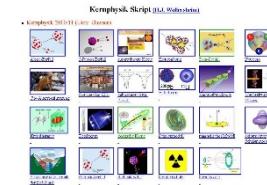


Outline: Nuclear rotation of odd-even nuclei

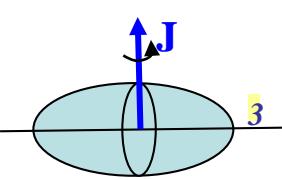
Lecturer: Hans-Jürgen Wollersheim

e-mail: h.j.wollersheim@gsi.de

web-page: <https://web-docs.gsi.de/~wolle/> and click on

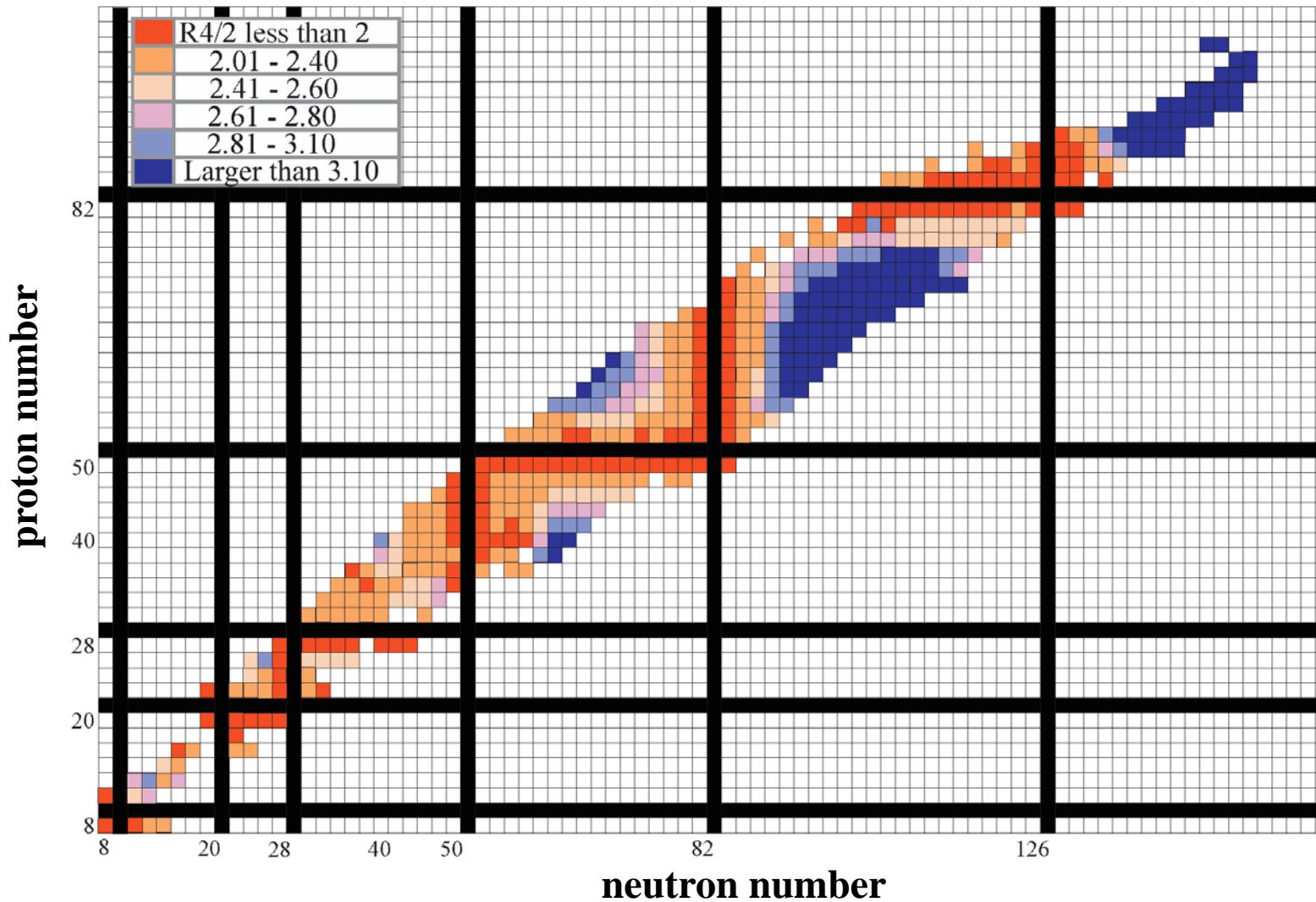


1. particle-rotor model
2. Euler angles
3. Example: ^{181}Ta
4. reduced transition probabilities



Broad perspective on structural evolution:

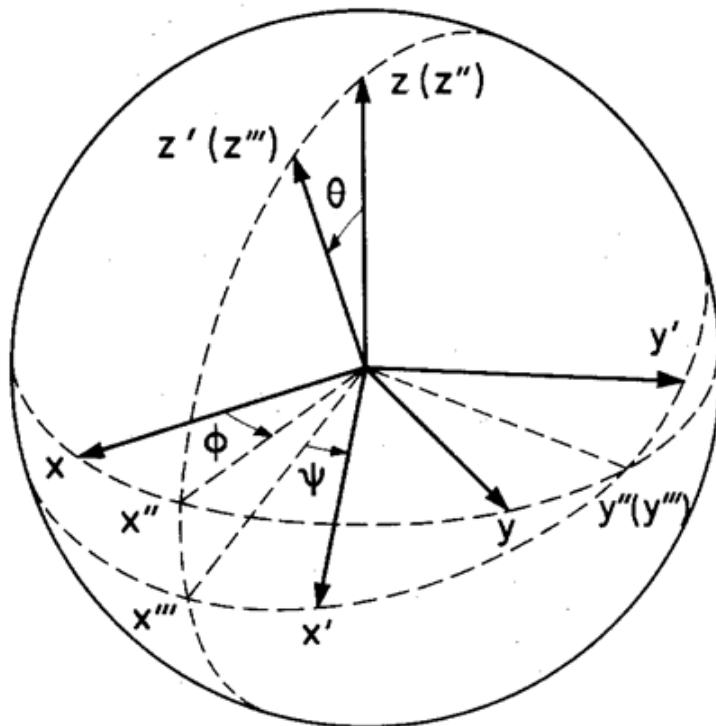
$$R_{4/2} = \frac{E(4_1^+)}{E(2_1^+)}$$



for even-even nuclei

The Euler angles

- It is important to recognize that for nuclei the intrinsic reference frame can have any orientation with respect to the lab reference frame as we can hardly control orientation of nuclei (although it is possible in some cases).
- One way to specify the mutual orientation of two reference frames of the common origin is to use Euler angles.



(x, y, z) axes of lab frame
(1,2,3) axes of intrinsic frame

- The rotation from (x,y,z) to (x',y',z') can be decomposed into three parts: a rotation by ϕ about the z axis to (x'', y'', z'') , a rotation of θ about the new y axis (y'') to (x'', y'', z'') , and finally a rotation of ψ about the new z axis (z''') .

Quantization

states : $|I, M, K\rangle$

laboratory axes : $[J_x, J_y] = i \cdot \hbar \cdot J_z$ and cyclic permutations

$$[J^2, J_k] = 0 \quad k = x, y, z$$

quantum numbers : $J_z \rightarrow \hbar \cdot M \quad J^2 \rightarrow \hbar^2 \cdot I(I + 1)$

body fixed axes : $[J_1, J_2] = i \cdot \hbar \cdot J_3$ and cyclic permutations

$$[J^2, J_i] = 0 \quad i = 1, 2, 3 \quad [J_z, J_3] = 0$$

quantum numbers : $J_3 \rightarrow \hbar \cdot K \quad J^2 \rightarrow \hbar^2 \cdot I(I + 1)$

Quantization

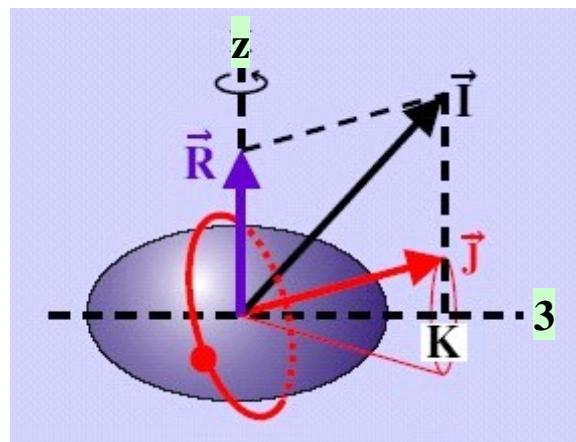
eigenstates: $| I, M, K >$

probability amplitude

for orientation of rotor: $\langle \psi, \theta, \phi | I, M, K \rangle = \left(\frac{2I+1}{8\pi^2} \right)^{1/2} D_{MK}^I(\psi, \theta, \phi)$

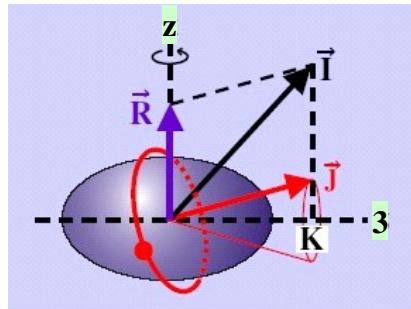
Wigner D – function

$$D_{MK}^I(\psi, \theta, \phi) = e^{iM\psi} d_{MK}^I(\theta) e^{iK\phi}$$





Rotational motion of a deformed nucleus



$$H_{rot} = \sum_{i=1}^3 \frac{\hat{R}_i^2}{2 \cdot \mathfrak{I}_i} = \frac{(\hat{R}^2 - \hat{R}_3^2)}{2 \cdot \mathfrak{I}_1} + \cancel{\frac{\hat{R}_3^2}{2 \cdot \mathfrak{I}_3}}$$

$\mathfrak{I}_1 = \mathfrak{I}_2$

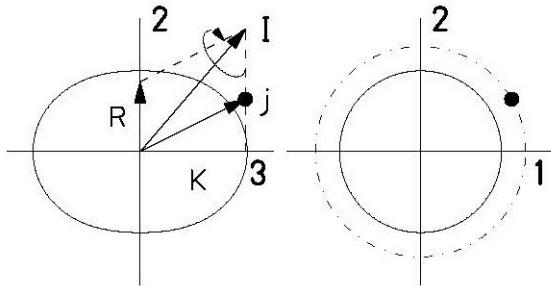
The nucleus does not have an orientation degree of freedom with respect to the symmetry axis

States with projections K and $-K$ are degenerated

$$\Psi_{IMK} = \left(\frac{2 \cdot I + 1}{16 \cdot \pi^2} \right)^{1/2} \cdot [D_{MK}^I \cdot \chi_K + (-1)^{I-K} D_{M-K}^I \cdot \chi_{-K}]$$

Particle-rotor model

K+4
K+3
K+2
K+1
K



$$H_{rot} = \sum_{i=1}^3 \frac{\hat{R}_i^2}{2 \cdot \mathfrak{J}_i} = \frac{(\hat{R}^2 - \hat{R}_3^2)}{2 \cdot \mathfrak{J}_1} + \cancel{\frac{\hat{R}_3^2}{2 \cdot \mathfrak{J}_3}}$$

$\mathfrak{J}_1 = \mathfrak{J}_2$

The nucleus does not have an orientation degree of freedom with respect to the symmetry axis

with $\vec{R} = \vec{I} - \vec{j}$

$$H_{rot} = \frac{\hbar^2}{2\mathfrak{J}_0} \{(I_1 - j_1)^2 + (I_2 - j_2)^2\}$$

$$H_{rot} = \frac{\hbar^2}{2\mathfrak{J}_0} (I^2 - I_3^2) + \frac{\hbar^2}{2\mathfrak{J}_0} (j_1^2 + j_2^2 - j_3^2) - \frac{\hbar^2}{2\mathfrak{J}_0} (j_+ I_- + j_- I_+)$$

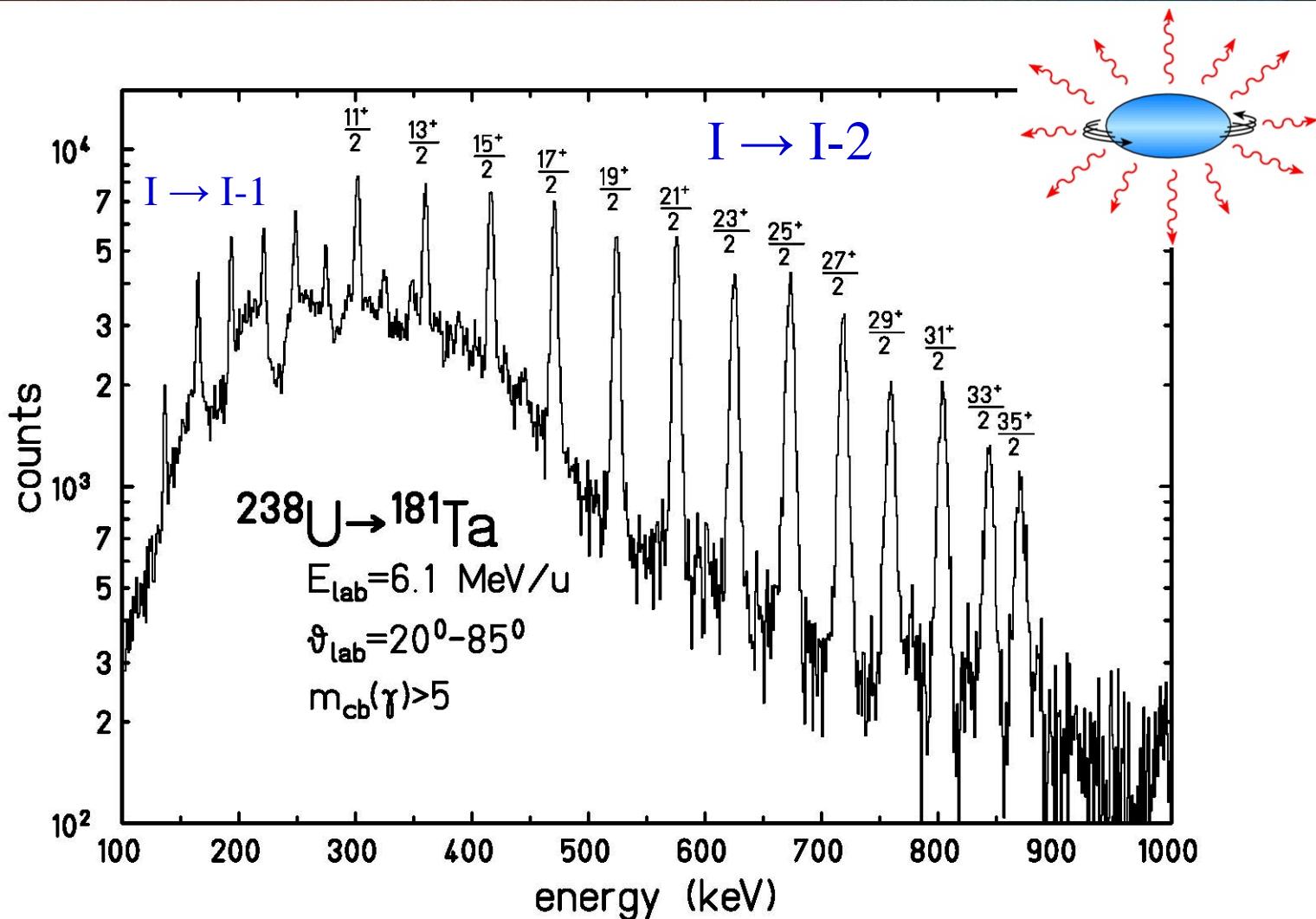
$$I_{\pm} = I_1 \pm i \cdot I_2 \quad j_{\pm} = j_1 \pm i \cdot j_2$$

$$E_K(I) = \epsilon_K + \frac{\hbar^2}{2\mathfrak{J}} [I(I+1) - K^2 + \delta_{K,1/2} \cdot a \cdot (-1)^{I+1/2} (I+1/2)]$$

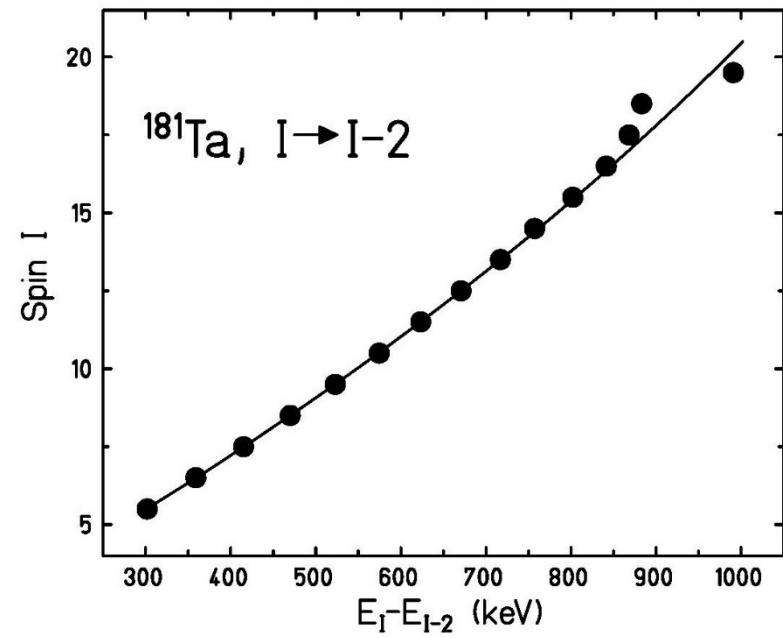
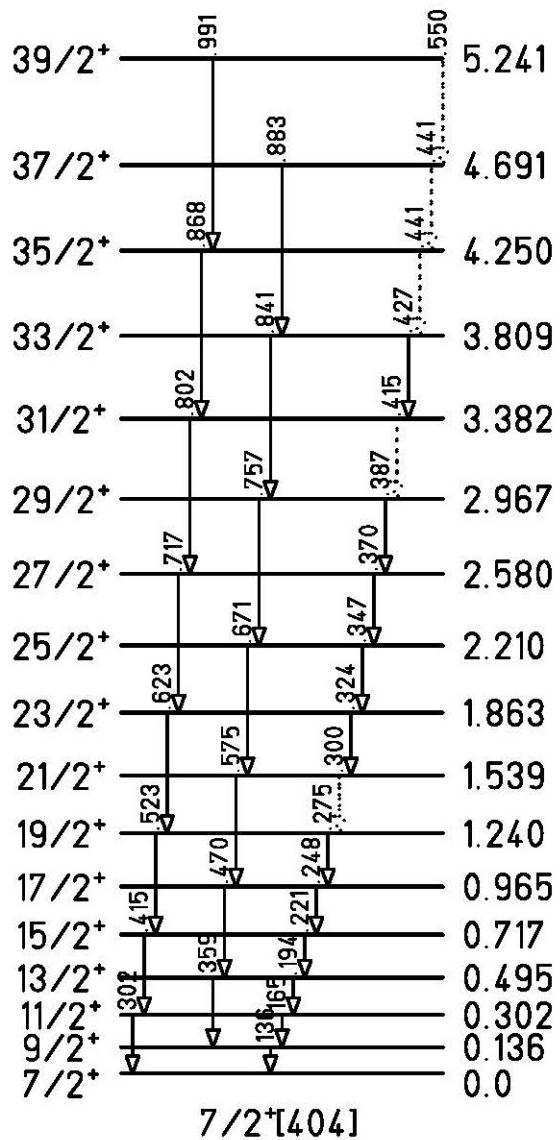
where a is the so-called *decoupling parameter*

