Study of B isotopes within the framework of No Core Shell Model

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Introduction

The nuclear shell model has been successfully used for explaining the structure of atomic nuclei. Recently, much progress has been made in the construction of realistic nucleon-nucleon (NN) interactions, derived from the first-principles. No Core Shell Model (NCSM) [1, 2] is an *ab initio* microscopic nuclear structure approach that successfully calculates nuclear properties for lighter nuclei. In NCSM, all nucleons are treated as active; there is no inert core. We have done a systematic NCSM study for Boron chain. In this paper, we have reported *ab initio* results for ground and excited states of ^{10}B isotope.

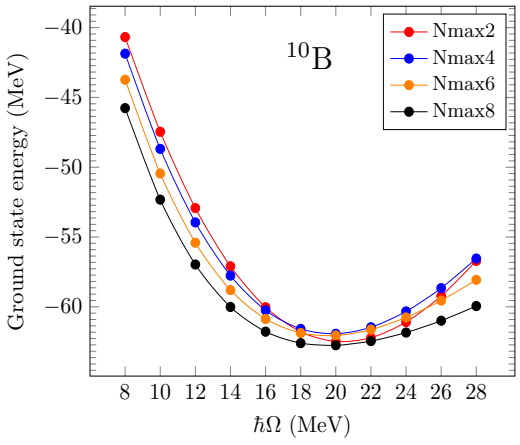

FIG. 1: The variation of g.s. energy with different frequencies and model sizes.

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Formalism

The Hamiltonian of *ab initio* NCSM is given by

$$H_A = T_{rel} + V = \frac{1}{A}\sum_{i<j}^{A}\frac{(\vec{p}_i - \vec{p}_j)^2}{2m} + \sum_{i<j}^{A} V_{NN,ij}$$

Here, m is the mass of nucleon, $V_{NN,ij}$ is the NN interaction.

By adding Harmonic Oscillator (HO) centre of mass Hamiltonian, we get the form

$$H_A^{\Omega} = H_A + H_{CM} = \sum_{i=1}^{A} h_i + \sum_{i<j}^{A} V_{ij}^{\Omega,A}$$
$$= \sum_{i=1}^{A}\left[\frac{\vec{p}_i{}^2}{2m} + \frac{1}{2}m\Omega^2\vec{r}_i{}^2\right] + \sum_{i<j}^{A}\left[V_{NN,ij} - \frac{m\Omega^2(\vec{r}_i - \vec{r}_j)^2}{A}\right]$$

We can use either Jacobi-coordinate HO basis or single-nucleon slater determinant HO basis, as per convenience of the problem. Inside Non-local Outside Yukawa (INOY) [3], which is an accurate NN potential, has been used in this paper. In this interaction, non-locality is present at short distances (up to $\sim$ 3 fm) [3] which becomes a local Yukawa tail at large distances. This interaction generates short-range correlations, and hence, cannot be used in many-nucleon HO basis. To account for these short-range correlations and obtain convergent results, we adopt a renormalization procedure which softens the potential. We make use of Okubo-Lee-Suzuki (OLS) [4] renormalization scheme.

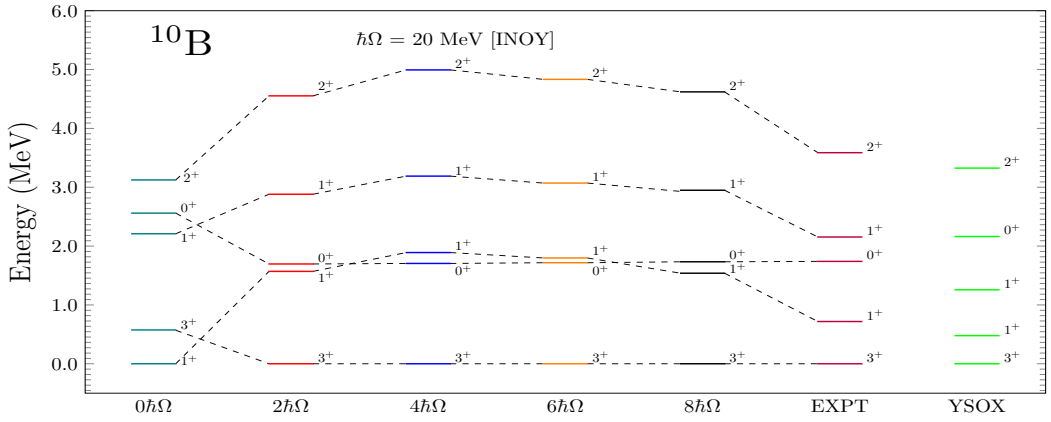

FIG. 2: Low-lying energy spectrum for ^{10}B.

In NCSM, there are two variational parameters: HO frequency $\hbar\Omega$ and basis truncation parameter N_{max} which is the maximum allowed HO quanta above the unperturbed ground state (g.s.) configuration of A nucleons.

Results and Discussions

We have performed the *ab initio* NCSM calculation for ^{10}B isotope, using INOY interaction. The HO frequency dependence on the g.s. energy of ^{10}B for different basis sizes is plotted in Fig. 1. It is evident from the figure that, as the basis size increases, the g.s. energy dependence on frequency decreases. Thus, the HO dependence is found to become flat for large values of N_{max}. The frequency with the least dependence on the g.s. is chosen to calculate the energy spectrum. In our case, this frequency is 20 MeV, which is used in further calculations. The calculations were done up to $N_{max} = 8\hbar\Omega$ and the corresponding g.s. energy was obtained to be -62.754 MeV. The experimental value of the g.s. energy is -64.751 MeV. It was reported that *NN+NNN* interaction is needed to reproduce the correct g.s. $J^p = 3^+$ for ^{10}B [5]. However, our calculations yield the experimental g.s. 3^+ using only the INOY *NN* interaction.

The correct ordering of excited energy states is also obtained for $N_{max} = 8\hbar\Omega$. It seems from the spectrum that as N_{max} increases, the energy of excited states approach the experimental values. The results with phenomenological YSOX interaction [6] are also shown in Fig. 2. The dimension of Hamiltonian matrix increases with model space (e.g. the dimension of ^{10}B is 1.6 x 10^8 for $N_{max} = 8\hbar\Omega$). So, powerful computational systems are required to carry out the calculations.

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