Predicting nuclear structure in the exotic neutron-rich nuclei using the purity of $(7/2)^n$- configuration

Anik Adhikari[1], S. Sarkar[1],* M. Saha Sarkar[2], and Abhijit Bisoi[1]
[1] *Indian Institute of Engineering Science and Technology, Shibpur, Howrah- 711103, INDIA and*
[2]*Saha Institute of Nuclear Physics, Kolkata- 700064, INDIA*

Introduction

Purity of nuclear $(1f^n_{7/2})$ - configuration can give estimate of low-lying multiplet states near closed shell or subshell. This will furnish particularly information on single particle energies (spes) and two-body matrix elements (tbmes), which can be used to predict low-lying multiplet states in other nuclei. This may be helpful for experimentalists going to plan, experiment and analyzing data on exotic nuclei. Also there may be some situation, as in some cases in astrophysical problems, where only low-lying states and their decay properties are of importance, the method seems to give reasonable estimates.

Calculation

It is well known that $(1f^n_{7/2})$ - configuration around double shell closure at ^{48}Ca has reasonably pure multiplet structure. Here n is the number of proton in $1f_{7/2}$ subshell, the neutron $1f_{7/2}$ subshell being full. Thus using the binding energy (BE) of ^{49}Sc Ref. [1] and BE and excitation energies of $(\pi 1f^2_{7/2})$ multiplet states $(2^+, 4^+, 6^+)$ of ^{50}Ti with respect to ^{48}Ca one obtains single particle energy (spe) of $\pi\ \epsilon 1f^n_{7/2}$ (-9.619 MeV) and four two-body matrix elements (tbmes) (E_{0^+}= -2.552, E_{2^+} = -0.995, E_{4^+} = 0.125, E_{6^+} = 0.645, all in MeV)of this model space. Using these one can predict the spectra of ^{51}V and ^{52}Cr, with the configurations $(\pi 1f^3_{7/2})$ and $(\pi 1f^4_{7/2})$ respectively. One obtains quite good agreement with experimental low-lying level energies and concludes purity of 3- and 4 particle configurations in the respective nuclei Ref. [2].

The method is discussed in Ref [2]. It consists of writing the energies $E'_I(\pi 1f^n_{7/2})$ in terms of $\pi\epsilon 1f_{7/2}$, and E_{0^+}= -2.552, E_{2^+} = -0.995, E_{4^+} = 0.125, E_{6^+} = 0.645, (all in MeVs) and Co-efficient of fractional parentage (single and double) and form the matrix equation, where E_I is (5×1) column matrix containing spe and tbmes of the model space. The dimensions of the column matrix $E'_I(\pi 1f^n_{7/2})$ and A depend on the number levels in the multiplet $(\pi 1f^n_{7/2})(n > 2)$. For n=3 and n=4, E'_I is (6×1), A is (6×5) and E'_I is (8×1), A is (8×5), respectively.

One can then also try the reverse problem. One treats the spe and tbmes of the $\pi 1f^{n=2}_{7/2}$ model space as parameters and adjust them to give the best fit to all the data. To obtain this one minimises the χ^2, where

$$\chi^2 = \{[\sum_{i=1}^{N}\{E'_i(\text{expt.}) - E_i(\text{theo})\}^2]/N\}^{1/2} \quad (1)$$

This leads to the matrix equation,

$$E = \Gamma^{-1} A^T E(\text{expt.}), \text{where}, \Gamma = A^T A \quad (2)$$

Results and Discussions

Following the above method, we first reproduced the best fit result for the five parameters of $\pi 1f^2_{7/2}$ configuration as discussed in Ref. [2]. We then move over to nuclei in the exotic neutron-rich domain above the doubly closed shell ^{132}Sn core. For the $2f^n_{7/2}$ configuration in this region, we only have ten pieces of experimental information Ref. [3]. We have excluded the result for ^{138}Sn, which we want to predict from this method. These values are shown in Table I along with the best fit values. In this case we have five parameters and matrix A is (10×5). The r.m.s deviation is

*Electronic address: ss@physics.iiests.ac.in

TABLE I: Comparison of experimental energies and best fit values.

Level	Input	Best fit
$\nu\epsilon_{2f_{7/2}}$	-2.402	-2.466
$E_{0^+}(^{134}Sn)$	-6.031	-6.034
$E_{2^+}(^{134}Sn)$	-5.356	-5.374
$E_{4^+}(^{134}Sn)$	-5.008	-4.985
$E_{6^+}(^{134}Sn)$	-4.834	-4.792
$E_{7/2^-}(^{135}Sn)$	-8.302	-8.298
$E_{0^+}(^{136}Sn)$	-11.680	-11.664
$E_{2^+}(^{136}Sn)$	-10.992	-11.004
$E_{4^+}(^{136}Sn)$	-10.601	-10.577
$E_{6^+}(^{136}Sn)$	-10.385	-10.423

TABLE II: Comparison of empirical matrix elements ($\nu-\nu$ tbmes) obtained from ^{134}Sn and from best fit .

Level	Input	Best fit
$E_{0^+}(^{134}Sn)$	-1.278	-1.1024
$E_{2^+}(^{134}Sn)$	-0.5521	-0.422
$E_{4^+}(^{134}Sn)$	-0.2043	-0.054
$E_{6^+}(^{134}Sn)$	-0.0303	+0.139

30 keV. In Table II, we present the empirical matrix elements ($\nu - \nu$ tbmes) obtained from ^{134}Sn only and from best fit.

We have also calculated the best fit for nuclei in the $\pi 1g^n_{7/2}$ and $(\pi 1g^1_{7/2} \times \nu 2f^n_{7/2})$ model spaces and obtained empirical $\pi\epsilon_{1g_{7/2}}$, $\pi - \pi$ tbmes (Table III) and $\nu - \pi$ tbmes, details of which will be presented along with results for A=138.

Conclusion

The method is a good one for reasonably pure multiplet structure and failure of it indicates configuration mixing in low-lying states. Most of the spin-parities of the multiplet states in this exotic domain are tentatively assigned. Our results indicate their correctness. We have obtained also the BE of ^{136}Sn from this fit by the input of the BE calculated from the systematics. The spes and tbmes obtained here are being included in the Hamiltonian in the $\pi(gdsh)$-$\nu(fphi)$ valence space for full basis shell model calculations to be presented.

TABLE III: Comparison of experimental energies, best fit values and $\pi-\pi$ tbmes. The rms deviation is 81.2 keV.

Level	Input	Best fit
$\pi\epsilon_{1g_{7/2}}$	-9.667	-9.654
$E_{0^+}(^{134}Te)$	-20.570	-20.555
$E_{2^+}(^{134}Te)$	-19.290	-19.406
$E_{4^+}(^{134}Te)$	-18.993	-18.921
$E_{6^+}(^{134}Te)$	-18.878	-18.839
$E_{7/2^+}(^{135}I)$	-29.112	-29.139
$E_{0^+}(^{136}Xe)$	-39.041	-38.971
$E_{2^+}(^{136}Xe)$	-37.728	-37.822
$E_{4^+}(^{136}Xe)$	-37.347	-37.206
$E_{6^+}(^{136}Xe)$	-37.149	-37.255
($\pi - \pi$ tbmes)		
$E_{0^+}(^{134}Te)$	-1.235	-1.247
$E_{2^+}(^{134}Te)$	0.0445	0.0979
$E_{4^+}(^{134}Te)$	0.3416	0.3876
$E_{6^+}(^{134}Te)$	0.4571	0.4692

References

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