Global Systematics of Spins of Nuclear Isomers

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Introduction

In this paper we present a global systematics of the spins of nuclear isomers. As pointed out in the accompanying paper [1], we have defined isomers as those excited states whose half-lives are equal to or, more than 1 ns. The limit of half-life of nuclear isomers is not so well defined. This limit has been lowered by workers with the passage of time. The limit was 1 sec in the early days while the mass table of Audi and Wapstra [2] took this limit as 100 ns. Walker et al [3] have used limits of 5 ns to define an isomer. More recently, Kondev et al. [4] have been using a limit of 1 ns to define a nuclear isomer.

Spin of a nuclear isomer is the total angular momentum associated with it. We find that the number of isomers with a given spin exhibit some very interesting features which are common across different mass regions. It may be noted that nuclei with odd mass number A carry half odd-integer spins, while even-A nuclei have integral spins associated with them.

Systematics of Spins

In the following, we plot the spin systematics of isomers having maximum spin value up to 16ħ; however, there are about 161 isomers which have spins larger than 16ħ which we have not included. For example, isomers having spins 35ħ and 66/7 ħ have been seen in ^{148}*Gd* and ^{151}*Er* respectively.

In figure 1(a), we plot the systematics of the Z=N=28-50 region. We find that the number of isomers having integral spins is more than that of half-integral spin between 5ħ and 8.5ħ. In this region, single particle excitation can produce the highest spin of 4.5ħ from the $g_{9/2}$ orbital active. Therefore, isomers having spins from 5ħ to 8.5ħ can be generated from two or three quasi-particle excitations only. The peaks in the figure represent even-A nuclear isomers having 2qp excitations.

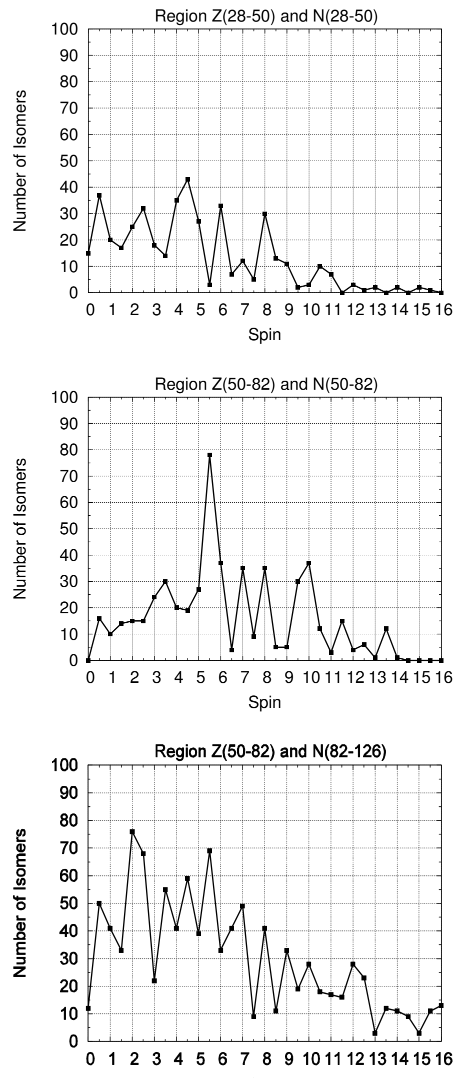

Fig. 1 Systematics of spins for the a) Region Z(28-50) and N(28-50) (top), b) Region Z(50-82) and N(50-82) (middle), and c) Region Z(50-82) and N(82-126) (bottom).

In figure 1(b), we plot the proton rich region of nuclear chart with proton and neutron number between magic numbers 50 and 82. We find that the number of isomers having integer spins is much larger than those having half-odd integer spin provided the spin lies between 6ħ to 8.5ħ. The highest spin that can arise from a single particle excitation in this mass region is 5.5ħ from $h_{11/2}$ orbital. The isomers having spins from 6ħ to 8.5ħ can, therefore, be generated from two or three quasi-particle excitations only. Integer spins will follow from 2qp excitations (in even-even or odd-odd nuclei) while half-integer spins will follow from 3qp states in odd-A nuclei. This feature is not observed below 6ħ where only single particle excitations are expected in odd-A but 2qp excitations in even-A nuclei.

In figure 1(c), the proton and neutron numbers lie between 50 to 82, and 82 to 126, respectively, which covers the deformed nuclei and the K-isomers. This region has largest number of isomers, nearly 993 [5]. We again find that the number of isomers having integer spins is much larger than those having half-odd integer spin provided the spin lies between 6.5ħ to 10.5ħ. We also observe that this pattern reverses completely for spins 3ħ to 6ħ where the half-integral spins occupy the peaks. In this mass region, the highest spin that can come from a single particle excitation is 6.5ħ from the $i_{13/2}$ orbital. It is, therefore, evident that the spin range keeps rising from 5 to 6 to 6.5ħ as per the active orbital of highest spin in that mass region.

In figure 2, the complete systematics are shown for the whole mass region from A=1-240. We note that the features noted above persist with a reversal of the role of spins around 6ħ. These features suggest that the high spin isomers are more likley in even-even or, odd-odd nuclei. This probably happens because higher spin excitations lie closer to the ground state in these nuclei. Maximum number of high spin isomers are observed at spin values 5.5, 6, 7 and 10ħ.

In all the figures shown here, we always find a peak at spin 0.5ħ. This is not surprising as 0.5ħ is the lowest possible spin and the likleyhood of a higher spin level occurring below it is statistically quite high. It may, therefore, become an isomer quite often.

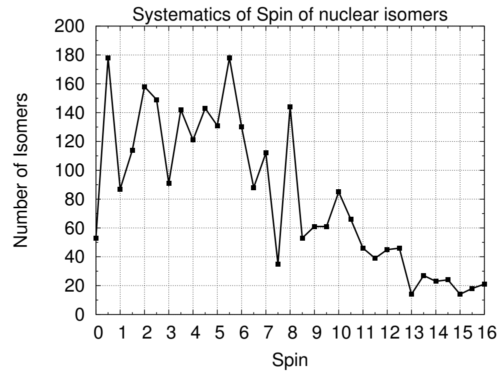

Fig. 2. Overall systematics of all the nuclear isomers.

Conclusion

It has been observed that nuclear isomers having half-integer spins are more in number as compared to nuclei having integral spins for spins less than 6 to 6.5ħ. This pattern changes its signature after 6.5ħ where we find integral spins lying at the peaks between 6 to 10.5ħ. There are additional features that we have not discussed here. Present study aims to understand these interesting features in the spins of isomers.

Acknowledgement

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References

[1] Monika Patial, A.K. Jain, P. Arumugam, Balraj Singh, Atlas of Nuclear Isomers, contribution to this DAE Symposium.

[2] G. Audi *et. al.*, Nuclear Physics A**729**, 3, (2003).

[3] F.G. Kondev, Workshop on "Nuclear Structure and Decay Data: Theory and Evaluation", Trieste, Italy, (2005).

[4] P.M. Walker, J. J. Carroll, Nuclear Physics News **17**, 2 (2007)

[5] National Nuclear Data Center, BNL, USA http://www.nndc.bnl.gov/ensdf.