γ -rays from a deformed band in ^{181}Ta

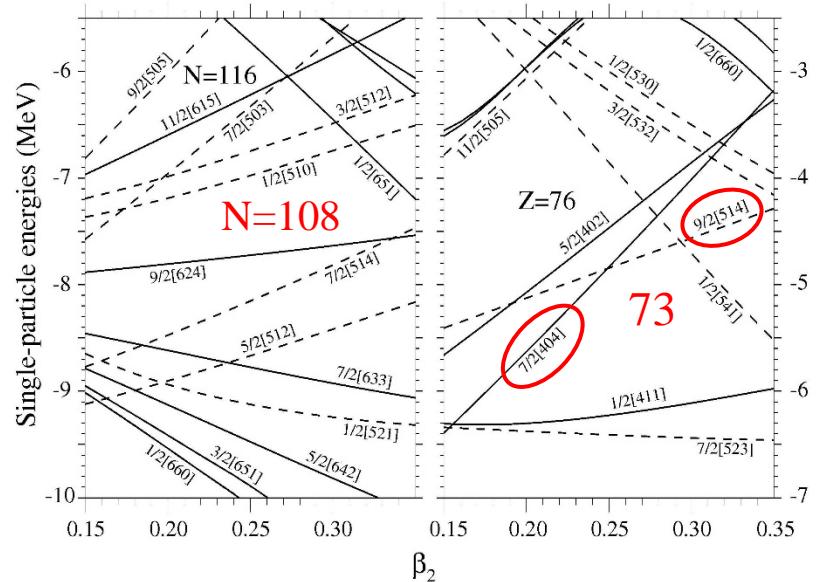
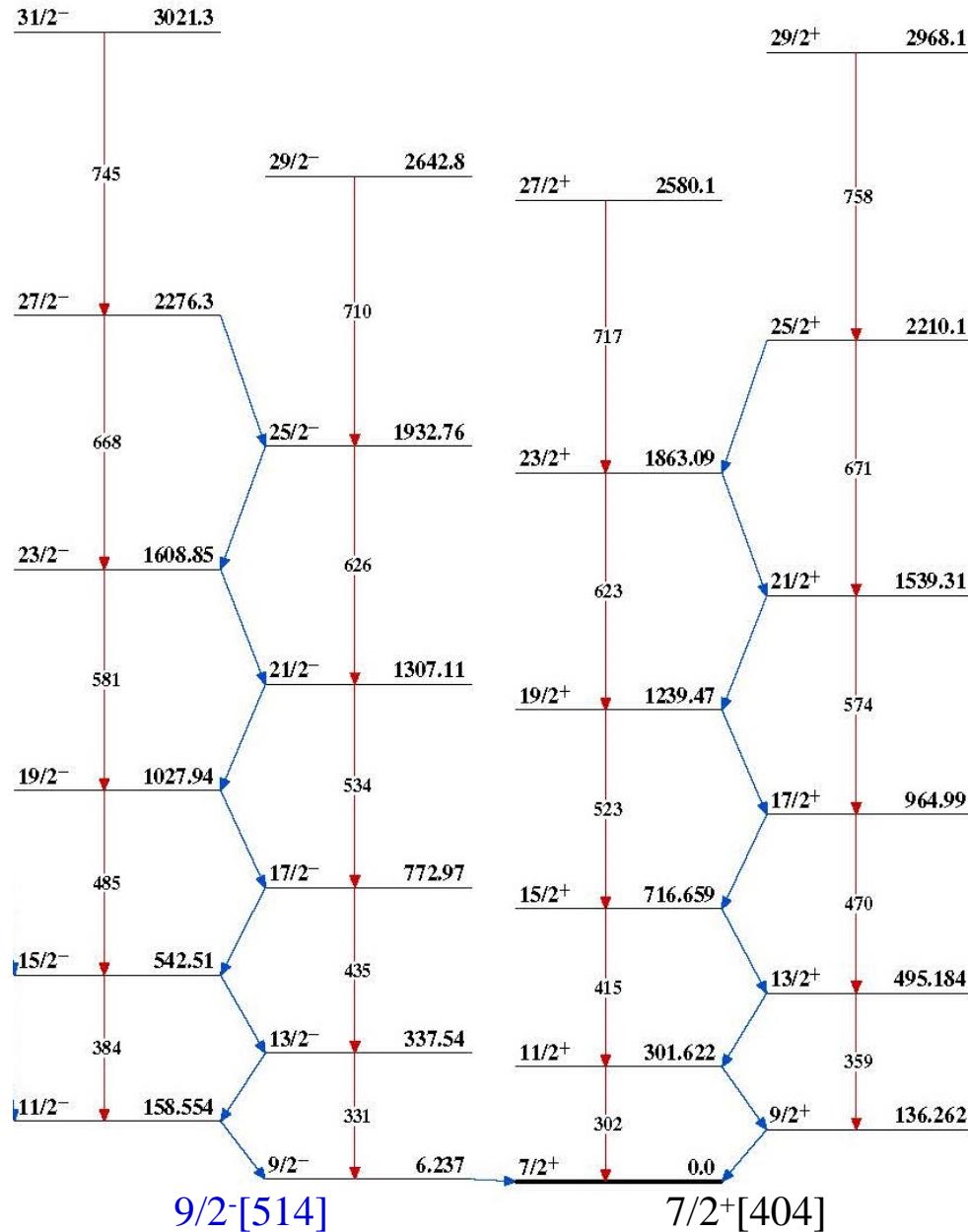
74	W	W158	W159	W160	W161	W162	W163	W164	W165	W166	W167	W168	W169	W170	W171	W172	W173	W174	W175	W176	W177	W178	W179	W180	W181	W182	W183	W184	W185	W186	W187	W188	W189			
	4.22(24)	0.9 ms	7.3 ms	9.1 ms	4.10 ms	1.39 s	0.78 s	5.1 s	1.83 s	0.78 s	1.93 s	0.73 s	1.4 s	2.42 s	2.38 s	7.0 s	6.52 s	3.1 s	25.2 s	2.51 s	3.35 s	21.6 s	20.05 s	0-+	1.1-17 s	75.14 s	0-+	0-+	0-+	0-+	0-+	0-+	0-+			
	1.32(24)	0-+	*	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+					
	1.32(24)	0-+	*	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+					
73	Ta	Ta156	Ta157	Ta158	Ta159	Ta160	Ta161	Ta162	Ta163	Ta164	Ta165	Ta166	Ta167	Ta168	Ta169	Ta170	Ta171	Ta172	Ta173	Ta174	Ta175	Ta176	Ta177	Ta178	Ta179	Ta180	Ta181	Ta182	Ta183	Ta184	Ta185	Ta186	Ta187	Ta188		
	1.04 ms	1.01 ms	3.65 ms	1.01 ms	0.57 s	1.35 s	2.73 s	1.04 s	2.52 s	1.04 s	1.42 s	3.10 s	1.04 s	1.04 s	1.04 s	1.04 s	1.04 s	1.04 s	1.04 s	1.04 s	1.04 s	1.04 s	1.04 s	1.04 s	1.04 s											
	1.25(19)	0-+	*	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+			
72	Hf	Hf154	Hf155	Hf156	Hf157	Hf158	Hf159	Hf160	Hf161	Hf162	Hf163	Hf164	Hf165	Hf166	Hf167	Hf168	Hf169	Hf170	Hf171	Hf172	Hf173	Hf174	Hf175	Hf176	Hf177	Hf178	Hf179	Hf180	Hf181	Hf182	Hf183	Hf184	Hf185	Hf186	Hf187	Hf188
	1.25(6)	0-+	*	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	0-+	



^{181}Ta



Nilsson diagram of ^{181}Ta



Coriolis band mixing calculation for the $7/2^+[404]$ band in ^{181}Ta

The Hamiltonian H_{rot} is the diagonal part of the rotational Hamiltonian. The eigenvalues are assumed to be given by

$$E_K(I) = \epsilon_K + \frac{\hbar^2}{2\mathfrak{J}} [I(I+1) - K^2 + \delta_{K,1/2} \cdot a \cdot (-1)^{I+1/2} (I+1/2)]$$

Off-diagonal terms are given by the Coriolis matrix elements

$$V_{K+1,K} = -\frac{\hbar^2}{2\mathfrak{J}} \sqrt{(I-K)(I+K+1)} \cdot \langle K+1|j_+|K\rangle$$

Results of Coriolis band mixing calculation for the ground-state rotational band in ^{181}Ta

State I^π	E_{calc} (keV)	Expansion coefficients						
		$\frac{1}{2}^+[422]$	$\frac{3}{2}^+[411]$	$\frac{3}{2}^+[402]$	$\frac{5}{2}^+[413]$	$\frac{5}{2}^+[402]$	$\frac{7}{2}^+[404]$	$\frac{9}{2}^+[404]$
$\frac{1}{2}^+$	0.0	0.0020	-0.0027	0.0	0.0417	-0.0304	0.9987	0.0
$\frac{3}{2}^+$	136.9	0.0040	-0.0053	0.0001	0.0630	-0.0459	0.9969	-0.0025
$\frac{11}{2}^+$	302.9	0.0065	-0.0085	0.0001	0.0818	-0.0594	0.9948	-0.0038
$\frac{13}{2}^+$	497.1	0.0093	-0.0123	0.0002	0.0995	-0.0720	0.9923	-0.0048
$\frac{15}{2}^+$	718.7	0.0127	-0.0167	0.0002	0.1167	-0.0840	0.9894	-0.0058
$\frac{17}{2}^+$	966.5	0.0163	-0.0216	0.0003	0.1335	-0.0955	0.9860	-0.0067
$\frac{19}{2}^+$	1239.3	0.0209	-0.0270	0.0	0.1501	-0.1067	0.9822	-0.0076
$\frac{21}{2}^+$	1535.7	0.0251	-0.0331	0.0004	0.1664	-0.1176	0.9781	-0.0084

Reduced transition probability

expectation value

$$\langle \hat{M}_{\lambda m}^{lab} \rangle = \int \Psi^* \hat{M}_{\lambda m}^{lab} \Psi d\tau$$

$$\hat{M}_{\lambda m}^{lab} = \sum_{m'} D_{mm'}^\lambda \hat{M}_{\lambda m'}^{intr}$$

wave function

$$\Psi_{IMK} = \sqrt{\frac{2I+1}{16 \cdot \pi^2}} \cdot [D_{MK}^I \cdot X_K + (-1)^{I-K} D_{M-K}^I \cdot X_{-K}]$$

$$\langle I_f M_f K | \hat{M}_{\lambda m}^{lab} | I_i M_i K \rangle = \frac{\sqrt{(2I_i + 1)(2I_f + 1)}}{8 \cdot \pi^2} \iiint D_{M_f K}^{I_f} X_K \sum_{m'=0} D_{mm'}^\lambda \hat{M}_{\lambda m'}^{intr} D_{M_i K}^{I_i} X_K d\tau$$

$$\iiint D_{M_1 M'_1}^{I_1} D_{M_2 M'_2}^{I_2} D_{M_3 M'_3}^{I_3} d\tau = \frac{8\pi^2}{2I_3 + 1} \cdot (I_1 I_2 M_1 M_2 | I_3 M_3) \cdot (I_1 I_2 M'_1 M'_2 | I_3 M'_3)$$

$$\langle I_f M_f K | \hat{M}_{\lambda m}^{lab} | I_i M_i K \rangle = \sqrt{\frac{2I_i + 1}{2I_f + 1}} \cdot (I_i \lambda M_i (M_f - M_i) | I_f M_f) \cdot (I_i \lambda K 0 | I_f K) \cdot \langle X_K | \hat{M}_{\lambda 0}^{intr} | X_K \rangle$$

Reduced transition probability

$$\langle I_f M_f K | \hat{M}_{\lambda m}^{lab} | I_i M_i K \rangle = \sqrt{\frac{2I_i + 1}{2I_f + 1}} \cdot (I_i \lambda M_i (M_f - M_i) | I_f M_f \rangle) \cdot (I_i \lambda K 0 | I_f K \rangle) \cdot \langle X_K | \hat{M}_{\lambda 0}^{intr} | X_K \rangle$$

Wigner-Eckart-Theorem (reduction of an expectation value):

$$\langle I_f M_f K | \hat{M}_{\lambda m}^{lab} | I_i M_i K \rangle = \frac{(I_i \lambda M_i (M_f - M_i) | I_f M_f \rangle)}{\sqrt{2I_f + 1}} \cdot \langle I_f K | \hat{M}_{\lambda}^{lab} | I_i K \rangle$$

$$\boxed{\langle I_f K | M(E\lambda) | I_i K \rangle = \sqrt{2I_i + 1} (I_i \lambda K 0 | I_f K \rangle) \cdot \langle X_K | \hat{M}_{\lambda 0}^{intr} | X_K \rangle}$$

special case: E2 transition $I \rightarrow I-2$

$$\langle I-2, K | M(E2) | I, K \rangle = \sqrt{\frac{15}{32\pi}} \cdot \sqrt{\frac{(I+K-1) \cdot (I+K) \cdot (I-K-1) \cdot (I-K)}{(I-1) \cdot (2I-1) \cdot I}} \cdot Q_2 e$$

reduced transition probability:

$$B(E\lambda; I_i \rightarrow I_f) = \frac{1}{2I_i + 1} |\langle I_f K | M(E\lambda) | I_i K \rangle|^2$$

Odd-even nucleus: ^{181}Ta

74	W	^{155}W	W158	W159	W160	W161	W162	W163	W164	W165	W166	W167	W168	W169	W170	W171	W172	W173	W174	W175	W176	W177	W178	W179	W180	W181	W182	W183	W184	W185	W186	W187	W188	W189	W190	
		^{155}W	0.9 ms 0+*	7.3 ms 0+*	9.1 ms 0+*	4.10 ms 0+*	1.39 ms 0+*	2.76 ms 0+*	5.1 ms 0+*	1.83 ms 0+*	1.93 ms 0+*	2.23 ms 0+*	1.83 ms 0+*	2.42 ms 0+*	2.38 ms 0+*	2.45 ms 0+*	2.36 ms 0+*	2.31 ms 0+*	2.52 ms 0+*	2.51 ms 0+*	2.64 ms 0+*	2.65 ms 0+*	2.64 ms 0+*	2.65 ms 0+*												
	Ta	^{155}Ta	1.04 ms 0+*	1.01 ms 0+*	1.05 ms 0+*																															
73	Hf	^{154}Hf	0.39 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*	1.5 ms 0+*					
72		Hf154	Hf155	Hf156	Hf157	Hf158	Hf159	Hf160	Hf161	Hf162	Hf163	Hf164	Hf165	Hf166	Hf167	Hf168	Hf169	Hf170	Hf171	Hf172	Hf173	Hf174	Hf175	Hf176	Hf177	Hf178	Hf179	Hf180	Hf181	Hf182	Hf183	Hf184	Hf185	Hf186	Hf187	Hf188

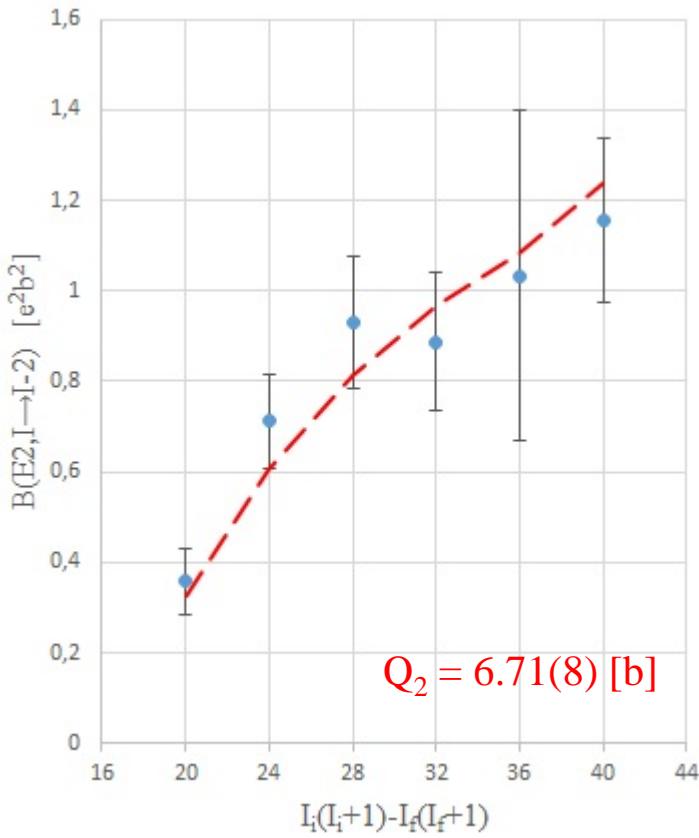
special case: E2 transition $I \rightarrow I-2$

$$\langle I-2, K | M(E2) | I, K \rangle = \sqrt{\frac{15}{32\pi}} \cdot \sqrt{\frac{(I+K-1) \cdot (I+K) \cdot (I-K-1) \cdot (I-K)}{(I-1) \cdot (2I-1) \cdot I}} \cdot Q_2 e$$

reduced transition probability:

$$B(E\lambda; I_i \rightarrow I_f) = \frac{1}{2I_i + 1} |\langle I_f K | M(E\lambda) | I_i K \rangle|^2$$

$$\frac{Q_2(9/2^-)}{Q_2(7/2^+)} = (0.9681 \pm 0.0002)$$



Matrix elements

$$\langle I-2, K | M(E2) | I, K \rangle = \sqrt{\frac{15}{32\pi}} \cdot \sqrt{\frac{(I+K-1) \cdot (I+K) \cdot (I-K-1) \cdot (I-K)}{(I-1) \cdot (2I-1) \cdot I}} \cdot Q_2 e$$

$$\langle I-1, K | M(E2) | I, K \rangle = -\sqrt{\frac{5}{16\pi}} \cdot \sqrt{\frac{3 \cdot (I+K) \cdot (I-K) \cdot K^2}{(I-1) \cdot I \cdot (I+1)}} \cdot Q_2 e$$

