Predicting low - lying level structure of exotic nuclei using Pandya theorem

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

1. Introduction

Low - lying level structure of some exotic nuclei can be obtained from the level structure of stable or less exotic nuclei by the use of Pandya transform given by S. P. Pandya sixty years back [1]. This is important for experimentalists going to perform experiments involving exotic nuclei. A prior theoretical knowledge of the low-lying few levels may provide a guidance for designing experiment, locating low-lying isomers, if any, as well as analyzing data. Moreover, for astrophysical scenarios, such as in stellar evolution calculations sometime only the knowledge of low-lying levels and their decay properties are of importance. Thus, when elaborate means of calculation is absent one can have a quick estimate of nuclear structure.

2. Calculation

Near closed shell or sub-shell, Pandya transform relates the spectrum of a nucleus with one nucleon in each of single particle orbits j' and j (particle - particle; p-p) to the spectrum of the nucleus with one particle in j' and one hole in j (particle-hole: p-h). The expression for this relationship is given by Eqn. (1) [2]. It represents the particle-hole interaction energies. The energies of the two configurations are geometrically related.

$$E_I(j'j^{-1};j'j^{-1}) = -\sum_K (2K+1)W(jj'j'j;IK)E_K(j'j;j'j) \quad (1)$$

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

The above relation gives the excitation energies.

Using Pandya relation (Eqn.(1)) structure of several particle-hole conjugate pairs can be correlated. The classical text book examples are ${}^{38}_{17}Cl_{21} \leftrightarrow {}^{40}_{19}K_{21}$ (1p - 1h) ${}^{92}_{41}Nb_{51} \leftrightarrow {}^{96}_{41}Nb_{55}$ (1p - 1h) ${}^{50}_{22}Ti_{28} \leftrightarrow {}^{54}_{26}Fe_{28}$ (2p - 2h) In the 2p-2h example the matrix elements of interaction between 2p states are the same as those between 2h states, as far as excitation spectrum is concerned [2].

We first reproduced the results of the text book examples of Ref.[2] for the ${}^{42}Sc$-${}^{48}Sc$ conjugates (Fig. 1). Then we have considered the ${}^{134}Sb$-${}^{140}Sb$ particle-hole conjugate in the $(\pi 1g_{7/2}\nu 2f_{7/2})$ valence space above the doubly magic ${}^{132}Sn$ core. The spectrum of highly neutron-rich ${}^{140}_{51}Sb_{89}$ with N/Z $\simeq$ 1.745, which is greater than 1.640 for ${}^{132}Sn$ and close to ${}^{140}Sn$ (N/Z = 1.800) has been predicted (Fig. 2) from the spectrum of ${}^{134}_{51}Sb_{83}$ (N/Z = 1.627).

3. Results and Discussions

The spectra of ${}^{42}Sc$-${}^{48}Sc$ p-h pair calculated by the use of Pandya tranformation is presented in Figure 1. For the ${}^{42}Sc$-${}^{48}Sc$ conjugate all levels except the 2^+ [2] have good agreement with Pandya theorem prediction. This was attributed to the less pure configuration in ${}^{42}Sc$. However in ${}^{134}Sb$ the low-lying states of multiplet are reasonably pure, originating from the $(\pi 1g_{7/2}\nu 2f_{7/2})$ - configuration. So similar error accumulation may not occur for ${}^{134}Sb$-${}^{140}Sb$ pair.

Very recently in Ref. [3], an isomer in ${}^{140}Sb$ has been reported from experiment. However, the authors could not determine the spin and parity of the ground state, neither those of the isomeric state. They found two correlated γs of energies 227 keV and 71 keV. Shell Model

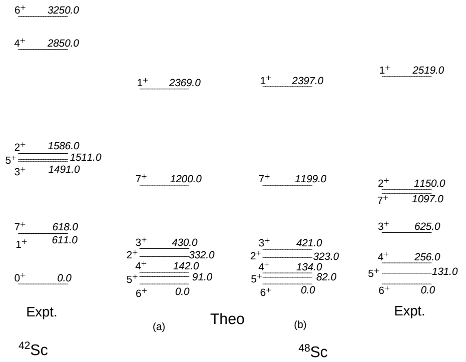

FIG. 1: Predicted spectrum of ^{48}Sc from the experimental spectrum of ^{42}Sc by Pandya transform. (a) Prediction of the present work, (b) As given in Ref. [2]. Experimental spectrum of ^{48}Sc is also shown for comparison.

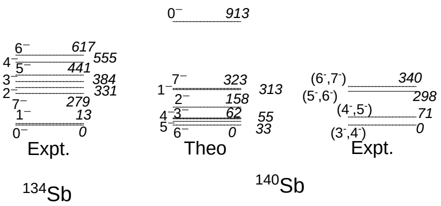

FIG. 2: Predicted spectrum of ^{140}Sb from the experimental spectrum of ^{134}Sb by Pandya transform. The experimental data [3] for ^{140}Sb is also shown for comparison.

calculation presented by them predicts a 2^- ground state. The possible origin of the isomeric state is discussed to be $\pi 1g_{7/2} - \nu 2f_{7/2}^{-1}$ configuration, resulting in either (6^-) or (7^-) spin-parity.

From the present work, Fig. 2 suggests 7^- state at 323 keV may be the isomeric level and the spectrum also indicates possibilities of γ-transition energies close to the observed ones in Ref. [3].

4. Conclusion

We have also predicted excitation spectra for other exotic nuclei. Calculations of electromagnetic transitions probabilities have been done to compare with the results of shell model calculations with empirical interaction in the proton($gdsh$)-neutron($fphi$) valence space.

5. Acknowledgement

We sincerely thank D. Pramanik, Department of Physics, IIESTS for her help in preparation of this manuscript.

References

[1] S. P. Pandya, Phys. Rev. **103**, 956 (1956).
[2] R. D. Lawson, Theory of the Nuclear Shell Model, Clarendon Press, OXFORD (1980).
[3] R. Lozeva *et al.*, Phys. Rev. C **93**, 014316 (2016)