MICROSCOPIC STUDY OF NUCLEAR QUADRUPOLE COLLECTIVE MOTIONS IN TERMS OF THE BOSON EXPANSION THEORY*

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Structures of the collective wave functions of the normal-ordered linked-cluster boson expansion theory (NOLC-BET) are investigated. Numerical results are presented for some low-lying collective states in neutron-deficient barium isotopes, and properties of excited 0^+ states and an evolution of the collective mode as the neutron number changes are discussed.

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1. Introduction

The microscopic description of anharmonicities in nuclear quadrupole collective motions, in terms of the fermion degree of freedom, is a long-standing and fundamental subject in the study of nuclear many-body systems. The NOLC-BET is a promising method for the subject if the coupling to non-collective states is faithfully included in the calculation [1]. It allows us to take into account higher-order terms neglected in the RPA, and the adiabatic condition for particle motions can be avoided.

There are quite a few indications that nature of low-lying excited 0^+ state is not well-understood [2, 3]. It was noticed that the low-lying 0^+ states in the $A = 130$ mass region could have a more complicated nature than the one implied by the simple geometrical interpretation in terms of β or (two-phonon) γ vibrations [4, 5]. Asai *et al.* [6] identified a number of higher-excited 0^+ states in ^{124,126,128,130}Ba and suggested from an extrapolation of the experimental data that energy relation between the 0_2^+ and 0_3^+ state would invert at ^{122}Ba or at more deformed Ba nuclei. In Ref. [7], the NOLC-BET was applied to low-lying collective states in ^{128}Ba, where structures of

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collective wave functions and natures of the 0_2^+ and 0_3^+ state were also partly investigated. In this paper, results of further applications of the NOLC-BET to the low-lying quadrupole collective states in neutron-deficient Ba isotopes are reported.

2. Theoretical framework

The theoretical framework of the present calculation is the same as that of Ref. [7]. In calculating the energy spectra, the only two adjustable parameters in the Hamiltonian, f_2 and g_2', are slightly varied around the vicinity of the predicted value, *i.e.* unity.

3. Results and discussion

The calculated energy levels for ^{120,122}Ba show γ-soft nature of these nuclei (Fig. 1). Though experimentally quasi γ-band has not been established yet for ^{120}Ba, staggerings of the theoretical quasi γ-bands seem to indicate that the γ-softness is more prominent for ^{122}Ba than for ^{120}Ba.

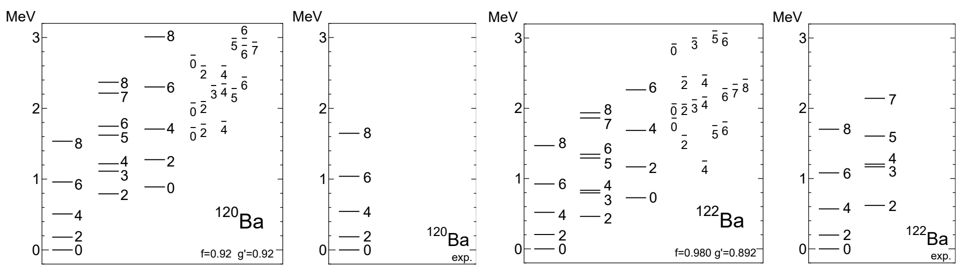

Fig. 1. Theoretical energy levels for ^{120,122}Ba are compared to experimental data [8, 9]. The states in the ground-bands, the quasi γ-bands or the 0_2^+ bands are separately accumulated, while other states (short bars) are assembled in their spin groups in columnar forms.

It is instructive to compare the BET wave functions of states in ^{120}Ba (Fig. 2) with those in ^{128}Ba (Figs. 4, 5 in Ref. [7]). A number of features are notable in the figures: *(i)* In the ground (0_1^+) state, the admixture of the three-phonon component is larger in ^{120}Ba than in ^{128}Ba. *(ii)* In the 0_2^+ state, the leading order component is $|N, v) = |3, 3)$ for both ^{120}Ba and ^{128}Ba, while the admixture of components in the $v = 0$ sequence, *i.e.*, $|0, 0)$, $|2, 0)$ and so on, is more meaningful for ^{120}Ba than for ^{128}Ba. *(iii)* The major component in the 0_3^+ state is $|2, 0)$ for both ^{120}Ba and ^{128}Ba. Its weight is smaller, while the admixture of components in the $v = 3$ sequence in the 0_3^+ state is larger for ^{120}Ba than for ^{128}Ba. *(iv)* In the 2_1^+ state, the weight of the major component $|1,1)$ is reduced and the admixture of components in the $v = 2$ sequence is increased, while in the 2_2^+ state, the weight of the major component $|2,2)$ is reduced and the admixture of components in the $v = 1$ sequence is increased in ^{120}Ba.

