Description and Prediction of Long -Lived Isomers in Neptunium (Z=93) Isotopes

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Long-lived isomer pairs have been identified/indicated [1] for well over 50 years in the odd-odd $^{236\text{-}244}$Np with the exception of ^{238}Np isotope. However, firm two-quasiparticle (2qp) configuration assignments, or even the relative energy placement, for any pair of these isomers remains undefined to-date. Using the rotor-particle model with the inclusion of residual n-p interaction contribution, Sood *et al.* [2] had developed a formalism, which has been extensively employed for credible description/prediction of 2qp structures of deformed odd-odd nuclei, both of the actinide [2,3] and the rare earth [4] regions. In a simplified semi-empirical version of this approach [4,5], the energy of a specific 2qp(Ω_p,Ω_n) state of an odd-odd deformed nucleus is written as follows:

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

$$E_{rot} \approx -\frac{\hbar^2}{2I}(2\Omega_<)\delta_{K,K^-};$$

$$\langle V_{pn}\rangle = -\left(\frac{1}{2}-\delta_{\Sigma,0}\right)E_{GM} + (-)^J E_N \delta_{K,0} \quad \ldots (1)$$

wherein, E_p/E_n are the experimental energies of neighboring odd-A isotope/isotone, and the GM doublet splitting energy E_{GM} and Newby parameter E_N for K=0 bands are the values of these quantities for respective band as observed in any odd-odd neighbor. Following the 3-step procedure adopted in our recent publications [5], we have carried out detailed analysis for ^{240,242,244}Np isotopes as summarized below.

As our first step, we map the 1qp configuration space by plotting, in Fig.1, the experimental E_x in the core ^{239}Np nucleus for proton (on right) and in ^{243}Pu for neutron orbitals (on left) of interest in n-rich odd-odd Np isotopes. The circled numbers denote large energy gaps, which give rise to isomer pairs in Np isotopes having A values shown in square boxes on connecting lines in Fig. 1.

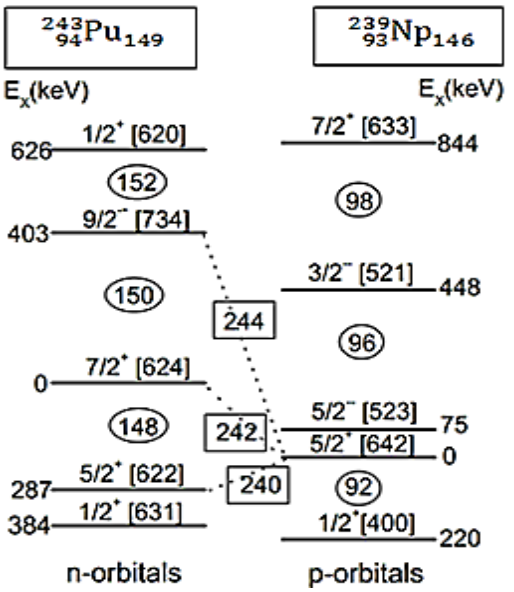

Fig. 1: Schematic plot of p/n orbitals of interest for n-rich odd-odd $_{93}$Np level structures. The orbital excitation energies E_x are experimental [1] values for ^{239}Np (on the right) and ^{243}Pu (on the left). Circled numbers indicate significant shell gaps. Numbers in square boxes denote A for the respective odd-odd Np isotope.

In the second step, we use the data in Fig.1 to enumerate the $K^{\pm}(\Omega_p\pm\Omega_n)$ doublets expected around the Fermi surface for each isotope. Table 1 lists the lowest 2qp structures, denoted by spins-triplet K_T (on left) and spins-singlet K_S (on right) following GM rule in each case. The entries herein are limited to summed (E_p+E_n) <150 keV in each case, since we are presently interested only in isomers close to Fermi surface. As evident herein, the lowest two bands in each case have ΔK=5, thus resulting in long-lived isomers having no significant IT/γ connection and hence no precise energy values.

