^{232}Th(p,2nγ) 1996Le01,2003Wu03

History

Type	Author	Citation	Literature Cutoff Date
Full Evaluation	Balraj Singh, Jagdish K. Tuli, and Edgardo Browne	NDS 185, 560 (2022)	31-Aug-2022

1996Le01 (also 1992De51): E(p)=14 MeV. Targets=200-500 mg/cm^2 thick. Measured Eγ, Iγ, $\gamma(\theta)$(90° and 50°), ce, (ce)γ-coin, (ce)(ce)-coin using four Compton-suppressed HPGe for γ rays, and two iron-free orange magnetic spectrometers for electrons at the cyclotron facility of Bonn University. 1996Le01 also report results from experiments for Coulomb excitation, (d,d′), (p,p′), and ^{231}U decay. Results were reanalyzed by 2003Wu03, as listed in their Table 2.

1992De51 (same group as 1996Le01): 22 γ rays reported from 84.3 to 564.6 keV, with the placement of six γ rays in a band. Iγ(90°)/Iγ(50°) were reported for ten γ rays, listed here in comments. Multipolarities of seven transitions were determined from conversion electron data, but no details are provided. The γ ray intensities were determined in coincidence with conversion electrons for three transitions. Evaluators assume that 1996Le01 and 2003Wu03 supersede data in 1992De51.

^{231}Pa Levels

E(level)[†]	J$^\pi$[@]	E(level)[†]	J$^\pi$[@]	E(level)[†]	J$^\pi$[@]	E(level)[†]	J$^\pi$[@]
0.0[&]	3/2$^-$	183.58[d] *16*	5/2$^+$	351.2[&] *7*	(13/2$^-$)	542.4[a] *11*	11/2$^+$
9.183[‡&] *19*	1/2$^-$	189.0[b] *4*	(13/2$^+$)	351.93[#e] *15*	5/2$^-$	550.9[&] *8*	(17/2$^-$)
58.6[&] *3*	7/2$^-$	193.2[&] *7*	9/2$^-$	392.5[a] *4*	9/2$^+$	604.30[#f] *19*	(3/2$^-$)
77.68[&] *10*	5/2$^-$	218.53[c] *21*	7/2$^-$	395.98[#e] *14*	7/2$^-$	632.25[#f] *20*	(5/2$^-$)
84.17[b] *12*	5/2$^+$	247.45[#d] *16*	7/2$^+$	406.35[#d] *24*	(11/2$^+$)	678.1[#f] *4*	(7/2$^-$)
101.408[‡b] *4*	7/2$^+$	275.03[#c] *17*	9/2$^-$	409.7[a] *9*	7/2$^+$	705.0[a] *5*	(17/2$^+$)
102.269[‡b]	3/2$^+$	304.7[#d] *3*	(9/2$^+$)	424.7[#c] *3*	13/2$^-$	734.3[#f] *4*	(9/2$^-$)
111.87[b] *16*	9/2$^+$	317.9[a] *6*	3/2$^+$	450.57[#e] *17*	9/2$^-$	785.5[&] *5*	23/2$^-$
168.7[&] *3*	11/2$^-$	320.22[#e] *13*	3/2$^-$	520.4[#c] *4*	(15/2$^-$)	787.4[&] *9*	(21/2$^-$)
171.50[#] *25*	11/2$^+$	328.6[&] *4*	15/2$^-$	525.2[a] *4*	13/2$^+$	929.3[a] *6*	21/2$^+$
174.18[c] *17*	5/2$^-$	344.78[#c] *24*	11/2$^-$	535.6[&] *4*	19/2$^-$		

[†] From a least-squares fit to γ-ray energies.
[‡] Level energy from the Adopted Levels, kept fixed for fitting the present level scheme.
[#] Level from 2003Wu03.
[@] As given in 1996Le01, based on multipolarity assignment from (p,2nγ) experiment, and from Coulomb excitation results.
[&] Band(A): π1/2[530].
[a] Band(B): π1/2[400]+π1/2[660].
[b] Band(C): π3/2[651].
[c] Band(D): π5/2[512].
[d] Band(E): π5/2[642].
[e] Band(F): π3/2[532].
[f] Band(G): π3/2[521].

