High-spin seniority isomers in the Z=50, 82 isotopic chains

Bhoomika Maheshwari,* P. C. Srivastava and Ashok Kumar Jain
Department of Physics, Indian Institute of Technology, Roorkee- 247667, INDIA.
*. * email: bhoomika.physics@gmail.com*

Introduction

Nuclear isomers are the excited metastable states of nuclei, which have gained attention due to wide range of possible applications, both fundamental and applied. Seniority isomers, identified in semi-magic nuclei, have now been placed in a separate class due to their properties.

The large amount of experimental data on nuclear isomers has been collected in the "Atlas of Nuclear Isomers", which lists more than 2460 isomers with a half-life ≥ 10ns [1]. This data set has revealed many novel systematic features. Nuclear isomers in the semi-magic nuclei represent an interesting subset of this data. The high spin isomers in the Z=50 isotopic and the N=82 isotonic chains, highly influenced by the $h_{11/2}$ intruder orbital, have recently been shown to exhibit very similar energy and half-life systematics and expand the scope of good seniority to j=11/2 [2].

In this paper, we extend our studies to include the energy systematics of the nuclear isomeric states arising from the $i_{13/2}$ intruder orbital in the Z=82 isotopic chains and contrast it with the Z=50 chain of isomers arising from the $h_{11/2}$ intruder orbital.

Experimental systematics

We have plotted the measured excitation energy for the $11/2^-$, $27/2^-$ and 10^+ isomers in the Z=50 and the $13/2^+$, $33/2^+$ and 12^+ isomers in the Z=82 isotopic chain, see fig. 1. We find that the $13/2^+$, $33/2^+$ and 12^+ isomers, which emerge from the $i_{13/2}$ orbital for the Z=82 isotopes, mirror a behavior very similar to the $11/2^-$, $27/2^-$ and 10^+ isomers for the Z=50 isotopes, which emerge from the $h_{11/2}$ orbital.

It is interesting to note that entirely different valence spaces of N=50-82 and N=82-126 chains having $h_{11/2}$ and $i_{13/2}$ intruder orbital respectively, lead to very similar systematic features for the isomers. The figures show double x-axes, where the top axis gives positive and negative numbers denoting the number of particles and holes respectively, while the bottom axis denotes the N-Z value.

We find that both the panels, the top and the bottom in Fig. 1, are almost a mirror image of each other. The $27/2^-$ and 10^+ isomers, and the $33/2^+$ and 12^+ isomers are observed to closely follow each other over a wide range of N-Z values. Further, the energy difference between the $33/2^+$ and $13/2^+$ isomers, and the 12^+ isomer and the 0^+ ground state remains constant at ~3 MeV over the same range of N-Z values for the Z=82 isotopes.

Outside of this range, the energy difference rises and becomes almost 4 MeV. A similar behavior is observed for the Z=50 isomers, where the gap of about 4 MeV arises between the $27/2^-$ and $11/2^-$ isomers, and the 10^+ isomers and the 0^+ ground state [2]. For some of the isotopes, the $13/2^+$ and $11/2^-$ isomers become the ground state and are depicted in the figure by a star symbol. We find that the hole number from 0 to 16, right side of the top panel in the fig. 1, for the Z=82 isotopic chain show very similar behavior to the particle number from 0 to 16, left side of the bottom panel in the fig. 1 for the Z=50 isotopic chain.

Calculated systematics

We have carried out large scale shell model calculations by using the Nushell code [3] along with the SN100PN interaction for the Z=50 isotopic chain [4] and the KHHE interaction for the Z=82 isotopic chain [5]. The valence space for Z=50 isomers consists of $0g_{7/2}$, $1d_{5/2}$, $1d_{3/2}$, $2s_{1/2}$, $0h_{11/2}$ orbitals; these results are reported by us in [2].

The valence space for Z=82 isomers consist of $1h_{9/2}$, $2f_{7/2}$, $2f_{5/2}$, $3p_{3/2}$, $3p_{1/2}$, and $1i_{13/2}$ orbitals. We have done the calculations with full open valence space up to 6 holes at N=120. We have then truncated the neutron valence space by adding some holes to the $p_{1/2}$, $f_{5/2}$ and $p_{3/2}$ orbitals, so that the calculations remain feasible but can be done in a shorter time.

