Level structures in the odd-odd heavy actinide $^{254}_{103}Lr_{151}$

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Occurrence of Long-lived Isomers (LLI) in deformed nuclei has been the subject of study for more than four decades. An early survey [1] of this phenomenon had concluded that such occurrences are much more likely in the odd-odd deformed nuclei. In particular, N=151 isotones in the actinide region presents a promising domain for such investigation due to the following reasoning. The N=151st neutron orbital 9/2⁻[734] has large energy gaps above and below it. On the other side high (>5/2) spin p-orbitals are observed in the deformed actinides [2]. Coupling of these (n,p) orbitals results in several 2qp GM doublets with large spin difference (ΔK≥5). With no significant γ-transition connecting the respective members of each doublets, their relative ordering / energy placement remains undetermined. As a part of our ongoing investigations on the level structures of odd-odd actinides, we present here the results of our analysis of the low-lying level structure of the heaviest N=151 odd-odd actinide, namely $^{254}_{103}Lr_{151}$.

This nucleus was first identified in 1985 [3] in α-decay of ^{258}Db. The latest data sheet (NDS) [4] lists only the gs and 5 other levels with E_x<400 keV. Excepting the $t_{1/2}$ =13 (3) s, no other information whatsoever is available for any other level. Even the excitation energies of the other five levels are quoted with an uncertainty of 75 keV each. We employ our well tested 3-step Two-Quasiparticle-Rotor-Model (TQRM) [5] to identify and characterize the low-lying levels of ^{254}Lr. First step in TQRM formulation involves mapping the relevant one-quasiparticle (1qp) configuration space from experimentally observed [4] energies of respective single particle orbitals in neighboring (A-1) isotopes/isotones. As summarized in a recent publication [6] the gs configuration for each one of the even Z {96(2)104} N=151 isotone is $9/2^-$[734]; the first excited state in all these nuclei is $5/2^+$[622] with E_x in the 150 to 230 keV range. For the protons the latest NDS [4] lists $7/2^-$[514]

Table 1: Physically admissible 2qp GM doublet bands (K_T & K_S) in ^{254}Lr for (E_p+E_n) ≤ 400 keV.

n_j E_n / p_i E_p	n_0 0 $9/2^-$[734↑]		n_1 167 $5/2^+$[622↑]	
p_0 0 $7/2^-$[514 ↓]	1^+	8^+	1^-	6^-
p_1 30 $1/2^-$[521↓]	4^+	5^+	2^-	3^-

as the gs for ^{253}Lr and $1/2^-$[521] as first excited state (with no specified E_x). For our calculations we have used E_x($1/2^-$[521]) = 30 keV from NUBASE 2016 [7]. In the next step we enumerate in Table 1 the physically admissible 2qp bands, namely, spins-parallel triplet K_T and spins-antiparallel singlet K_S placed according to the GM rule. Finally we evaluate the bandhead energies for each (p_i,n_j) configuration using the TQRM expressions [4]

$E(p_i,n_0) = E_0 + E(p_i) + E(n_0) + E_{rot} + < V_{np} >$ with

$$< V_{np} > = -\left[\frac{1}{2} - \delta_{\Sigma,0}\right] E_{GM} + (-)^I E_N \delta_{K,0}.$$

$$E_{rot} = \frac{\hbar^2}{2I}\left[K - \left(\Omega_p + \Omega_n\right)\right] = \frac{\hbar^2}{2I}(\Omega_<)\delta_{K,K^-}$$

The parameter E_{GM} has been taken as 100 keV & the rotational parameter A≈6 keV is used for all bands. The model evaluated energies for 2qp bandheads, using the notation of Table 1, are shown in Fig. 1.

As seen in Table 1, coupling of the $7/2^-$ proton orbital with the $9/2^-$ neutron orbital gives rise to the gs GM doublet with the spins parallel triplet state 1^+ placed lower in energy than the spins-antiparallel 8^+ state. Our TQRM evaluation places the $K^\pi = 8^+$ state at ~150 keV. The only other bandhead below this is $K^\pi = 4^+(p_1n_o)$ around 70 keV. As can be inferred from Fig. 1 energy placements, de-excitation of the 8^+ to either the 4^+ or the 1^+ band levels would be highly hindered because of ΔK ≥ 4. It is thus evident that this $8^+(p_on_0)$ will be a long

