = 1$  and  $L = 2$  of the  $pn$  pair are aligned to  $J = 3$  to feel strong attractive interaction at the surface of the core. As a result of the alignment, the  $^{10}\text{B}$  ground state has the finite spin  $J^\pi = 3^+$ .

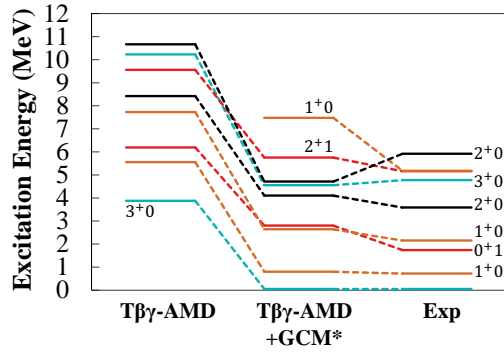
On the other hand, in the first excited state ( $1_1^+0$ ), the  $S = 1$   $pn$  pair moves in  $S$ -wave and it is not attracted to the core. For this state, the feature of the  $pn$  pair is similar to the  $T = 1$   $pn$  pair in the  $^{10}\text{B}(0_1^+1)$  or the  $nn$  pair in the  $^{10}\text{Be}(0_1^+1)$ . For the  $1_2^+0$  state, we found strong  $E2$  transition to the  $1_1^+0$  because of the core rotation.

Focusing on the  $T = 1$  spectra, the lowest state ( $0_1^+1$ ) has a  $pn$  pair and it moves in the  $S$ -wave around the core. This state is the isobaric analogue state of  $^{10}\text{Be}$ . We obtained a remarkably large  $B(M1)$  from the  $0_1^+1$  to  $1_1^+0$  consistently with the experimental data. These two states, the  $0_1^+1$  and  $1_1^+0$ , have similar spatial structures and show difference in the spin configuration ( $S = 0$  and  $S = 1$ ) of the  $T = 1$  and  $T = 0$   $pn$  pairs. Therefore, these states can be regarded as spin partners.

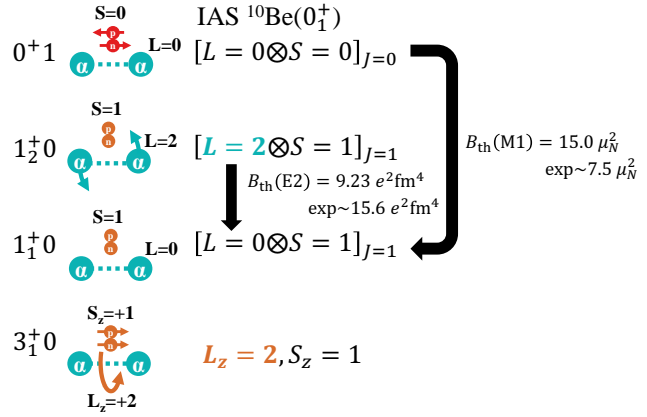
In the present framework of the  $T\beta\gamma$ -AMD+GCM, we can treat not only isospin competition but also spin configuration through the isospin projection and antisymmetrization. We can separately describe low-lying levels of  $N = Z$  odd-odd nuclei in terms of spin configurations.

#### 4. summary

We extended the AMD framework to that with the isospin projection. In this method, we can treat each isospin eigenstate of the  $pn$  pair and control its spin configuration using this method. We investigated the structures of  $^{10}\text{B}$ . The reason why the lowest state ( $3_1^+0$ ) has the finite spin is that the  $S = 1$   $pn$  pair rotates around the  $2\alpha$  core in the  $D$ -wave so as to gain the spin-orbit



**Figure 2.** The spectra without GCM (left), those with GCM (middle) and the experimental data (right) of  $^{10}\text{B}$ . This figure is taken from Ref. [4] with a slight modification.



**Figure 3.** The structures of the low-lying spectra of  $^{10}\text{B}$ .  $B_{\text{th}}$  refers to the reduced transition probability of the present calculation.

potential. The first excited state ( $1_1^+0$ ) has the  $T = 0$   $pn$  pair moving in the  $S$ -wave and its spatial structure is similar to the lowest  $T = 1$  state ( $0_1^+1$ ). Accordingly, we obtained the strong  $M1$  transition from the  $0_1^+1$  to the  $1_1^+0$ .

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