γ(^{231}Pa)

E$_\gamma$[†]	E$_i$(level)	J$^\pi_i$	E$_f$	J$^\pi_f$	Mult.[&]	Comments
(9.2[#])	9.183	1/2$^-$	0.0	3/2$^-$		
(17.2[#])	101.408	7/2$^+$	84.17	5/2$^+$		
(18.1[#])	102.269	3/2$^+$	84.17	5/2$^+$		
58.6 *3*	58.6	7/2$^-$	0.0	3/2$^-$	(E2)	Iγ=5.4 *15* (coin with ce(L2)(110γ)), 2.0 *6* (coin with ce(L2)(160γ)), 0.7 *2* (coin with ce(L2)(207γ)).

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^{232}Th(p,2nγ) 1996Le01,2003Wu03 (continued)

γ(^{231}Pa) (continued)

Eγ[†]	Iγ[@]	Ei(level)	J^π_i	Ef	J^π_f	Mult.[&]	Comments
x60.5[‡] 3	0.8 2						
(68.5 1)		77.68	5/2−	9.183	1/2−		Eγ: from the Adopted Gammas.
72.8[‡] 2	3.1 1	174.18	5/2−	101.408	7/2+		Iγ=16 3 (coin with ce(L2)(59γ)), 4.2 12 (coin with ce(L2)(110γ)), 1.0 3 (coin with ce(L2)(160γ)), 0.4 1 (coin with ce(L2)(207γ)).
(77.5)		189.0	(13/2+)	111.87	9/2+		Eγ: from Coulomb excitation. Not seen in ^{232}Th(p,2nγ).
81.6[a‡] 3	1.3[a] 1	183.58	5/2+	102.269	3/2+		
81.6[a‡] 3	1.3[a] 1	183.58	5/2+	101.408	7/2+		
84.0 4		84.17	5/2+	0.0	3/2−		Iγ=16 3 (coin with ce(L2)(59γ)), 7.8 23 (coin with ce(L2)(110γ)), 2.1 6 (coin with ce(L2)(160γ)), 1.6 5 (coin with ce(L2)(207γ)).
89.9[‡] 3	12 2	174.18	5/2−	84.17	5/2+		
100.4[‡] 8	0.8 2	275.03	9/2−	174.18	5/2−		
106.6[‡] 6	1.0 6	218.53	7/2−	111.87	9/2+		
110.2 2		168.7	11/2−	58.6	7/2−	(E2)	Iγ=80 8 (coin with ce(L2)(59γ)), 23.6 24 (coin with ce(L2)(160γ)), 3.3 10 (coin with ce(L2)(207γ)).
(115.5)		193.2	9/2−	77.68	5/2−		Eγ: from Coulomb excitation. Not seen in ^{232}Th(p,2nγ).
116.8[‡] 8	1.5 1	218.53	7/2−	101.408	7/2+		
121.1[‡] 8	0.4 2	304.7	(9/2+)	183.58	5/2+		
126.3[‡] 5	0.6 2	344.78	11/2−	218.53	7/2−		
x128.4 3							Iγ=2.0 6 (coin with ce(L2)(110γ)), 2.0 6 (coin with ce(L2)(160γ)), 1.1 3 (coin with ce(L2)(207γ)).
132.7 9		525.2	13/2+	392.5	9/2+		Iγ=6.5 20 (coin with ce(L2)(59γ)).
134.4[‡] 2	1.9 1	218.53	7/2−	84.17	5/2+		
134.6 9		193.2	9/2−	58.6	7/2−		Iγ=12 3 (coin with ce(L2)(59γ)), <0.4 (coin with ce(L2)(110γ)), <0.4 (coin with ce(L2)(160γ)), <0.4 (coin with ce(L2)(207γ)).
135.7[‡] 5	0.6 2	247.45	7/2+	111.87	9/2+		
136.4[‡] 3	0.85 8	320.22	3/2−	183.58	5/2+		
x139.5[‡] 5	0.6 2						
139.5 5		328.6	15/2−	189.0	(13/2+)		Iγ<0.4 (coin with ce(L2)(110γ)), <0.4 (coin with ce(L2)(160γ)), 1.6 5 (coin with ce(L2)(207γ)).
x141.9 4							Iγ=4.6 14 (coin with ce(L2)(110γ)), <0.4 (coin with ce(L2)(160γ)), 0.6 2 (coin with ce(L2)(207γ)).
145.9[‡] 2	0.4 2	247.45	7/2+	101.408	7/2+		
x155.5[‡] 3	0.6 2						
158.8[‡] 5	0.4 2	406.35	(11/2+)	247.45	7/2+		
160.0 2		328.6	15/2−	168.7	11/2−	(E2)	Iγ=100 10 (coin with ce(L2)(59γ)), 100 10 (coin with ce(L2)(110γ)), 8.6 26 (coin with ce(L2)(207γ)). Iγ(50°)/Iγ(90°)=1.00 4 (1992De51), normalized to 1.0 for ΔJ=2, E2.
163.5[a‡] 3	1.40[a] 9	247.45	7/2+	84.17	5/2+		
163.5[a‡] 3	1.40[a] 9	275.03	9/2−	111.87	9/2+		
x171.5 4							Iγ=9 3 (coin with ce(L2)(59γ)), 3.6 12 (coin with ce(L2)(110γ)), <0.4 (coin with ce(L2)(160γ)), <0.4 (coin with ce(L2)(207γ)).
173.5[‡] 2	3.17 5	275.03	9/2−	101.408	7/2+		Eγ: 173.2 6 in 1996Le01, unplaced.