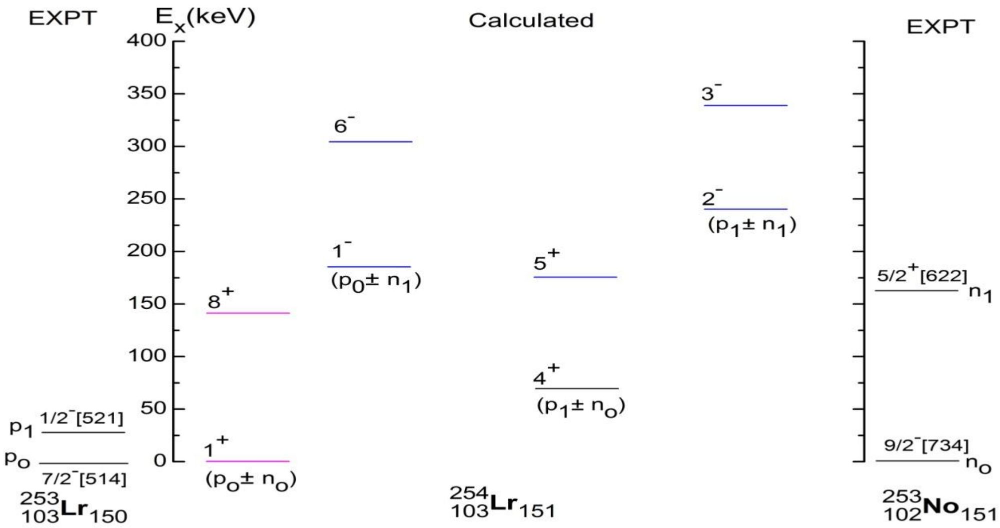

Fig. 1: TQRM model calculated bandhead energies of low-lying 2qp GM doublets in ^{254}Lr.

lived isomeric state. On similar lines, the $4^{+}(p_1n_0)$ level should also be an isomeric, albeit comparatively shorter lived, state.

Only information of ^{254}Lr level scheme comes from 4.3 s ^{258}Db α-decay, wherein five ^{254}Lr levels are populated in the energy range 100-400 keV [3]. As shown in Table 2, the upper 4 levels therein correspond to HF in the range 25-120. According to the rules of α-decay the observed HF values require that the parent and the daughter states in each of these α-feedings have one common orbital. With ^{258}Db (4.3 s) indicated [3] 2qp configuration {p:1/2^{-}[521] ⊗ n:11/2^{-}[725]} and the 2qp admissible configuration of ^{254}Lr as listed in Table 1, the α-populated states in ^{254}Lr necessarily have p:1/2^{-}[521] as a constituent. Under these constraints a comparison of experimental and our model calculated data are presented below in Table 2.

Table 2: Comparison of α-decay populated levels in ^{254}Lr with our TQRM evaluation.

NDS [3]		Calculated	
E_x (keV)	HF	E_x (keV)	Config
205	≥32	200	$6^{+}4$ (p_1n_0)
240	≥25	233	$2^{-}2$ (p_1n_1)
324	≈34	320	$4^{-}2$ (p_1n_1)
396	≈117	388	$4^{-}3$ (p_1n_1)

However, even though the agreement is apparently very good, considering the α-groups experimental uncertainties (75 keV) [4] and ambiguities in the model parameters, we can consider our model evaluated energies as location guides for more precise experiments.

We draw a comparison between the low-lying level structures of ^{254}Lr and ^{252}Md. In both these nuclei, the $K^{\pi}=1^{+}$ constitutes the gs, with $K^{+} = 8^{+}$ state being the low-lying high-spin LLI. Additionally with $K^{\pi} = 4^{+}$ state constituting a shorter lived isomer, these three states form an isomer triplet in both these nuclei. Detailed investigations of the level structures of both these nuclei are being pursued.

References

[1] P. C. Sood and R K Sheline, Nucl. Inst. Meth. **B24/25** (1987) 473.

[2] A. K. Jain et al., Rev. Mod. Phys. **62** (1990) 393.

[3] M. Thoennessen, At. Data Nucl. Data Tables **99** (2013) 312.

[4] ENSDF & XUNDL: continuously updated data files at NNDC/BNL (**Aug 2018 version**).

[5] P.C. Sood et al., At. Data Nucl. Data Tables **58** (1994) 167 and references therein.

[6] K. Rezynkina et al., Phys. Rev. **C97 (2018) 0**54332.

[7] G. Audi et al., NUBASE 2016, Chin. Phys. **C 41** (2017) 030001.