N forbidden allowed β-decays in deformed nuclei

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Spin-parity (J^{π}) selection rules for β-decays designate the decays, wherein $\Delta J = 0$ or 1, $\Delta\pi$ = no, as 'allowed'. Experiments usually list 'log ft' value for each β branch. A global 'Review of log ft values in β-decay'[1] arrived at log ft = 6.0 (1.0), by fitting data for over a thousand odd-A allowed decays from all across the periodic table. Accordingly, allowed decays with log ft > 7.0 may be termed as 'highly hindered'. A survey of experimental log ft values [1] related to just 15 mass chains with Z = 60 – 74 reveals that 104 listed values therein fall in this category. We have taken up investigations seeking physical explanation for such high hindrances. Since the energy levels in deformed nuclei are labeled by $J^{\pi}K$, inclusion of the rotational band quantum number K brings in the K-selection rule which limits $\Delta K \leq \Delta I$. The K-forbidden allowed β-transitions in heavy (A>228) nuclei have been investigated earlier in detail by Sood et al. [2].

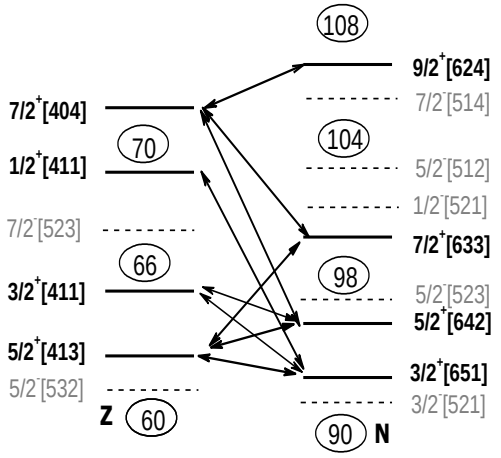

Fig. 1: Filling order of Single Particle Nilsson orbitals [4] for protons on left and neutrons on right. The connecting lines represents the allowed decays. For details see text.

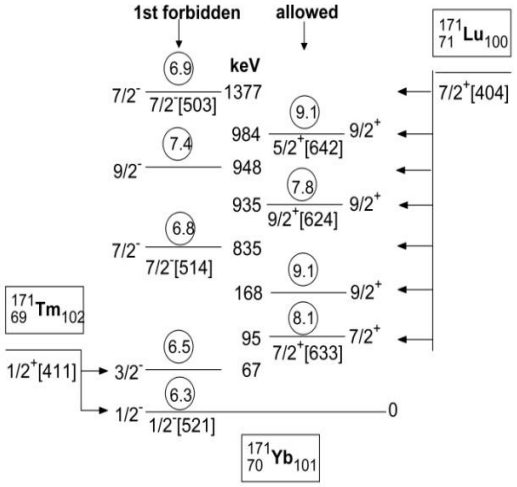

Fig. 2: Energy levels in ^{171}Yb [5] populated through allowed β decays (right) and 1f decays (left). Circled numbers are respective log ft values.

Presently we focus on another category of highly-hindered β-transitions in medium-heavy (A = 150-190) region, wherein $\Delta K \leq \Delta I$, and as such, K- forbiddenness is not operative. For this category, one invokes additional selection rules involving the asymptotic quantum numbers $[Nn_3\Lambda]$. In this report, we examine the validity of the remark by Mottelson and Nilsson [3] that "selection rule associated with N should be somewhat stronger than the rules connected with other asymptotic quantum numbers''.

First we look at the physically admissible Nilsson (1qp) configuration space in this region. In Fig. 1, we sketch the approximate filling order [4] of the 1qp Nilsson orbitals for protons (on the left) and neutrons (on the right). A very interesting, and rather unique, feature is revealed in this figure, i.e., whereas all the negative parity (NP) orbitals for both the protons and neutrons

Table 1: Log *ft* values [5] for ΔN=2 allowed β-transitions in Odd-A medium heavy nuclei.

