Systematics of low-lying isomeric states 150<A<160 Odd-odd Tb Isotopes

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Introduction

The nuclear structure and properties of doubly odd deformed nuclei in the mass regions 150<A<190 are complex and exhibit intriguing properties, primarily due to the coupling of the properties of the unpaired proton and neutron states that form the energy levels. As discussed in our earlier report [1], one of the important features is the existence of low-lying long-lived ($t_{1/2} \geq 1$s) isomers both as pairs and in some cases as triplets in many nuclei in this region. While experimental studies have been successful in establishing the high-energy band structure in many of these nuclei, their low-energy level schemes have many ambiguities and unknown parameters including uncharacterized isomeric states.

In this work, our nuclei of interest are the doubly odd Z=65 Tb isotopes in the mass region A=152(2)160, in an attempt to characterize the low-lying isomers. Both ^{154}Tb and ^{156}Tb are known to have low-lying long-lived isomer triplets with the same spin values: J = 0, 3 and 7 [2], albeit having tentative J^π assignments and no energy values. On comparison with the neighboring isotopes, we observe that an isomer triplet exists in ^{158}Tb too, though the $t_{1/2}$ of one of the isomers is relatively small. However, in the higher mass neighboring isotopes and in lower mass ^{150,152}Tb we do not find such instances of isomer triplets.

1qp n and p orbital systematics

We have used the well-tested Two Quasiparticle Rotor Model (TQRM) [3,4] to identify and characterize the isomeric states. As a first step, we map the relevant 1qp p and n Nilsson orbitals from the neighboring odd-A isotopes/isotones. Our survey of the systematics of the 1qp n and p orbitals of interest in this mass region has revealed the following trends. Specifically, we notice from Fig. 1, that the ν3/2[521] remains the ground state in A=153-159 odd-mass Gd isotopes. The ν3/2[402] orbital undergoes strong ΔN=2 non-coriolis mixing with ν3/2[651] and has some components of $i_{13/2}$ Nilsson states in ^{155}Gd [2,5]. Also, the experimental data confirms that the $5/2^+$ level of this band lies lower in energy than the $3/2^+$ bandhead. Another important n-orbital trend observed in A=153-157 mass region is the steep drop in energy of ν11/2[505] after which it increases to very higher energies.

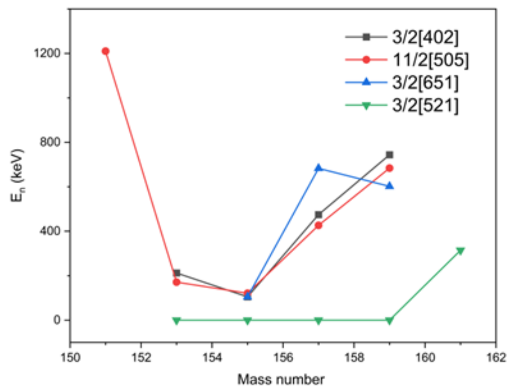

Fig. 1: *The neutron orbital systematics of relevant 1qp orbitals in the A=150-160 mass region as taken from odd-mass Gd isotopes.*

As for the relevant 1qp p-orbitals, the π5/2[402] is the g.s in ^{153}Tb following which there is a sharp rise in its energy while the π3/2[411] drops down from 150 keV and remains as g.s consistently in ^{155,157,159}Tb. This crossover, added to the fact that coupling of π5/2[402] with any of the low-lying n-orbitals will not yield spins of J=0 or 3, makes the choice of π3/2[411] as the lowest p-orbital for determining the 2qp states in ^{154,156,158}Tb.

^{154}Tb: Current NDS report the existence of low-lying isomer triplets in ^{154,156,158}Tb [2]. For ^{154}Tb, the g.s spin is listed as J=0 with an uncertain parity assignment. In view of the above-mentioned systematics of the n and p orbitals, we categorically rule out positive parity and assign $J^\pi=0^-$ for the ^{154}Tb g.s. However it should be noted here that according to the GM rule, the spins parallel triplet $K_T=3^-$ is expected to be the g.s while strong experimental evidences reveal that the spins-antiparallel $K_S=0^-$ is indeed the g.s.