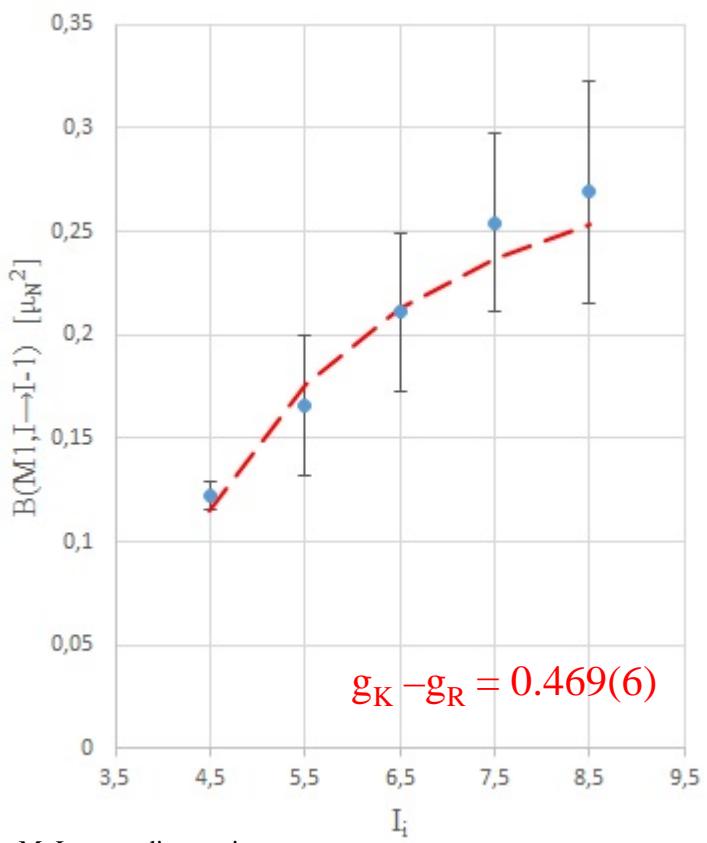
$$\langle I, K | M(E2) | I, K \rangle = -\sqrt{\frac{5}{16\pi}} \cdot \sqrt{\frac{2I+1}{(2I-1) \cdot I \cdot (I+1) \cdot (2I+3)}} \cdot (I^2 - 3K^2 + I) \cdot Q_2 e$$

Odd-even nucleus: ^{181}Ta

74	W	2^+	W158	0.5 ms	W159	7.3 ms	W160	9.1 ms	W161	4.0 ms	W162	1.39 s	W163	0.76 s	W164	5.1 s	W165	1.83 s	W166	$(1.9\pm 0.1)\text{ s}$	W167	$1.9\pm 0.1\text{ s}$	W168	$7.4\pm 0.1\text{ s}$	W169	$2.42\pm 0.1\text{ s}$	W170	$2.38\pm 0.1\text{ s}$	W171	$7.4\pm 0.1\text{ s}$	W172	$6.6\pm 0.1\text{ s}$	W173	$7.0\pm 0.1\text{ s}$	W174	$3.1\pm 0.1\text{ s}$	W175	$25.2\pm 0.1\text{ s}$	W176	$7.5\pm 0.1\text{ s}$	W177	$13.5\pm 0.1\text{ s}$	W178	$21.6\pm 0.1\text{ s}$	W179	$20.05\pm 0.1\text{ s}$	W180	$0^-\pm 0^-\text{ s}$	W181	$121.2\pm 0.4\text{ d}$	W182	$0^-\pm 0^-\text{ s}$	W183	$1.1\text{--}17\text{ d}$	W184	$75.1\pm 0.4\text{ d}$	W185	$0^-\pm 0^-\text{ s}$	W186	$23.72\pm 0.4\text{ d}$	W187	$0^-\pm 0^-\text{ s}$	W188	$11.5\pm 0.4\text{ d}$	W189	$0^-\pm 0^-\text{ s}$	W190	$0^-\pm 0^-\text{ s}$				
73	Ta	$5/2^-$	Ta156	1.04 ms	Ta157	1.01 ms	Ta158	$0.57\pm 0.1\text{ ms}$	Ta159	$1.35\pm 0.1\text{ ms}$	Ta160	$2.72\pm 0.1\text{ ms}$	Ta161	$0.57\pm 0.1\text{ ms}$	Ta162	$2.82\pm 0.1\text{ ms}$	Ta163	$1.04\pm 0.1\text{ ms}$	Ta164	$1.42\pm 0.1\text{ ms}$	Ta165	$3.44\pm 0.1\text{ ms}$	Ta166	$1.4\pm 0.1\text{ ms}$	Ta167	$2.0\pm 0.1\text{ ms}$	Ta168	$4.9\pm 0.1\text{ ms}$	Ta169	$4.76\pm 0.1\text{ ms}$	Ta170	$23.3\pm 0.1\text{ ms}$	Ta171	$36.3\pm 0.1\text{ ms}$	Ta172	$31\pm 1\text{ ms}$	Ta173	$31\pm 1\text{ ms}$	Ta174	$1.05\pm 0.1\text{ ms}$	Ta175	$10.5\pm 0.1\text{ ms}$	Ta176	$56.56\pm 0.1\text{ ms}$	Ta177	$9.31\pm 0.1\text{ ms}$	Ta178	$7.78\pm 0.1\text{ ms}$	Ta179	$1.87\pm 0.1\text{ ms}$	Ta180	$319.1\pm 0.1\text{ ms}$	Ta181	$99.98\pm 0.1\text{ ms}$	Ta182	$14.43\pm 0.1\text{ ms}$	Ta183	$5.1\pm 0.1\text{ ms}$	Ta184	$49.4\pm 0.1\text{ ms}$	Ta185	$3.7\pm 0.1\text{ ms}$	Ta186	$10.5\pm 0.1\text{ ms}$	Ta187	$29.4\pm 0.1\text{ ms}$	Ta188	116				
72	Hf	2^+	Hf154	$0.39\pm 0.1\text{ ms}$	Hf155	$0.5\pm 0.1\text{ ms}$	Hf156	$1.05\pm 0.1\text{ ms}$	Hf157	$0.88\pm 0.1\text{ ms}$	Hf158	$3.6\pm 0.1\text{ ms}$	Hf159	$3.6\pm 0.1\text{ ms}$	Hf160	$1.6\pm 0.1\text{ ms}$	Hf161	$1.6\pm 0.1\text{ ms}$	Hf162	$3.6\pm 0.1\text{ ms}$	Hf163	$3.6\pm 0.1\text{ ms}$	Hf164	$40.9\pm 0.1\text{ ms}$	Hf165	$111\pm 1\text{ ms}$	Hf166	$4.75\pm 0.1\text{ ms}$	Hf167	$25.00\pm 0.1\text{ ms}$	Hf168	$1.34\pm 0.1\text{ ms}$	Hf169	$11.1\pm 0.1\text{ ms}$	Hf170	$16.00\pm 0.1\text{ ms}$	Hf171	$12.1\pm 0.1\text{ ms}$	Hf172	$13.7\pm 0.1\text{ ms}$	Hf173	$25.6\pm 0.1\text{ ms}$	Hf174	$70.4\pm 0.1\text{ ms}$	Hf175	$70.4\pm 0.1\text{ ms}$	Hf176	$1.01\pm 0.1\text{ ms}$	Hf177	$2.02\pm 0.1\text{ ms}$	Hf178	$12.60\pm 0.1\text{ ms}$	Hf179	$22.97\pm 0.1\text{ ms}$	Hf180	$1.63\pm 0.1\text{ ms}$	Hf181	$41.30\pm 0.1\text{ ms}$	Hf182	$1.80\pm 0.1\text{ ms}$	Hf183	$1.80\pm 0.1\text{ ms}$	Hf184	$41.1\pm 0.1\text{ ms}$	Hf185	$3.5\pm 0.1\text{ ms}$	Hf186	$0.7\pm 0.1\text{ ms}$	Hf187	$0.7\pm 0.1\text{ ms}$	Hf188	116

$$\langle I-1, K | M(M1) | I, K \rangle = - \sqrt{\frac{3}{4\pi}} \sqrt{\frac{(I+K)(I-K)}{I}} \cdot K \cdot (g_K - g_R) [1 + \delta_{K,1/2} (-1)^{I+1/2} b_0] \mu_N$$

The quantity b_0 depends on the magnetic decoupling parameter



$$\mu(7/2^+) = 2.3705 \pm 0.0007$$

$$\mu = \frac{K}{I+1} \cdot (g_K - g_R) \cdot K + g_R \cdot I$$

$$g_R = 0.313(5)$$

$$g_K = 0.782(2)$$

$$\mu(9/2^-) = 5.28 \pm 0.09$$

$${}^{9/2^-}(g_K - g_R) = \frac{22}{81} \left({}^{9/2^-} \mu - {}^{7/2^+} \mu \frac{9}{7} + {}^{7/2^+} (g_K - g_R) \frac{7}{2} \right)$$

$${}^{9/2^-}(g_K - g_R) \approx {}^{7/2^+}(g_K - g_R) \frac{77}{81} + 0.606 = 1.052$$

Odd-even nucleus: ^{181}Ta

74	^{181}W	$\frac{1}{2}^+$	W158	$\frac{9}{2}^-$	W159	$\frac{7}{2}^-$	W160	$\frac{9}{2}^-$	W161	$\frac{4}{1}0$	W162	$\frac{9}{2}^-$	W163	$\frac{5}{2}1$	W164	$\frac{9}{2}3$	W165	$\frac{5}{2}1$	W166	$\frac{13}{2}3$	W167	$\frac{9}{2}3$	W168	$\frac{9}{2}3$	W169	$\frac{7}{2}3$	W170	$\frac{2}{3}2$	W171	$\frac{7}{2}1$	W172	$\frac{9}{2}1$	W173	$\frac{7}{2}1$	W174	$\frac{3}{2}1$	W175	$\frac{25}{2}2$	W176	$\frac{7}{2}1$	W177	$\frac{13}{2}1$	W178	$\frac{21}{2}4$	W179	$\frac{17}{2}0$	W180	$\frac{13}{2}1$	W181	$\frac{13}{2}1$	W182	$\frac{1}{2}1$	W183	$\frac{11}{2}1$	W184	$\frac{9}{2}1$	W185	$\frac{7}{2}1$	W186	$\frac{9}{2}1$	W187	$\frac{23}{2}2$	W188	$\frac{11}{2}0$	W189	$\frac{23}{2}0$	W190	$\frac{9}{2}0$				
73	^{181}Ta	$\frac{5}{2}1$	Ta156	$\frac{1}{2}1$	Ta157	$\frac{1}{2}1$	Ta158	$\frac{1}{2}1$	Ta159	$\frac{9}{2}1$	Ta160	$\frac{7}{2}1$	Ta161	$\frac{2}{3}2$	Ta162	$\frac{1}{2}1$	Ta163	$\frac{1}{2}1$	Ta164	$\frac{13}{2}1$	Ta165	$\frac{9}{2}1$	Ta166	$\frac{3}{2}4$	Ta167	$\frac{9}{2}1$	Ta168	$\frac{2}{3}2$	Ta169	$\frac{4}{3}1$	Ta170	$\frac{4}{3}1$	Ta171	$\frac{23}{2}3$	Ta172	$\frac{3}{2}3$	Ta173	$\frac{1}{2}1$	Ta174	$\frac{3}{2}1$	Ta175	$\frac{1}{2}1$	Ta176	$\frac{23}{2}1$	Ta177	$\frac{9}{2}1$	Ta178	$\frac{3}{2}1$	Ta179	$\frac{1}{2}1$	Ta180	$\frac{13}{2}1$	Ta181	$\frac{1}{2}1$	Ta182	$\frac{1}{2}1$	Ta183	$\frac{11}{2}1$	Ta184	$\frac{9}{2}1$	Ta185	$\frac{7}{2}1$	Ta186	$\frac{9}{2}1$	Ta187	$\frac{23}{2}2$	Ta188	$\frac{11}{2}0$				
72	^{181}Hf	$\frac{5}{2}1$	Hf154	$\frac{1}{2}1$	Hf155	$\frac{1}{2}1$	Hf156	$\frac{1}{2}1$	Hf157	$\frac{1}{2}1$	Hf158	$\frac{3}{2}1$	Hf159	$\frac{3}{2}1$	Hf160	$\frac{1}{2}1$	Hf161	$\frac{13}{2}1$	Hf162	$\frac{3}{2}1$	Hf163	$\frac{13}{2}1$	Hf164	$\frac{3}{2}1$	Hf165	$\frac{3}{2}1$	Hf166	$\frac{1}{2}1$	Hf167	$\frac{3}{2}1$	Hf168	$\frac{1}{2}1$	Hf169	$\frac{1}{2}1$	Hf170	$\frac{1}{2}1$	Hf171	$\frac{13}{2}1$	Hf172	$\frac{3}{2}1$	Hf173	$\frac{1}{2}1$	Hf174	$\frac{3}{2}1$	Hf175	$\frac{1}{2}1$	Hf176	$\frac{23}{2}1$	Hf177	$\frac{9}{2}1$	Hf178	$\frac{3}{2}1$	Hf179	$\frac{1}{2}1$	Hf180	$\frac{13}{2}1$	Hf181	$\frac{1}{2}1$	Hf182	$\frac{1}{2}1$	Hf183	$\frac{11}{2}1$	Hf184	$\frac{9}{2}1$	Hf185	$\frac{7}{2}1$	Hf186	$\frac{9}{2}1$	Hf187	$\frac{23}{2}2$	Hf188	$\frac{11}{2}0$

$$13/\frac{1}{2}^+ \quad 0.495 \quad \tau = 9.1 \pm 1.2 \text{ ps}$$

$$11/\frac{1}{2}^+ \quad 0.302 \quad \tau = 23.1 \pm 4.3 \text{ ps}$$

$$9/\frac{1}{2}^+ \quad 0.136 \quad \tau = 57.0 \pm 2.3 \text{ ps}$$

$$7/\frac{1}{2}^+ \quad 0.0 \quad \text{E2 + M1}$$

^{181}Ta

$$\tau = \left\{ \sum_K \sum_\ell [\varepsilon_{N \rightarrow K}^2(\lambda) + \delta_{N \rightarrow K}^2(\lambda)] \right\}^{-1}$$

$$\tau = T_{1/2} / \ln 2$$

$$\delta_{N \rightarrow M}(\lambda) = \left\{ \frac{8\pi(\lambda+1)}{\lambda[(2\lambda+1)!!]^2} \frac{1}{\hbar} \left(\frac{\hbar\omega}{\hbar c} \right)^{2\lambda+1} \right\}^{1/2} \cdot (2I_N + 1)^{-1/2} \cdot \langle I_M \parallel \mathcal{M}(\lambda) \parallel I_N \rangle$$

$$\delta_{N \rightarrow M}(E2) = \{1.225 \cdot 10^{13} \cdot E_\gamma^5 (\text{MeV})^5\}^{1/2} \cdot (2I_n + 1)^{-1/2} \cdot \langle I_M \parallel \mathcal{M}(E2) \parallel I_N \rangle$$

$$\delta_{N \rightarrow M}(M1) = \{1.758 \cdot 10^{13} \cdot E_\gamma^3 (\text{MeV})^3\}^{1/2} \cdot (2I_n + 1)^{-1/2} \cdot \langle I_M \parallel \mathcal{M}(M1) \parallel I_N \rangle$$

$$\varepsilon_{N \rightarrow M}^2(\ell) = \delta_{N \rightarrow M}^2(\ell) \cdot \alpha_{N \rightarrow M}(\ell)$$

conversion coefficient.: bricc.anu.edu.au

Odd-even nucleus: ^{181}Ta

74	^{181}W	0.2660	W158	0.5 ms	W159	7.3 ms	W160	9.1 ms	W161	4.0 ms	W162	1.39 s	W163	2.76 s	W164	5.1 s	W165	13.3 s	W166	0.9 s	W167	1.9 s	W168	2.3 s	W169	7.4 s	W170	2.42 s	W171	2.38 s	W172	4.5 s	W173	7.0 s	W174	3.1 s	W175	25.2 s	W176	2.5 s	W177	3.5 s	W178	21.4 s	W179	20.05 s	W180	0-*	W181	121.2 d	W182	0-*	W183	1.1-17 s	W184	75.1 d	W185	0-*	W186	23.72 s	W187	0-*	W188	11.5 s	W189	0-*	W190	30.0 s				
73	^{181}Ta	54.0	Ta156	1.04 ms	Ta157	1.01 ms	Ta158	0.57 s	Ta159	1.05 s	Ta160	2.72 s	Ta161	0.57 s	Ta162	2.82 s	Ta163	1.04 s	Ta164	1.02 s	Ta165	3.10 s	Ta166	3.44 s	Ta167	1.4 s	Ta168	2.0 s	Ta169	4.9 s	Ta170	4.76 s	Ta171	23.3 s	Ta172	36.3 s	Ta173	3.1 s	Ta174	1.05 s	Ta175	10.5 s	Ta176	56.56 s	Ta177	9.31 s	Ta178	1.03 s	Ta179	1.02 s	Ta180	1.03 s	Ta181	99.98 s	Ta182	1.04 s	Ta183	5.1 s	Ta184	49.4 s	Ta185	0-*	Ta186	10.5 s	Ta187	12.3 s	Ta188	0-*				
72	^{181}Hf	54.0	Hf154	0.39 s	Hf155	0.5 s	Hf156	1.05 ms	Hf157	0.38 s	Hf158	3.6 s	Hf159	3.6 s	Hf160	1.05 s	Hf161	1.05 s	Hf162	3.6 s	Hf163	40.0 s	Hf164	1.05 s	Hf165	25.0 s	Hf166	1.05 s	Hf167	25.0 s	Hf168	1.05 s	Hf169	1.05 s	Hf170	1.05 s	Hf171	13.1 s	Hf172	1.07 s	Hf173	23.6 s	Hf174	70.4 s	Hf175	70.4 s	Hf176	1.07 s	Hf177	1.07 s	Hf178	1.07 s	Hf179	1.07 s	Hf180	1.07 s	Hf181	41.1 s	Hf182	9.6 s	Hf183	1.08 s	Hf184	1.08 s	Hf185	1.08 s	Hf186	3.5 s	Hf187	0-*	Hf188	0-*

$$13/2^+ \quad 0.495 \quad \tau = 9.1 \pm 1.2 \text{ ps}$$

$$\tau = \left\{ \sum_K \sum_\ell [\varepsilon_{N \rightarrow K}^2(\lambda) + \delta_{N \rightarrow K}^2(\lambda)] \right\}^{-1}$$

