Level Structures in the Odd-Odd Nucleus $^{186}_{75}Re_{111}$

R. Gowrishankar, K. Vijay Sai and P. C. Sood

[1]*Department of Physics, Sri Sathya Sai Institute of Higher Learning, Prasanthi Nilayam,(A.P.) 515134*

**email: rgowrishankar@sssihl.edu.in*

Identification and characterization of level scheme of the odd-odd transitional nucleus $^{186}_{75}Re_{111}$ has been the subject of various studies ever since its first observation in 1969 as documented in the latest Nuclear Data Sheets (NDS2003) and subsequent reports [1,2]. The adopted level set therein lists 50 levels for E_x up to 1 MeV. It includes a long-lived isomer (LLI) ($t_{1/2}$ = 2x10^5 y) in ^{186}Re, at an energy ~150 keV and J^π = (8^+) assignment with the remarks that "this energy is comparable to that of possible 8^+ states in ^{182}Re (154 keV) and in ^{184}Re (188 keV)". Wheldon *et al*. [3], in their ^{187}Re(p,d)^{186}Re transfer reaction studies extended the range to E_x~2.5 MeV and observed 30 new levels with E_x >400 keV. Specifically they noted that the 180 keV 6^- level lies above the 150 keV 8^+ level, hence permitting only a high multipole decay path (E5 to 100 keV 3^- level) thus justifying its very long half-life. As recently as 2015, two investigations [4,5] address this question. Matters *et al.* [4] identified decaying γs from higher spin levels (9^+8 and 10^+8) of the 8^+ band and hence more precisely determined its bandhead energy to be 148.2(5) keV. On the other hand, thermal neutron capture studies on enriched ^{185}Re target of Berzins *et al.* [5] observed that "a number of unsolved structure problems remained, especially for positive parity levels". In particular, they raised serious questions about the various positive parity bands including that of the J^π=(8^+) character of the long-lived isomer. Noting that there are two low-lying K^π=8^+ bands corresponding to the configurations {p:9/2[514] ⊗ n:7/2[503]} and {p:5/2[402] ⊗ n:11/2[615]}, they remarked that "one cannot predict with certainty which K^π=8^+ state would be lower in ^{186}Re.

In view of the conflicting assignments, we proceed to characterize the low energy spectrum of ^{186}Re, using the well tested Two Quasi-particle Rotor Model (TQRM) [6] as demonstrated in our recent investigations on the neighbouring ^{184,186}Ta isotopes [7,8].

Table 1: Physically admissible 2qp GM doublet bands (K_T and K_S) in $^{186}_{75}Re_{111}$ from coupling of observed single particle orbitals in the respective (A±1) isotopes (top row) and isotones (first column) with summed ($E_p + E_n$) up to 600 keV.

E_p → / E_n ↓	p_0: $5/2^+$[402↑] (0)		p_1: $9/2^-$[514↑] (290)	
	K_T	K_S	K_T	K_S
n_0: $3/2^-$[512↓] (0)	1^-	4^-	3^+	6^+
n_1: $1/2^-$[510↑] (17)	3^-	2^-	5^+	4^+
n_2: $11/2^+$[615↑] (150)	8^+	3^+	10^-	1^-
n_3: $7/2^-$[503↑] (250)	6^-	1^-	8^+	1^+

In our three step TQRM formulation, we first map the relevant physically admissible one-quasiparticle (1qp) configuration space using the experimentally observed [2] energies of the respective single p/n orbitals in neighbouring odd-A isotopes/isotones. Since this nucleus falls in the transitional region, the Fermi surface for the odd-odd nucleus is taken at the average energy with respect to the corresponding (A±1) isotopes/isotones, i.e., average of E_p in ^{185}Re and ^{187}Re and of E_n in ^{185}W and ^{187}Os.

