Level Structures in n-rich Np(Z=93) Isotopes

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As a part of our continuing investigations on level structures of deformed nuclei away from the stability line, we report here results of our studies on highly n-rich Np (Z=93) nuclei, against the background of our recent report on ^{240}Np [1] and the earlier one on ^{242}Np [2]. Presently no data is available [3] on any levels in ^{241}Np or in ^{244}Np. The only experimental studies [3] related to these nuclei include the transfer reaction studies on ^{244}Pu targets of Flynn *et al.* [4] and Moody *et al.* [5] resulting in identification of a few levels of ^{243}Np in the (t,α) pick up reaction [4] and of ^{244}Np (2.29 m) decay, presumably from its ground state (gs) [5]. We critically examine the suggested ^{243}Np energy levels [3,4] and work out a level scheme for ^{244}Np using the well tested 3-step Two-Quasiparticle-Rotor-Model (TQRM) [1,6].

The first step in TQRM formulation consists of mapping the relevant physically admissible one-quasiparticle (1qp) configuration space by a plot of the experimentally observed [3] energies of respective single particle orbitals in neighboring odd-A isotopes/isotones. This plot for odd-A Np (Z=93) nuclei is shown on the left in Fig. 1. Since the experimental data is very scarce beyond ^{239}Np (N=146), we have also included herein on the right the data for Am (Z=95) isotones. Evidently the trends and also the respective level spacings are very similar for Np-Am plots and lead us to confidently accept the $5/2^+$- $5/2^-$ levels crossover in N=150 nuclides in ^{243}Np as well. Experimental confirmation for $J^\pi = 5/2^-[523\downarrow]$ as ^{243}Np gs comes from (t,α) study [4], wherein the analyzing power measurements explicitly assign $J=l-1/2$ (spin down) character to this level. We also agree with their $1/2^+[400]$ assignment for 76 keV level and $3/2^-$ (105 keV) and $7/2^-$ (175 keV) as rotational levels of $1/2^-[530]$ band. Correspondence with ^{245}Am data suggests $\Delta E(5/2^+ - 5/2^-) \sim 30$ keV. In respect of n-orbitals the current data tables [3] place n_0: $9/2^-[734]$ orbital as gs in all N=151 nuclides with the first excited state having $E_x > 190$ keV in each case. Since presently we are focusing only on low lying ($E_x < 190$ keV) ^{244}Np levels, n-orbitals other than n_0 are not being considered.

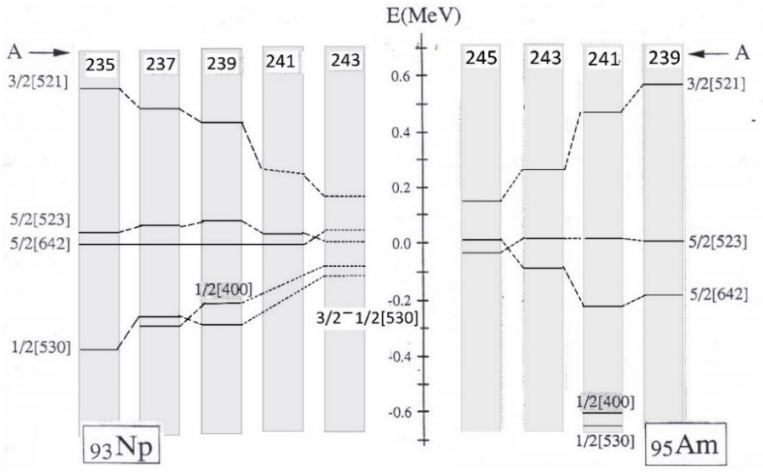

Fig. 1: Single Particle Nilsson orbitals in the odd-A Np isotopes (on the left) and odd-A Am isotopes (on the right), indicating the crossover of the $5/2^+$ - $5/2^-$ levels in the respective N=150 isotopes.

