Canonical base in self-consistent constrained HFB in odd-A nuclei[†]

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We developed a program for solving the self-consistent Hartree-Fock-Bogoliubov (CHFB) equation under four constraints, one each on the total angular-momentum I, proton number Z_+ in the + parity proton shell (p^+), proton number Z_- in the − parity proton shell (p^-), and neutron number N, so that it reproduces the $11/2^-$ band in ^{135}Pr. We choose the signature-invariant base C_k and $C_{\hat{k}}$, where $\hat{k}$ is the time-reversed level of k, and adopt a Hamiltonian with spherical single-particle energies plus the residual quadrupole-quadrupole, monopole-pairing, and quadrupole-pairing interactions. In this signature-invariant base, the generalized density matrix $K(=K^2)$ is expressed in terms of $\rho^1_{kl} = \langle C^\dagger_l C_k \rangle$, $\rho^2_{\hat{k}\hat{l}} = \langle C^\dagger_{\hat{l}} C_{\hat{k}} \rangle$ and $\kappa_{\hat{k}l} = \langle C_l C_{\hat{k}} \rangle$, where the state $|\,\rangle$ is the quasiparticle vacuum. The CHFB equation is given as Eq. (1) in Ref. 1). After rendering the dangerous term zero through the iteration procedure, we can transform the elements in K to the canonical forms, *i.e.*, $(F^1)^{-1}_{km}\rho^1_{mn}F^1_{nk} \equiv \rho^{1c}_{kk}$ and $(F^2)^{-1}_{\hat{k}\hat{m}}\rho^2_{\hat{m}\hat{n}}F^2_{\hat{n}\hat{k}} \equiv \rho^{2c}_{\hat{k}\hat{k}}$; thus $(F^2)^{-1}_{\hat{k}\hat{m}}\kappa_{\hat{m}n}F^1_{nk} \equiv \kappa^c_{\hat{k}k}$. In other words, K is transformed to K_c, and the relation $K_c^2 = K_c$ follows. Subsequently, we obtain $\rho^{1c} = \rho^{2c}$. If we apply the same transformation to the CHFB matrix (see Eq. (1) in Ref. 1)), we obtain

$$\rho^{1c}_{ii} = \rho^{2c}_{\hat{i}\hat{i}} = \frac{1}{2}\left(1 - \frac{(\xi^1_{ii}+\xi^2_{\hat{i}\hat{i}})/2}{\sqrt{(\Delta^c_{\hat{i}i})^2 + ((\xi^1_{ii}+\xi^2_{\hat{i}\hat{i}})/2)^2}}\right), \qquad (1)$$

where $\xi^1 = (F^1)^{-1}(h^1 - \omega j_x)F^1$, $\xi^2 = (F^2)^{-1}(h^2 + \omega j_x)F^2$, and $\Delta^c = (F^2)^{-1}\Delta F^1$. Here h^1, h^2, and Δ are defined in Eq. (1) in Ref. 1). In Fig. 1, we compare the CHFB solution under three constraints for $I = 31/2$, $Z = Z_+ + Z_-$, and N (open squares and open circles) with the CHFB solution under four constraints (filled squares and filled circles). Here, the circles correspond to the p^+ shell, and squares correspond to the p^- shells. The quantities represented by the red filled square under the constraint $Z_- = 17$ and the red open square under $Z = 31$ are composed of the contribution mainly from the $\mathrm{h}_{11/2}$ level with $j_z = 5/2$. The number $Z = 31$ corresponds to the proton number outside core 28 for ^{135}Pr. As shown in (A) of Fig. 1, $\rho^{1c} = \rho^{2c} \sim 1/2$, *i.e.*, $1/2 \times 2 = 1$ in the p^- shell, we confirm that the solution certainly describes the negative parity band in the odd-Z nucleus ($11/2^-$ band in ^{135}Pr). In (B) of Fig. 1, we compare $\Delta^c_{\hat{i}i}$ between the CHFB solution under three constraints and the CHFB solution under four constraints The blocking effect is clearly indicated by the red filled or open squares because these gap values are much smaller than those for the other levels.

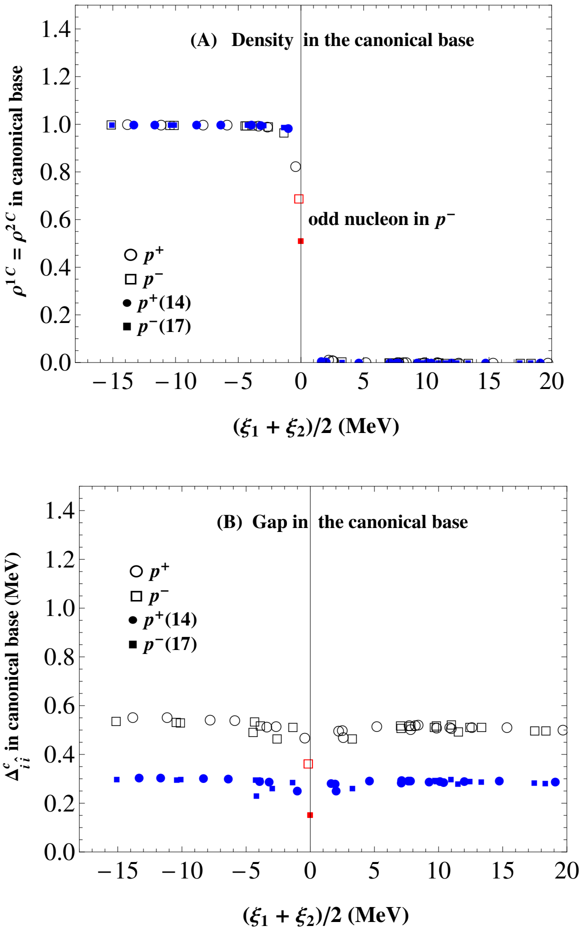

Fig. 1. (A) $\rho^{1c} = \rho^{2c}$ in the canonical base as a function of $(\xi^1 + \xi^2)/2$ at the $I = 31/2^-$ state. (B) Δ^c in the canonical base as a function of $(\xi^1 + \xi^2)/2$ at the $I = 31/2^-$ state. In both figures, filled circles represent the proton levels in the p^+ shell with $Z_+ = 14$, and filled squares represent the proton levels in the p^- shell with $Z_- = 17$. Open circles and open squares indicate the CHFB solution under $Z = 14+17 = 31$. The red filled-square level with $Z_- = 17$ and the red open-square level with $Z = 31$ are mainly from $\mathrm{h}_{11/2}$. See the text for further details.

Reference

1) K. Sugawara-Tanabe, K. Tanabe, RIKEN Accel. Prog. Rep. **52**, 1148 (2019).

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