Benchmarking V_{UCOM} in the No-Core Shell Model *

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One of the prime goals of modern nuclear theory is the description of low-energy nuclear structure on the basis of QCD-motivated realistic nucleon-nucleon interactions. For p-shell nuclei this can be achieved, e.g., within the ab initio no-core shell model (NCSM), which provides an essentially exact solution of the quantum many-body problem [1]. However, to cover the nuclear chart beyond the p-shell one has to resort to approximate many-body schemes. In contrast to the NCSM, those approaches cannot describe the strong short-range correlations induced by realistic interactions and, therefore, rely on effective interactions.

One scheme to derive a universal phase-shift equivalent effective interaction is the unitary correlation operator method (UCOM) [2]. The short-range central and tensor correlations are described explicitly by a system-independent unitary transformation. The unitary transformation of the Hamiltonian defines the correlated interaction V_{UCOM}. Unlike the bare NN potential, the Argonne V18 potential in our case, the correlated interaction has two important properties: (i) It is a soft interaction, which does not induce strong short-range correlations anymore. In the language of the shell-model the matrix elements of the interaction are pre-diagonalized and lead to a rapid convergence with increasing model-space size. (ii) The size of the net three-body interaction, which is the sum of the bare three-body interaction and the repulsive three-body terms induced by the unitary transformation, can be controlled via the range of the tensor correlation operator. In particular one can choose the correlation operator such that the net contribution of the total three-body interaction to the energy is minimal. This was done in NCSM calculations for three- and four-body systems [2]. Heavier nuclei have been studied using this V_{UCOM} in Hartree-Fock-based approaches employing perturbation theory or RPA ring summations to include long-range correlations [3].

Here we employ the ab initio NCSM to obtain detailed spectroscopic information for p-shell nuclei based on V_{UCOM}. In order to enhance convergence further, the Lee-Suzuki transformation has been used. All calculations have been performed using the ANTOINE code [4].

Figure 1 depicts the spectra of ^{6}Li and ^{10}B obtained with V_{UCOM} for different model-space sizes ranging from $0\hbar\omega$ to $14\hbar\omega$ and $8\hbar\omega$, respectively. The right-hand column represents the experimental spectrum. For both cases, the spectra are very stable w.r.t. model-space size and oscillator frequency and in good agreement with experiment. Also the absolute ground state energy agrees well with experiment. This result is remarkable given that we use a pure two-nucleon interaction, V_{UCOM}, for these calculations. For all bare realistic NN interactions it is known that neither the ground-state energy nor the structure of the spectrum are reproduced without including a three-nucleon interaction. One example is the ground state spin of ^{10}B which is wrongly predicted to be 1^+ when omitting the three-body interaction [5]. The correlated interaction V_{UCOM} reproduces these subtle phenomena already on the two-body level through its momentum dependence. This demonstrates that the UCOM transformation provides a powerful and practical way to reduce the impact of the three-body potential by transforming it into a momentum dependence.

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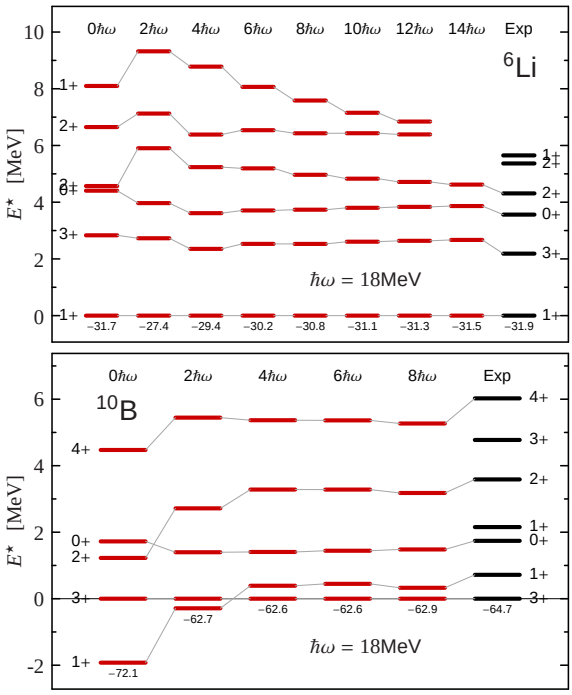

Figure 1: Spectrum of ^{6}Li (top) and ^{10}B (bottom) obtained within the NCSM for different modes-space sizes using V_{UCOM}. The absolute ground state energies in [MeV] are given at the bottom.