Level Structures in the N=91 Odd-Odd Nucleus $^{156}_{65}Tb_{91}$

P. C. Sood[1], R. K. Sheline[2], R. Gowrishankar[1*] and K. Vijay Sai[1]
[1]*Department of Physics, Sri Sathya Sai Institute of Higher Learning, Prasanthi Nilayam,(A.P.) 515134*
[2] *Departments of Physics and Chemistry, Florida State University, Tallahassee, FL 32306 USA*
**email: rgowrishankar@sssihl.edu.in*

With medium heavy deformed nuclei domain starting at (Z=60, N=90), the isobaric odd-odd nuclei $^{156}_{61}Pm_{95}$ and $^{156}_{65}Tb_{91}$ can reasonably be viewed as 'mirror pair' with similar structures normally amenable to a 'Two Quasi-particle Rotor Model (TQRM)' description. However, while ^{156}Pm spectra are well described in TQRM [1], the same for ^{156}Tb [2,3] presents quite a contrasting picture on several counts. For instance, presence of a low-lying $11/2^-$ orbital in N=91 nuclei leads to the occurrence of long-lived isomer triplets [4]. Also Coriolis-admixed $i_{13/2}$ bands and the ΔN=2 band-mixing bring in additional complications. Specifically the (A-1) $^{155}_{64}Gd_{91}$ isotone constituent of ^{156}Tb exhibits these features distinctively, i.e., (i) $E_x(11/2^-)$ = 121 keV, (ii) $5/2^+$ rotational level of $3/2^+[651]$ band lies lower in energy (E_x = 87 keV) than its $3/2^+$ band head (E_x = 105 keV), and (iii) ΔN=2 admixed levels in the two $K^\pi = 3/2^+$ bands from $3/2^+[651]$ and $3/2^+[402]$ configurations.

In Table 1, we list the physically admissible GM doublets, K_T and K_S, in $^{156}_{65}Tb_{91}$ in TQRM format [1] for (E_p + E_n) up to 400 keV corresponding to the observed 1qp levels in the (A-1) isotope ^{155}Tb and isotone ^{155}Gd. As evident therein, even in this low-energy (E_x<400 keV) domain, we expect 22 2qp bands in ^{156}Tb spectrum; however, presently available experimental data [2] identifies only 6 band structures. This situation is in sharp contrast to that of isotonic odd-odd neighbour $^{154}_{63}Eu_{91}$ wherein 32 bands have been clearly identified. Our TQRM evaluation of bandhead energies, with the inclusion of band mixing contribution, is presented in Fig. 1.

One distinctive feature of ground state (gs) I^π in the $_{64}$Gd isotopes with N=89/91/93/95 is that in all these cases we have $I^\pi(gs) = 3/2^-[521]_n$ (due to Nilsson level crossings with increasing deformation), which then couples with the $I^\pi(gs) = 3/2^+[411]_p$ in odd-mass Tb isotopes to yield very similar $K^\pi = 3^-$ and 0^- GM doublet bands in ^{156,158,160}Tb isotopes, as shown in Fig. 2. Analysis of these data enables us to add one more rotational level to each of the two (p_0n_0) bands in ^{156}Tb; we determine $E_x(5^-3)$ = 196 keV and $E_x(0^-0)$ = 100(1) keV for these as yet unidentified levels.

A significant open question in the available [2] ^{156}Tb data is the location and the decay route of the 24.4 h isomer. Our analysis is in agreement with its suggested $I^\pi = 7^-$ and configuration ($p:3/2^+ \otimes n:11/2^-$) assignment. Further our model determines $E_x(7^-)$ = 140(10) keV. Our evaluation

Table 2: Expected 2qp bands in $^{156}_{65}Tb_{91}$ from coupling of observed single particle orbitals in $^{155}_{65}Tb_{90}$ (for Z=65) and in $^{155}_{64}Gd_{91}$ (for N=91) with summed (E_p + E_n) up to 400 keV.

^{155}Gd (E_n) / ^{155}Tb (E_p)	n_0: $3/2^-[521\uparrow]$ (0)		n_1: $3/2^+[651\uparrow]$ (103)[a]		n_2: $11/2^-[505\uparrow]$ (121)		n_3: $5/2^+[642\uparrow]$ (267)		n_4: $3/2^+[402\downarrow]$ (269)	
	K_T	K_S	K_T	K_S	K_T	K_S	K_T	K_S	K_T	K_S
p_0: $3/2^+[411\uparrow]$ (0)	3^-	0^-	3^+	0^+	7^-	4^-	4^+	1^+	0^+	3^+
P_1: $5/2^-[532\uparrow]$ (227)	4^+	1^+	4^-	1^-	8^+	3^+	-	-	-	-
P_2: $5/2^+[413\downarrow]$ (271)	1^-	4^-	1^+	4^+	3^-	8^-	-	-	-	-

[a] Due to considerable Coriolis (ΔK=1) mixing of $i_{13/2}$ orbitals, the lowest level in this $K^\pi=3/2^+$ band is $I^\pi K = 5/2^+3/2$ with E_x = 87 keV. This band also has ΔN=2 mixing with n_4 $K^\pi = 3/2^+$ band.