Next the 2qp GM doublet bands within a specified energy range are enumerated in accordance with the GM rule which places the spins-parallel triplet (K_T) band lower in energy than its spins-antiparallel singlet band (K_S) counterpart. The physically admissible GM doublets, K_T and K_S, for (Ep + En) up to 600 keV in ^{186}Re are listed in Table 1.Finally, we evaluate the bandhead energies for each (p_i,n_j) configuration using the TQRM expressions [7]

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

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

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

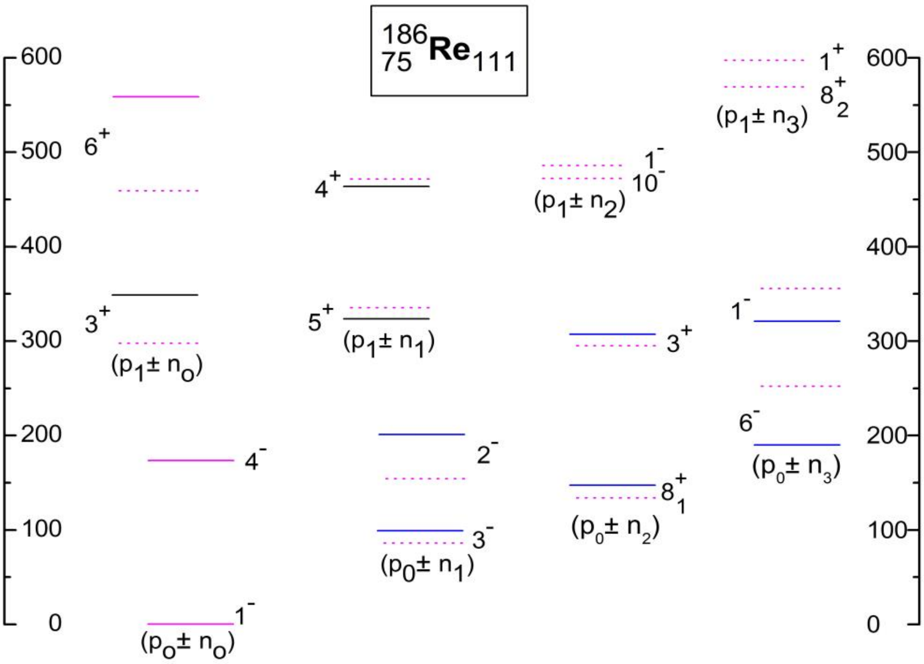

Fig. 1: Comparison of model calculated 2qp bandhead energies (dotted line) and corresponding experimental data (full line) and low-lying in $^{186}_{75}Re_{111}$.

The model evaluated energies for the 2qp bands listed, and in the notation of, Table 1 are plotted in Fig. 2, in comparison with experimental data [1,2]. It is relevant out point out at this stage that the model calculated values do not have any input whatsoever from the experimental data for the odd-odd nucleus ^{186}Re except the ground band doublet. In our formulation the calculated values are location guides for the respective 2qp configurations. Against this background the agreement in respect of the experimental and observed of 2qp bands is evident in Fig 1. This consideration gives us confidence of placing the as yet unobserved 2qp structures in this spectrum.

We note that experimental summed energies of single particle constituents (E_n + E_p) from Table 1 is 150 keV for 8^+_1 (p_0n_2) level and 540 keV for 8^+_2 (p_1n_3) level (ref Fig. 1). No conceivable physical or mathematical procedure can bring down 8^+_2 (p_1n_3) level in the vicinity of 150 keV which is the observed LLI excitation energy. Moreover the 8^+2 (p_1n_3) level certainly lies above the 10^- (p_1n_2) and also 6^- (p_0n_3) levels and hence admits of M2 decay (and hence $t_{1/2}$ ~ ns) to either of them. We thus confirm 8^+_1 (p_0n_2) configuration for LLI with E_x ~150 keV. Further our evaluation also places a low-lying high-spin $K^\pi=10^-$ (p_1n_2) level around 500 keV admitting its M2 decay to 8^+_1 LLI, thus signifying its isomeric character. The analogous $K^\pi=10^-$ (p_1n_2) isomeric state ($t_{1/2}$ < 5ns) has been identified [2] at 917 keV in ^{184}Re. Detailed analyses of these and other features of ^{186}Re level scheme are being pursued.

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