Doubly open-shell nuclei with *ab initio* approaches

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1. Introduction

Recently, it is possible to study lower *sd* shell nuclei using *ab initio* approaches due to advancement in the computational facility. Using *ab initio* approaches: In-Medium Similarity Renormalization Group (IM-SRG) and Coupled Cluster Effective Interaction (CCEI) approaches, the electromagnetic properties and Gamow-Teller (GT) transition strengths are calculated for *sd* shell nuclei within the framework of shell model in Refs. [1, 2]. It is very challenging to test predictive power of *ab initio* calculations for doubly-open shell nuclei for the description of deformation in the medium-mass region.

In the present work our motivation is to test the *ab initio* Hamiltonians derived from different approaches IM-SRG, CCEI and the interaction from chiral effective field theory (CEFT) to calculate the spectra and $B(E2)$ transitions in the doubly-open *sd* shell nuclei. In the present work we have reported results of ^{20}Ne, more results of other doubly-open shell nuclei will be presented during meeting.

2. Formalism

A mass-dependent Hamiltonian is used for *sd* shell nuclei using IM-SRG. The derivative of the Hamiltonian which is parametrized with flow parameter 's'

$$\frac{dH(s)}{ds} = [\eta(s), H(s)], \tag{1}$$

where, $\eta(s)$ is the anti-Hermitian generator of unitary transformation.

Eq. 1 is also known as flow equation for Hamiltonian. Here, the *sd* valence space is decoupled from the core and higher shells as $s \to \infty$. Now, the shell model calculations are done with $\hbar\Omega$ =24 MeV using final Hamiltonian.

The Hamiltonian developed from the CCEI approach is A- dependent and can be extended as-

$$H_{CCEI} = H_0^{A_c} + H_1^{A_c+1} + H_2^{A_c+2} + ... \tag{2}$$

In this approach Hartree-Fock ground state in thirteen oscillator major shells with $\hbar\Omega$=20 MeV is used. Here, $H_0^{A_c}$, $H_1^{A_c+1}$, and $H_2^{A_c+2}$ are called core, one body, and two body cluster Hamiltonians respectively. This expansion is known as valance cluster expansion. Any operator can be expanded in the valence space same as the Hamiltonian for the shell model calculations.

The $B(E2)$ values are calculated with the formula:

$$B(E2) = \frac{1}{2J_i+1} \mid (J_f \mid\mid \sum_i e_i r_i^2 Y_2(\theta_i, \phi_i) \mid\mid J_i) \mid^2 . \tag{3}$$

Where, J_i and J_f are the initial and final state spins, respectively. The $B(E2)$ values are calculated with the effective charges e_p=1.5e and e_n=0.5e.

3. Results and Discussions

^{20}Ne, provide good example of rotational spectra [3] in the lower *sd* shell. The comparison of rotational energy levels for ^{20}Ne using USDB, IM-SRG, CCEI and CEFT interactions is shown in the Fig. 1 and rotational spectra is well reproduced in our *ab initio* calculations. To know more details of calculated wavefunctions, we have also calculated the $B(E2; 2_1^+ \to 0_1^+)$ transitions using *ab initio* interactions and the results are also compared with phenomenological interaction USDB and SDPF-MU along with experimental data [4]

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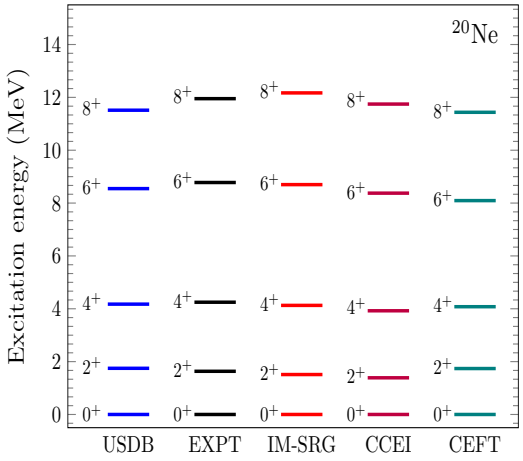

FIG. 1: Comparison of energy levels in ^{20}Ne using USDB, IM-SRG, CCEI, and CEFT interactions.

for even Ne isotopes with N = 8-22. The energy of 2_1^+ and $B(E2)$ values for Ne isotopes are shown in the Fig. 2. The USDB results for $E_{2_1^+}$ are close to experimental data up to $N = 16$ but above this results are deviating. The IM-SRG results are best and close to the experimental data from $N = 10$ to $N = 18$. At $N = 20$, CCEI and SDPF-MU interactions show the same pattern as the experimental data but all the other interactions going upward and giving far value from the experiment, see upper panel of Fig. 2. Experimentally, $N = 18$ shows less collectivity in comparison to $N = 16$ and an enhancement in collectivity at $N = 20$. From all the interactions the collectivity is decreasing from $N = 18$ to $N = 20$. From the literature the $N = 20$ lies on the boundary of "island of inversion" [5] and $0\hbar\omega$ shell model calculations are not able to reproduce the enhancement in collectivity at $N = 20$. The calculation in $sd - pf$ space with SDPF-MU interaction by allowing two neutrons excitation for sd to pf shell shows increase in collectivity at $N = 22$. It is clear that even in the $sd-pf$ model space the 2p-2h excitation shell model calculations are not sufficient to explain the pattern of $B(E2)$ values at $N = 20$.

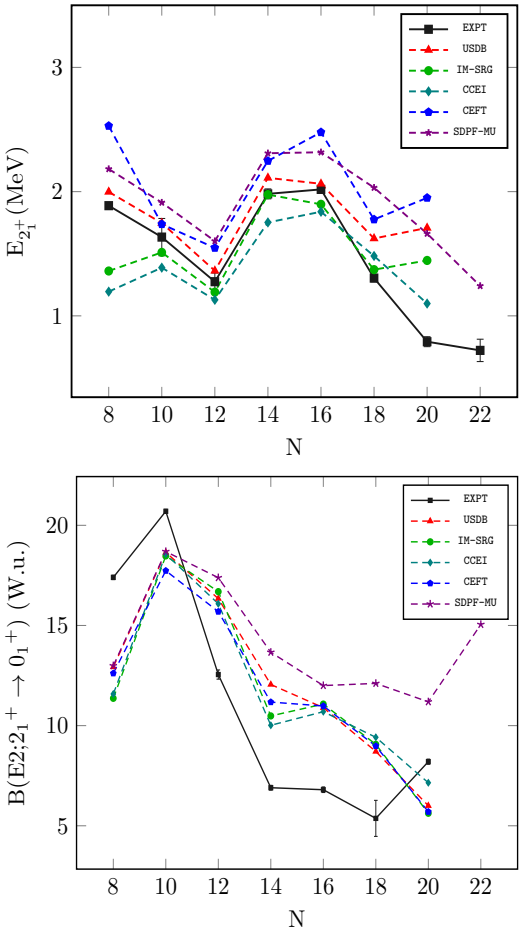

FIG. 2: Energy of $2_1{}^+$ and $B(E2)$ values for even $^{18-30}$Ne isotopes.

References

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