Shell model study of ^{118}Sn with excitations across N=82 shell gap

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Introduction

Nuclei close to a doubly closed shell nucleus act as testing ground of different nuclear models. In this region, the excitation spectra typically show admixture of two different excitation mechanisms. One mode of excitation arises from the valence single particles excited within the shell and the other involves excitations across the shell gaps, especially important at higher exciation energies. In general, to describe the low energy states, different effective interactions are used, involving at best the intruder orbital from the higher opposite parity shell. Whereas, the high energy states of cross-shell excitations warrant inclusion of other orbitals across the shell, such interactions involving adequate cross-shell excitation possibilities are usually not very frequently available for heavy nuclei, apart from a few recent ones [1]. However, unrestricted calculations over such large valence space encompassing two large major shells is mostly computationally challenging - thus asking for suitable truncation schemes.

Over a long period of time, the structure below doubly magic ^{132}Sn in A $\approx$ 130 mass region has grabbed the attention not only of experimentalists but also of theoreticians because of its utter significance in both nuclear structure physics and nuclear astrophysics. To describe this region, several shell model interactions are available and generally the model space contains five orbits (1g$_{7/2}$, 2d$_{5/2}$, 2d$_{3/2}$, 3s$_{1/2}$, 1h$_{11/2}$) above Z, N=50 shell both for neutrons and protons. These interactions are quite successful to interpret the structure to some extent but the transition probability of hindered transitions, particularly the E1 transitions cannot be calculated because of the limitation in the valence space. There are no opposite parity orbitals in the space with Δ J= 1 to generate non-zero E1 transition density. However, E1 transitions are frequently observed in these nuclei and play important roles in their low lying spectra. Not only in regions near the shell closure but also in the mid-shell (near ^{118}Sn region) E1 transitions are observed. In the present work, we intend to extend the basis space such that these limitations can be removed. The test of this expansion has been done by calculating the B(E1) values for a few cases in ^{118}Sn apart from revalidating the energy spectra predictions.

Formalism: Model space and modified Hamiltonian

For mid-shell Sn isotopes, like $^{112-118}Sn$, unrestricted full-space calculations are computationally challenging [2]. Three more negative parity neutron orbitals i.e. 1h$_{9/2}$, 2f$_{7/2}$, 3p$_{3/2}$ from the above N = 82 shell have been included in the neutron valence space. Thus, it makes the problem of handling larger dimension of the matrix even worse.

In order to make the calculations tractable, the proton space has been restricted to two proton orbitals π1g$_{7/2}$ and π2d$_{5/2}$. The neutron space has also been restricted by removing the ν1g$_{7/2}$ and ν2d$_{5/2}$ orbits from the model space, as mostly the region of interest is above ^{116}Sn. So, the inert core instead of ^{100}Sn is now ^{114}Sn and the model space contains two proton orbitals (π1g$_{7/2}$ and π2d$_{5/2}$) and six neutron orbitals (ν2d$_{3/2}$, ν3s$_{1/2}$, ν1h$_{11/2}$, ν1h$_{9/2}$, ν2f$_{7/2}$, ν3p$_{3/2}$).

To set up the new interaction, primarily two body matrix elements (tbmes) from two in-

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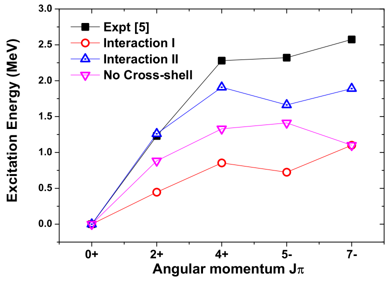

FIG. 1: Comparison of experimental excitation spectra for ^{118}Sn with calculated ones with different interactions.

teractions, *sn*100*pn* and *CWG* [3] have been used. Both of these realistic interactions are derived from CD Bonn nucleon-nucleon interaction. While setting up the cross-shell tbmes, the charge independence and isospin invariance of nuclear interaction have been considered. However, a few tbmes which could not be obtained from these two interactions, have been either assigned zero values (0.00001) (Intearction I) or calculated using zero range DELTA interaction [4] (Intearction II). There are thus total 720 tbmes (21 pp elements, 287 nn elements and 412 pn elements) in the new interaction.

The single particle energy (spe) of neutron orbits below N = 82 shell are adjusted to reproduce the experimental low-lying levels of ^{115}Sn [5]. For the orbitals above N = 82 shell, spes are adjusted to reproduce the low-lying spectra of of ^{133}Sn [5]. The spes of proton orbitals are adjusted based on experimental data of ^{115}Sb [5]. The single particle energies (in MeV) for protons ($\pi 1g_{7/2}$ and $\pi 2d_{5/2}$) are 2.286, 1.5622 respectively and for neutron spes ($\nu 2d_{3/2}$, $\nu 3s_{1/2}$, $\nu 1h_{11/2}$, $\nu 1h_{9/2}$, $\nu 2f_{7/2}$, $2p_{3/2}$) are -8.1974, -8.694, -7.9804, -5.9404, -7.051, -6.1977 respectively. Large basis shell model calculations have been performed using NushellX@MSU code [6].

Results and Discussion

At first, the excitation energies of low-lying states have been calculated for ^{118}Sn without including any cross-shell excitation. Later results are compared with those with Interactions I and II. Theoretical predictions have been compared with the experimental data (Fig. 1). The excitation energy of the 2^+ state could be only reproduced by the Interaction II, whereas all others underpredict them.

Reduced B(E1) value for ($5^-{}_1 \rightarrow 4^+{}_1$) transition is calculated with both the Interactions I, II with e_n^{eff}=0.5 I. With zero tbme, B(E1) gives better agreement with experimental data [5], indicating need for tuning of effective charge for Interaction II. There are few more E1 transitions in the excitation spectra of ^{118}Sn, which will also be calculated to improve the effective charge tuning.

In the present model space, there are only two possible ways to have non-zero one body E1 transition density, *viz.*, $\nu 3p_{3/2} \rightarrow \nu 3s_{1/2}$ and $\nu 3p_{3/2} \rightarrow \nu 2d_{3/2}$. However, with increasing neutron numbers, the option gradually reduces to one - impacting the B(E1) rates. With increasing valence particle in the model space, $3s_{1/2}$ orbital fills up and the possibility of having non-zero B(E1) reduces. So, in a future endeavour, to have an improved systematic study, there is a need to expand the model space further. However, that will again enhance the dimensionality problem. To tackle that, one shall have to work on considering proper restrictions in the particle numbers in different orbitals.

TABLE I: Comparison of calculated B(E1) values for ($5^-{}_1 \rightarrow 4^+{}_1$) transition in ^{118}Sn with experimental data .

	B(E1) in e^{2}fm^2
Expt [5]	8.83E-5
Interaction I	4.77E-5
Interaction II	4.95E-4

References

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