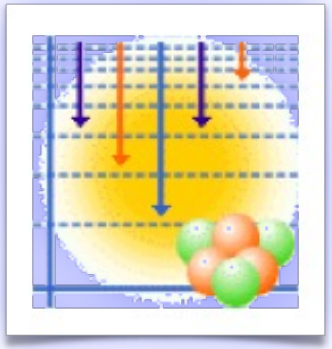
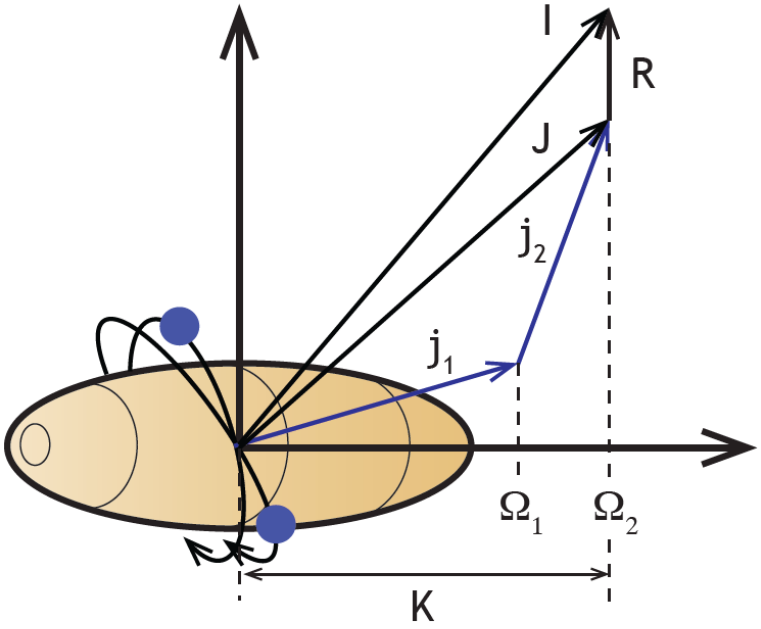
K forbiddenness in beta decay

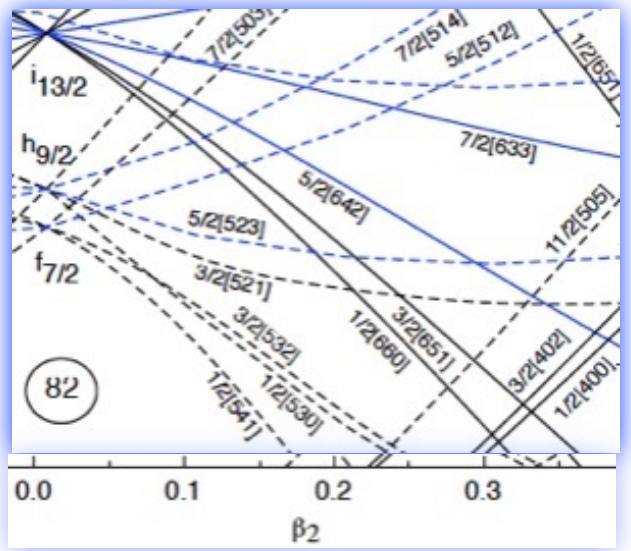
F.G. Kondev
Physics Division, Argonne National Laboratory



USNDP meeting, November 13-15, 2023, BNL

K quantum number & deformation





S.G. Nilsson, Dan. Mat. Fys. Medd. 29 (16) (1955)

deformed nuclei – Nilsson model: $\Omega^{\pi}[Nn_z\Lambda]$; $\Lambda=\Omega \pm 1/2$

G. Alaga, K. Alder, A. Bohr, B.R. Mottelson, Mat. Phys. Medd. Dan. Vid. Selsk. 29, 9 (1955)

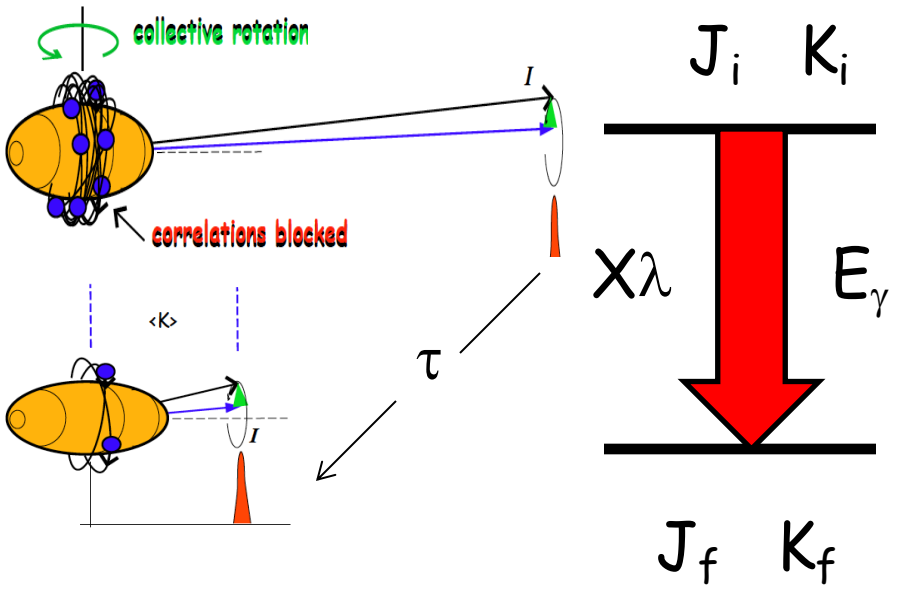
G. Alaga, Phys. Rev. 100 (1955) 432

⇒ each nuclear level in well-deformed nuclei has E, $T_{1/2}$, L, S , J^{π}, and $K^{\pi}(\Omega^{\pi})$

