Ab initio no-core shell model study of ^{20}Ne

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1. Introduction:

Ab initio theories of nuclear physics focus on describing various nuclear systems starting from the free nucleon nucleon interactions among the nucleons. The no-core-shell model (NCSM) [1] is one such approach which is very successful in describing different nuclear properties in the lighter mass region. Motivated from the encouraging results of the previous works [2–4], we have done comprehensive study the Ne isotopic chain from neutron shell closure $N = 8$ to $N = 14$ for several nuclear properties. In this paper, we have presented our study on ^{20}Ne isotope using two realistic NN interactions, inside non-local outside Yukawa (INOY) and optimized next-to next-to leading order (N^2LO_{opt}).

2. Formalism:

In the NCSM, a system of non-relativistic nucleons interacting via realistic NN or $NN+3N$ interactions among themselves are considered. In this approach the concept of the core is not there and all the nucleons are considered to be active. So, the NCSM Hamiltonian is given by

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

where, T_{rel}, m and V_{ij}^{NN} are relative kinetic energy, mass of the nucleon and NN interaction containing both nuclear and Coulomb part, respectively. The above Hamiltonian is made Ω dependent by adding the center-of-mass Hamiltonian (H_{CM}) to it:

$$H_A^{\Omega} = H_A + H_{CM} = \sum_{i=1}^{A}[\frac{p_i^2}{2m} + \frac{1}{2}m\Omega^2 r_i^2] + \sum_{i<j}^{A}[V_{NN,ij} - \frac{m\Omega^2}{2A}(r_i - r_j)^2]$$

where, $H_{CM} = T_{CM} + U_{CM}$. As, H_A is a translationally invariant Hamiltonian, the addition of H_{CM} to it does not change the fundamental property of the system and it is subtracted out in a subsequent step. Also, the Lawson projection term, $\beta(H_{CM} - \frac{3}{2}\hbar\Omega)$ is added to the above Hamiltonian when m-scheme HO basis is used.

In the NCSM, the eigenstates of H_A are obtained by solving a large-scale matrix eigenvalue problem within a many-body model space constructed by using the HO single particle states. The NCSM calculations are dependent on two parameters: N_{max} and $\hbar\Omega$. The maximum no. of total oscillator quanta allowed above the minimum HO configuration in many-body basis is denoted as N_{max},

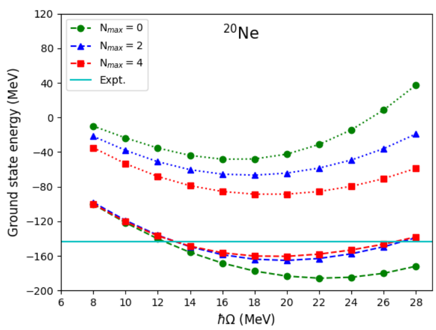

FIG. 1: Variation of the g.s. energy with H.O. frequency for INOY (dashed lines) and N^2LO_{opt} (dotted lines) interactions.

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whereas $\hbar\Omega$ is the HO energy.

The NCSM calculations are performed in a truncated HO basis space whereas the NN interactions act in the full Hilbert space. So, to obtain converged results "effective" interactions are employed in the NCSM calculations. In this work, we have used the Okubu-Lee-Suzuki (OLS) transformation scheme to obtain effective interactions.

3. Results and discussions:

In Fig. 1, the variation of the g.s. energy of ^{20}Ne with $\hbar\Omega$ obtained from INOY and N^{2}LO$_{opt}$ are shown and the optimum frequencies obtained from this figure are 20 and 18 MeV, respectively. At this frequency, the ground state energy is least dependent on frequency corresponding to the maximum possible N_{max}.

The low-energy spectra of ^{20}Ne are shown in Fig. 2. The excitation energy of the first excited state (2^+) is 1.633 MeV and the calculated energies of this state are obtained to 1.034 and 1.328 MeV from INOY and N^{2}LO$_{opt}$ interactions corresponding to $N_{max} = 4$. Both these interactions are able to reproduce correct ordering of states: 0_1^+-2_1^+-4_1^+ up to excitation energy 5 MeV.

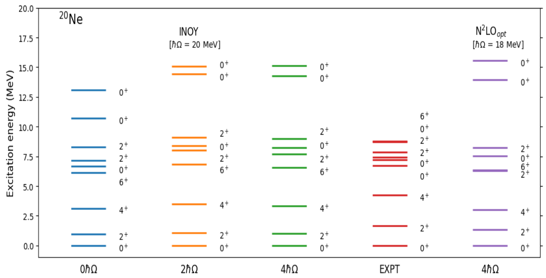

FIG. 2: Low-energy spectra of ^{20}Ne.

Some of the electromagnetic properties of ^{20}Ne are summarized in Table I. As seen from the table, the calculated binding energy of the g.s. obtained from INOY and the magnetic moment of the first excited state obtained from both of the interactions are close to the experimental data. But, the $E2$ moments and transition strengths obtained from these two interactions are not in good agreement with the experimental data. Thus, we need even higher N_{max} calculations for better agreement with the experimental values.

TABLE I: The g.s. energy and electromagnetic properties of ^{20}Ne corresponding to the largest $N_{\rm max}$ at their optimal HO frequencies. Quadrupole moments, magnetic moments, g.s. energies and $E2$ transition strengths are in barn (b), nuclear magneton (μ_N), MeV and e^2 fm^4, respectively. Experimental values are taken from Refs. [5, 6].

^{20}Ne	Expt.	INOY	N2LO$_{opt}$
Q(2^+)	-0.23	-0.065	-0.730
$\mu(2^+)$	1.08	1.044	1.044
E$_{g.s.}$(0^+)	-160.645	-160.545	-88.717
$B(E2; 2_1^+ \to 0_1^+)$	65.4(32)	10.346	16.483
$B(E2; 4_1^+ \to 2_1^+)$	71.0(64)	12.567	11.706

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[5] Data extracted using the NNDC World Wide Web site from the ENSDF, https://www.nndc.bnl.gov/ensdf/.
[6] IAEA,https://www-nds.iaea.org/nuclearmoments/.