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Structure of the low-lying positive and negative parity states in even–even $^{144-154}$Nd isotopes

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The low-lying positive and negative parity states of even–even $^{144-154}$Nd isotopes are studied using the interacting boson model (IBM). The negative parity states are involved within the IBM model by adding a single angular momentum ($L = 3$) boson with intrinsic negative parity f-boson to s and d-bosons model space. For these nuclei, the potential energy surfaces $V(\beta, \gamma)$, transition probability $B(E1)$, $B(E2)$ and $B(E3)$ are calculated. Phase transition from the $U(5)$ limit to the $SU(3)$ limit is observed in the chain and the critical point has been determined for ^{150}Nd isotope. It is found that the calculated positive and negative parity energy spectra of Nd-isotopes agree well with the experimental data.

Keywords: Nuclear structure; energy levels; transitions; interacting boson model; $A = 144-154$; Nd-isotopes.

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1. Introduction

The $X(5)$ model was proposed by Iachello[1] to study the nuclear structure of the nuclei at the critical point and is called the symmetry of the critical point. There are two phase-transitional points in symmetry triangle for the nuclear structure, $X(5)$ and $E(5)$, which are solutions to the Bohr Hamiltonian. The $X(5)$ critical point is a first-order phase shape transition between the $U(5)$ vibrator and the $SU(3)$ rotor,[2–6] while $E(5)$ is a second-order phase transition between $U(5)$ and $O(6)$ γ-unstaple. Many theoretical studies have been performed on the structure of the neodymium isotopes. Long[7] studied the structure of the neutron-rich Nd isotopes, and the phase transition from vibrational to rotational is confirmed. Kara *et al.*[8] investigated the structure evolution of Nd isotopes including the ground state

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energy and charge radii. Gupta[9] analyzed the level structure of $^{144-150}$Nd isotopes taking into account the available experimental data. The varying limitations of the boson model in these isotopes are investigated. Kalish *et al.*[10] studied magnetic moment measurements of the first-excited 2^+ states in $^{144-148}$Nd isotopes. Krücken *et al.*[4] predicted that ^{152}Sm and ^{150}Nd are close manifestations of the $X(5)$ critical point symmetry, also they compared the reduced transition probabilities in ^{150}Nd with the predictions of the critical point symmetry $X(5)$ for $N = 90$. Zhang[11] performed calculations using the cranked shell model with pairing correlations and satisfactorily reproduced the excitation energy levels and moments of inertia of neutron-rich Nd isotopes. The rotational properties of the band's structure are investigated. Xiang *et al.*[12] described the shapes and low-energy shape coexistence of $^{126-140}$Nd isotopes using a five-dimensional quadrupole collective Hamiltonian. Thŭrauf *et al.*[13] investigated the nature of low-lying 3^- states in ^{144}Nd in the cold neutron-capture reaction. Nikšić *et al.*[14] described shape transitions in $^{142-152}$ Nd isotopes using the relativistic mean-field model, and also described the singular properties of excitation spectra and transition rates at the critical point of quantum shape phase transition. This study aims to test the features of $X(5)$ symmetry in the $^{144-156}$Nd isotopes. More importantly, the phase transition in the structure of the positive and negative-parity states is studied.

2. The Interacting Boson Model

Arima and Iachello[15] suggested an algebraic nuclear model called the interacting boson model (IBM). It describes the low-lying collective states in many media and heavy even–even nuclei. In the IBM, the valence nucleons can be coupled together in pairs to form bosons with angular momentum $L = 0$ called (s-bosons) and $L = 2$ called (d-bosons). In this model, if there is no distinction made between neutron and proton bosons, the model is called IBM-1, otherwise is called IBM-2.[15–17] In the IBM-2 space, for a given nucleus, the number N_ν (neutron–neutron boson) and N_π (proton–proton boson) are found by counting neutrons and protons from the nearest closed shell. For the even–even lighter nuclei, the N_δ (neutron–proton boson) must be included in addition to the N_ν and N_π bosons in the IBM-2 to form an isospin triplet in sd-boson space.[18–20] The Hamiltonian of the IBM-1 is given[21]

$$H = \sum_{i=1}^{N} \varepsilon_i + \sum_{i>j}^{N} V_{ij}, \tag{1}$$

where ε_i is the intrinsic boson energy and V_{ij} is the interaction strength between i and j bosons. The IBM-1 Hamiltonian can be written in multipole expansions[22,24]

$$H_{sd} = \varepsilon_d \hat{n}_d + a_0 \hat{P}^\dagger \cdot \hat{P} + a_1 \hat{L} \cdot \hat{L} + a_2 \hat{Q} \cdot \hat{Q} + a_3 \hat{T}_3 \cdot \hat{T}_3 + a_4 \hat{T}_4 \cdot \hat{T}_4, \tag{2}$$

where ε_d is the d-boson energy, in which