⇒ in most case the band-head (the lowest state) has J=K, BUT …

- due to decoupling & Coriolis interactions -> $J=5/2^-$, $K=1/2^-$ for 1/2[541] ($h_{9/2}$)
- due to residual proton-neutron interactions -> $J=1^-$, $K=0^-$ for isomer in ^{176}Lu

K-hindered decays & K isomers



$$1/\tau \sim E_\gamma^{\,2\lambda+1} \, |\langle \psi_f | \, T \, | \psi_i \rangle|^2$$

- ✓ hindrance $F_w = \tau_\gamma / \tau_W$
- ✓ reduced hindrance $f_\nu = F_w^{\,1/\nu}$

- ✓ transition of multipolarity λ can only change the K projection by at most λ.
- ✓ the shortfall is the degree of "forbiddenness" $\nu = \Delta K - \lambda$.

typically f_ν = 20 – 300, but many exceptions… because of K mixing

Atomic Data and Nuclear Data Tables 103–104 (2015) 50–105

Contents lists available at ScienceDirect

Atomic Data and Nuclear Data Tables

journal homepage: www.elsevier.com/locate/adt

Configurations and hindered decays of K isomers in deformed nuclei with A > 100

F.G. Kondev [a,*], G.D. Dracoulis [b,1], T. Kibédi [b]

IOP Publishing

Reports on Progress in Physics

Rep. Prog. Phys. **79** (2016) 076301 (46pp)

doi:10.1088/0034-4885/79/7/076301

Review

Review of metastable states in heavy nuclei

G D Dracoulis[1,4], P M Walker[2] and F G Kondev[3]

K isomers in atomic nuclei

P.M. Walker[1] and F.G. Kondev[2]

[1]Department of Physics, University of Surrey, Guildford, GU2 7XH, United Kingdom.
[2]Physics Division, Argonne National Laboratory, Lemont, 60439, Illinois, USA.

Eur. Pjys. J. ST, in press

Det Kongelige Danske Videnskabernes Selskab

Matematisk-fysiske Meddelelser, bind **29**, nr. 9

Dan. Mat. Fys. Medd. **29**, no. 9 (1955)

G. ALAGA, K. ALDER, A. BOHR, AND B. R. MOTTELSON

Matematisk-fysiske Skrifter

udgivet af

Det Kongelige Danske Videnskabernes Selskab

Bind **1**, nr. 8

Mat. Fys. Skr. Dan. Vid. Selsk. **1**, no. 8 (1959)

BEN R. MOTTELSON AND SVEN GÖSTA NILSSON

INTRINSIC EXCITATIONS OF NUCLEI WITH STABLE EQUILIBRIUM DEFORMATION

C. J. GALLAGHER

Physics Department, Columbia University, New York

Eur. Phys. J. A **39**, 101–106 (2009)
DOI 10.1140/epja/i2008-10687-1

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article – Theoretical Physics

K-forbidden allowed β transitions in heavy nuclei

P.C. Sood[1,a], O.S.K.S. Sastri[2], and R.K. Jain[2]

IOP Publishing — Journal of Physics G: Nuclear and Particle Physics

J. Phys. G: Nucl. Part. Phys. **44** (2017) 065101 (8pp) — https://doi.org/10.1088/1361-6471/aa65f0

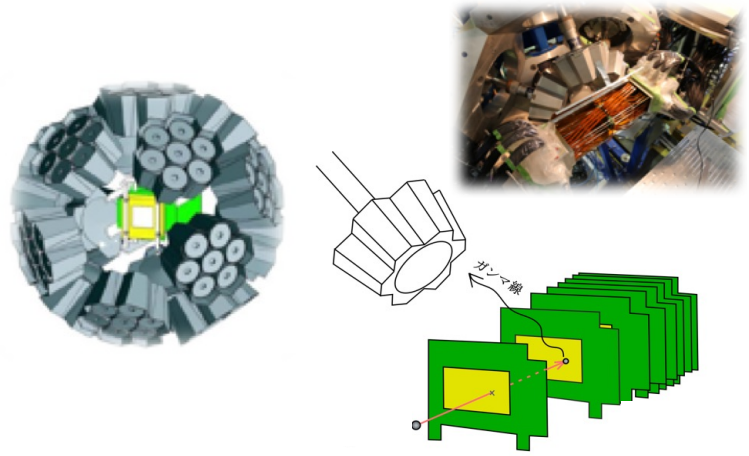
K-hindered beta and gamma transition rates in deformed nuclei and the halflife of $^{180}Ta^{m}$