$$11/2^+ \quad 0.302 \quad \tau = 23.1 \pm 4.3 \text{ ps}$$

$$\tau = T_{1/2} / \ln 2$$

$$9/2^+ \quad 0.136 \quad \tau = 57.0 \pm 2.3 \text{ ps}$$

$$7/2^+ \quad 0.0 \quad \text{E2 + M1}$$

^{181}Ta

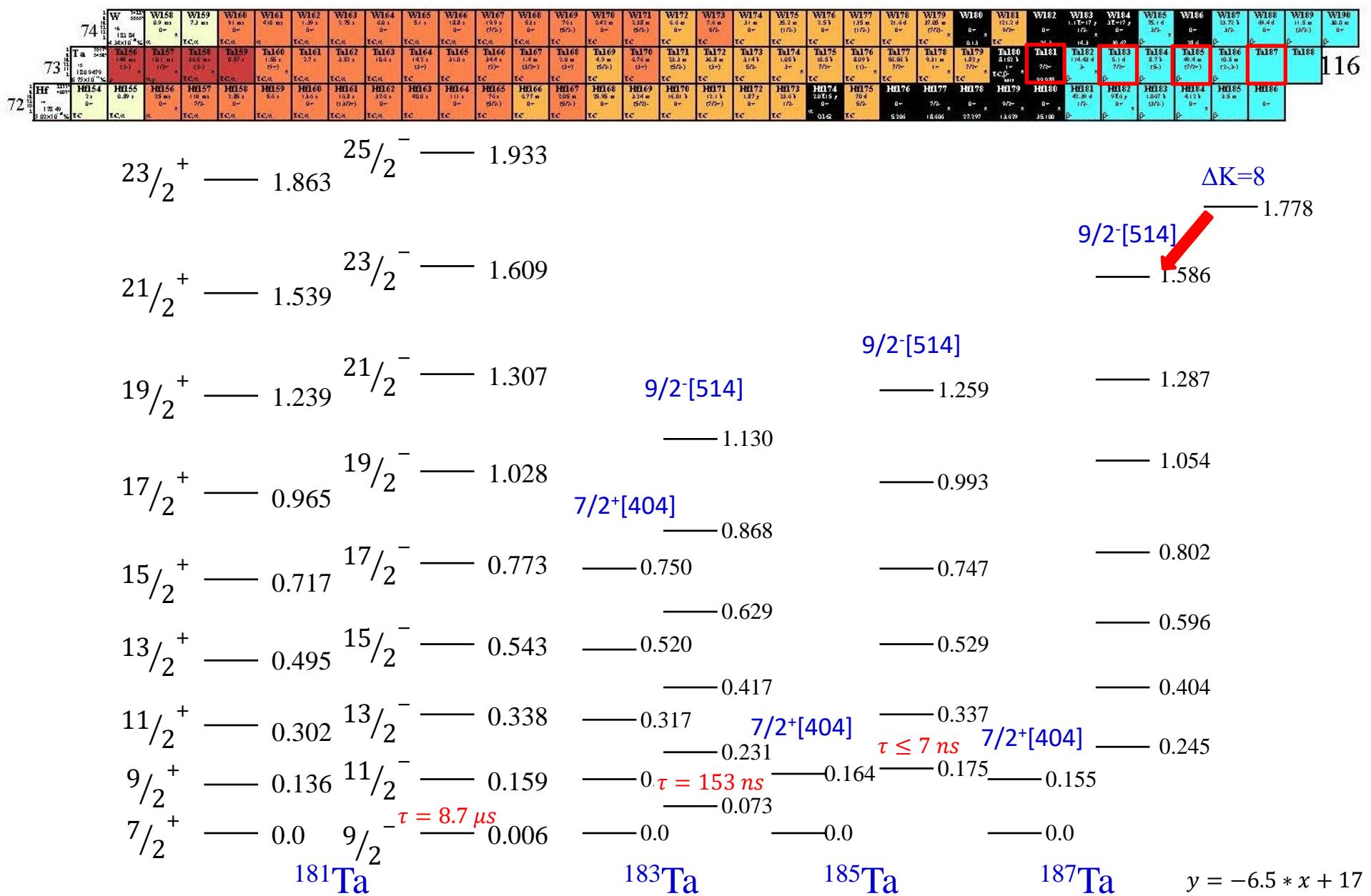
	Spin I	E_γ (MeV)	$(2I+1)^{-1/2}$	$\langle I-1/M(0)/I \rangle$	delta	α_T	ϵ^2	τ (ps)
	9/2	0.1365	0.3162	-3.899 (E2)	-29594.	1.1	$9.98 \cdot 10^8$	533
				1.103 (M1)	73591	1.8	$9.75 \cdot 10^9$	58.7
	11/2	0.1654	0.2887	-4.291 (E2)	-48238	0.6	$1.33 \cdot 10^9$	274
				1.413 (M1)	115044	1.0	$1.38 \cdot 10^{10}$	32.6
	11/2	0.3017	0.2887	1.977 (E2)	99868	0.1	$8.08 \cdot 10^8$	24.1

T. Inamura et al., Nucl. Phys. A270 (1976) 255

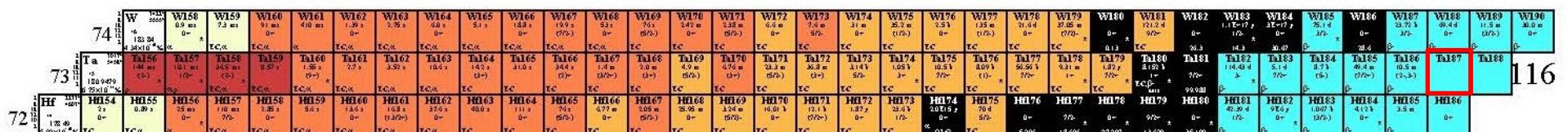
Odd-proton-even nuclei

		μ	$(g_K - g_R)$	$B(M1)W.u.$	$(g_K - g_R)$
^{153}Eu	$5/2^+$	+1.5324(3)	0.551	0.00608(28)	0.185
^{159}Tb	$3/2^+$	+2.014(4)	1.556	0.173(8)	1.471
^{165}Ho	$7/2^-$	+4.177(5)	1.012	0.275(14)	0.973
^{169}Tm	$1/2^+$	-0.2316(15)		0.0342(8)	
^{175}Lu	$7/2^+$	+2.2327(11)	0.298	0.0354(14)	0.349
^{181}Ta	$7/2^+$	+2.3705(7)	0.352	0.068(4)	0.484
^{185}Re	$5/2^+$	+3.1871(3)	1.217	0.28(5)	1.252
^{187}Re	$5/2^+$	+3.2197(3)	1.242	0.260(18)	1.206

Ta-nuclei: level schemes



^{187}Ta level scheme



expected lifetimes

$$\Delta K=8$$

$$(25/2^-) \text{--- } 1.778 \quad \tau = 10.5(13) \text{ s}$$

$$9/2^-[514] \quad \quad \quad (21/2^-) \text{--- } 1.586 \quad \tau = 0.6 \text{ ps}$$

$$(19/2^-) \text{--- } 1.287 \quad \tau = 1.1 \text{ ps}$$

$$(17/2^-) \text{--- } 1.054 \quad \tau = 1.1 \text{ ps}$$

$$(15/2^-) \text{--- } 0.802 \quad \tau = 2.2 \text{ ps}$$

$$(13/2^-) \text{--- } 0.596 \quad \tau = 3.4 \text{ ps}$$

$$(11/2^-) \text{--- } 0.404 \quad \tau = 7.9 \text{ ps}$$

$$7/2^+[404] \quad (9/2^-) \text{ --- } 0.245 \quad \tau \sim 40 \text{ ns}$$

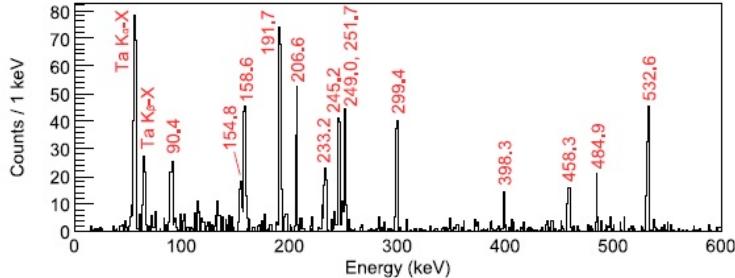
$$(9/2^+) \text{ --- } 0.155$$

$$(7/2^+) \text{ --- } 0.0$$

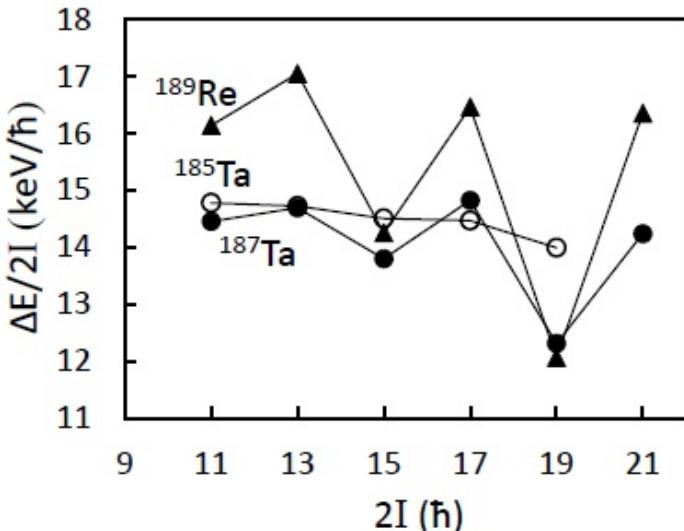
^{187}Ta P.M. Walker; Phys. Rev. Lett. 125 192505

$I \rightarrow I - 1$

$I \rightarrow I - 2$

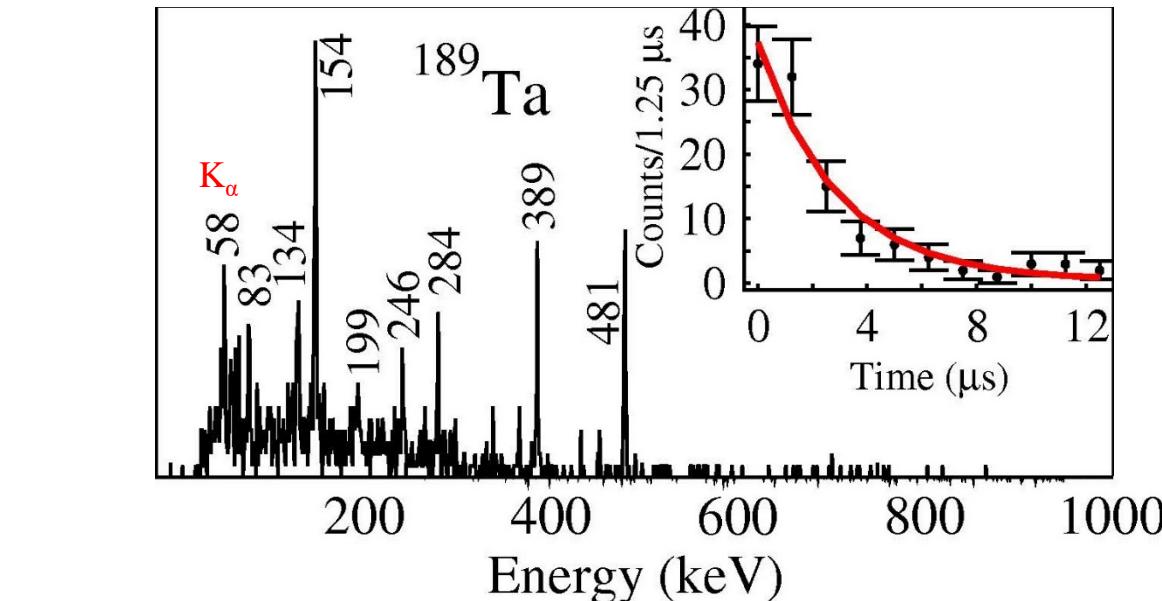


Sum of $\gamma\gamma$ -coincidence energy spectra

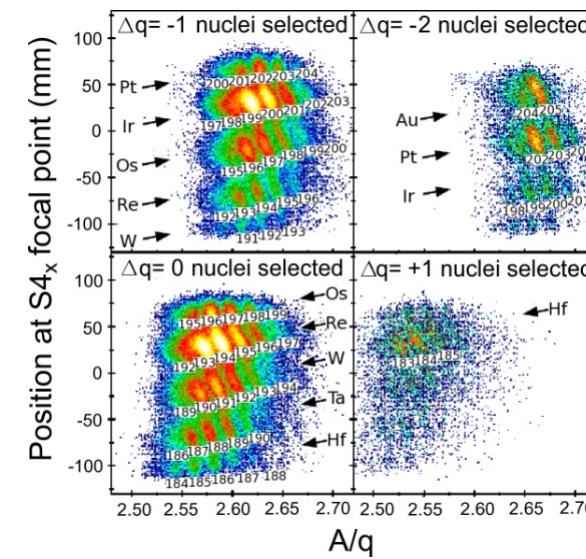
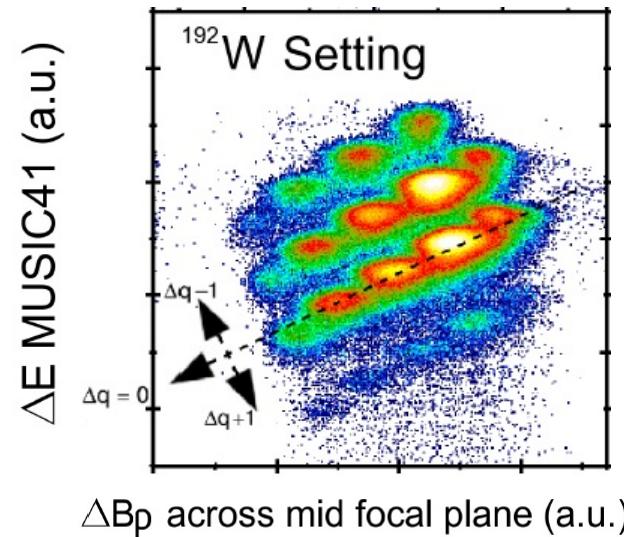


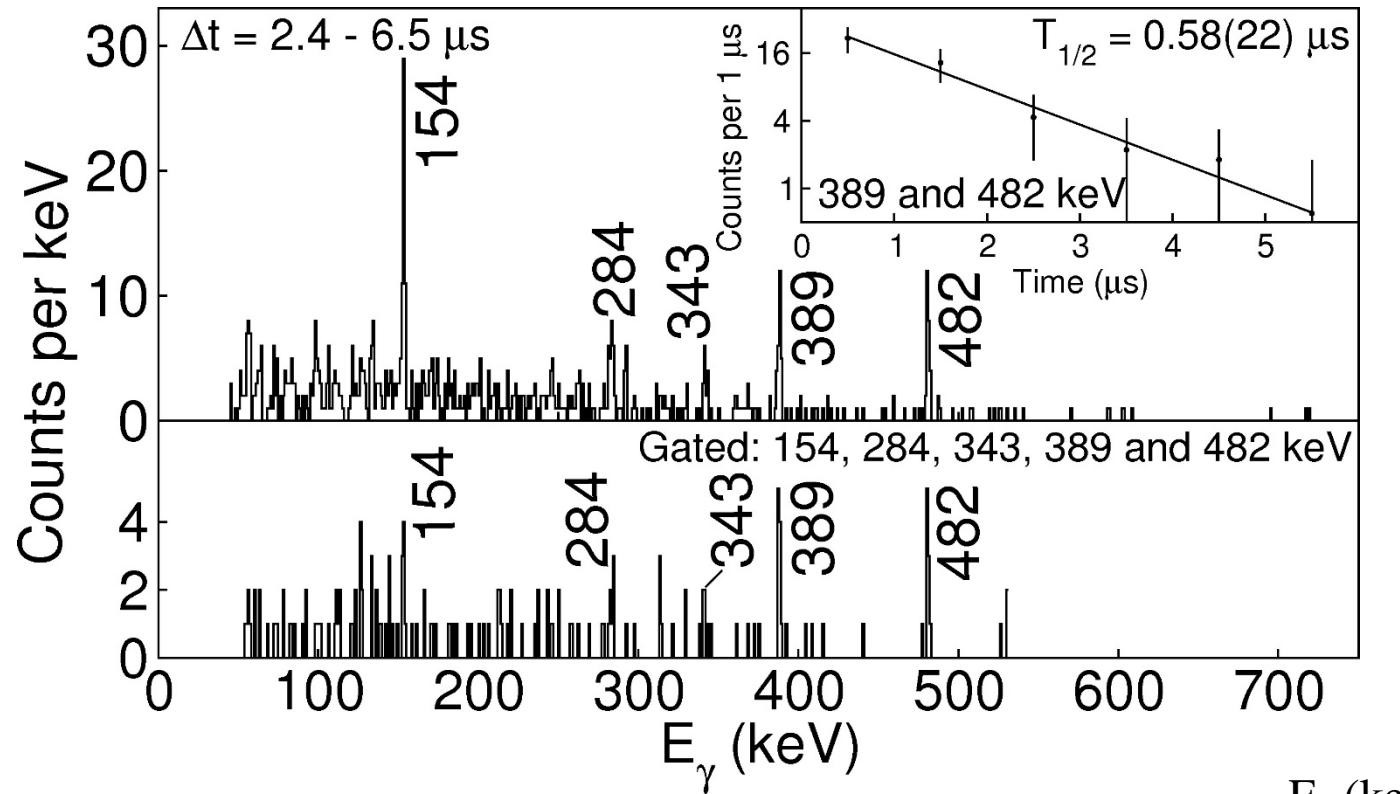
Signature splitting versus angular momentum

Experimental information on ^{189}Ta



^{208}Pb primary beam



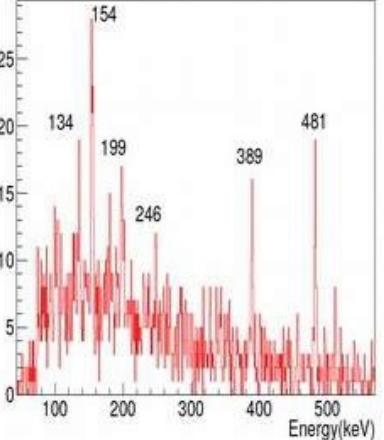
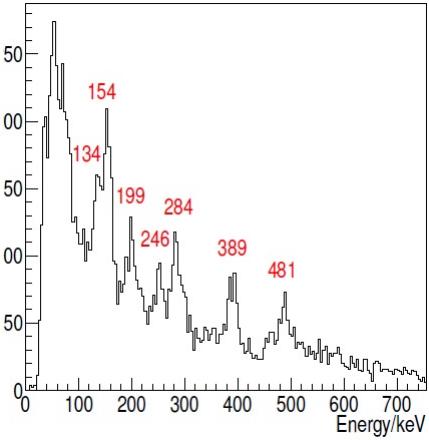
Experimental information on ^{189}Ta 

E_{γ} (keV)	intensity
153.9	100(19)
283.7	73(17)
342.5	47(13)
388.7	80(19)
481.6	97(21)

