Nucleon pair approximation of the backbending phenomena

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The SD-pair model can describe very well the γ-unstable feature of low-lying collective states of nuclei with mass A around 130, which is known as a manifestation of the O(6) symmetry in the IBM. This model, however, cannot treat the backbending phenomena because it does not take into account the aligned neutron $(h_{11/2})^2$ configuration. Its configuration results in the backbending as known from many experimental investigations [1]. If we intend to describe the O(6)-like symmetry and the backbending phenomena simultaneously, we need an extension of the SD-pair model. Here we introduce the $SD+H$-pair model.

The S-, D- and H-pair creation operators, which are used as the building blocks of the $SD+H$-pair model, are defined as

$$S^\dagger = \sum_j \alpha_j A_0^{\dagger(0)}(jj), \quad D_M^\dagger = \sum_{j_1 j_2} \beta_{j_1 j_2} A_M^{\dagger(2)}(j_1 j_2), \quad H_M^{\dagger(K)} = A_M^{\dagger(K)}(\tfrac{11}{2}\tfrac{11}{2}),$$
$$A_M^{\dagger(J)}(j_1 j_2) = \sum_{m_1 m_2} (j_1 m_1 j_2 m_2 | JM)\, c_{j_1 m_1}^\dagger c_{j_2 m_2}^\dagger, \tag{0·1}$$

where $K = 0, 2, 4, 6, 8$ and 10, and $c_{jm}^\dagger$ is the nucleon creation operator. The structure coefficients α and β are determined so as to maximize the collectivity of the S- and D-pairs. Using the S-, D- and H-pairs, the collective states of even-even nuclei are constructed on the core $|-\rangle$ as

$$(S^\dagger)^{n_s}(D^\dagger)^{n_d}(H^\dagger)^{n_h}\,|-\rangle = |S^{n_s} D^{n_d} H^{n_h}\ I\rangle\,, \tag{0·2}$$

where I is the total angular momentum of the nuclear state, and $n_s + n_d + n_h$ gives the number of active pairs. In the present calculation, only up to one neutron H-pair is considered.

All the five orbitals are considered in the $50 \le N(Z) \le 82$ major shell for neutrons (protons). The single-particle energies are extracted from excitation energies in Refs. 2). The two-body effective interaction among like nucleons employed in our calculation consists of the monopole pairing, quadrupole pairing and quadrupole-quadrupole interactions, and these force strengths are denoted as $G_{0\tau}$, $G_{2\tau}$ and κ_τ ($\tau = \nu$ or π), respectively. The two-body effective interaction between protons and neutrons is the quadrupole-quadrupole interaction, and this force strength is denoted as $\kappa_{\nu\pi}$. The adopted force strengths are $G_{0\tau} = 0.090$MeV, $G_{2\tau} = G_{0\tau} \times 0.2 = 0.018$MeV, $\kappa_\nu = 0.135$MeV, $\kappa_\pi = 0.040$MeV and $\kappa_{\nu\pi} = 0.100$MeV. The usage of this interaction is given in details in Refs. 3).

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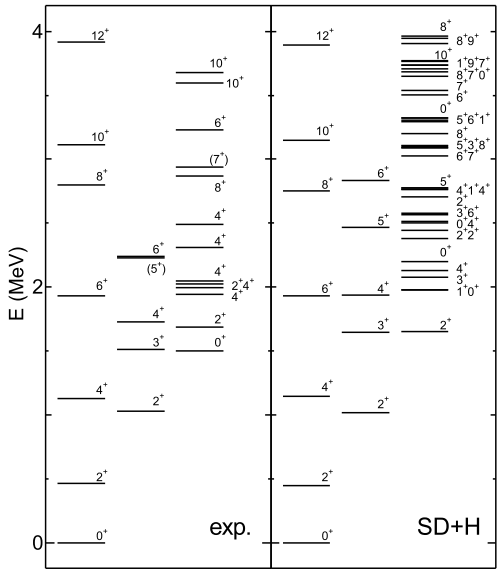

Fig. 1. Comparison of experimental energy spectra[4] (exp.) to the $SD+H$-pair model (SD+H) results for ^{132}Ba.

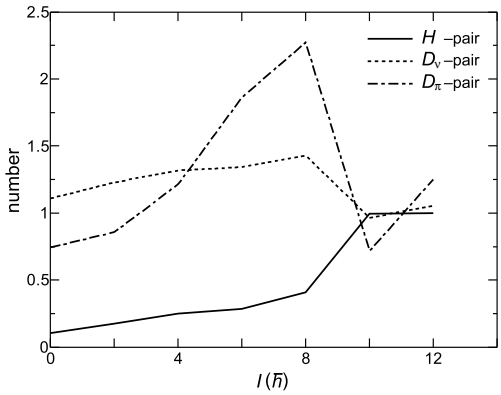

Fig. 2. Expectation values of pair-numbers of the D- and H-pairs as a function of the spin I.

The theoretical and experimental spectra for positive parity levels are compared in Fig. 1. The calculated spectrum of the even-spin yrast band excellently agrees with experiment. Especially the sudden decrease of a level spacing around the states of spin 10^+ is well reproduced. The quasi-γ band is well reproduced except for the 6^+ state. Especially the energy staggering of even-odd spin states on quasi-γ band is fairly well reproduced.

In Fig. 2, expectation values of pair-numbers in the yrast states are plotted as a function of the spin I. Up to the spin 8^+, the number of D-pairs increases with spin, and the number of H-pairs is small. Above the spin 10^+, the number of H-pairs suddenly increases. This means that the SD collective nucleon pairs play essential roles in describing low-lying states and yet the pair of $h_{11/2}$ neutrons is indispensable for high-spin states.

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