H Ejiri and T Shima

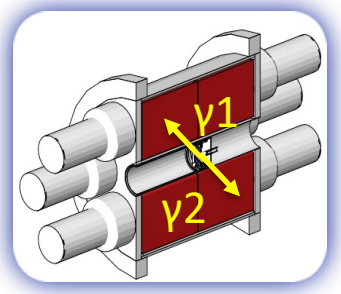
$$B_{if} \simeq \frac{|M_{if}|^2}{2J_i+1} = Const\,\frac{I_{\beta_{if}}}{f(Z,Q_\beta - E_f)\times T_{1/2}} = Const\,\frac{1}{ft}$$

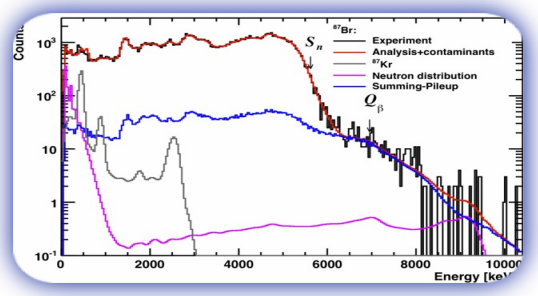
⇒ β–decay spectra are not discrete

- I_β are not directly measured

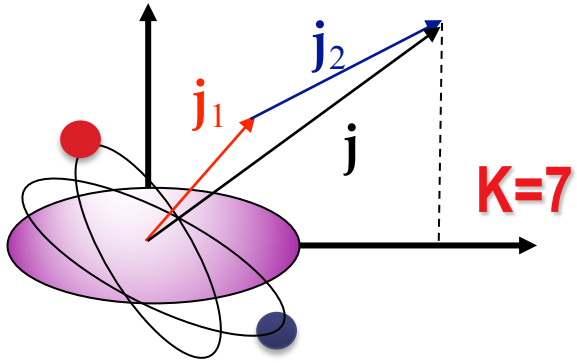


- discrete γ-ray spectroscopy



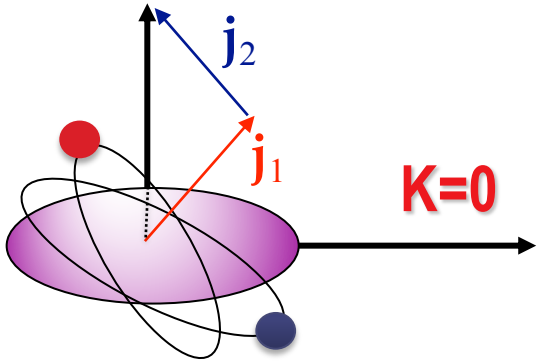


- total absorption γ-ray spectroscopy (TAGS)



^{176}Lu

$\pi 7/2^+[404]$ $\nu 7/2^-[514]$



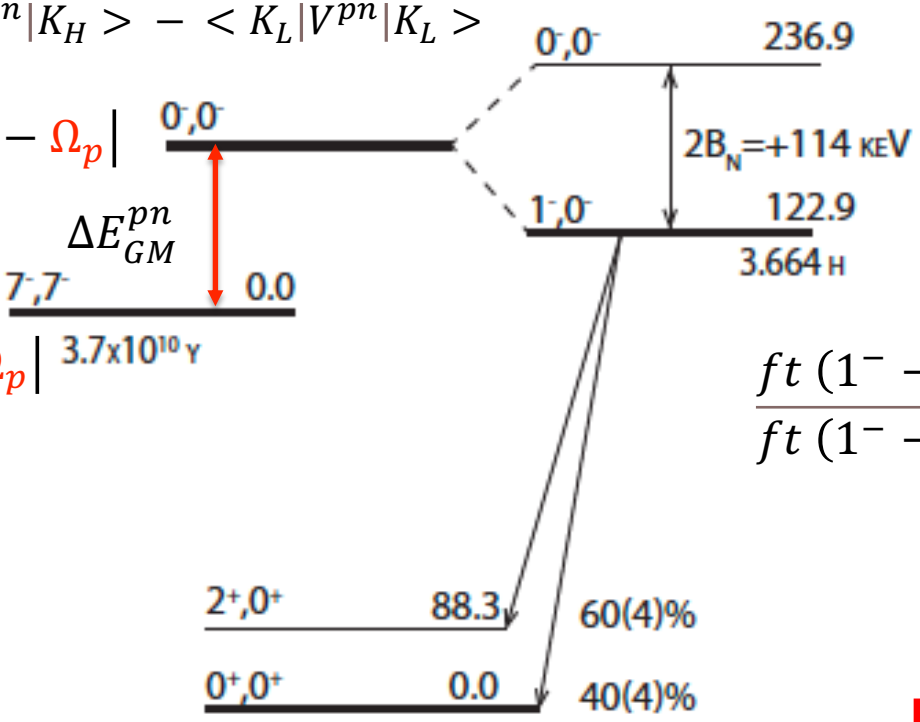
$$\Delta E_{GM}^{pn} = E_{K_H}^{pn} - E_{K_L}^{pn} = < K_H|V^{pn}|K_H > - < K_L|V^{pn}|K_L >$$