Experimental information on ^{189}Ta

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74	W^{+2}	W158 0.9 m	W159 7.3 m	W160 9.1 m	W161 4.0 m	W162 1.39 s	W163 0.76 s	W164 0.6 s	W165 1.93 s	W166 0.3 s	W167 1.93 s	W168 0.3 s	W169 2.42 s	W170 2.38 s	W171 2.4 s	W172 0.3 s	W173 3.1 m	W174 25.2 s	W175 2.5 s	W176 1.35 s	W177 21.6 d	W178 21.05 s	W179 21.05 s	W180 0 s	W181 131.2 d	W182 1.1-17	W183 1.1-17	W184 10.5 m	W185 75.1 d	W186 0 s	W187 23.72 s	W188 0.4 d	W189 11.5 s	W190 0.0 s		
73	Ta^{54}	Ta156 1.04 s	Ta157 1.01 s	Ta158 0.57 s	Ta159 1.05 s	Ta160 2.7 s	Ta161 2.5 s	Ta162 1.04 s	Ta163 2.1 s	Ta164 1.42 s	Ta165 3.0 s	Ta166 3.42 s	Ta167 1.4 s	Ta168 2.0 s	Ta169 4.9 s	Ta170 4.76 s	Ta171 23.3 s	Ta172 36.3 s	Ta173 3.14 s	Ta174 3.05 s	Ta175 10.5 s	Ta176 56.56 s	Ta177 4.31 s	Ta178 1.87 s	Ta179 3.12 s	Ta180 31.92 s	Ta181 1.04 s	Ta182 49.4 s	Ta183 5.1 d	Ta184 49.4 s	Ta185 10.5 m	Ta186 13.5 s	Ta187 41.1 s	Ta188 0 s		
	Hf^{72}	Hf154 0.39 s	Hf155 0.51 s	Hf156 0.51 s	Hf157 1.10 m	Hf158 0.38 s	Hf159 3.5 s	Hf160 1.65 s	Hf161 1.11 s	Hf162 3.55 s	Hf163 40.9 s	Hf164 1.43 s	Hf165 1.34 s	Hf166 0.75 s	Hf167 10.0 s	Hf168 1.34 s	Hf169 0.40 s	Hf170 13.1 s	Hf171 32.6 s	Hf172 31.5 s	Hf173 1.05 s	Hf174 10.5 s	Hf175 70.4 d	Hf176 70.4 d	Hf177 70.4 d	Hf178 0 s	Hf179 99.98 s	Hf180 41.30 s	Hf181 0 s	Hf182 1.1-17	Hf183 1.1-17	Hf184 1.1-17	Hf185 1.1-17	Hf186 1.1-17	Hf187 3.5 s	Hf188 0 s



E_γ	ΔE_γ	γ -intensity	a_{tot}	intensity	S.J. Steer	$T_{1/2}$ (μs)	
154	3.2	149.5 ± 14.1	100%	0.734	E1:119/E2:173	100%	1.09(4)
199	4.2	67.1 ± 9.0	44.9 ± 7.4	0.303	58.5 ± 9.6		
198	2.5	32.3 ± 9.6	21.6 ± 6.7	0.308	28.3 ± 8.8		
200.5	2.5	31.1 ± 9.6	20.8 ± 6.7	0.295	26.9 ± 8.7		
247.2	1.8	36.9 ± 7.1	24.7 ± 5.3	0.149	28.4 ± 6.1		
284.6	2.4	37.5 ± 8.3	25.5 ± 6.0	0.025	E1:26.1±6.2	73±22	1.16(7)
342.7	2.6	29.4 ± 7.0	19.7 ± 5.0	0.056	20.8 ± 5.3	47±16	
389.3	2.5	110.5 ± 10.9	73.9 ± 10.1	0.039	76.8 ± 10.4	80±24	1.08(6)
481	3.2	131.6 ± 12.5	88.0 ± 11.8	0.022	90±12	97±28	1.12(7)
							0.202(12)
							0.284(11)

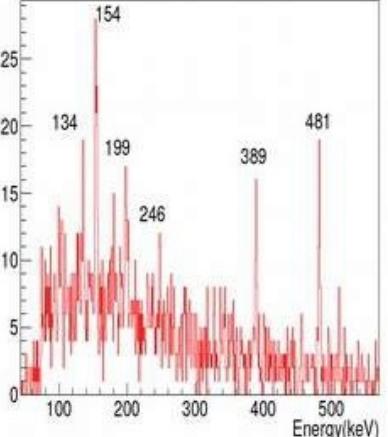
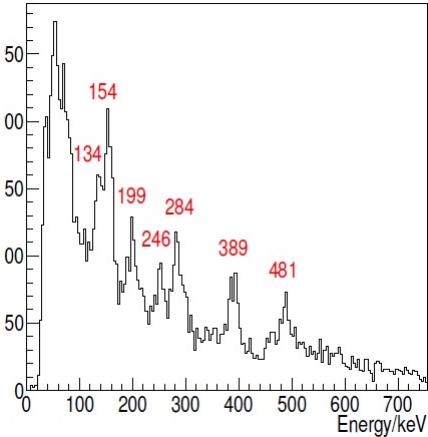
gate

481	154	284	389	-
389	154	284	-	481
284	154	-	389	481
343	154	199	246	-
246	154	199	-	343
199	154	-	389	481
154	134	154	246	343
134			284	389
			481	

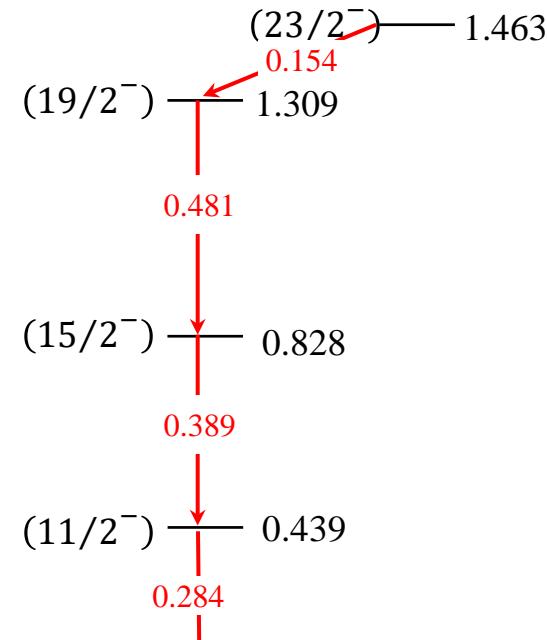
Experimental information on ^{189}Ta

72

74	W	W155	W158	W159	W160	W161	W162	W163	W164	W165	W166	W167	W168	W169	W170	W171	W172	W173	W174	W175	W176	W177	W178	W179	W180	W181	W182	W183	W184	W185	W186	W187	W188	W189	W190			
73	Ta	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190
72	Hf	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190
71	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	
70	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	



$$\alpha = +1/2 \quad \alpha = -1/2$$



gate

481	154		284	389	-
389	154		284	-	481
284	154		-	389	481
343	154	199	246	-	
246	154	199	-	343	370
199	154	-		389	481
154	134	154	246	343	284
134			343		389

$7/2^+ [404]$

$(9/2^+) \longrightarrow 0.154$

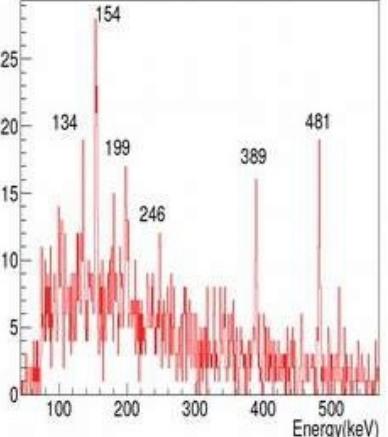
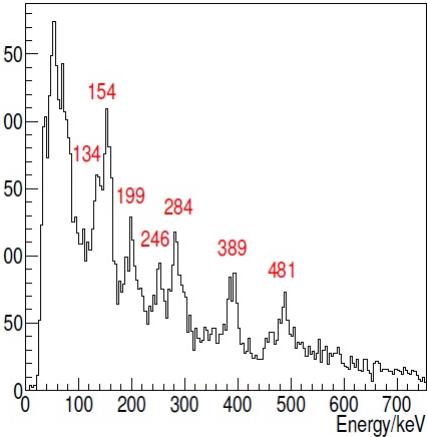
$(7/2^+) \longrightarrow 0.0$

^{189}Ta

Experimental information on ^{189}Ta

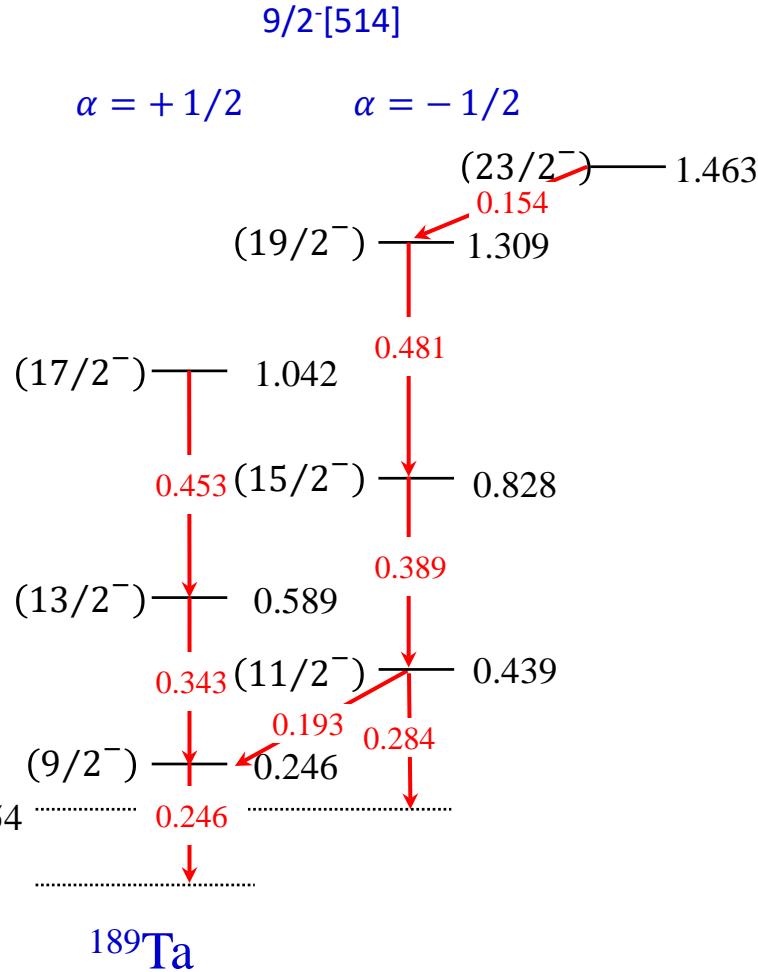
72

74	W	W155	W158	W159	W160	W161	W162	W163	W164	W165	W166	W167	W168	W169	W170	W171	W172	W173	W174	W175	W176	W177	W178	W179	W180	W181	W182	W183	W184	W185	W186	W187	W188	W189	W190
73	Ta	54.0	4.22 0.04	7.3 0.03	9.1 0.03	4.10 0.03	1.39 0.03	2.76 0.03	5.1 0.03	1.83 0.03	2.0 0.03	1.93 0.03	2.33 0.03	2.42 0.03	2.38 0.03	2.4 0.03	2.38 0.03	2.3 0.03	2.1 0.03	2.0 0.03	1.95 0.03	2.0 0.03	2.0 0.03	2.1 0.03	2.1 0.03	2.1 0.03	2.1 0.03	2.1 0.03	2.1 0.03	2.1 0.03	2.1 0.03	2.1 0.03	2.1 0.03	2.1 0.03	
72	Hf	12.0	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	1.25 0.02	
		Ta156	Ta157	Ta158	Ta159	Ta160	Ta161	Ta162	Ta163	Ta164	Ta165	Ta166	Ta167	Ta168	Ta169	Ta170	Ta171	Ta172	Ta173	Ta174	Ta175	Ta176	Ta177	Ta178	Ta179	Ta180	Ta181	Ta182	Ta183	Ta184	Ta185	Ta186	Ta187	Ta188	
		1.04 0.03	1.01 0.03	1.05 0.03	0.97 0.03	1.05 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03	1.04 0.03

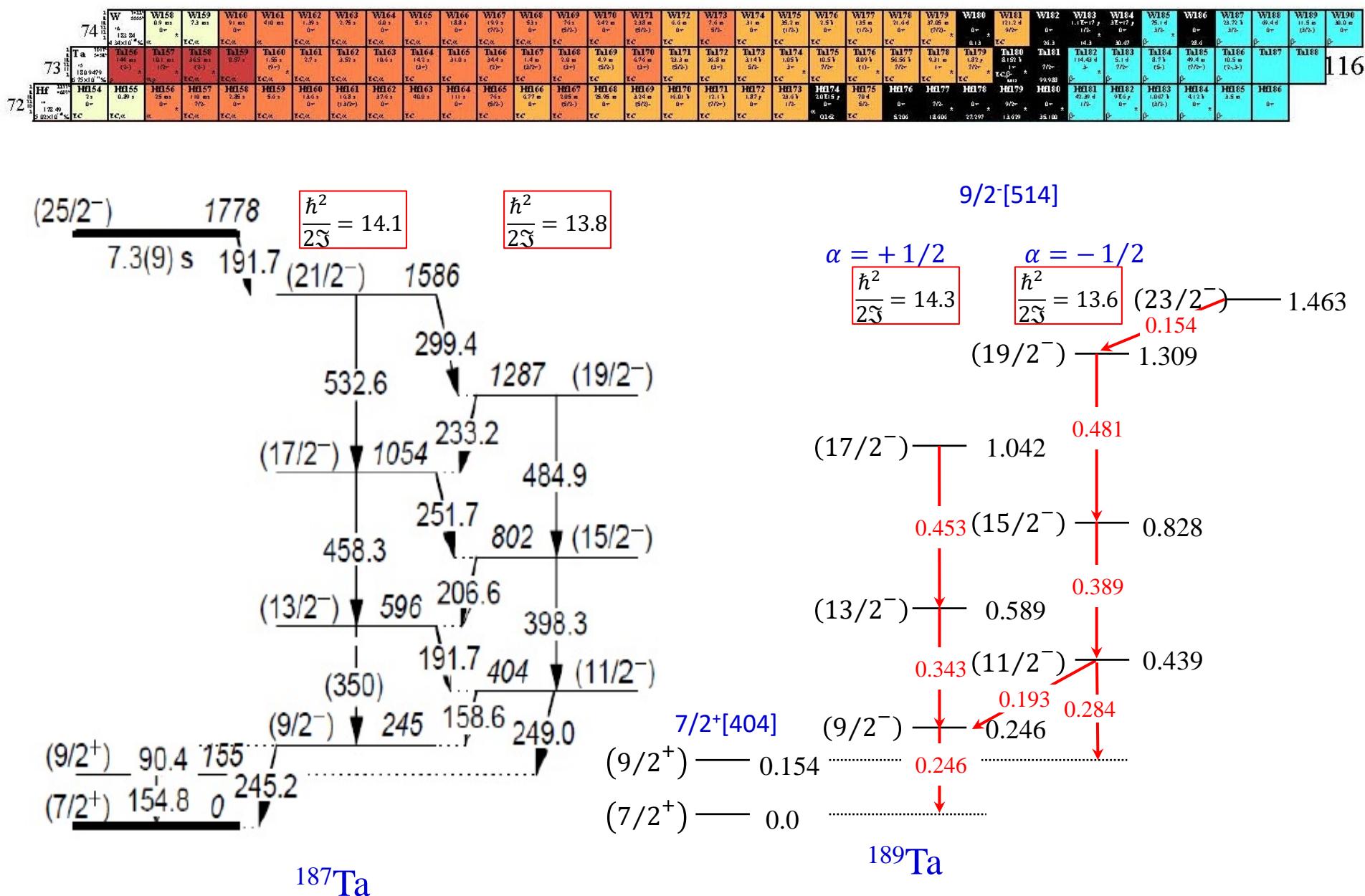


gate

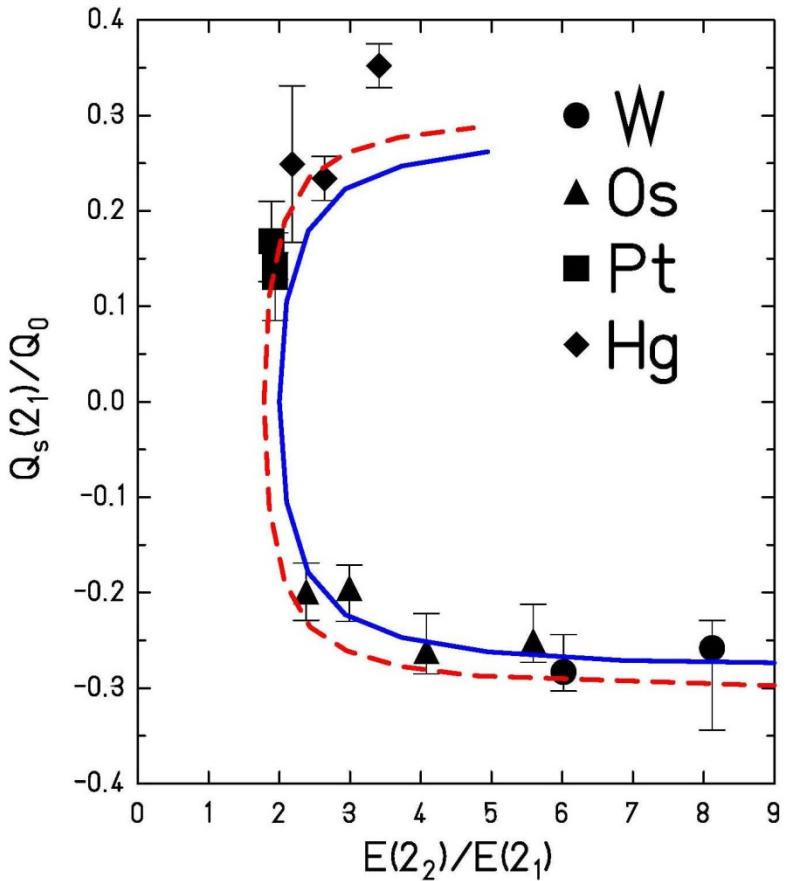
481	154		284	389	-
389	154		284	-	481
284	154		-	389	481
343	154	199	246	-	
246	154	199	-	343	370
199	154	-		389	481
154	134	154	246	343	284
134					389