Table 2: Expected 2qp bands in $^{244}_{93}Np_{151}$ from coupling of observed single particle orbitals in $^{243}_{93}Np_{150}$ (for Z=93) and n_0 for N=151. The values below the configurations in 2nd row and 1st column are observed excitation energies in keV in respective odd-A nuclide.

p_i / n_i	p_0: 5/2⁻[523↓] 0		p_1: 5/2⁺[642↑] 28		p_2: 1/2⁺[400↑] 76		p_3: 3/2⁻ 1/2 [530↑] 105	
	K_T	K_S	K_T	K_S	K_T	K_S	K_T	K_S
n_0: 9/2⁻[734↑] 0	2^+	7^+	7^-	2^-	5^-	4^-	6^+	3^+

Coming to the odd-odd $^{244}_{93}Np_{151}$ level structures, we first enumerate the physically admissible 2qp GM doublet bands K_T and K_S with n-orbital n_0:9/2[734] coupling with respective p_i orbital (Fig. 1) for ^{243}Np for the summed $(E_p+E_n)<150$ keV. Results from this exercise are listed in Table 1. Mention may be made that we have included only p_i orbitals with $E_p<150$ keV whereof a suggested configuration from (t,α) reaction studies [3,4] is available. Next we evaluate the bandhead energies for each (p_i,n_0) configuration using the TQRM expression [1,6]

$E(p_i,n_0) = E_0 + E(p_i) + E(n_0) + E_{rot} + < V_{np} >$ 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 parameters E_{GM} for (p_0n_0) and (p_1n_0) are the ones from ^{246}Am study [2], while for the other two 2qp bands, we use the average E_{GM}=80 keV. The rotational parameter A≈6 keV is used for all bands. The model evaluated energies for 2qp bands, using the notation of Table 1, are shown in Fig. 2. The current data files [3] list $J^\pi=7^-$ (p_1n_0) as ^{244}Np gs, using the argument that 'the 93rd proton is probably in 5/2[642] state in analogy with A=235(2)241 Np isotopes'. However, the recent A=243 NDS evaluation [7] lists $J^\pi=5/2^-[523]$ for ^{243}Np gs from (t,α) reaction study [4]; this has also been confirmed by us, as discussed above. Using this as input, ^{244}Np lowest-lying, and hence its gs, level is assigned the configuration $J^\pi=2^+(p_0n_0)$, with $J^\pi=7^-(p_1n_0)$ placed at around 90(20) keV above it. Based on the decay features of ^{244}Np (2.29 m), Moody *et al.* [5] concluded a high spin (probable $J^\pi=7^-$) for the parent state, while explicitly stating that 'we cannot exclude the existence of a shorter-lived isomer'. Thus our assignment of $J^\pi=2^+(p_0n_0)$ as ^{244}Np(gs) and a higher-lying (~90 keV) high-spin $J^\pi=7^-(p_1n_0)$ β-decaying isomer ($t_{1/2}$ = 2.29 m) is consistent with all the available information.

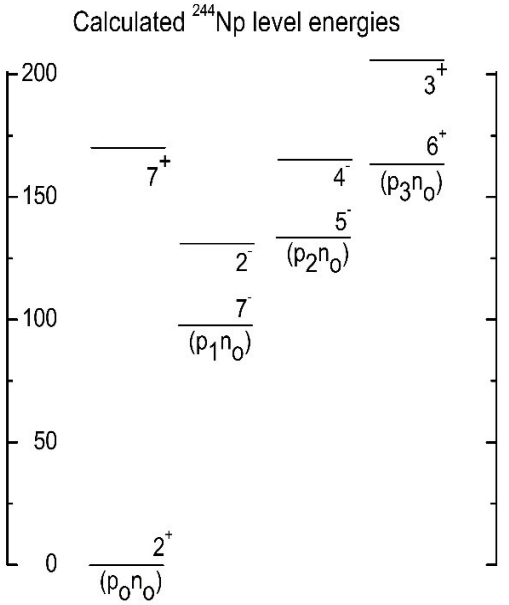

Fig. 2: TQRM model calculated bandhead energies of low-lying 2qp GM doublets in ^{244}Np. The p/n orbitals are abbreviated in the notation of Table 1.

References

[1] P. C. Sood *et al.*, Phys. Rev. **C 89** (2014) 034308.
[2] P. C. Sood, Phys. Scr. **29** (1984) 540.
[3] ENSDF & XUNDL: continuously updated data files at NNDC/BNL (Aug 2015 version).
[4] E. R. Flynn *et al.*, Phys. Rev. **C19** (1979) 355.
[5] K. J. Moody *et al.*, Z. Phys. **A328** (1987) 417.
[6] P. C. Sood *et al.*, At. Data Nucl. Data Tables **58** (1994) 167.
[7] C. D. Nasaraja and E. A. Mccutehan, Nucl. Data Sheets **121** (2014) 695.