Two-Particle States in n-rich ^{184,186,188}Ta (Z=73) Isotopes

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The transitional region of odd-odd nuclei with A~180-190 admits of several high-spin long-lived isomers, primarily due to presence of high-spin n/p orbitals. A unique instance of this phenomenon is witnessed in ^{180}Ta wherein the $I^{\pi}=1^{+}$ ground state (gs) $t_{1/2}$ is just 8 h whereas $I^{\pi}=9^{-}$ isomer with E_x = 75 keV is the 'nature's rarest stable' species. The ^{182}Ta levels have been investigated through 10 different experiments [1, 2] which identified levels assigned to 20 2qp bands, including an $I^{\pi}=10^{-}$ ($t_{1/2}$ ~16 m) isomer with E_x = 520 keV. Surprisingly, the more n-rich odd-odd Ta isotopes have been rarely studied. The only study of ^{184}Ta levels was undertaken over 40 years ago [3] with very limited data deduced from ^{184}Hf decay. Situation is worse for ^{186,188}Ta isotopes [1], wherein no credible characterization of even gs has been reported to date, even though all these n-rich isotopes have overlapping configuration space with widely studied ^{182}Ta [2]. Following the earlier detailed investigation of ^{182}Ta levels [4], and our recent studies on odd-odd nuclei, both of the rare-earth and the actinide regions [5], we report here results from similar analysis for ^{184,186,188}Ta isotopes.

Our Two-Quasiparticle Rotor Model (TQRM) involves a 3-step procedure. We start by mapping the relevant 1qp configuration space, and enumerate therefrom the 2qp GM doublets bands within the specified energy range.

The admissible 2qp bands (GM doublets) in ^{184}Ta with (E_p+E_n) < 750 keV are listed in Table 1, which also includes experimental E_{GM} values as observed in neighboring isotope/isotone [6].

The 2qp bandhead energies are then calculated using the following expression [5]:

$$E^{K}(\Omega_p,\Omega_n) = E_0 + E_p + E_n + E_{rot} + \langle V_{np} \rangle;$$

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

The 2qp band level energies evaluated using eq.(1) with data from Table 1 are shown in Fig. 1. The level scheme of Fig. 1, in contrast to earlier reported information [1,3], brings forth two striking features. Firstly, whereas earlier study [3] had observed only 3 β-branches in ^{184}Hf decay, our analysis points to 6 such branches from $I^{\pi}=0^{+}$ parent corresponding to ΔI ≤ 1 transitions, and 10 if we include $I^{\pi}=2^{-}$ levels fed by 1f^{u} ΔI = 2 transitions. Since Q value for ^{184}Hf decay is 1340 keV [1], the possibility of still higher lying levels being populated in this decay cannot be ruled out. Secondly our analysis also predicts a high-spin ($I^{\pi}=10^{-}$) long-lived isomer around 350 keV excitation. In our analysis, we also take into account the oft-neglected important factor that, while assigning configurations to beta populated levels, the daughter state must correspond to an 'empty' 2qp level, while the parent should be an 'occupied' one.

Table 2: Low-lying (≤ 750 keV) 2qp bands expected in ^{184}Ta. The entries within parenthesis in each row are the 'experimental' E_{GM} values for a given GM doublet in neighboring nuclei [6].

Z=73 \ N=111	n_0: 3/2$^-$[512] K_T	K_S	n_1: 1/2$^-$[510] K_T	K_S	n_2: 11/2$^+$[615] K_T	K_S	n_3: 7/2$^-$[503] K_T	K_S	n_4: 9/2$^+$[624] K_T	K_S
p_0: 7/2$^+$[404]	5^-	2^-	3^-	4^-	2^+	9^+	0^-	7^-	1^+	8^+
	(128)		(93)		(140)		(122)		(90)	
P_1: 9/2$^-$[514]	3^+	6^+	5^+	4^+	10^-	1^-	8^+	1^+	9^-	0^-
	(110)		(147)		(300)		(100)		(120)	
P_2: 5/2$^+$[402]	1^-	4^-	3^-	2^-	-	-	-	-	-	-
	(140)		(115)							

