Shell Model Calculations for $A \sim 30$ nuclei approaching the Island of Inversion: Is there a need to modify the Single Particle Energies.

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Introduction

The intriguing properties, such as deformed ground states, of the nuclei in the island of inversion, are attributed to the occupation of intruder orbitals *viz.*, the *fp* orbitals, from the next major shell. Recent shell model calculations in this mass region have established the role of the spin-isospin flip and the tensor force behind such phenomenon [1].

The low lying positive parity states in nuclei approaching the island of inversion are well explained by the the USD interaction, thus ruling out the possibility of any contribution from the occupation of the deformation driving intruder orbitals, in these *sd* shell nuclei at moderate spins. The negative parity states in these nuclei are of special interest, since they originate due to the occupation of the intruder orbitals. Investigations of the structure of such nuclei which form a pathway from the valley of stability to the island of inversion are expected to complement our understanding of the evolution of the shell gaps as a function of the increasing neutron number. Also, since the correlation energy is directly proportional to the number of particle or holes in the $d_{5/2}$ orbit, it is of interest to explore the level structure of nuclei wherein we expect the $\pi(d_{5/2})^{-n} \otimes \nu((s_{1/2}, d_{5/2})^{(-1)}, (f_{7/2})^1)$, excitations. From this point of view ^{30}Mg, ^{30}Al, ^{30}Si, ^{32,34}P, ^{34}S ($N = 16 - 19$) nuclei seemed ideal candidates to explore the aforementioned features.

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Earlier Shell Model Calculations

Monte-Carlo shell model calculations have demonstrated that the effective single particle energies go down as a whole as proton number increases from Z =8 for N = 20 nuclei, due to the modification of the monopole part of the interaction. This modified interaction was referred to as SDPF-M [1]. The shell model calculations for the aforementioned N∼20 nuclei have been mostly carried out by resorting to either (i) tweaking of the Single Particle Energies (SPE) or (ii) lowering of the predicted excitation energies, in a rather ad-hoc manner [2]. It is worth mentioning that the earlier workers justified this reduction (tweaking) as an indication of the reduction of the energy gap between the neutron Fermi surface and the *fp* shell.

In our earlier work on ^{34}P we have demonstrated that one does not have to resort to such ad-hoc approximations and the shell model predictions are in reasonable agreement with the experimental observables [3]. Hence, we do not comprehend the need to tweak the SPE by the earlier workers. It is worth mentioning that most of the earlier calculations were performed using the Two-Body-Matrix-Element (TBME) which are optimized for $A \sim 10 - 22$ nuclei, referred to as WBP. The TBME wherein the SPE of the $f_{7/2}$ and the $p_{3/2}$ orbitals were reduced from the original WBP value, is referred to as WBP-a [2]. The TBME used by us for ^{32,34}P are optimized for $A \sim 30$ region, referred to as *sdpfmw* [4]. This interaction does include the strong effects of the $T = 0$ proton-neutron interaction.

Present Shell Model Calculations

We performed the shell model calculations ^{30}Mg, ^{30}Al, ^{30}Si and ^{34}S nuclei using the

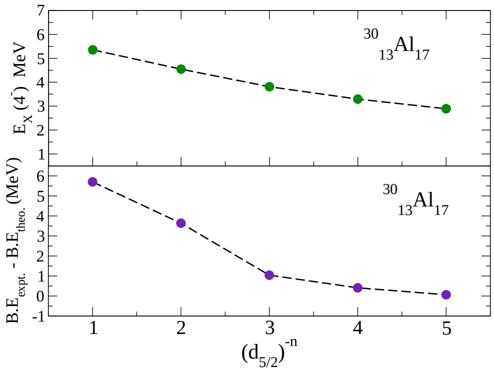

FIG. 1: Effect of truncation of model space on the predicted excitation energies.

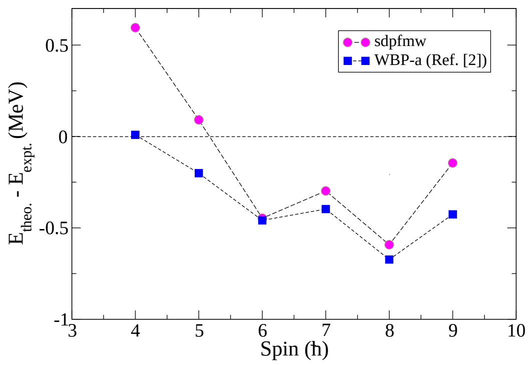

FIG. 2: Difference between the predicted and the experimental yrast negative parity levels of ^{30}Al.

TBME referred to as *sdpfmw* in the code NUSHELL@MSU [5]. We first performed the $1\hbar\omega$ shell model calculations for ^{34}S, since the detailed experimental level scheme is established. It was then compared with the shell-model calculations carried out by Mason *et al* [6] using the SDPF-M and the *sdpf* interactions. The level structure was well predicted and this comparison provided a yard-stick for the choice of the TBME used.

Apart from the choice of TBME, the prediction of excitation energies at higher values than their experimental counterparts can plausibly be attributed to the truncation of the model space. It is a well established observation of the shell model that truncation of the model space renders the ground state less bound resulting in the predicted states occurring at higher excitation energies. To explore this effect we have performed truncated shell model calculations for ^{30}Al without lowering the single particle energies, as a function of $(d_{5/2})^{-n}$ excitations. The results (Fig. 1) demonstrate that the predicted ground state energy and the excitation energy of the first intruder state approach the experimental value with increase in $(d_{5/2})^{-n}$ excitations. The calculations (Fig. 2) with a maximum excitation of $n = 5$ particles from $d_{5/2}$ successfully reproduced the experimental level structure of ^{30}Al, without any tinkering of the SPE or the excitation energies as done by Steppenbeck *et al.* [2]. Similar results were obtained by us for ^{30}Mg and ^{30}Si nuclei as well.

Conclusion

The success of the present shell model calculations without any ad-hoc adjustments for nuclei in the vicinity of the "island of inversion" indicates, that the inclusion of important configurations and appropriate matrix elements can explain the structure of these nuclei which form an integral path to the island of inversion.

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