C.J. Gallagher and S.A. Moszkowski, Phys. Rev. 111 (1958) 1282

$|\Omega_n - \Omega_p|$

$|\Omega_n + \Omega_p|$

ΔE_{GM}^{pn}



$$B_N = < K = 0|V^{pn}|K = 0 >$$

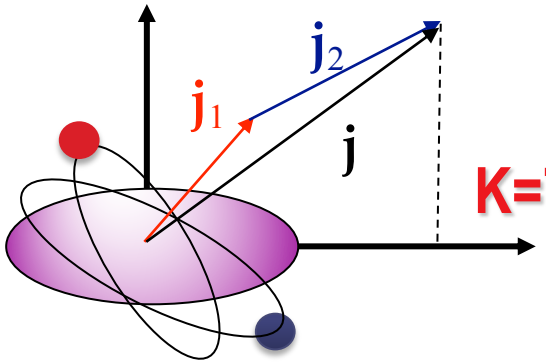
N.D. Newby, Phys. Rev. 125 (1962) 2036

$$\frac{ft\,(1^- \to 2^+)}{ft\,(1^- \to 0^+)} = \begin{cases} \left(\frac{\langle 1010|00\rangle}{\langle 1010|20\rangle}\right)^2 = 0.5 & \text{K=0} \\ \left(\frac{\langle 111-1|00\rangle}{\langle 111-1|20\rangle}\right)^2 = 2.0 & \text{K=1} \end{cases}$$

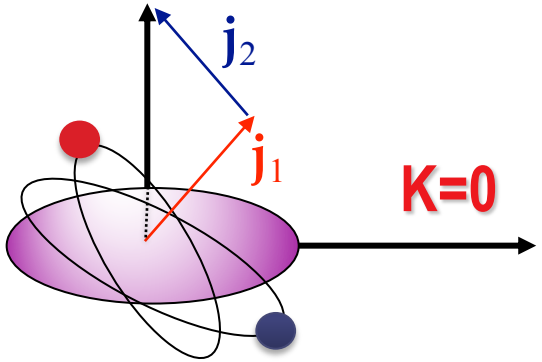
$$\frac{ft\,(1^- \to 2^+)}{ft\,(1^- \to 0^+)}\ \text{EXP}\sim 0.56$$

I.Rezanka et al., Izvest. Akad. Nauk SSSR, Ser. Fiz. 26, 127 (1962)

