Low-lying structures in neutron rich $^{256}_{99}Es_{157}$

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The heaviest even mass isotope of Es, namely $^{256}_{99}Es_{157}$, was first reported in 1981 [1] using neutron irradiation of ^{255}Es. While assigning a β-decay half-life of 25.4 min to this nucleus, the authors had pointed out the occurrence of a high-spin isomer with a $t_{1/2}$ of 7.6 h [2]. Since then, there has been no further experimental information on the levels of this nucleus. The latest data sheet for A=256 [3] lists only two levels, namely the ground state (gs) and the isomeric state, with tentative spin-parity assignments.

As such, occurrence of long-lived isomers (LLI) in deformed nuclei have been investigated and documented by several researchers. In one of the earliest survey [4] of this phenomenon, Sood *et al*. had concluded that such occurrences are more likely in doubly odd deformed nuclei, with the possibility of isomer pairs having $\Delta I \geq 7$. In particular, for N>155, the presence of high spin neutron orbitals $7/2^+$[613] and $9/2^+$[615] and their coupling with the $7/2^+$[633], $7/2^-$[514] and $9/2^+$[624] proton orbitals results in several 2qp GM doublets with large spin difference in Es, Md and Lr nuclides. In our ongoing investigations on such isomer pairs in doubly odd transuranic actinides, we present here our analysis of the low-lying level structure of ^{256}Es.

To this end, we employ our well tested 3-step Two-Quasiparticle-Rotor-Model (TQRM) [5] to identify and characterize the low-lying levels of ^{256}Es. As a first step in this TQRM formulation, we map the relevant one-quasiparticle (1qp) configuration space from experimentally observed [6] energies of respective single particle orbitals in the neighboring (A±1) isotopes/isotones. In Table 1 we have listed energies of the two lowest proton orbitals in odd mass Es isotopes from A=245(2)257. As evident therein, the gs configuration of the lighter isotopes of Es with N<152 is $3/2^-$[521]. However, we note that beyond the N=152 shell closure, a crossover occurs due to which all the heavier isotopes of Es have $7/2^+$[633] as their gs.

Table 1: Relative placement (in keV) of the two lowest intrinsic states in Z=99 odd-A nuclei.

A ↓	7/2+[633]	3/2-[521]
245	30	0
247	30	0
249	0	?
251	8.3	0
253	0	106
255	0	?
257	0	?

The next step in the TQRM is to determine the physically admissible two quasiparticle (2qp) GM doublet bands arising from the coupling of the 1qp proton and neutron orbitals. In the odd-odd nuclei, each coupling of the proton and neutron orbitals gives rise to two bands namely $K^{\pm} = |\Omega_p \pm \Omega_n|$, with the spins-parallel triplet K_T placed below in energy to the spins-antiparallel singlet K_S according to the GM rule. The physically admissible 2qp bandheads in ^{256}Es for each ($p_i n_j$) for a summed energy of ($E_p + E_n \leq$ 200 keV) are enumerated in Table 2.

Table 2: Physically admissible 2qp GM doublet bands (K_T & K_S) in ^{256}Es.

n_j E_n / p_i E_p	n_0 0 $9/2^+$[615↓]	n_1 x $3/2^+$[622↓]
p_0 0 $7/2^+$[633↑]	1^+ 8^+	2^+ 5^+
p_1 106 $3/2^-$[521↑]	3^- 6^-	0^- 3^-

Finally we evaluate the bandhead energies for each ($p_i n_j$) configuration using the TQRM expressions [5]

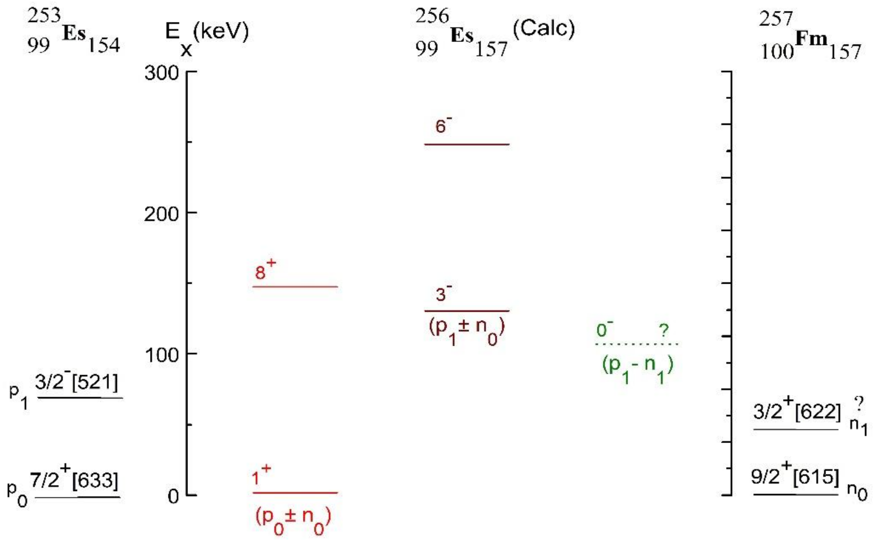

Fig. 1: TQRM model calculated bandhead energies of low-lying 2qp GM doublets in ^{256}Es.

$E(p_i,n_j) = E_0 + E(p_i) + E(n_j) + E_{rot} + < V_{np} >$ 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 while the rotational parameters are obtained from the experimental data of 1qp proton orbitals. The model evaluated energies for 2qp bandheads, using the notation of Table 1, are shown in Fig. 1.

^{256}Es gs: The NDS [3] lists the gs spin parity as $J^{\pi} = (1^+,0^-)$ with the possible configuration p:7/2$^+$[633]⊗n:9/2$^+$[615] or p:3/2$^-$[521]⊗n:3/2$^+$[622] "in analogy to ^{253}Es and to ^{257}Fm". Looking at the available information on the neutron levels, we find that the 3/2[622] orbital does not appear either as gs or as excited state in all the known N=157 isotones, including ^{257}Fm (as misread by NDS evaluators). However, in both ^{257}Fm and ^{259}No, the gs configuration is 9/2$^+$[615]. Taking note of the crossover of the 7/2$^+$ and 3/2$^-$ bands in Es isotopes (Table 1) beyond the N=152 shell closure, it is evident that the lowest proton orbital (p_0) that would couple with any neutron orbital is 7/2$^+$[633]. As seen in Table 2, coupling of p3/2$^-$⊗n3/2$^+$ will place the $0^-(p_1n_1)$ level at least 100 keV above the $1^+(p_0n_0)$. Hence we categorically rule out the possibility of 0^- and assign 1^+{p:7/2$^+$[633]–n:9/2$^+$[615]} as the gs configuration in ^{256}Es.

LLI in ^{256}Es: NDS [3] lists a 7.6 h LLI with a tentative assignment of $J^{\pi}=(8^+)$. As seen in Table 2 and Fig. 1, coupling of 7/2$^+$ and 9/2$^+$ gives rise to the gs GM doublet (1^+, 8^+), with the 8^+ state placed at ~150 keV. The only other level below it is $K^{\pi} = 3^-(p_1n_o)$ at ~130 keV. It is hence evident that this $K^{\pi}=8^+$ constitutes the LLI in ^{256}Es, as de-excitation of this to any of the levels below would be highly hindered because of $\Delta K \geq 5$. The situation is similar to the low-lying level structures of both ^{254}Lr and ^{252}Md, wherein $K^{\pi}=1^+$ constitutes the gs, with $K^+ = 8^+$ state being the low-lying high-spin long-lived isomer.

References

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