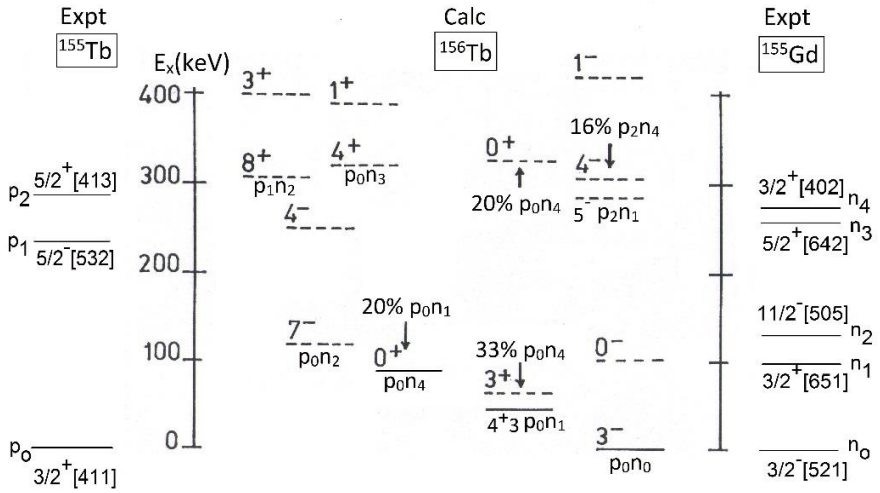

Fig. 1: Plot of experimental low-lying (up to 400 keV) bandhead energies in isotopic ^{155}Tb (on the left) and in isotonic ^{155}Gd (on the right), and model calculated 2qp levels in ^{156}Tb (in the middle).

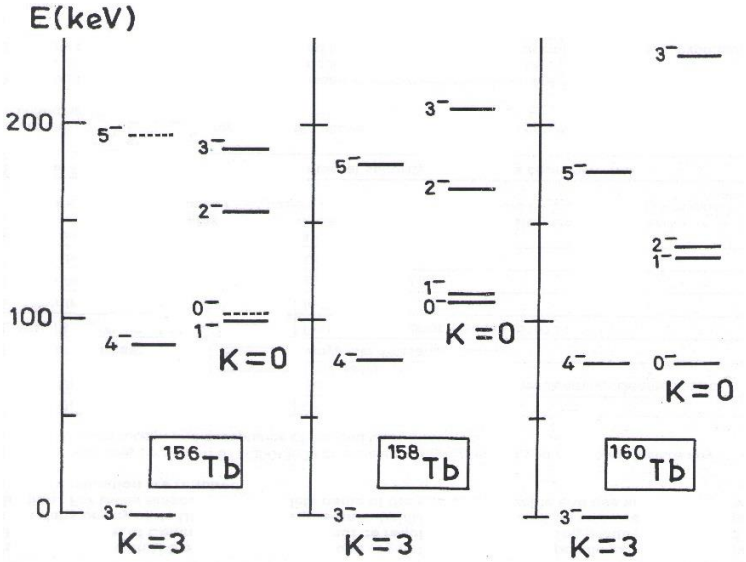

Fig. 2: $K_T^\pi = 3^-$ and $K_S^\pi = 0^-$ GM doublet band levels in ^{156,158,160}Tb isotopes

admits its decay to the 496 keV 4^+ level by an E3 (E_γ = 90(10) keV) transition which has the same energy as that of the reported 88.4 keV ($0^+ \rightarrow 3^-$gs) E3 transition, suggesting an unresolved doublet thereof. Another open question concerns the nature of the signature split high-spin ($I^\pi \geq 4^-$) band based on the observed 379 keV level. Our analysis rules out its $K^\pi = 6^-$ assignment and supports (p:5/2$^-$ $\otimes$ n:$i_{13/2}$ 5/2|3/2) configuration for it. Detailed examination of the proposed level scheme is being pursued.

References

[1] P.C. Sood *et al.*, Phys. Rev. **C83** (2011) 027303; Eur. Phys. J **A48** (2012) 136.

[2] C.W. Reich, Nucl. Data Sheets **113** (2012) 2537.

[3] ENSDF & XUNDL: continuously updated data files at NNDC/BNL (Aug 2015 version).

[4] R. Gowrishankar *et al.*, Proc. DAE Symp. Nucl. Phys. **59** (2014) 62.