Ta-nuclei: level schemes



Prolate-oblate shape transition



Pb190	Pt191	Pb192	Pb193	Pb194	Pb195	Pb196	Pb197	Pb198	Pb199	Pb200	Pb201	Pb202	Pb203	Pb204	Pb205	Pb206	Pb207	Pb208
1.2 m (2.3) EC, γ	1.3 m (2.3) EC, γ	3.2 m (3.2) EC	11.0 m (1.2) EC	11.0 m (1.2) EC	11.6 m (1.2) EC	33.0 m (1.2) EC	11.6 m (1.2) EC	1.84 m (1.2) EC	11.99 m (1.2) EC	11.99 m (1.2) EC	11.99 m (1.2) EC	11.99 m (1.2) EC	11.99 m (1.2) EC	11.99 m (1.2) EC	11.99 m (1.2) EC	11.99 m (1.2) EC	11.99 m (1.2) EC	
11139	11190	11191	11192	11193	11194	11195	11196	11197	11198	11199	11199	11199	11199	11199	11199	11199	11199	
1.2 m (1.2) EC	2.6 m (1.2) EC	9.6 m (1.2) EC	11.6 m (1.2) EC	11.6 m (1.2) EC	11.6 m (1.2) EC	33.0 m (1.2) EC	11.6 m (1.2) EC	1.84 m (1.2) EC	7.41 h (1.2) EC	24.1 h (1.2) EC	71.91 h (1.2) EC	112.0 h (1.2) EC						
Hg188	Hg189	Hg190	Hg191	Hg192	Hg193	Hg194	Hg195	Hg196	Hg197	Hg198	Hg199	Hg200	Hg201	Hg202	Hg203	Hg204	Hg205	
8.4 m (1.2) EC, γ																		
Au187	Au188	Au189	Au190	Au191	Au192	Au193	Au194	Au195	Au196	Au197	Au198	Au199	Au200	Au201	Au202	Au203	Au204	
8.4 m (1.2) EC, γ																		
Pr186	Pr187	Pr188	Pr189	Pr190	Pr191	Pr192	Pr193	Pr194	Pr195	Pr196	Pr197	Pr198	Pr199	Pr200	Pr201	Pr202	Pr203	
8.4 m (1.2) EC, γ																		
Ir185	Ir186	Ir187	Ir188	Ir189	Ir190	Ir191	Ir192	Ir193	Ir194	Ir195	Ir196	Ir197	Ir198	Ir199	Ir200	Ir201	Ir202	
14.4 h (1.2) EC	14.4 h (1.2) EC	10.5 h (1.2) EC	41.5 h (1.2) EC	13.4 h (1.2) EC	11.78 d (1.2) EC	73.83 d (1.2) EC	15.4 d (1.2) EC	15.4 d (1.2) EC	1.82 h (1.2) EC	1.28 h (1.2) EC	52.1 h (1.2) EC	5.8 h (1.2) EC	1.28 h (1.2) EC	1.28 h (1.2) EC	1.28 h (1.2) EC	1.28 h (1.2) EC	1.28 h (1.2) EC	
Os184	Os185	Os186	Os187	Os188	Os189	Os190	Os191	Os192	Os193	Os194	Os195	Os196	Os197	Os198	Os199	Os200	Os201	
5.6 d (1.2) EC, γ	9.8 d (1.2) EC, γ	2.0 d (1.2) EC, γ	1.0 d (1.2) EC, γ															
Re183	Re184	Re185	Re186	Re187	Re188	Re189	Re190	Re191	Re192	Re193	Re194	Re195	Re196	Re197	Re198	Re199	Re200	
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
W182	W183	W184	W185	W186	W187	W188	W189	W190	W191	W192	W193	W194	W195	W196	W197	W198	W199	
2.8 d (1.2) EC, γ																		
28.3	14.2	30.67	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	

108 110 112 114 116 118 120

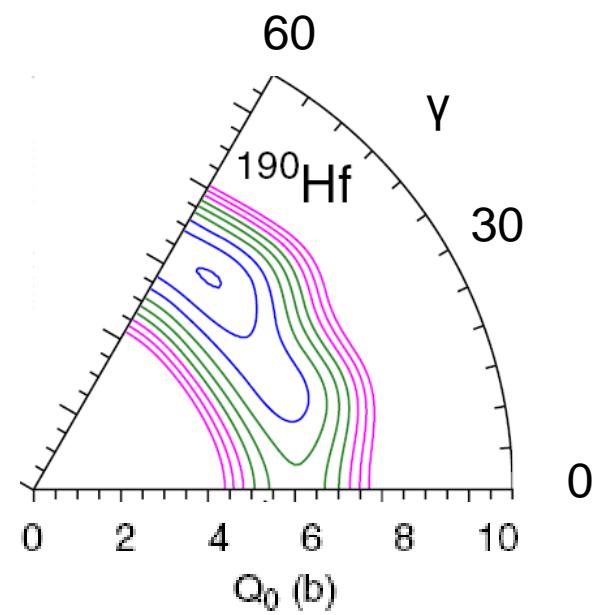
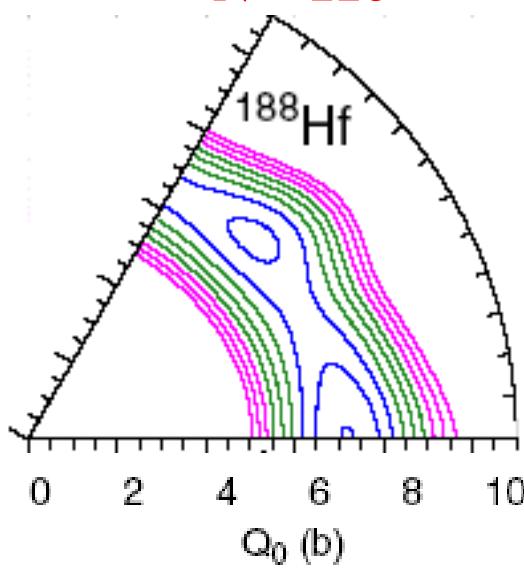
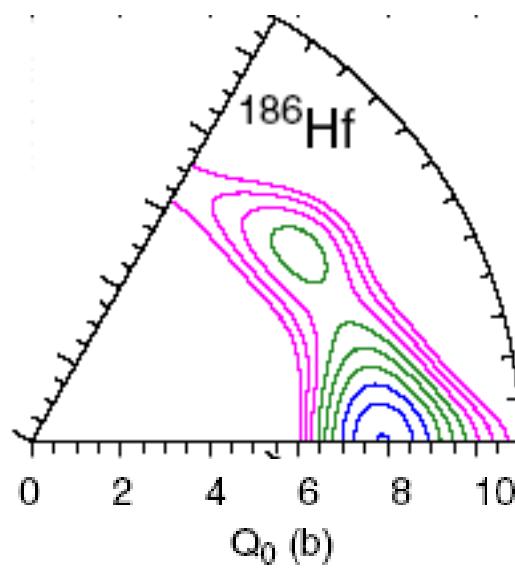
isotope	β	γ
^{182}W	0.274	11.4^0
^{184}W	0.258	13.8^0
^{186}W	0.223	15.9^0
^{186}Os	0.196	16.5^0
^{188}Os	0.185	19.2^0
^{190}Os	0.184	22.3^0
^{192}Os	0.168	25.2^0
^{192}Pt	0.146	-
^{194}Pt	0.134	-
^{196}Pt	0.135	-
^{198}Hg	0.106	36.3^0
^{200}Hg	0.098	39.1^0
^{202}Hg	0.082	33.4^0
^{204}Hg	0.068	31.5^0

Prolate-oblate shape transition

n-rich hafnium ground states

critical point

N = 116



Band crossing prediction in ^{180}Hf

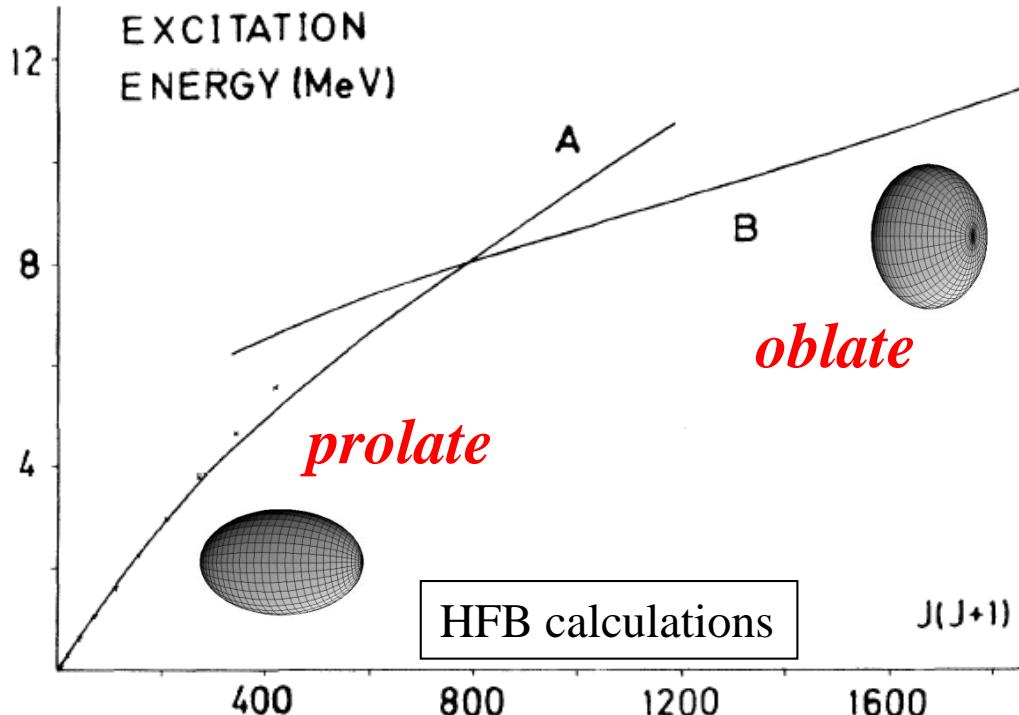
74	W	W158	W159	W160	W161	W162	W163	W164	W165	W166	W167	W168	W169	W170	W171	W172	W173	W174	W175	W176	W177	W178	W179	W180	W181	W182	W183	W184	W185	W186	W187	W188	W189	W190									
73	Ta	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180					
72	Hf	HH154	HH155	HH156	HH157	HH158	HH159	HH160	HH161	HH162	HH163	HH164	HH165	HH166	HH167	HH168	HH169	HH170	HH171	HH172	HH173	HH174	HH175	HH176	HH177	HH178	HH179	HH180	HH181	HH182	HH183	HH184	HH185	HH186	HH187	HH188	HH189	HH190					
71		12.8	13.0	13.1	13.2	13.3	13.4	13.5	13.6	13.7	13.8	13.9	14.0	14.1	14.2	14.3	14.4	14.5	14.6	14.7	14.8	14.9	15.0	15.1	15.2	15.3	15.4	15.5	15.6	15.7	15.8	15.9	16.0	16.1	16.2	16.3	16.4	16.5	16.6	16.7	16.8		
		12.0	12.2	12.4	12.6	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.2	14.4	14.6	14.8	15.0	15.2	15.4	15.6	15.8	16.0	16.2	16.4	16.6	16.8	17.0	17.2	17.4	17.6	17.8	18.0	18.2	18.4	18.6	18.8	19.0	19.2	19.4	19.6	19.8	19.9	20.0

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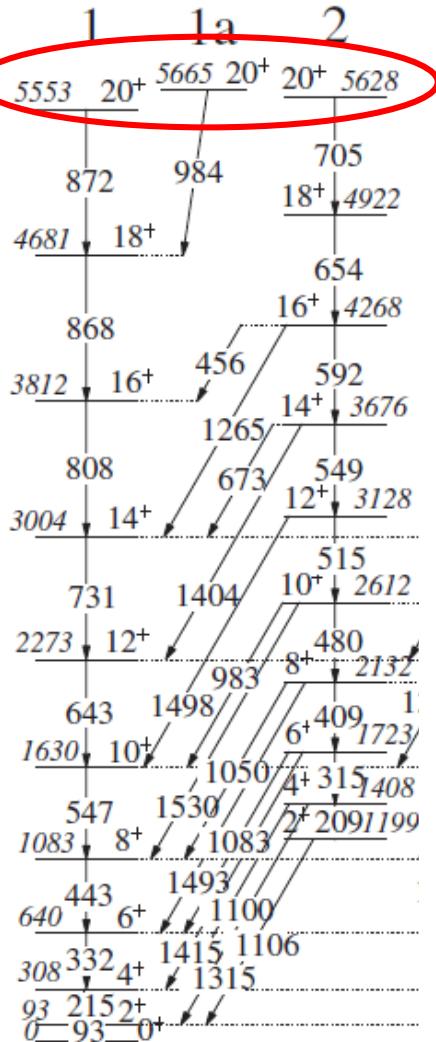
(Received 6 September 1979)

Giant backbending is predicted to occur in ^{180}Hf at $J \approx 26\hbar$. The effect is clearly seen to be the result of the crossing of two bands with very different intrinsic structure.



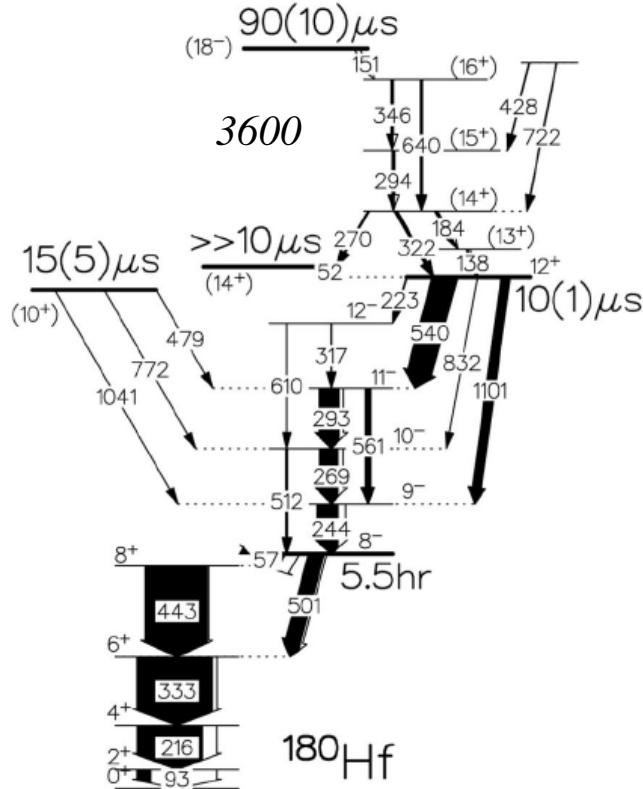
180Hf oblate band?

74	W154	W155	W159	W160	W161	W162	W163	W164	W165	W166	W167	W168	W169	W170	W171	W172	W173	W174	W175	W176	W177	W178	W179	W180	W181	W182	W183	W184	W185	W186	W187	W188	W189	W190		
73	1.23(24) 1.31(24) 1.23(24)	0.95(2) 0.95(2)	7.3(2)	9.1(2)	4.10(2)	1.39(2)	2.7(2)	5.1(2)	1.93(2)	2.0(2)	1.4(2)	2.0(2)	2.42(2)	2.38(2)	2.7(2)	2.0(2)	2.0(2)	2.0(2)	2.0(2)	2.0(2)	2.0(2)	2.0(2)	2.0(2)	2.0(2)	2.0(2)	2.0(2)	2.0(2)	2.0(2)	2.0(2)	2.0(2)	2.0(2)	2.0(2)	2.0(2)			
72	Ta	Ta156	Ta157	Ta158	Ta159	Ta160	Ta161	Ta162	Ta163	Ta164	Ta165	Ta166	Ta167	Ta168	Ta169	Ta170	Ta171	Ta172	Ta173	Ta174	Ta175	Ta176	Ta177	Ta178	Ta179	Ta180	Ta181	Ta182	Ta183	Ta184	Ta185	Ta186	Ta187	Ta188		
	Hf	Hf154	Hf155	Hf156	Hf157	Hf158	Hf159	Hf160	Hf161	Hf162	Hf163	Hf164	Hf165	Hf166	Hf167	Hf168	Hf169	Hf170	Hf171	Hf172	Hf173	Hf174	Hf175	Hf176	Hf177	Hf178	Hf179	Hf180	Hf181	Hf182	Hf183	Hf184	Hf185	Hf186	Hf187	Hf188

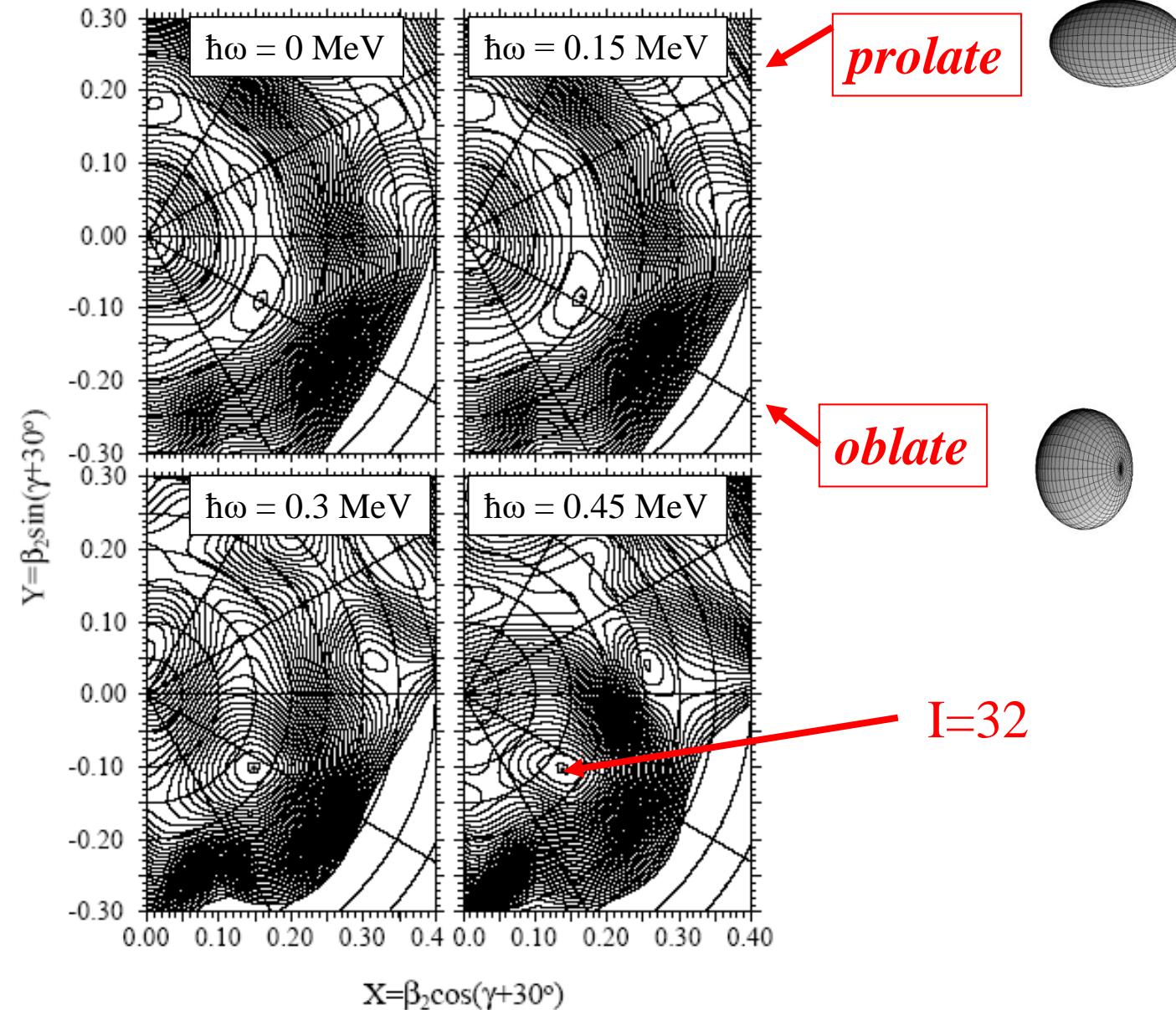


Tandel et al.,
Phys. Rev. Lett. 101 (2008) 182503
with Gammasphere

pre-Gammasphere
high-K yrast isomers:
d'Alarcao et al., Phys. Rev. C59 (1999) 1227(R)

