Forbidden, but Fast, β-transitions in lighter rare-earth nuclei

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Experimentally deduced log ft values in β-decays are commonly used to determine the allowed or forbidden character of such decays, and therefrom to assign spin-parities J^{π} to the involved states. A comprehensive global compilation of evaluated log ft values [1] arrived at their following inter-relationship with ΔJ^{π} in such decays:

	ΔJ	Δπ	log ft	
Allowed β:	0,1	no	6.2 (1.1)	
1st forbidden β:	0,1	yes	7.3 (1.0)	….. (1)

wherein the quoted averaged log ft values refer to the centroid with the respective width listed in parentheses for each category. An earlier exhaustive survey of all the available allowed and first forbidden (1f) decays in heavy (A ≥ 228) nuclei by Sood et al. [2] had surprisingly yielded a very similar distribution of log ft values for both categories in contrast to (1) above; this observation led them to conclude that 'the allowed and 1f transitions of this region cannot be distinguished on the basis of log ft values'. Presently we explore the region of medium-heavy deformed nuclei to look for occurrence, or otherwise, of such a feature therein.

For our analysis, we restrict ourselves only to the evaluated data wherein the observed log ft values for 1f decays are less than one width apart from their central global value, i.e., log ft ≤ 6.3 as per eq. (1) above. Such forbidden transitions can thus be termed as 'Fast' since, though forbidden, their transition rate overlaps considerably with the 'fast' allowed (log ft < 6.2) transition rate. They are also considerably faster than what had been earlier (log ft = 6.5 ± 0.5) termed first forbidden fast (1ff) for heavy nuclei [3]. For our log ft data base, we presently use the global compilation [1].

Our survey has identified over 30 'fast' (log ft ≤ 6.3) 1f transitions in the mass range A=157-167. Strikingly, 19 such cases have been found in just 6 odd-A chains in the A=157(2)167 domain. Following the procedure adopted in the earlier similar study for heavy nuclei [3], we have analysed these transitions by examining the structures of involved states in terms of their Nilsson orbitals $\Omega[Nn_3\Lambda]$ composition, and to identify the underlying transformation in each case with a view to derive some guidelines for such occurrences.

Illustrative examples from our analysis are presented in Table 1, wherein cases with the same underlying transformation, listed as a caption for each subset, are grouped together. By examining the change in each of the asymptotic quantum numbers $\Omega^{\pi}[Nn_3\Lambda]$, our preliminary conclusion appears to point to the following selection rule for these Fast transitions

1ff (Δπ=yes): $\Delta N=(\Delta n_3+\Delta\Lambda) = 1$
Allowed fast: $\Delta N=(\Delta n_3+\Delta\Lambda) = 0$ …….(2)

From the limited cases listed in Table 1, we find spin-flip (ΔΣ=yes) only for the first subset, namely for p:3/2[521↑] ↔ p:1/2[411↓] transitions; in all other listed transformations, we find ΔΣ= no.

It is interesting to point out that Nuclear Data Sheets (NDS) evaluators follow the explicitly enunciated 'strong rule' as the bases for spin-parity assignments that: "if log ft < 5.9, the β transition is allowed: ΔJ=0 or 1, Δπ=no." All the β transitions identified by us have log ft = 5.9± 0.4, with Δπ=yes, and thus provide multiple instances of violation of their 'strong rule'. At a more fundamental level, we may remark that parity is not a good quantum number for reflection-asymmetric shapes, and consequently the distinction between the allowed and the 1f transitions disappears for such shapes. Further implications of this phenomenon are under investigation.

References

[1] B. Singh et al., Nucl. Data Sheets 84 (1998) 487.
[2] P. C. Sood et al., Phys. Rev. C69 (2004) 057303.
[3] P. C. Sood et al., J. Phys. G29 (2003) 1237.

Table 1: Illustrative instances of first-forbidden FAST (log ft ≤ 6.3) beta transitions in medium heavy nuclei. For parent states $I^\pi = K^\pi$ in all cases; for daughter states $I^\pi = K^\pi$ unless listed otherwise.

