Studies of Nuclear Isomers from Medium mass to Heavy mass Nuclei

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Introduction

Nuclear Isomers are longer lived excited states. Large amount of data is now available. Our recent "Atlas of Nuclear Isomers" catalogues about 2470 nuclear isomers with a half-life $\geq$ 10 *ns* [1]. The occurrence of nuclear isomers throughout the nuclear chart is very fascinating. An understanding of their formation may sometimes require new physics reasons and this is the main aim of our work. While sifting through the huge isomeric data, we have found many interesting systematics in the semi-magic nuclei, where the concept of seniority applies. The concept of seniority is based on the role of pairing of nucleons in nuclei, and is well known to describe the features of semi-magic nuclei. It is a general belief since long that the seniority isomers arise only in *E2* decays for the single-j orbital. Though the concept of generalized seniority is also known for decades, no quantitative description is available so far. This has motivated us to study the nuclear isomers in semi-magic nuclei by using the concept of seniority and generalized seniority. How the seniority selection rules of the single-j orbital modify in going towards the multi-j orbitals is the main question.

Formalism

This thesis is mainly based on the concept of seniority and generalized seniority, which itself is rooted in the nuclear shell model. We, therefore, use the large scale shell model (LSSM) calculations to validate the configuration mixings as suggested by generalized seniority. We extend the single-j seniority picture to the multi-j generalized seniority using the simple quasi-spin scheme and present a simple microscopic formalism for generalized seniority in multi-j degenerate orbitals [2].

We could establish that the decay transition probabilities for both even and odd tensor electric transitions behave similar to each other in generalized seniority. The reduced transition probabilities *B(EL)*, for both even and odd *L*, between the initial and final states is therefore given by

$$B(EL) = \frac{1}{2J_i+1}\left|\left\langle J_f \left\| \sum_i r_i^L Y^{(L)}(\theta_i,\phi_i) \right\| J_i \right\rangle\right|^2 \quad \text{...(1)}$$

Where the reduced matrix elements can be written in terms of the seniority reduction formula for Δv = 0 and Δv = 2 transitions, respectively, by defining a mixed configuration $\tilde{j} = j \otimes j' \otimes ....$ as follows [2],

$$\left\langle \tilde{j}^n v l J_f \left\| \sum_i r_i^L Y^{(L)} \right\| \tilde{j}^n v l' J_i \right\rangle = \quad \text{...(2)}$$
$$\left(\frac{\Omega-n}{\Omega-v}\right)\left\langle \tilde{j}^v v l J_f \left\| \sum_i r_i^L Y^{(L)} \right\| \tilde{j}^v v l' J_i \right\rangle$$

$$\left\langle \tilde{j}^n v l J_f \left\| \sum_i r_i^L Y^{(L)} \right\| \tilde{j}^n v-2, l' J_i \right\rangle = \quad \text{...(3)}$$
$$\left(\sqrt{\frac{(n-v+2)(2\Omega+2-n-v)}{4(\Omega+1-v)}}\right)$$
$$\left\langle \tilde{j}^v v l J_f \left\| \sum_i r_i^L Y^{(L)} \right\| \tilde{j}^v v-2 l' J_i \right\rangle$$

Here, the total pair degeneracy for a *n*-particle configuration with *v* number of unpaired nucleons is given by $\Omega = \frac{1}{2}\sum_j (2j+1) = \frac{1}{2}(2\tilde{j}+1)$.

Hence, the *B(EL)* trend shows a dip and peak in the middle for Δv = 0, and Δv = 2 transitions, respectively, irrespective of the nature of the tensor *L*, as shown in Fig. 1. Note that the proportionality constants carry the information about the radial matrix elements and becomes a very useful quantity in developing the realistic effective interactions in LSSM calculations.

We show in Fig. 1, a comparison of the schematic plot for the electric and magnetic transition probabilities in the single-j and multi-shell for both Δv = 0 and Δv = 2 transitions. We may follow the similarities and differences in both the single-j and multi-j shells. Hence, for the very first time, we establish that the seniority isomers may also exist due to the odd electric (*E1,E3,…*) transitions in the generalized seniority, see Fig. 1.

Results and Conclusion

We have applied these results to the 10^+, 13^-, and 15^- isomers in $^{116-130}$Sn isotopes and shown that the *B(E1)* values in the 13^- isomers behave similar to the *B(E2)* values in the 10^+ and 15^- isomers. Hence, we have found a new kind of seniority isomers, i.e. *E1* decaying 13^- seniority isomers [2]. We also find that the configuration mixing is essential to fully describe the *E2* isomers, like the 10^+ isomers which were interpreted as pure $h_{11/2}$ isomers so far [2]. We have also compared these high-spin Sn-isomers with the 10^+ isomers in the N=82 isotones and the 12^+ isomers in the Pb isotopes. We conclude that all these high-spin isomers in different semi-magic chains behave similar to each other due to the *goodness of generalized seniority,* though they have a different set of valence orbitals in different valence spaces.

We further apply the same scheme to the seniority changing $\Delta v = 2$ transitions for the first excited 2^+ and 3^- states of Sn isotopes. These simple calculations reproduce the experimental *B(E2)* trend quite well along with a dip in the middle of the 50-82 neutron valence space, which is due to the change in the active orbitals before and after the middle [3]. We also successfully explain the octupole character of the 3^- states as an inverted parabolic behavior of *B(E3)* values in Sn isotopes using the same scheme.

We also apply the same concept to explain the very n-rich 6^+ isomers in $^{134-138}$Sn isotopes successfully [4]. Further, we have done LSSM calculations to validate the generalized seniority results. These results further become a tool to confirm the uncertain neutron single particle energy of $i_{13/2}$ orbital in this *n*-rich region. We also demonstrate the applicability of this generalized scheme to the high-spin isomers in odd-A Sn isotopes and compare their identical trend with the high-spin isomers in odd-A Pb isotopes. Interestingly, the generalized seniority provide us a single key to study the nuclear isomers from medium mass to heavy mass nuclei, particularly in the semi-magic nuclei. This also guides one, in choosing the correct configuration mixing for a set of states in the LSSM calculations. These studies further help in the exploration of the isomers at the nuclear limits along with checking the effective interactions, and single-particle energies in very p-rich/n-rich nuclei by using LSSM calculations. Useful predictions can also be made.

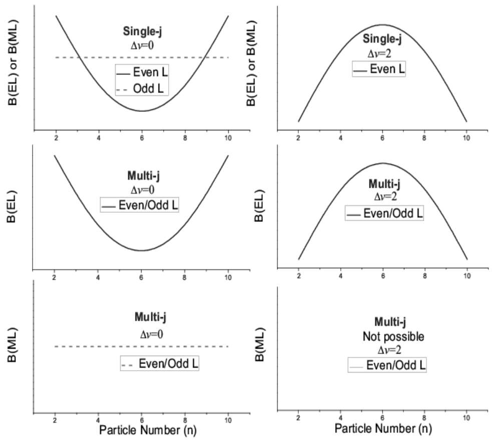

Fig. 1 Comparison of the schematic plot of the electric and magnetic reduced transition probabilities between $\Delta v = 0$ and $\Delta v = 2$ transitions in single-j and multi-j shell by using pure seniority and generalized seniority rules, respectively.

The overall conclusion is that *the generalized seniority behaves as a reasonably good quantum number,* which governs the identical behavior of the high-spin isomers as well as the other excited states in the different semi-magic chains, from medium mass to heavy mass region. Financial support from MHRD (Govt. of India) to BM is acknowledged.

References

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