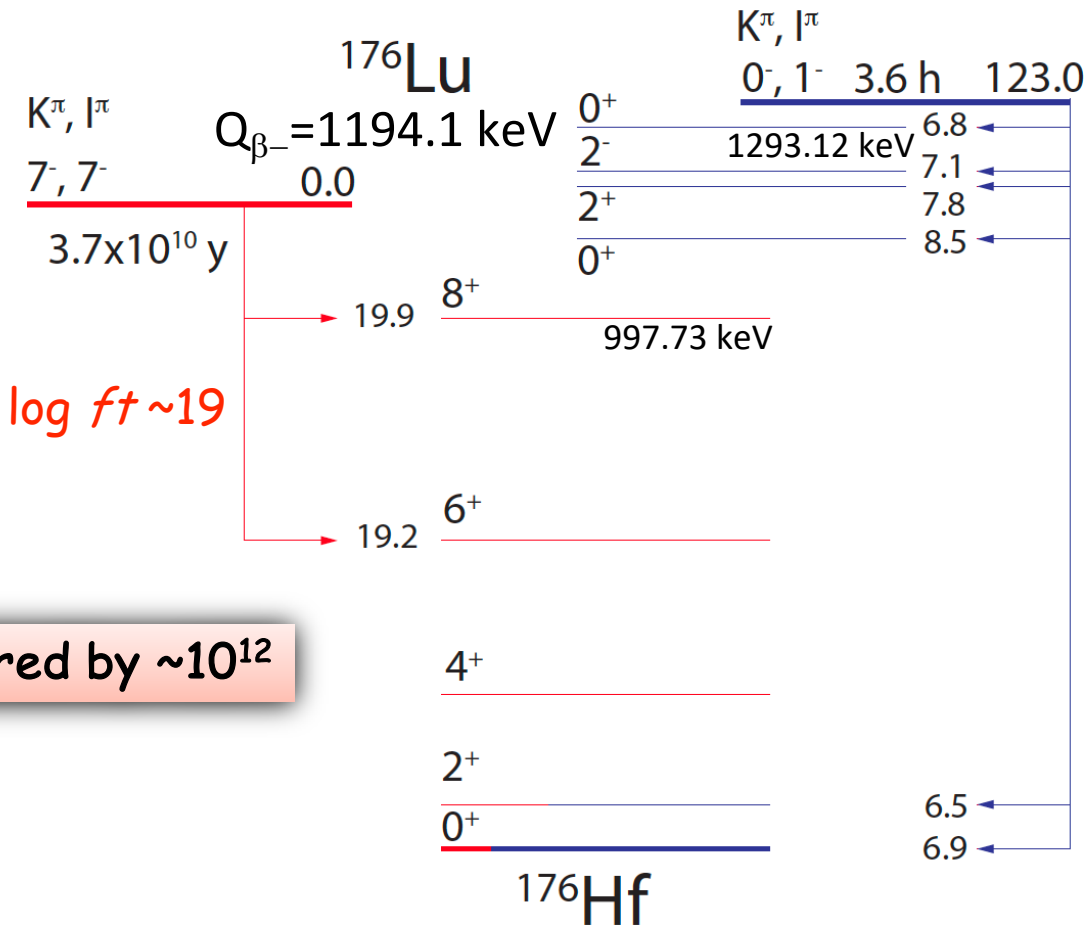
^{176}Hf



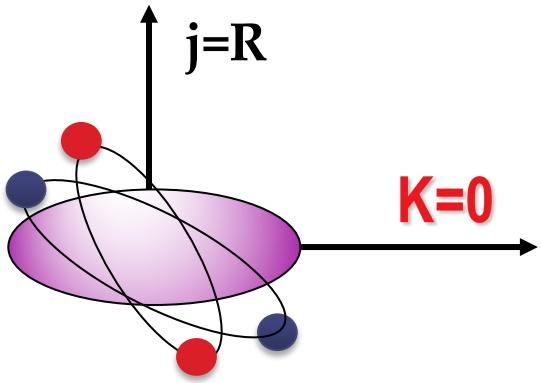
^{176}Lu



$\pi 7/2^+[404]\ \nu 7/2^-[514]$



hindered by ~10^{12}

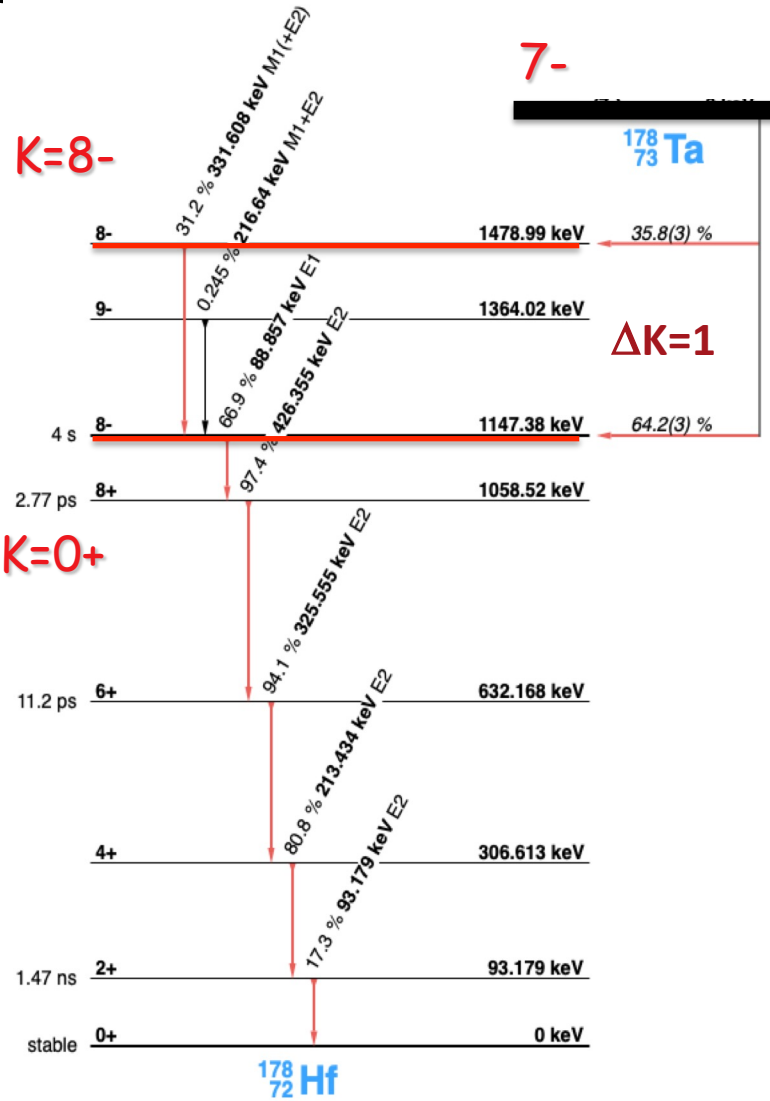


^{178}Ta

Q_{EC}=1837 keV

$\nu 7/2^-[514]$ $\pi 7/2^+[404]$

$|\Omega_n + \Omega_p|$



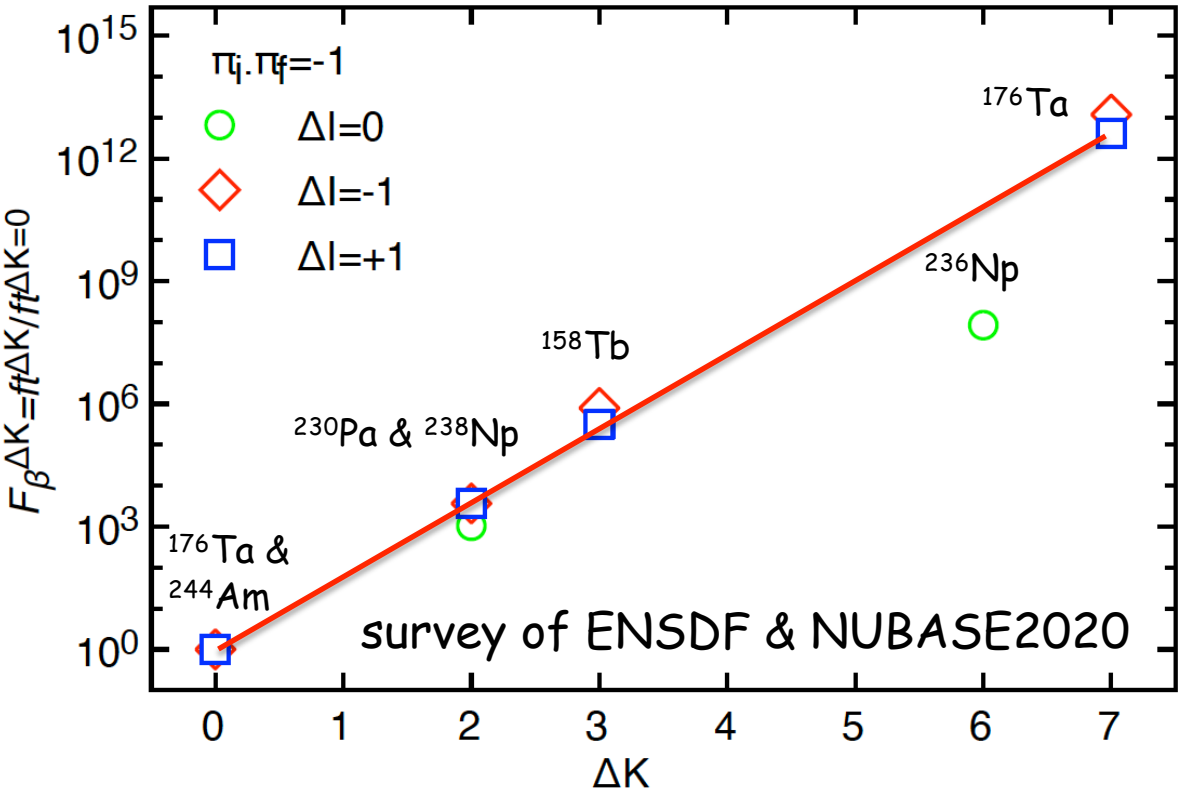
$\pi 9/2^-[514]$ $\pi 7/2^+[404]$

log *ft* =4.8 spin flip Au

$\nu 7/2[514]$ -> $\pi 9/2[514]$

Quantifying the K forbiddenness

- relatively simple decay schemes – low $Q_{\beta-}$
- known $J\pi$ – directly measured