Initial State							Final State	
${}^A_ZX_N$	I^π	Config	β^-/ε	Log ft	${}^A_ZX_N$	E_x(keV)	I^π K	Config
				(a) n: 3/2[521] ↔ p: 1/2[411]				
${}^{159}_{68}Er_{91}$	$3/2^-$	3/2[521]	ε	6.3	${}^{159}_{67}Ho_{92}$	205.9	$1/2^+$	1/2[411]
${}^{159}_{68}Er_{91}$	$3/2^-$	3/2[521]	ε	6.3	${}^{159}_{67}Ho_{92}$	212.8	$3/2^+$ 1/2	1/2[411]
${}^{160}_{70}Yb_{90}$	0^+	p:1/2[411]^2	ε	6.1	${}^{160}_{69}Tm_{91}$	0.0	1^-	{ 3/2[521] 1/2[411]
${}^{162}_{70}Yb_{92}$	0^+	p:1/2[411]^2	ε	5.5	${}^{162}_{69}Tm_{93}$	0.0	1^-	{ 3/2[521] 1/2[411]
${}^{163}_{70}Yb_{93}$	$3/2^-$	3/2[521]	ε	5.6	${}^{163}_{69}Tm_{94}$	0.0	$1/2^+$	1/2[411]
${}^{163}_{70}Yb_{93}$	$3/2^-$	3/2[521]	ε	5.7	${}^{163}_{69}Tm_{94}$	13.5	$3/2^+$ 1/2	1/2[411]
				(b) n: 3/2[521] ↔ p: 3/2[411]				
${}^{163}_{65}Tb_{98}$	$3/2^+$	3/2[411]	β^-	6.3	${}^{163}_{66}Dy_{97}$	421.8	$3/2^-$	3/2[521]
				(c) n: 3/2[521] ↔ p: 5/2[402]				
${}^{159}_{69}Tm_{90}$	$5/2^+$	5/2[402]	ε	6.0	${}^{159}_{68}Er_{91}$	0.0	$3/2^-$	3/2[521]
${}^{159}_{69}Tm_{90}$	$5/2^+$	5/2[402]	ε	6.0	${}^{159}_{68}Er_{91}$	59.2	$5/2^-$ 3/2	3/2[521]
${}^{159}_{69}Tm_{90}$	$5/2^+$	5/2[402]	ε	5.9	${}^{159}_{68}Er_{91}$	144.1	$7/2^-$ 3/2	3/2[521]
				(d) n: 5/2[642] ↔ p: 7/2[523]				
${}^{161}_{67}Ho_{94}$	$7/2^-$	7/2[523]	ε	6.3	${}^{161}_{66}Dy_{95}$	43.8	$7/2^+$5/2	5/2[642]
				(e) n: 5/2[523] ↔ p: 5/2[413]				
${}^{161}_{64}Gd_{97}$	$5/2^-$	5/2[523]	β^-	6.22	${}^{161}_{65}Tb_{96}$	314.9	$5/2^+$	5/2[413]
				(f) n: 1/2[521] ↔ p: 1/2[411]				
${}^{168}_{69}Tm_{99}$	3^+	{ 7/2[633] 1/2[411]	ε	6.28	${}^{168}_{68}Er_{100}$	1541.6	3^-	{ 7/2[633] 1/2[521]
${}^{171}_{69}Tm_{102}$	$1/2^+$	1/2[411]	β^-	6.3	${}^{171}_{70}Yb_{101}$	0.0	$1/2^-$	1/2[521]
${}^{172}_{68}Er_{104}$	0^+	n:1/2[521]^2	β^-	5.89	${}^{172}_{69}Tm_{103}$	535.1	1^- 0	{ 1/2[521] 1/2[411]
${}^{172}_{69}Tm_{103}$	2^-	{ 5/2[512] 1/2[411]	β^-	6.29	${}^{172}_{70}Yb_{102}$	1608.5	2^+	{ 5/2[512] 1/2[521]
				(g) n: 7/2[633] ↔ p: 7/2[523]				
${}^{165}_{66}Dy_{99}$	$7/2^+$	7/2[633]	β^-	6.19	${}^{165}_{67}Ho_{98}$	0.0	$7/2^-$	7/2[523]
${}^{166}_{66}Dy_{100}$	0^+	n:7/2[633]^2	β^-	5.9	${}^{166}_{67}Ho_{99}$	82.5	1^- 0	{ 7/2[633] 7/2[523]
${}^{168}_{67}Ho_{101}$	3^+	{ 1/2[521] 7/2[523]	$\beta^{-`}$	6.15	${}^{168}_{68}Er_{100}$	1541.3	3^-	{ 1/2[521] 7/2[633]