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Properties of the 0_2^+ state and isospin excitation in the $N = Z$ nucleus ^{68}Se

Falih H. Al-Khudair, Y. S. Li, and G. L. Long

Key Laboratory for Quantum Information and Measurements and Department of Physics, Tsinghua University, Beijing 100084, People's Republic of China and

Center of Nuclear Theory, Lanzhou National Laboratory of Accelerators, Lanzhou 730000, People's Republic of China

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Band structure and electromagnetic transition properties of the low-lying states in the $N = Z$ ^{68}Se nucleus were studied within the framework of interacting boson model 3. The isospin excitation states with $T > T_Z$ are identified. The $M1$ and $E2$ matrix elements for low-lying states have been investigated and were used to identify the low-lying mixed symmetry states. Special attention is given to the occurrence of 0_2^+ state, recently predicted by the projected shell-model (PSM) calculation. The present predicted spectrum for ^{68}Se is close to the recent PSM results and confirms the results for the 0_2^+ state. The calculated results are compared with available experimental data, and they are in general good agreement.

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I. INTRODUCTION

During recent years comprehensive new experimental information on energy levels in the $N \simeq Z$ nuclei have been collected [1–5]. Because isospin excitations have been observed at modest excitation energies in these nuclei, this region is of specific interest because different microscopic theoretical approaches can be compared and tested. These nuclei are expected to give new insight into the neutron-proton correlation. The studies [6–8] have demonstrated that mixing between $T = 0$ and $T = 1$ modes and between $T_z = \pm 1$ and $T_z = 0$ in the $T = 1$ mode are necessary in an isospin invariant approach. In even-even $Z = N$ nuclei, the 0_1^+, $T = 0$ ground state is separated from the excited $T = 1$ states by a relatively large energy gap and isospin symmetry forces the isovector pairing to be identical in all three $T = 1$ pairing channels. However, the relative dominance of $T = 0$ versus $T = 1$ pairing in $N = Z$ nuclei has been shown to be linked to the energy separation of the two types of pair and hence to the separation of the $T = 0$ and $T = 1$ states in odd-odd $N = Z$ nuclei. Over the past few years, the structure of these nuclei have received intensive attention [9–17]. Many detailed theoretical description of these nuclei were available, due largely to the fact that the structure of these nuclei provides a sensitive test for the isospin symmetry of nuclear force. The isospin effect were studied in Refs. [18–23].

In this work, we shall examine an alternative description of the band structure and isospin excitation states ($T > T_z$) of ^{68}Se in the interacting boson model 3 (IBM-3). As we shall see, this model can provide a relatively simple, yet accurate, description for the states. This work can be considered a continuation of the work in Ref. [24] and a partial effort to the comprehensive understanding of the nuclear structure in this region. Before going to the IBM-3 treatment, it is worth mentioning the following work. The excitation states of ^{68}Se were investigated in Refs. [25,26], where the levels were inferred from the ^{12}C(^{58}Ni,$2n$) and ^{40}Ca(^{36}Ar,2α) reactions. The nuclear structure of coexistence of differently deformed shapes has been found in ^{68}Se, where the ground-state band has an oblate deformation whereas an excited band has prolate deformation [27]. Some effort has been made to provide a more sophisticated description of these low-lying states. However, these calculations are generally restricted to the study of nuclear shape and band structure with isospin ($T_z = 0$).

More recently, several theoretical investigations of ^{68}Se isotope have been carried out:

(i) Sun [28], has performed systematic analysis of even-even ^{68}Se isotope in the projected shell model, satisfactorily reproduced the excitation energy levels of this nucleus, including the coexisting oblate and prolate minima, the backbending at $J = 8^+$ and 16^+ and a number of high K isomers at approximately 5 MeV above the ground state.

(ii) Kaneko *et al.* [29] have considered the configuration space ($2p_{3/2}, 1f_{5/2}, 2p_{1/2}, 1g_{9/2}$) and performed shell model and constrained Hartree-Fock calculations for some $N = Z$ nuclei. The authors found shape transition from prolate to oblate deformation in these $N = Z$ nuclei and oblate-prolate coexistence at ^{68}Se. The ground state of ^{68}Se has an oblate shape, whereas the shape of ^{60}Zn and ^{64}Ge are prolate.

(iii) Afanasjev and Frauendorf [30], have performed calculations using the cranked relativistic mean field, cranked relativistic Hartree-Bogoliubov theories, and cranked Nilsson-Strutinsky approach for ^{68}Se isotope; their calculations strongly suggest that the presence of strong isovector *np* pairing at low spin and the strength is restricted by the isospin symmetry.

(iv) Sun *et al.* [31] have investigated shape isomeric states using a multi-mass-zone x-ray burst model, given a two waiting point nuclei ^{68}Se and ^{72}Kr that are characterized by shape coexistence. The ground state takes an oblate shape with ($\varepsilon_2 = 0.25$) and another local minimum with a prolate shape ($\varepsilon_2 = 0.4$) is found to be 1.1 MeV(^{68}Se) and 0.7 MeV (^{72}Kr), which were interpreted as isomeric states.

II. THE MODEL HAMILTONIAN AND THE PARAMETER

The IBM describes the low-lying energy levels in the even-even nuclei, starting from the symmetric coupling of bosons. In