- known $J\pi$ for the daughter levels
- evaluated $T_{1/2}$ and BR



$$F_\beta^{\Delta K} = \frac{ft^{\Delta K}}{ft^{\Delta K=0}}$$

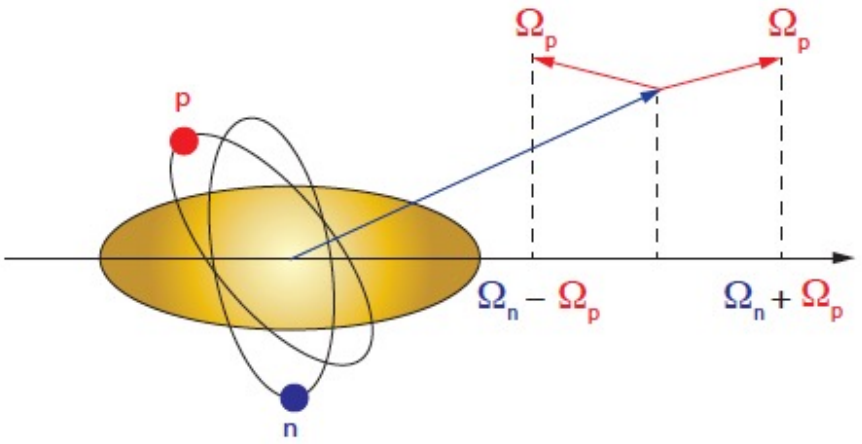
$$F_\beta^{\Delta K} = 10^{(1.9\times\Delta K)}$$

$$\log ft^{\Delta K} = 1.9\times\Delta K + \log ft^{\Delta K=0}$$

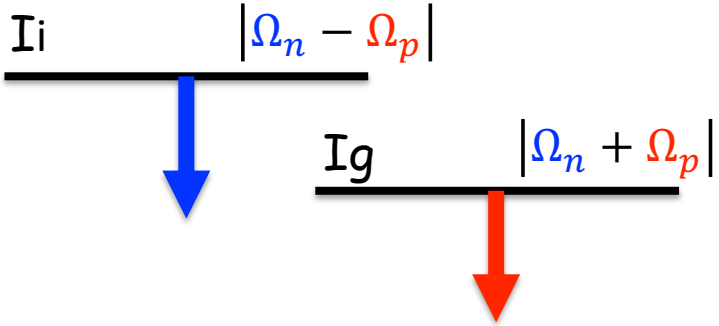
for 4+ to 4+, ΔK=4 -> log *ft*~14

P.M. Walker & F.G. Kondev, Eur. Phys. J., in press

Spin-trap isomers in deformed odd-odd nuclei



$$\frac{1}{\tau_\gamma} \propto \Delta E^{2\lambda+1} \langle \psi_i | T | \psi_g \rangle^2$$



