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Electric quadrupole transitions for some isotopes of Xenon; considering rigidity for $\gamma = 30°$ collective parameter

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Abstract

In this article, Davydov–Chaban Hamiltonian is investigated in presence of Davidson potential. Using analytical approach, wave function corresponding of considered system has been derived. Then energy spectra and B(E2) transition rate have been calculated numerically in detail as well. The results are compared with experimental data for three isotope of Xenon.

Keywords: Davydov–Chaban Hamiltonian; Davidson potential; Energy spectra; B(E2) transition rate

1. Introduction

Describing nuclei at points of shape phase transitions between different limiting symmetries called Critical point symmetries [1,2] that have recently attracted considerable attention because they yield to parameter independent predictions which are found to be in good agreement with experiment [3–7]. They have different names for various situations such as the transition from vibrational $[U(5)]$ to γ-unstable $[O(6)]$ nuclei, $E(5)$ is critical point symmetry [1], describing the transition from vibrational $[U(5)]$ to prolate axially symmetric $[SU(3)]$ nuclei called the $X(5)$ critical point symmetry [2]. Both of theses cases can be obtained by solving Bohr

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Hamiltonian [8]. If the potential is assumed to depend only on the collective variable β in Bohr Hamiltonian, this is the $E(5)$ case but if there are dependencies of both collective variables β and γ, this is the $X(5)$ case. F. Iachello [1,2] suggested new class of symmetry, which can be related to zeros of Bessel functions to describe spectra of systems that undergo a second order phase transition between the algebraic structures U (n − 1) and SO (n) [1] as well as he presented an approximate solution at the critical point of the spherical to axially deformed shape phase transition in nuclei [2]. D. Bonatsos et al. used Davidson potential to describe ground band state bands of the E(5) and X(5) critical symmetries [9], or they derived in another paper an expression for a system in which the mass has a dependency to the nuclear deformation [10] and also they utilized super symmetric quantum mechanics technique to establish a model according Kratzer potential in Bohr Hamiltonian [11]. Naderi et al. considered time-dependent potential for Bohr Hamiltonian and derived wave function corresponding time-dependent interaction [12]. If for γ parameter, we assume rigidity situation, this changes Bohr Hamiltonian into Davydov–Chaban Hamiltonian [13]. Buganu and Budaca evaluated an analytically solution for the Davydov–Chaban Hamiltonian with a sextic oscillator potential for the variable β which is conventionally called $Z(4)$-sextic [14] and Bonatsos et al. [15] investigated a version of the $X(5)$ model that γ variable is fixed to $\gamma = 0$, within a harmonic oscillator potential and recently we have shown how we can describe unstable nuclei using approach Davydov–Chaban [16].

In this article, we are interested in considering Davidson potential for Davydov–Chaban Hamiltonian to evaluate corresponding wave function and energy spectra. Then by doing some numerical calculation, we want to compare our results for three isotopes of Xenon experimental data. Although our results are compared with experimental data but we'd like to suggest readers to compare results of this paper with original papers of Z[4] [17] and Z[5] [18] models. Also we will derive energy spectrum of considered system which is similar to what Yigitoglu and Bonatsos had derived in their article [19]. So we have organized this article as follows: Introducing Davydov–Chaban Hamiltonian in Sec. 2. Deriving the wave function considering Davidson potential and energy spectra in Sec. 3. In the last section, in addition we bring details of numerical calculation of energy spectrum normalized to the energy of the first excited state and $B(E2)$ transition rate, our results have been compared with experimental data.

2. Davydov–Chaban Hamiltonian

As it was mentioned before, Davydov–Chaban Hamiltonian can be obtained considering rigidity for γ variable in Bohr Hamiltonian. So the eigen value problem corresponding this model is [14]

$$\frac{-\hbar^2}{2B}\left[\frac{1}{\beta^3}\frac{\partial}{\partial\beta}\beta^3\frac{\partial}{\partial\beta}-\frac{1}{4\beta^2}\sum_{k=1}^{3}\frac{\hat{Q}_k^2}{\sin^2\left(\gamma-\frac{2\pi}{3}k\right)}\right]\Psi(\beta,\Omega)+V(\beta)\Psi(\beta,\Omega)=E\Psi(\beta,\Omega), \tag{1}$$

in which the mass parameter is shown by B, intrinsic deformation coordinates are denoted by β, γ and $\hat{Q}_k$ the operators of the total angular momentum projections in the intrinsic reference frame, while with Ω as the rotation Euler angles $(\Omega_1, \Omega_2, \Omega_3)$. Note that here, γ is assumed as parameter, not a variable. By this consideration and recalling Bohr Hamiltonian, it can be got that $\Psi(\beta, \Omega)$ depends on four variables. Following separation of variables as $\Psi(\beta, \Omega) = \phi(\beta)\Phi(\Omega)$ we will obtain following equation for β part of wave function