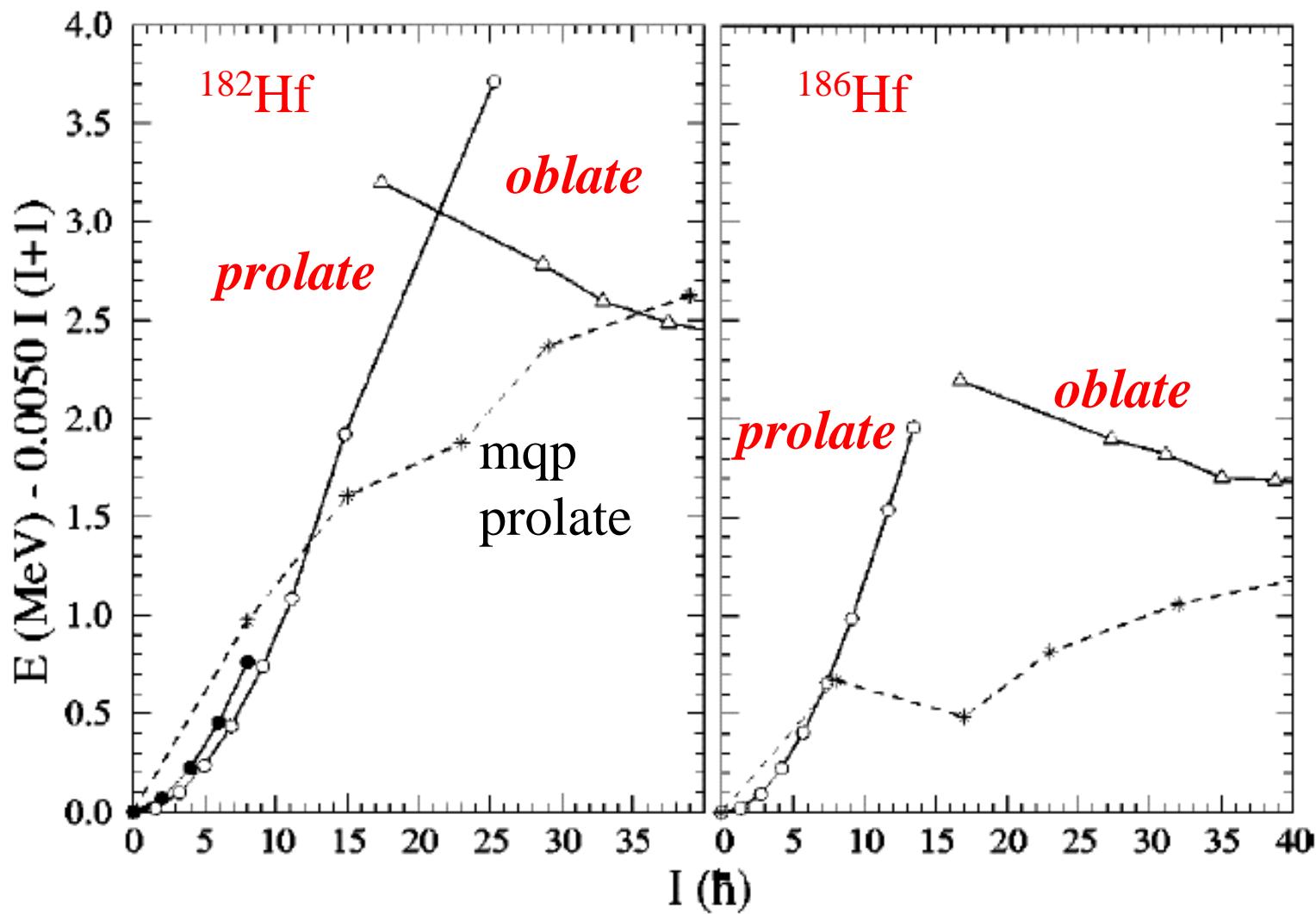


^{190}Hf TRS oblate rotor beyond the critical point



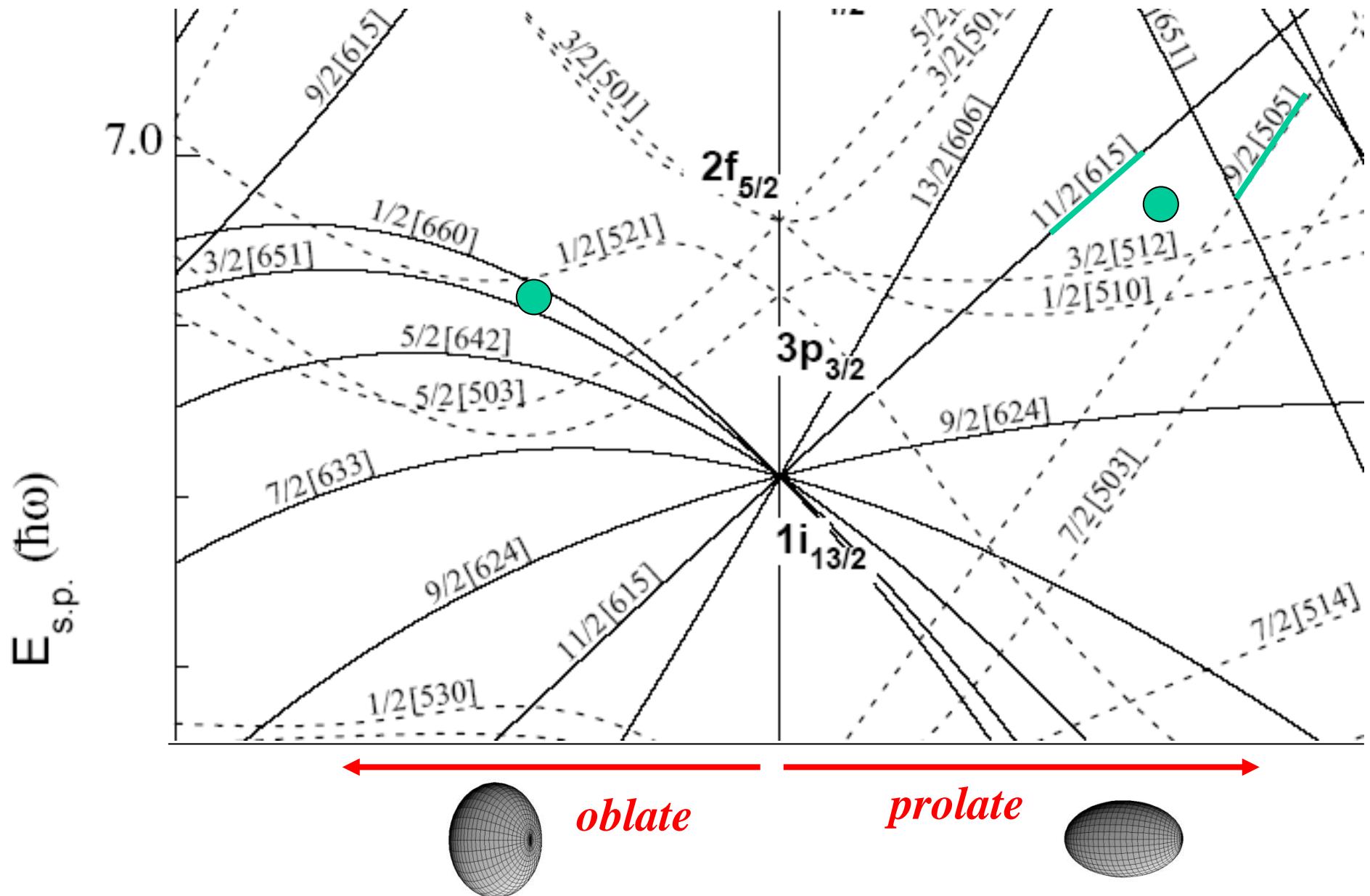
Xu et al., unpublished

Hf prolate vs oblate



Nilsson single-particle diagram

● N = 116 (^{188}Hf , ^{190}W , ^{192}Os)



Appendix: Odd-even nuclei

Er150 18.5 s 0+	Er151 23.5 s (7/2-) \pm	Er152 10.3 s 0+ (7/2-)	Er153 3.75 m 0+ (7/2-)	Er154 5.3 m 0+ (7/2-)	Er155 19.5 m 0+ (7/2-)	Er156 18.65 m 0+ (7/2-)	Er157 2.29 h 0+ (3/2-)	Er158 2.29 h 0+ (3/2-)	Er159 3.6 m 0+ (3/2-)	Er160 28.58 h 0+ (5/2-)	Er161 3.21 h 0+ (3/2-)	Er162 0.14 0+ (5/2-)	Er163 75.0 m 0+ (5/2-)	Er164 10.36 h 0+ (5/2-)	Er165 33.6 0+ (5/2-)	Er166 33.6 0+ (7/2+) \pm	Er167 22.95 0+ (7/2+) \pm	Er168 26.8 0+ (7/2+) \pm	Er169 9.40 d 0+ (1/2-)	Er170 14.9 0+ (1/2-)	Er171 7.516 h 0+ (5/2-)	Er172 49.3 h 0+ (7/2-)	Er173 1.4 m 0+ (7/2-)	Er174 3.3 m 0+ (9/2+)	Er175 1.2 m (9/2+)
EC	EC	EC	EC, α	EC, α	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC			
Hol149 21.1 s (11/2-) \pm	Hol150 72 s 2- \pm	Hol151 35.2 s 16.8 s (11/2-) \pm	Hol152 2.01 m 2- \pm	Hol153 11.76 m 11/2- \pm	Hol154 48 m 11.76 m (2-) \pm	Hol155 56 m 48 m (4+) \pm	Hol156 12.6 m 11.3 m (5+) \pm	Hol157 33.05 m 12.6 m (4+) \pm	Hol158 33.05 m 11.3 m (5+) \pm	Hol159 25.6 m 2.48 h (5+) \pm	Hol160 4570 y 25.6 m (5+) \pm	Hol161 15.0 m 2.48 h (1+) \pm	Hol162 4570 y 15.0 m (1+) \pm	Hol163 29 m 4570 y (1+) \pm	Hol164 29 m 4570 y (1+) \pm	Hol165 100 7/2- \pm	Hol166 26.83 h 26.83 h 0- \pm	Hol167 2.99 m 3.1 h 7/2- \pm	Hol168 4.7 m 3.1 h 7/2- \pm	Hol169 2.76 m 3.1 h (6+) \pm	Hol170 53 s 53 s (7/2-)	Hol171 25 s 53 s (7/2-)	Hol172 25 s 53 s (7/2-)	Hol173 Hol174	Hol174 Hol174
EC	EC	EC, α	EC, α	EC, α	EC, α	EC, α	EC, α	EC	EC	EC	EC	EC	EC	EC, β	EC	EC	EC	EC	EC	EC	EC	EC			
Dy148 3.1 m 0+ (7/2-) \pm	Dy149 4.20 m 0+ (7/2-) \pm	Dy150 7.17 m 0+ (7/2-)	Dy151 17.9 m 0+ (7/2-)	Dy152 2.38 h 0+ (7/2-)	Dy153 6.4 h 0+ (7/2-)	Dy154 3.0E-6 y 0+ a	Dy155 9.9 h 0+ a	Dy156 3/2- \pm 0.06	Dy157 8.14 h 0+ a	Dy158 144.4 d 0+ 0.10	Dy159 144.4 d 0+ 0.10	Dy160 Dy161	Dy162 0+ 2.34	Dy163 5/2- \pm 18.9	Dy164 0+ 25.5	Dy165 2.334 h 0+ 24.9	Dy166 81.6 h 0+ 28.2	Dy167 62.0 m 0+ 0+ a	Dy168 8.7 m 0+ 0+ a	Dy169 39 s (5/2-) 0+ a	Dy170 Dy171	Dy171 Dy172	Dy172 Dy173	Dy173 Dy173	
EC	EC	EC, α	EC, α	EC, α	EC, α	a	a	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC			

$$\langle I - 2, K | M(E2) | I, K \rangle = \sqrt{\frac{15}{32\pi}} \cdot \sqrt{\frac{(I + K - 1) \cdot (I + K) \cdot (I - K - 1) \cdot (I - K)}{(I - 1) \cdot (2I - 1) \cdot I}} \cdot Q_2 e$$

$$\langle I_f | M(E2) | I_i \rangle \quad Q_2 (b)$$

¹⁶²Dy	2.32 \pm 0.02 eb	7.36 \pm 0.03
¹⁶³Dy	2.31 \pm 0.02 eb	7.29 \pm 0.12
¹⁶⁴Dy	2.38 \pm 0.01 eb	7.54 \pm 0.04
¹⁶⁶Er	2.42 \pm 0.01 eb	7.67 \pm 0.03
¹⁶⁷Er	2.24 \pm 0.01 eb	7.60 \pm 0.10
¹⁶⁸Er	2.40 \pm 0.02 eb	7.61 \pm 0.06

Appendix: Odd-even nuclei

Erl150 18.5 s 0+	Erl151 23.5 s (7/2-) ±	Erl152 10.3 s 0+	Erl153 37.1 s (7/2-)	Erl154 3.75 m 0+	Erl155 5.3 m 7/2-	Erl156 19.5 m 0+	Erl157 18.65 m 3/2- ±	Erl158 2.29 h 0+	Erl159 36 m 3/2-	Erl160 28.58 h 0+	Erl161 3.21 h 3/2-	Erl162 0.14 0+	Erl163 75.0 m 5/2-	Erl164 0.06 0+	Erl165 10.36 h 5/2-	Erl166 33.6 0+	Erl167 22.95 7/2+ ±	Erl168 26.8 0+	Erl169 9.40 d 1/2-	Erl170 14.9 0+	Erl171 7.516 h 0+	Erl172 49.3 h (7/2-)	Erl173 1.4 m 0+	Erl174 3.3 m (7/2-)	Erl175 1.2 m (9/2+)
EC	EC	EC	EC,α	EC,α	EC,α	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	β	β	β	β	β	β	β	β	β
Hol149 21.1 s (11/2-) ±	Hol150 72 s 2- ±	Hol151 35.2 s (11/2-) ±	Hol152 161.8 s 2- ±	Hol153 2.01 m 11/2- ±	Hol154 11.76 m 11/2- ±	Hol155 48 m 48 m	Hol156 12.6 m 5/2+ ±	Hol157 11.3 m (4+) ±	Hol158 33.05 m 7/2- ±	Hol159 25.6 m 5+ ±	Hol160 2.48 h 7/2- ±	Hol161 15.0 m 1+ ±	Hol162 4570 y 7/2- ±	Hol163 29 m 7/2- ±	Hol164 1+ ±	Hol165 100 7/2- ±	Hol166 26.83 h 0- ±	Hol167 2.99 m 7/2- ±	Hol168 4.7 m 3+ ±	Hol169 2.76 m 7/2- ±	Hol170 53 s (6+) ±	Hol171 25 s (7/2-)	Hol172 53 s (7/2-)	Hol173 Hol173	Hol174
EC	EC	EC	EC,α	EC,α	EC,α	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC,β	β	β	β	β	β	β	β	β	β	β
Dy148 3.1 m 0+	Dy149 4.20 m (7/2-) ±	Dy150 7.17 m 0+	Dy151 17.9 m 7/2(-)	Dy152 2.38 h 0+	Dy153 6.4 h 7/2(-)	Dy154 3.0E-6 y a	Dy155 9.9 h 3/2- ±	Dy156 0.06 a	Dy157 8.14 h 3/2- ±	Dy158 144.4 d 0+	Dy160 0+	Dy161 5/2+ ±	Dy162 0+	Dy163 5/2- ±	Dy164 0.10 0.10	Dy165 2.334 h 0+	Dy166 81.6 h 7/2+ ±	Dy167 620 m 0+	Dy168 8.7 m (1/2-)	Dy169 39 s (5/2-)	Dy170 0+	Dy171 Dy171	Dy172 0+	Dy173	
EC	EC	EC,α	EC,α	EC,α	EC,α	a	EC	EC	EC	EC	EC	EC	EC	EC	EC	β	β	β	β	β	β	β	β	β	β

$$\langle I-2, K | M(E2) | I, K \rangle = \sqrt{\frac{15}{32\pi}} \cdot \sqrt{\frac{(I+K-1) \cdot (I+K) \cdot (I-K-1) \cdot (I-K)}{(I-1) \cdot (2I-1) \cdot I}} \cdot Q_2 e$$

$$\langle I-1, K | M(E2) | I, K \rangle = -\sqrt{\frac{5}{16\pi}} \cdot \sqrt{\frac{3 \cdot (I+K) \cdot (I-K) \cdot K^2}{(I-1) \cdot I \cdot (I+1)}} \cdot Q_2 e$$

¹⁶³Dy:

$$\frac{B(E2; 5/2 \rightarrow 7/2)}{B(E2; 5/2 \rightarrow 9/2)} = 2.76 \pm 0.14 \text{ (} 2.86_{theo} \text{)}$$

¹⁶⁷Er:

$$\frac{B(E2; 7/2 \rightarrow 9/2)}{B(E2; 7/2 \rightarrow 11/2)} = 3.81 \pm 0.15 \text{ (} 3.89_{theo} \text{)}$$