⇒ high Ω orbitals near both the proton & neutron Fermi levels

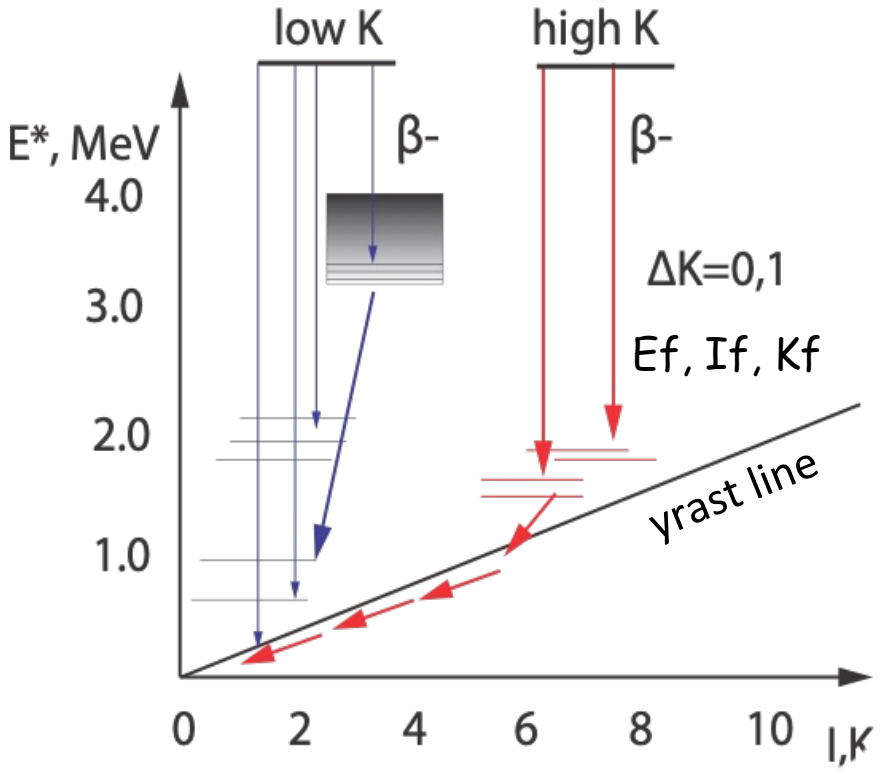
⇒ states populated in the daughter nucleus

- ΔI=0, +/-1 but also ΔK=0, +/-1
- related structure – Alaga: Ah or Au

⇒ distinctive γ-ray decay pattern

⇒ different beta-decay half-lives

- $\frac{1}{\tau_\beta} \propto (Q_\beta - E_f)^5$



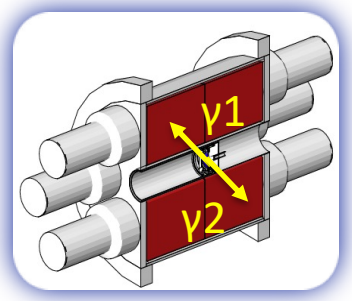
PHYSICAL REVIEW C **103**, 035803 (2021)

β-decay feeding intensity distributions for ^{103,104m}Nb

J. Gombas,[1,2,*] P. A. DeYoung,[1,†] A. Spyrou,[2,3,4,‡] A. C. Dombos,[2,3,4] A. Algora,[5,6] T. Baumann,[3] B. Crider,[3] J. Engel,[7] T. Ginter,[3] E. Kwan,[3] S. N. Liddick,[3,4,8] S. Lyons,[3,4,§] F. Naqvi,[3,4] E. M. Ney,[7] J. Pereira,[3,4] C. Prokop,[3,8] W. Ong,[3,2,4] S. Quinn,[2,3,4] D. P. Scriven,[2] A. Simon,[9] and C. Sumithrarachchi[3]

TAGS measurement using SUN at NSCL/MSU

- ^{104m}Nb is associated with 0.9 s β-decaying state
- no decay scheme was established – based on ENSDF



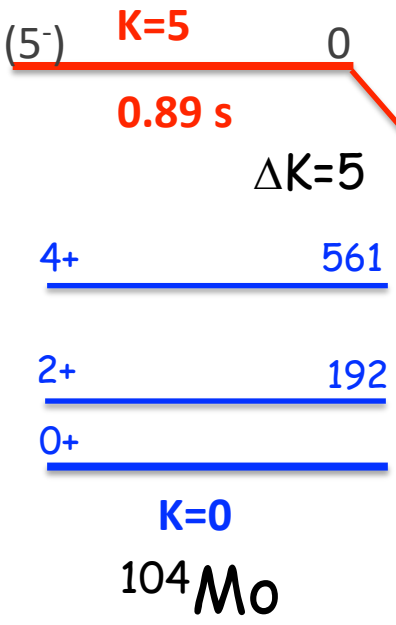


TABLE III. $I_\beta(E)$ for ^{104m}Nb. All intensity values that were below 10^{-3}% were set to 0.