Initial State		Decay mode	log *ft*	Final State		
$^{A}_{Z}X_{N}$	J^{π} [$Nn_3\Lambda$]			$^{A}_{Z}X_{N}$	E (keV)	J^{π} K[$Nn_3\Lambda$]
$^{155}_{63}Eu_{92}$	$5/2^+$[413]	β^-	7.9	$^{155}_{64}Gd_{91}$	105	$3/2^+3/2$[651]
			7.5		87	$5/2^+3/2$[651]
			8.7		118	$7/2^+3/2$[651]
$^{157}_{63}Eu_{94}$	$5/2^+$[413]	β^-	7.2	$^{157}_{64}Gd_{91}$	64	$5/2^+5/2$[642]
$^{155}_{65}Tb_{90}$	$3/2^+$[411]	ε	7.5	$^{155}_{64}Gd_{91}$	87	$5/2^+3/2$[651]
$^{171}_{71}Lu_{100}$	$7/2^+$[404]	ε	8.1	$^{171}_{70}Yb_{101}$	95	$7/2^+7/2$[633]
			9.1		168	$9/2^+7/2$[633]
$^{173}_{71}Lu_{102}$	$7/2^+$[404]	ε	8.3	$^{173}_{70}Yb_{103}$	351	$7/2^+7/2$[633]
			8.9		413	$9/2^+7/2$[633]
$^{175}_{73}Ta_{102}$	$7/2^+$[404]	ε	8.0	$^{175}_{72}Hf_{103}$	644	$9/2^+9/2$[624]
			>8.7		733	$5/2^+5/2$[642]
			8.5		807	$7/2^+5/2$[642]
$^{183}_{73}Ta_{110}$	$7/2^+$[404]	β^-	7.7	$^{183}_{74}W_{109}$	623	$9/2^+9/2$[624]
$^{169}_{70}Yb_{99}$	$7/2^+$[633]	ε	8.5	$^{169}_{69}Tm_{100}$	316	$7/2^+7/2$[404]
			9.8		433	$9/2^+7/2$[404]
$^{177}_{70}Yb_{107}$	$9/2^+$[624]	β^-	7.2	$^{177}_{71}Yb_{106}$	121	$9/2^+7/2$[404]
			8.2		269	$11/2^+7/2$[404]
$^{181}_{74}W_{107}$	$9/2^+$[624]	ε	7.8	$^{181}_{73}Ta_{108}$	136	$9/2^+7/2$[404]

have N=5, all the positive parity (PP) orbitals for protons have N=4 and for neutrons they have N=6. Thus all the 'allowed' β-transitions connecting PP states (shown by connecting arrows in Fig. 1) have ΔN=2, and hence data therefore can yield a measure of N-forbiddenness.

As an illustration of our procedure and analysis, we present, in Fig.2, a few β-populated [both PP and NN] states in $^{171}_{70}Yb_{101}$. The data shown in Fig. 2 reveal that the 4 'allowed' β-transitions have log ft $\geq$ 7.8 whereas the 5 'First –forbidden' (1f) transitions have log ft $\leq$ 7.4, leading us to make a surprising observation that '***ΔN=2 allowed β-transitions are even more forbidden than the normally labeled forbidden ones***'.

A set of ΔN=2 allowed β- transitions in odd-mass nuclei across the specified region is presented Table 1. The data in this table is just a representative (not an exhaustive) set. We encounter numerous similar cases of N forbidden allowed transitions for both the odd-A and the even-A decays of nuclei in this region.

References

[1] B. Singh et al., Nucl. Data Sheets **84** (1998) 487.

[2] P. C. Sood et al., Eur. Phys. J. A **39** (2009) 101.

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[4] A. K. Jain et al., Rev. Mod. Phys. **62** (1990) 393.

[5] ENSDF & XUNDL data files (August 2015 version) from NNDC, Brookhaven, USA.