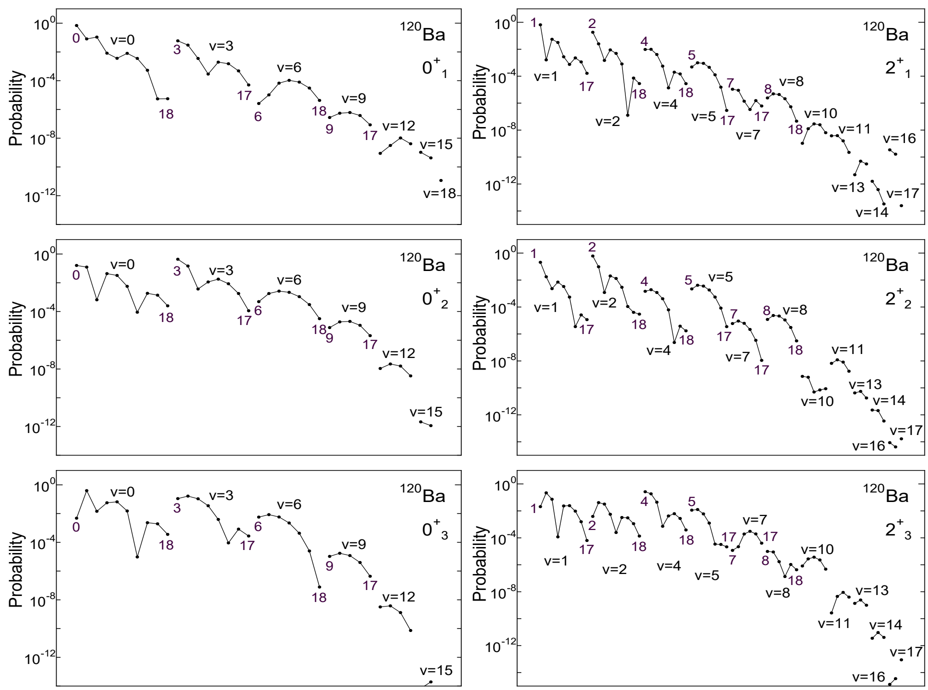

Fig. 2. Probability distributions of the boson numbers N and the seniorities v in the theoretical wave functions for 0_1^+, 0_2^+, 0_3^+, 2_1^+, 2_2^+ and 2_3^+ states in ^{120}Ba. Components of the same seniority are separately accumulated and connected in the ascending order of N. The numbers attached at some beginning or ending points represent the boson numbers.

For ^{128}Ba, it was indicated in Ref. [7] that the 0_2^+ state is difficult to interpret as a β bandhead. For the neutron-deficient Ba isotopes, present calculations seem to suggest that the β vibrational character may gradually be increased in the 0_2^+ state with decreasing the neutron number.

In Fig. 3, one can see that the two-quasiparticle probabilities in the collective Tamm–Dancoff (TD) mode, which is a primal building block of the collective boson mode in the present formalism, are dispersed wider for ^{120}Ba than for ^{128}Ba, and the main component of the collective TD mode is $(\pi g_{7/2})^2$ with a probability of 0.195 for ^{120}Ba, while it is $(\nu h_{11/2})^2$ with a probability of 0.272 for ^{128}Ba. These features may be associated with an evolution of quadrupole collectivities and nuclear shapes.

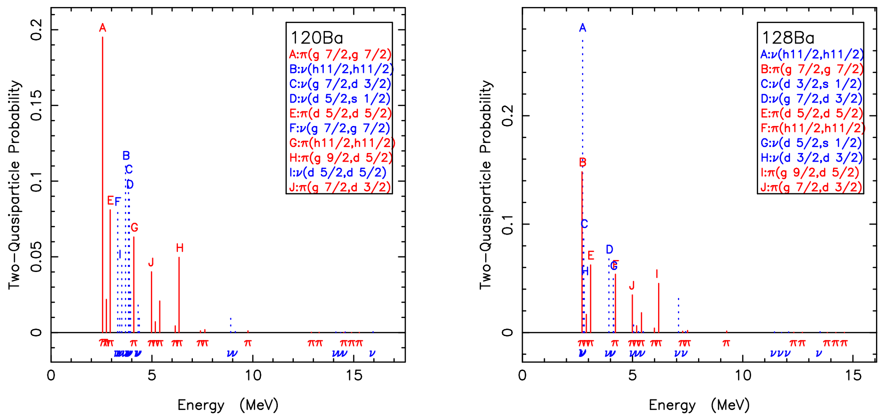

Fig. 3. (Color online) Calculated two-quasiparticle probabilities in the adiabatic collective Tamm–Dancoff mode are plotted against the two-quasiparticle energies for ^{120}Ba (left), together with those for ^{128}Ba (right) for comparison. The scripts π and ν are attached to distinguish the proton components (solid/red lines) and the neutron components (dotted/blue lines). The figure for ^{128}Ba is taken form Fig. 1 of Ref. [7].

4. Summary

Structures of the collective wave functions of the NOLC-BET are investigated. In the present results, the main contribution to the 0_2^+ state comes from the three-phonon component, while the two-phonon component is dominant in the 0_3^+ state for ^{120}Ba as well as for ^{128}Ba. However, the underlying collective boson changes its microscopic structure as the neutron number changes, which may be associated with the evolution of quadrupole collectivities and nuclear shapes. Concerning the energy relation between the 0_2^+ and 0_3^+ state suggested by Asai *et al.* [6], relevant experimental data are still missing, and further systematic investigations are called for.

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