	Energy (keV)	Intensity (%)	Error (±)	Energy (keV)		
0+	0	5.6	1.3	3050		
	192	0		3130		
4+	561	2.9	0.6	3210	1.4	0.4
	812	2.2	0.7	3290	0	
	886	0		3370	0	
	1028	0		3450	0	
	1080	0		3530	0	
	1215	0		3630	0.87	0.14
	1275	0.02	0.06	3730	0	
	1469	0.4	0.3	3830	0	
	1475	1.7	0.4	3930	0	
	1545	0		4030	1.65	0.23
	1583	1.9	0.3	4130	0.0	0.3
	1607	0		4230	3.4	0.5
	1611	0		4330	0.00	0.21
	1624	0.3	0.3	4430	0	
	1790	1.0	0.3	4530	0.00	0.08
				4730	2.3	0.3
			1.5	4930	0.84	0.21
				5130	0.40	0.11
			1.5	5330	1.0	0.3
	2671	1.3	1.0	5530	0.7	0.3
	2685	4.6	0.7	5730	0.8	0.3
	2792	3.6	0.8	5930	0.6	0.5
	2888	0		6030	0.02	0.07
	2890	3.9	0.6	6530	1.6	0.3
	2970	7.4	1.1	7030	2.2	0.5

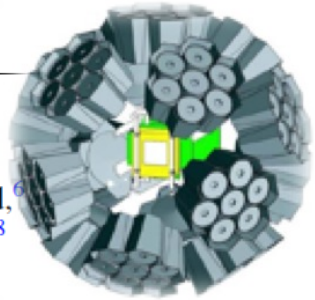
log *ft* (exp)=6.4, but 5⁻ to 0⁺, ΔJ=5 transition (5F) & ΔK=5 forbidden

5⁻ to 4⁺; ΔJ=1 1F with log *ft* (exp)=7.4, but log *ft* ~ 16 for ΔK=5 forbidden

PHYSICAL REVIEW C **103**, 024323 (2021)

Ground-state and decay properties of neutron-rich ^{106}Nb

A. J. Mitchell,[1,*] R. Orford,[2,3,†] G. J. Lane,[1] C. J. Lister,[4] P. Copp,[4,‡] J. A. Clark,[3] G. Savard,[3,5] J. M. Allmond,[6] A. D. Ayangeakaa,[7,8] S. Bottoni,[3,§] M. P. Carpenter,[3] P. Chowdhury,[4] D. A. Gorelov,[3,9] R. V. F. Janssens,[7,8] F. G. Kondev,[3] U. Patel,[1,‖] D. Seweryniak,[3] M. L. Smith,[1,¶] Y. Y. Zhong,[1] and S. Zhu[3,#]



^{106}Nb

$(4^-$ or $5^+)$

J> 3 by the authors

1.097 (21) s

Q_{β^-}=9925 (9) keV

$\pi 3/2[301]\ \nu 5/2[413]$, K=4

$\pi 5/2[422]\ \nu 5/2[413]$, K=5

ΔK=4 or 5

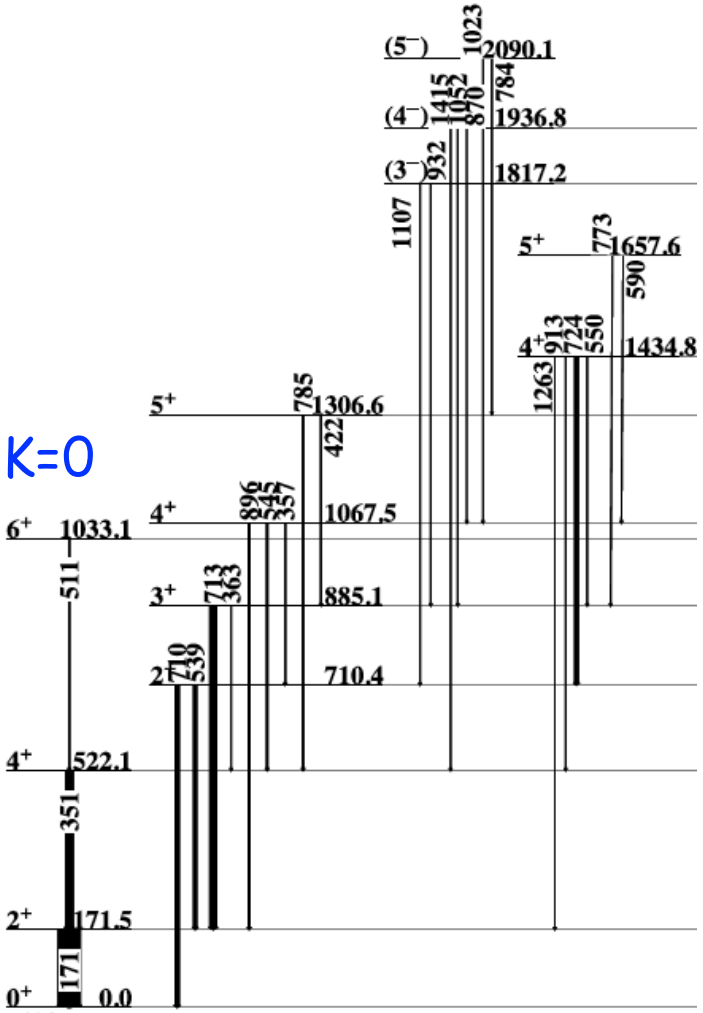
log *ft* Iβ⁻ K=0

7.2 1.6(1)%

6.4 12.1(8)%

10(3)%

^{106}Mo



⇒ data indicate 2 beta-decaying states

⇒ log *ft* ~ 14 or 16 for ΔK=4 or 5