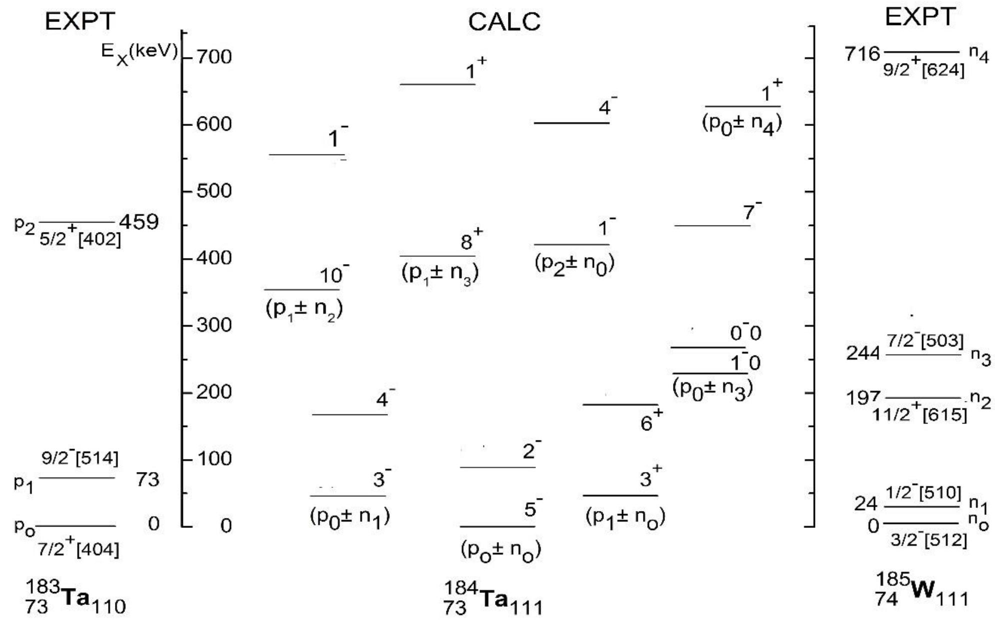

Fig. 1: Plot of experimental low-lying (~700 keV) band-head energies in isotopic ^{183}Ta (on the left) and in isotonic ^{185}W (on the right), and model calculated 2qp level energies in ^{184}Ta (in the middle).

The latest data files [1] list the 10.5 m ^{186}Ta gs to have $I^{\pi}=(2^-,3^-)$ with the (p_0-n_0) or (p_0-n_1) configurations of our Table 1. Later experiments by Yanbing *et al.* [7] identified an isomeric ^{186}Ta^m with $t_{1/2}$ = 1.54(5) m; neither E_x nor I^{π} were suggested for this isomer therein. More recently, projectile fragmentation experiments [8] identified a 3 m ^{186}Ta^m isomer with E_x =336(20) keV. Whereas these investigators left its I^{π} assignment as an open question, they opined that the (presumably high spin) isomer identified by them could be the same as one reported earlier [7]. In our analysis, we note that experimentally [1] all Z=73 isotopes have I^{π}(gs) = 7/2[404] and all N=113 isotones have 3/2[512] as their ground states… same as (p_0, n_0) in our Fig. 1. Also the first excited orbitals are the same as (p_1, n_1), albeit with different E_x. Hence the only physically admissible I^{π}(^{186}Ta gs) is 5^-, and its GM singlet partner I^{π} = 2^- possibly is an isomer which may undergo IT (M3) γ as well as β-decay. Our analysis places I^{π} (p_0, n_1) = 3^- level higher in energy than this 2^- suggested isomer. Neither of these 2^- or 3^- states can thus constitute ^{186}Ta gs. Further, as seen in ^{182}Ta [2] and suggested here for ^{184}Ta, we propose that the 3 m isomer [8] is a higher-lying high-spin isomer. Detailed results from this analysis will be reported.

The ^{188}Ta gs is listed in current data files [1] with unspecified I^{π}, $t_{1/2}$, and decay mode; the listing mentions, in addition, an ^{188}Ta^m isomer emitting ‘a possible 292 keV γ’. Detailed model calculations, similar to those outlined above, are being pursued to arrive at a credible ^{188}Ta picture.

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