Appendix: Odd-even nuclei

Erl50 18.5 s 0+	Erl51 23.5 s (7/2-) \pm	Erl52 10.3 s 0+ (7/2-)	Erl53 37.1 s 0+ (7/2-)	Erl54 3.75 m 0+ (7/2-)	Erl55 5.3 m 7/2-	Erl56 19.5 m 0+ EC	Erl57 18.65 m 3/2- EC	Erl58 2.29 h 0+ EC	Erl59 3.6 m 3/2- EC	Erl60 28.58 h 0+ EC	Erl61 3.21 h 3/2- EC	Erl62 0.14 0+ EC	Erl63 75.0 m 5/2- EC	Erl64 0+ 1.61 EC	Erl65 10.36 h 5/2- EC	Erl66 0+ 33.6 7/2+ \pm EC	Erl67 9.40 d 0+ 22.95 7/2+ \pm EC	Erl68 1/2- 0+ 26.8 7/2+ \pm EC	Erl69 7.516 h 5/2- 0+ 14.9 7/2+ \pm EC	Erl70 0+ Hol149 21.1 s (11/2-) \pm EC	Erl71 7.516 h 5/2- 0+ Hol150 72 s 2- \pm EC	Erl72 49.3 h 0+ 0+ Hol151 35.2 s 16.8 s 2- \pm EC	Erl73 1.4 m (7/2-) 0+ Hol152 2.01 m 11.2- \pm EC	Erl74 3.3 m 0+ 0+ Hol153 11.76 m 11.2- \pm EC	Erl75 1.2 m (9/2+) \pm 0+ Hol154 48 m 12.6 m 5/2+ \pm EC
Hol149 21.1 s (11/2-) \pm EC	Hol150 72 s 2- \pm EC	Hol151 35.2 s 16.8 s 2- \pm EC	Hol152 2.01 m 11.2- \pm EC	Hol153 11.76 m 11.2- \pm EC	Hol154 48 m 12.6 m 5/2+ \pm EC	Hol155 56 m 12.6 m 5/2+ \pm EC	Hol156 11.3 m 33.05 m (4+) \pm EC	Hol157 12.6 m 3.5+ \pm EC	Hol158 11.3 m 23.6 m 5+ \pm EC	Hol159 25.6 m 2.48 h 7/2- \pm EC	Hol160 25.6 m 2.48 h 5+ \pm EC	Hol161 15.0 m 2.48 h 7/2- \pm EC	Hol162 4570 y 1+ \pm EC	Hol163 29 m 1+ \pm EC	Hol164 29 m 1+ \pm EC	Hol165 100 7/2- \pm EC	Hol166 26.83 h 3.1 h 0- \pm EC	Hol167 2.99 m 3.1 h 7/2- \pm EC	Hol168 2.99 m 3.1 h 7/2- \pm EC	Hol169 4.7 m 2.76 m 0- \pm EC	Hol170 53 s 2.76 m (6+) \pm EC	Hol171 53 s (7/2-) 0+ Hol172 25 s 0+ EC	Hol173 Hol174 0+ Hol174		
Dy148 3.1 m 0+ EC	Dy149 4.20 m (7/2-) \pm EC	Dy150 7.17 m 0+ EC	Dy151 17.9 m 7/2(-) EC	Dy152 2.38 h 0+ EC	Dy153 6.4 h 7/2(-) EC	Dy154 3.0E-6 y 0+ EC	Dy155 9.9 h 3/2- EC	Dy156 0.06 EC	Dy157 0.06 EC	Dy158 144.4 d 0+ EC	Dy159 144.4 d 0+ EC	Dy160 0+ 2.34 EC	Dy161 52+ 0+ EC	Dy162 0+ 25.5 EC	Dy163 5/2- 0+ 24.9 EC	Dy164 0+ 28.2 EC	Dy165 2.334 h 0+ EC	Dy166 81.6 h 0+ EC	Dy167 81.6 h 0+ EC	Dy168 8.7 m 0+ EC	Dy169 8.7 m 0+ EC	Dy170 Dy171 0+ Dy172 0+ Dy173			
Dy149 4.20 m (7/2-) \pm EC	Dy150 7.17 m 0+ EC	Dy151 17.9 m 7/2(-) EC	Dy152 2.38 h 0+ EC	Dy153 6.4 h 7/2(-) EC	Dy154 3.0E-6 y 0+ EC	Dy155 9.9 h 3/2- EC	Dy156 0.06 EC	Dy157 0.06 EC	Dy158 144.4 d 0+ EC	Dy159 144.4 d 0+ EC	Dy160 0+ 2.34 EC	Dy161 52+ 0+ EC	Dy162 0+ 25.5 EC	Dy163 5/2- 0+ 24.9 EC	Dy164 0+ 28.2 EC	Dy165 2.334 h 0+ EC	Dy166 81.6 h 0+ EC	Dy167 81.6 h 0+ EC	Dy168 8.7 m 0+ EC	Dy169 8.7 m 0+ EC	Dy170 Dy171 0+ Dy172 0+ Dy173				

$^{11/2^-}$ — 0.282 $\tau = 0.38 \pm 0.07$ ns

$$\tau = \left\{ \sum_K \sum_{\ell} [\varepsilon_{N \rightarrow K}^2(\ell) + \delta_{N \rightarrow K}^2(\ell)] \right\}^{-1}$$

$^{9/2^-}$ — 0.167 $\tau = 0.49 \pm 0.09$ ns

$^{7/2^-}$ — 0.073 $\tau = 2.18 \pm 0.07$ ns

$^{5/2^-}$ — 0.0

$$\delta_{N \rightarrow M}(\ell) = \left\{ \frac{8\pi(\ell+1)}{\ell[(2\ell+1)!!]^2} \frac{1}{\hbar} \left(\frac{\hbar\omega}{\hbar c} \right)^{2\ell+1} \right\}^{1/2} \cdot (2I_N + 1)^{-1/2} \cdot \langle I_M | \mathcal{M}(\ell) | I_N \rangle$$

$$\delta_{N \rightarrow M}(E2) = \{1.225 \cdot 10^{13} \cdot E_{\gamma}^5 (MeV)^5\}^{1/2} \cdot (2I_n + 1)^{-1/2} \cdot \langle I_M | \mathcal{M}(E2) | I_N \rangle$$

$$\delta_{N \rightarrow M}(M1) = \{1.758 \cdot 10^{13} \cdot E_{\gamma}^3 (MeV)^3\}^{1/2} \cdot (2I_n + 1)^{-1/2} \cdot \langle I_M | \mathcal{M}(M1) | I_N \rangle$$

$$\varepsilon_{N \rightarrow M}^2(\ell) = \delta_{N \rightarrow M}^2(\ell) \cdot \alpha_{N \rightarrow M}(\ell)$$

conversion coefficient.: bricc.anu.edu.au

Appendix: Odd-even nuclei

Erl50 18.5; 0+	Erl51 23.5; (7/2)-	Erl52 10.3; 0+	Erl53 37.1; (7/2)-	Erl54 3.75 m 0+	Erl55 5.3 m 7/2-	Erl56 19.5 m 0+	Erl57 18.65 m 3/2- ±	Erl58 2.29 h 0+	Erl59 3.6 m 3/2-	Erl60 28.58 h 0+	Erl61 3.21 h 3/2-	Erl62 0.14 EC	Erl63 75.0 m 5/2-	Erl64 0+ EC	Erl65 10.36 h 5/2-	Erl66 0+ EC	Erl67 7/2+ ±	Erl68 0+ EC	Erl69 9.40 d 1/2-	Erl70 0+ EC	Erl71 7.516 h 5/2-	Erl72 49.3 h 0+	Erl73 1.4 m (7/2)-	Erl74 3.3 m 0+	Erl75 1.2 m (9/2+)
EC	EC	EC, <i>a</i>	EC, <i>a</i>	EC, <i>a</i>	EC, <i>a</i>	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	33.6	22.95	26.8	β	14.9	β	β	β	β	β
Hol49 21.1; (11/2)-	Hol50 72; 2- ±	Hol51 35.2; 16.8;	Hol52 2.01 m 2- ±	Hol53 11.76 m 11/2- ±	Hol54 48 m 11/2- ±	Hol55 56 m 5/2+	Hol56 12.6 m (4+) ±	Hol57 11.3 m 7/2-	Hol58 33.05 m 5+ ±	Hol59 25.6 m 7/2- ±	Hol60 2.48 h 5+ ±	Hol61 15.0 m 7/2- ±	Hol62 4570 y 1+ ±	Hol63 29 m 7/2- ±	Hol64 1+ ±	Hol65 100	Hol66 26.83 h β	Hol67 2.99 m 0- ±	Hol68 3.1 h 7/2- ±	Hol69 4.7 m 3+ ±	Hol70 2.76 m (6+) ±	Hol71 53 s (7/2-)	Hol72 25 s	Hol73 Hol74	Hol74
EC	EC	EC, <i>a</i>	EC, <i>a</i>	EC, <i>a</i>	EC, <i>a</i>	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	β	β	β	β	β	β	β	β	β	β
Dy148 3.1 m 0+	Dy149 4.20 m (7/2)-	Dy150 7.17 m 0+	Dy151 17.9 m 7/2(-)	Dy152 2.38 h 0+	Dy153 6.4 h 7/2(-)	Dy154 3.0E-6 y a	Dy155 9.9 h 3/2-	Dy156 0+	Dy157 3/2- ±	Dy158 0+	Dy159 144.4 d 3/2-	Dy160 0+	Dy161 52+ ±	Dy162 0+	Dy163 5/2- ±	Dy164 0.10	Dy165 2.334 h 2.34	Dy166 81.6 h 0+	Dy167 2.334 h 7/2+ ±	Dy168 81.6 h 0+	Dy169 39 s (5/2-)	Dy170 0+	Dy171 Dy172	Dy173 Dy173	
EC	EC	EC, <i>a</i>	EC, <i>a</i>	EC, <i>a</i>	EC, <i>a</i>	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	β	β	β	β	β	β	β	β	β	β

$^{11/2^-}$ ————— 0.282

$^{9/2^-}$ ————— 0.167 $\tau = 0.49 \pm 0.09 \text{ ns}$

$^{7/2^-}$ ————— 0.073 $\tau = 2.18 \pm 0.07 \text{ ns}$

$^{5/2^-}$ ————— 0.0

^{163}Dy

$$\tau = \left\{ \sum_K \sum_\ell [\varepsilon_{N \rightarrow K}^2(\ell) + \delta_{N \rightarrow K}^2(\ell)] \right\}^{-1}$$

Appendix: Odd-even nuclei

Erl50 18.5; 0+	Erl51 23.5; (7/2)-	Erl52 10.3; 0+	Erl53 37.1; (7/2)-	Erl54 3.75 m 0+	Erl55 5.3 m 7/2-	Erl56 19.5 m 0+	Erl57 18.65 m 3/2- ±	Erl58 2.29 h 0+	Erl59 3.6 m 3/2-	Erl60 28.58 h 0+	Erl61 3.21 h 3/2-	Erl62 0.14 0+	Erl63 75.0 m 5/2-	Erl64 10.36 h 5/2-	Erl65 33.6 0+	Erl66 9.40 d 7/2+ ±	Erl67 0+	Erl68 9.40 d 1/2-	Erl69 9.40 d 0+	Erl70 14.9 β	Erl71 7.516 h 5/2-	Erl72 49.3 h 0+	Erl73 1.4 m (7/2)-	Erl74 3.3 m 0+	Erl75 1.2 m (9/2+)
EC	EC	EC	EC,α	EC,α	EC,α	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC
Hol49 21.1; (11/2)-	Hol50 72; 2- ±	Hol51 35.2; (11/2)-	Hol52 161.8; 2- ±	Hol53 2.01 m 11/2- ±	Hol54 11.76 m 11/2- ±	Hol55 48 m 5/2+	Hol56 56 m (4+) ±	Hol57 12.6 m 7/2-	Hol58 11.3 m 5+ ±	Hol59 33.05 m 7/2- ±	Hol60 25.6 h 5+ ±	Hol61 2.48 h 7/2- ±	Hol62 15.0 m 7/2- ±	Hol63 4570 y 7/2- ±	Hol64 29 m 1+ ±	Hol65 100 7/2-	Hol66 26.83 h 0- ±	Hol67 2.99 m 7/2- ±	Hol68 3.1 h 7/2- ±	Hol69 4.7 m 7/2- ±	Hol70 2.76 m (6+) ±	Hol71 53 s (7/2-)	Hol72 25 s β	Hol73 Hol73	Hol74 Hol74
EC	EC	EC	EC,α	EC,α	EC,α	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC
Dy148 3.1 m 0+	Dy149 4.20 m (7/2)-	Dy150 7.17 m 0+	Dy151 17.9 m 7/2(-)	Dy152 2.38 h 0+	Dy153 6.4 h 7/2(-)	Dy154 3.0E-6 y 0+	Dy155 9.9 h 3/2-	Dy156 Dy156 0.06	Dy157 3/2- ±	Dy158 Dy158 0.10	Dy159 144.4 d 3/2-	Dy160 0+	Dy161 5/2+ ±	Dy162 0+	Dy163 5/2- ±	Dy164 0+	Dy165 2.334 h 7/2+ ±	Dy166 81.6 h 0+	Dy167 81.6 h 7/2+ ±	Dy168 6.20 m (1/2-)	Dy169 39 s (5/2-)	Dy170 0+	Dy171 Dy171	Dy172 Dy172	Dy173 Dy173
EC	EC	EC	EC,α	EC,α	EC,α	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC	EC

$^{13/2} \text{—————}^+$ 0.295 $\tau = 0.38 \pm 0.07 \text{ ns}$

$$\tau = \left\{ \sum_K \sum_{\ell} [\varepsilon_{N \rightarrow K}^2(\ell) + \delta_{N \rightarrow K}^2(\ell)] \right\}^{-1}$$

$^{11/2} \text{—————}^+$ 0.178 $\tau = 0.49 \pm 0.09 \text{ ns}$

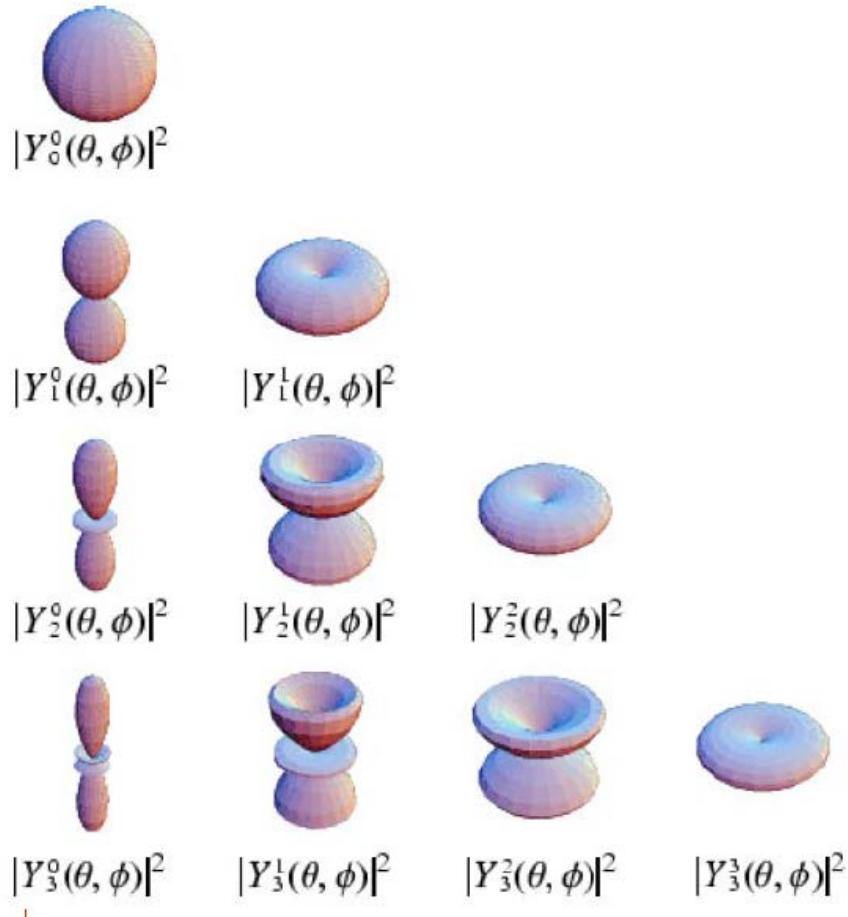
$^{9/2} \text{—————}^+$ 0.079 $\tau = 2.18 \pm 0.07 \text{ ns}$

$^{7/2} \text{—————}^+$ 0.0

^{167}Er

Spin I	E_{γ} (MeV)	$(2I+1)^{-1/2}$	$\langle I-1//M()//I\rangle$	delta	α_T	ε^2	τ (ns)
7/2	0.0734	0.3536	-3.886 (E2)	-7019.1	8.9	$4.38 \cdot 10^8$	2.05
9/2	0.0939	0.3162	0.108 (M1)	3183.7	5.7	$5.78 \cdot 10^7$	1.80
	0.167	0.3162	-4.002 (E2)	-11968	3.4	$4.87 \cdot 10^8$	1.59
			0.153 (M1)	5837.1	2.9	$9.88 \cdot 10^7$	1.31
			2.299 (E2)	29133	0.4	$3.65 \cdot 10^8$	0.51

Appendix: Spherical harmonics



$$Y_{00}(\theta, \phi) = \frac{1}{\sqrt{4\pi}}$$

$$Y_{10}(\theta, \phi) = \frac{1}{2} \cdot \sqrt{\frac{3}{\pi}} \cdot \cos \theta$$

$$Y_{1\pm 1}(\theta, \phi) = \mp \frac{1}{2} \cdot \sqrt{\frac{3}{2\pi}} \cdot \sin \theta \cdot e^{\pm i\phi}$$

$$Y_{20}(\theta, \phi) = \sqrt{\frac{5}{16\pi}} \cdot (3 \cdot \cos^2 \theta - 1)$$

$$Y_{2\pm 1}(\theta, \phi) = \mp \sqrt{\frac{15}{8\pi}} \cdot \sin \theta \cdot \cos \theta \cdot e^{\pm i\phi}$$

$$Y_{2\pm 2}(\theta, \phi) = \sqrt{\frac{15}{32\pi}} \cdot \sin^2 \theta \cdot e^{\pm 2i\phi}$$

$$Y_{30}(\theta, \phi) = \sqrt{\frac{7}{16\pi}} \cdot (2 \cos^3 \theta - 3 \cos \theta \sin^2 \theta)$$

$$Y_{3\pm 1}(\theta, \phi) = \mp \sqrt{\frac{21}{64\pi}} \cdot (4 \cos^2 \theta \sin \theta - \sin^3 \theta) \cdot e^{\pm i\phi}$$

$$Y_{3\pm 2}(\theta, \phi) = \sqrt{\frac{105}{32\pi}} \cdot \cos \theta \sin^2 \theta \cdot e^{(\pm 2)i\phi}$$

$$Y_{3\pm 3}(\theta, \phi) = \mp \sqrt{\frac{35}{64\pi}} \cdot \sin^3 \theta \cdot e^{(\pm 3)i\phi}$$