Table 1: Low lying (E_x < 200 keV) pairs of GM doublet bands expected in ^{240,242,244}Np nuclei. The entries in each box list respectively K^π for the spins parallel (K_T) and spins antiparallel (K_s) band from the indicated 2qp configuration.

p→ / n↓	p_0 $5/2^+[642\uparrow]$		p_1 $5/2^-[523\downarrow]$	
147 $5/2^+[622\uparrow]$	$\mathbf{5^+}$	$\mathbf{0^+}$	$\mathbf{0^-}$	$\mathbf{5^-}$
149 $7/2^+[624\downarrow]$	$\mathbf{1^+}$	$\mathbf{6^+}$	$\mathbf{6^-}$	$\mathbf{1^-}$
151 $9/2^-[734\uparrow]$	$\mathbf{7^-}$	$\mathbf{2^-}$	$\mathbf{2^+}$	$\mathbf{7^+}$

As an illustration, we briefly discuss here our results for ^{240}Np. Out of the 4 bands for ^{240}Np, listed in row 1 of Table 1, the 5^+ band appears [6] as ^{240}Np g.s., while the other 3 bands are observed in the isotonic neighbor ^{242}Am [1]. Using these data in eq (1), the evaluated energies of these 4 bandheads and also J=1 level of K=0 band are shown in Fig.2. Our analysis confirms {π5/2[642] + ν5/2[622]} configuration, which is listed as 'probable' in latest NDS [6], for the 62m ^{240}Np high-spin isomer (HSI). For the 7.22m low-spin isomer [LSI], NDS [6] lists $1^+0\{\pi7/2[633]\text{-}\nu7/2[624]\}$ configuration. Hseuh *et al.* [7] had proposed this configuration, albeit with many ifs and buts, by considering just one β-branch from 7.22m ^{240}Np decay to 597 keV $J^\pi K=1^-0$ level in ^{240}Pu and a 1976 model (QPM) based 2qp decomposition of this octupole state. However, they did point out that E_X of suggested p-orbital is too high (>500 keV) to constitute a particle-hole structure for this vibrational level. Even the β-branches ^{240}U(0^+) ⟶ ^{240}Np(1^+) and ^{40}Np(1^+) ⟶ ^{240}Pu(0^+) were not considered to cross check this assignment.

As seen in Fig.1, the π7/2[633] 1qp state is experimentally [1] indicated at 844 keV in ^{239}Np and hence cannot form a constituent of LSI close to ^{240}Np g.s. Further with $Q_{\beta^-}(^{240}U)$ ~ 400 keV, such a high-lying state cannot be populated in this β-decay. These, and other equally strong, arguments clearly establish

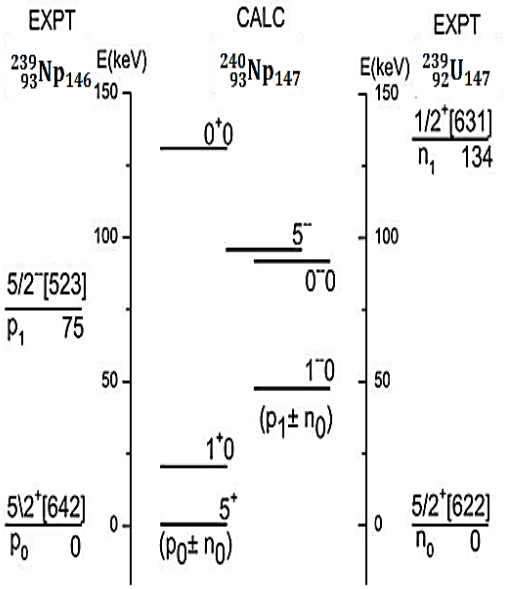

Fig. 2: Plot of experimental 1qp bandhead energies in isotopic ^{239}Np (on the left) and in isotonic ^{239}U (on the right), and model calculated 2qp level energies in ^{240}Np (in the middle).

$J^\pi K=1^+0\{\pi5/2[642]\text{-}\nu5/2[622]\}$ - - - (2)

as the only physically acceptable configuration for the 7.22m ^{240}Np isomer.

Similar analysis and critical examination of isomer pairs in other odd-odd Np isomers form a part of this study, and will be reported.

References

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