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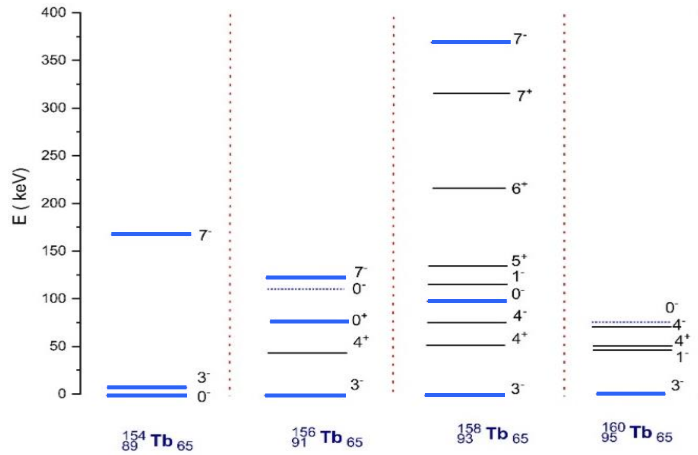

***Fig 2**: A comparison of the low-lying rotational levels of odd-odd Tb isotopes of interest in the present study.*

Hence, a clear violation of GM rule is observed in ^{154}Tb. The coupling of the low-lying high-spin ν11/2^{-}[505] orbital with the π3/2[411] gives rise to the low-lying J^{π}=7^{-} state, experimentally reported as the third isomeric state in ^{154}Tb.

^{156}Tb: In our previous extensive TQRM study of ^{156}Tb [6], the spin, parity, energies and orbital configurations of low-lying isomer triplet were reported. The J^{π}=3^{-} and 7^{-} isomeric states are similar to that in ^{154}Tb. However, as observed in the systematics of the 1qp n-orbitals of interest, the 3/2[402] is responsible for the formation of the second isomeric state with the configuration J^{π}=0^{+}:{3/2[411]⊗3/2[402]}, at a reported energy of 88 keV. While there is no reported observation of the J^{π}=0^{-} K_S partner of the g.s GM doublet, our calculations place this level at E_x ~120 keV, slightly above the 0^{+} isomer.

^{158}Tb and beyond: Extending our study, we find a similar set of isomer triplet in ^{158}Tb, albeit well characterized as compared to ^{154,156}Tb. However, the three isomers with J^{π}=3^{-}, 0^{-} and 7^{-} differ from the other two isotopes in two aspects: i) they do not have comparable half-lives and ii) the 7^{-} state lies at a much higher energy (388 keV). The 7^{-} isomer is observed to de-excite to the $I^{\pi}K$=7^{+}4 level at 323 keV, with a K-hindrance (ΔK=3) and hence a measurable life-time. From the next Tb isotope in line, ^{160}Tb, this set of isomeric states cease to exist due to a J^{π}=1^{-}{3/2[411]⊗5/2[523]} state below the J^{π}= 0^{-} level as seen in Fig. 2.

In summary, this particular pattern of J^{π}=3^{-}, 0^{-} and 7^{-} isomeric states in the odd-odd Tb isotopic chain can be explained through the low-lying 1qp n-orbital systematics. The J^{π}= (3^{-}, 0^{-}) 2qp doublet is formed as a result of the π3/2[411] and ν3/2[521] 1qp orbitals consistently remaining as the lowest p and n orbitals in the A=153-157 mass region. The ΔN=2 non-Coriolis mixing of 3/2[651] and 3/2[402] n-orbitals and its presence at low energy in ^{155}Gd leads to the formation of the J^{π}=0^{+} isomeric state in ^{156}Tb. The high-spin J^{π}=7^{-}isomeric state is the result of the coupling of π3/2[411]⊗ν11/2[505] in ^{154,156,158}Tb. The stark low energy trend of 11/2[505] in the A=153-157 mass region places the J^{π}=7^{-} state lower in energy making it a low-lying high spin isomer. Beyond A=157, this n-orbital trend changes, consequently breaking this pattern. This distinctive systematics of the proton and neutron Nilsson orbitals in this mass region 150<A<160 remains as the key factor behind the formation of the same-spin J= 0, 3 and 7 isomer triplets.

References

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