We have plotted the calculated excitation energies for the isomers in the Z=50 and 82 isotopic chains in Fig. 2. We find that the calculated results reproduced the experimental systematic features quite well except for the fact that the relative gap of the isomeric states is systematically smaller due to the applied truncations for both the chains.

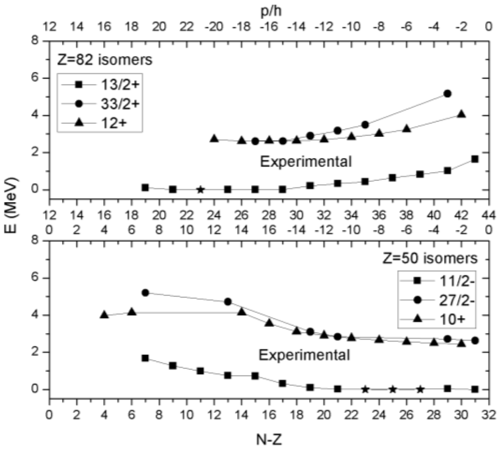

Fig. 1 The excitation energy systematics for the isomers in the Z=50 and 82 isotopic chains.

From the discussion presented in [2], we find that the 10^+ and $27/2^-$ isomers come from the two and three aligned neutrons in the intruder $h_{11/2}$ orbital, i.e. seniority 2 and 3 states, after the mid-shell for the Z=50 chain. However, the 10^+ and $27/2^-$ isomers have a larger seniority before the mid-shell. The $11/2^-$ state comes from the odd-particle/ hole in the $h_{11/2}$ orbital for the whole chain. The change in the seniority causes the energy transition near the mid-shell.

Similar to this, the $13/2^+$ isomeric state comes from the odd-particle/ hole in the unique-parity $i_{13/2}$ orbital for the Z=82 chain, i.e. the seniority v=1 remain constant for this state throughout the chain. Due to mirror image like situation, the 12^+ and $33/2^+$ isomers should come from the two and three aligned neutrons i.e. seniority v=2 and 3 states, in the $i_{13/2}$ orbital near the mid-shell, and up to the hole number 16. Afterwards, the seniority becomes larger for the $33/2^+$ and 12^+ isomeric states leading to the rise in the excitation energy. The different relative position for the $h_{11/2}$ and $i_{13/2}$ intruder orbitals in their valence space is responsible for this kind of mirror behavior. Therefore, the $33/2^+$ and 12^+ isomers show alignment, from the N-Z value of 18 to 31, due to the dominant role of $i_{13/2}$ orbital. Afterwards, the mixing of other orbitals causes seniority mixing and a rise in the excitation energy.

Conclusion

We find that the $13/2^+$, $33/2^+$ and 12^+ isomers from the Z=82 chain, behave similar to the $11/2^-$, $27/2^-$ and 10^+ isomers from the Z=50 chain. The mirror systematic is due to the different position of the intruder $h_{11/2}$ and $i_{13/2}$ orbital in their respective valence space. We can conclude that these isomers also behave as seniority isomers. The remaining gaps in the Z=82 chain should be occupied by isomers not observed so far, predicting many new isomers.

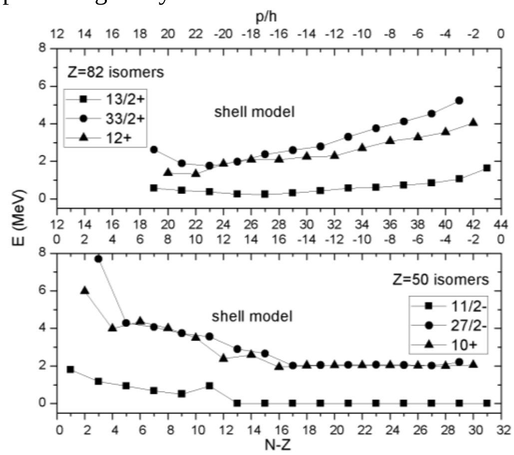

Fig. 2 The same as Fig.1 but calculated.

We acknowledge financial support from MHRD, DST and DAE (Govt. of India).

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