Shell Model Calculations for Negative Parity States in $sd - pf$ Nuclei

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Introduction

The correct interpretation of the observed level structure of a nucleus is arrived at only after a detailed model calculation. Nuclei at the interface of the $sd - pf$ shells are of interest in the contemporary nuclear structure pursuits. The impetus has been to probe the evolution of the microscopic (shell) structure with the increasing number of neutrons, consequently leading to the large neutron-proton asymmetry, as one approaches the domain of island of inversion consisting of neutron rich isotopes of Na, Mg and Ne with $Z \sim 10$ and $N \sim 20$. The transitional nuclei from the valley of β-stability to the island of inversion *eg.* ^{29}Si, $^{24-26}$Mg is expected to couch the signatures of the evolving structure and have been probed in many recent studies. Of particular interest are the negative parity states in these nuclei whose strcuture would reveal the shell-gap between the sd & pf obitals, as they originate due to the cross-shell excitations. However, to the best of our knowledge, shell model calculations for these negative parity states in these nuclei have not been reported out so far.

Our group has been actively pursuing systematic investigations of the structure of this transitional region. In conjuction with the experimental endeavours, shell model calculations have also been carried out to validate the experimental observations as well as to revisit the previous calculations [1] in the light of modified interactions and extend the same with developed computational infrastructure. A High Performance Computing (HPC) System has recently been installed at the UDCSR, Kolkata Centre for the aforesaid large basis shell model calculations. The system is characterized by 80-cores on 8 nodes, 576 GB of memory and is expected to substantially elevate the computational possibilities. In particular it has been possible, for the first time, to calculate negative parity states in certain nuclei in the $sd - pf$ region. In this paper, we report the calculations for Mg ($Z = 12$) and Si ($Z = 14$) isotopes, carried out using the shell model code NuShellX @ MSU [1]. The model space used for the purpose is *sdpf*, consisting of $1d_{5/2}, 1d_{3/2}, 2s_{1/2}, 1f_{7/2}, 1f_{5/2}, 2p_{3/2}, 2p_{1/2}$ orbitals, with different truncation schemes being adopted for the positive and the negative parity states, as discussed in the subsequent sections. The interaction used is *sdpfmw*, that has been successfully applied to other nuclei in this region [2].

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Calculations for Mg Isotopes

The positive parity states have been calculated using $0\hbar\omega$ excitations (sd configurations) and the results, for $^{24-29}$Mg, are in satisfactory agreement with the experimental observations.

As far as the negative parity states are concerned, excitations of nucleons to the fp shell have to be considered. The same has been carried out primarily with one particle excitation ($1\hbar\omega$) has been allowed in the pf shell. For the ^{26}Mg isotope, the resulting level energies are in satisfactory compliance with the experimental numbers. Particularly for $J^\pi = 5^-, 6^-$, the agreement is at the level of within $\sim$ 40-100 keV while for lower spins $J^\pi = 3^-, 4^-$, it is $\sim$ 400-700 keV. It is understood that, in principle, the negative parity states would require both p to sd as well as sd to pf excitations. Such configuration could

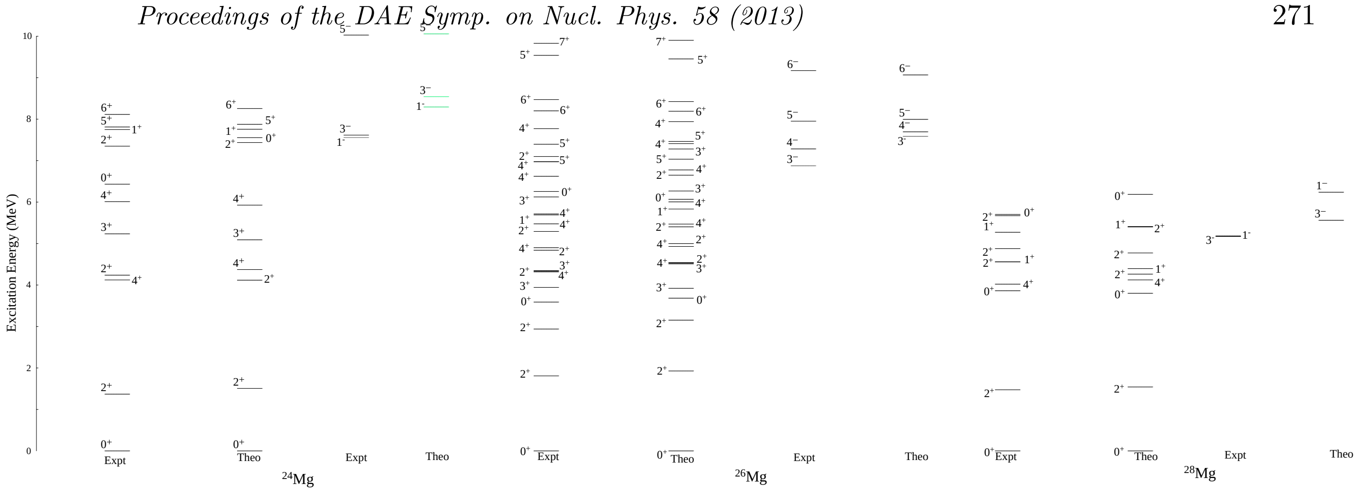

FIG. 1: Comparison of the energy levels (observed & predicted) for Mg isotopes

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not be simultaneously considered with in the present calculations. Nevertheless, reasonable agreement in the level energies have been obtained with *sd* to *pf* excitations, not only in the ^{26}Mg nucleus but in the neighbouring isotopes.

The agreement observed level structure in the neighbouring isotopes Fig. 1 ^{25,26,27,28}Mg is also excellent. These calculations have helped us resolve quite a few ambiguities in the earlier assignments. The discrepancy in particular for the lower negative parity levels could plaussibly be attributed to the exclusion of configuration such as $(p)^{-1} \otimes (sd)^{+1}$, which may have significant contributions.

Calculations have also been performed for ^{27,29}Si and the results are in reasonable agreement with the observed level structure. The stringent tests for these calculations would be provided by the comparison of the predicted transition probabilities, which are been experimentally deduced from the observed lifetimes (which are being reported in a seperate contriubution). The agreement between the predicted and observed transition probabilities are reasonable. The predicted Quadrupole Moment for the levels would help us elucidate the underlying shape and its subsequent evolution in these gamma-soft nuclei

As seen from the systematics for Mg isotopes, the excitation energy of the lowest negative parity level decreases as a function of increasing neutron number, which may plausibly be attributed to the enhnaced interaction between the valence nucleons. The present results are consistent with the level associations made in by the previous workers, for the positive parity states, but add much in terms of the recent experimental work and for the first time attempts to elucidate the configurations for the negative parity states.

References

[1] W.A.Ricther & B.A Brow, PRC **C80**, 034301 (2009).

[2] R.Chakrabarti *et al.*, PRC **84**, 054325 (2011).