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^{232}Th(p,2nγ) 1996Le01,2003Wu03 (continued)

γ(^{231}Pa) (continued)

E_γ[†]	I_γ[@]	E_i(level)	J^π_i	E_f	J^π_f	Mult.[&]	Comments
							Iγ=9 *3* (coin with ce(L2)(59γ)), 1.2 *4* (coin with ce(L2)(160γ)), 0.4 *1* (coin with ce(L2)(207γ)).
[x]176.8 *6*							Iγ<0.4 (coin with ce(L2)(110γ)), 1.7 *5* (coin with ce(L2)(160γ)), 1.4 *4* (coin with ce(L2)(207γ)).
180.0 *9*		705.0	(17/2$^+$)	525.2	13/2$^+$		Iγ=0.8 *3* (coin with ce(L2)(110γ)), 0.4 *1* (coin with ce(L2)(160γ)).
182.5 *6*		351.2	(13/2$^-$)	168.7	11/2$^-$		Iγ=2.0 *6* (coin with ce(L2)(110γ)), <0.4 (coin with ce(L2)(160γ)).
[x]186.3 *5*							Iγ=4.5 *15* (coin with ce(L2)(110γ)), 1.4 *4* (coin with ce(L2)(160γ)), 0.8 *3* (coin with ce(L2)(207γ)).
[x]196.9[‡] *2*	1.0 *1*					(E1)	Mult.: from 1992De51. Iγ(50°)/Iγ(90°)=1.23 *9* (1992De51).
196.9 *3*		525.2	13/2$^+$	328.6	15/2$^-$	(E1)	Iγ=30 *3* (coin with ce(L2)(59γ)), 12.2 *25* (coin with ce(L2)(110γ)), 12.0 *24* (coin with ce(L2)(160γ)), 0.8 *3* (coin with ce(L2)(207γ)).
199.7 *3*		550.9	(17/2$^-$)	351.2	(13/2$^-$)	(E2)	Iγ=14 *3* (coin with ce(L2)(59γ)), 14.5 *29* (coin with ce(L2)(110γ)), 13.0 *26* (coin with ce(L2)(160γ)). Iγ(50°)/Iγ(90°)=1.09 *7* (1992De51).
203.3[‡] *3*	0.8 *2*	304.7	(9/2$^+$)	101.408	7/2$^+$		
207.0 *2*		535.6	19/2$^-$	328.6	15/2$^-$	(E2)	Iγ=20 *4* (coin with ce(L2)(59γ)), 19.8 *40* (coin with ce(L2)(110γ)), 19.8 *40* (coin with ce(L2)(160γ)). Iγ(50°)/Iγ(90°)=0.98 *5* (1992De51).
218.2[‡] *2*	4.1 *1*	320.22	3/2$^-$	102.269	3/2$^+$	(E1)	Eγ=218.2 *2*, E1 in 1996Le01, unplaced. Iγ=41 *4* (coin with ce(L2)(59γ)), 39 *4* (coin with ce(L2)(110γ)), 1.8 *6* (coin with ce(L2)(160γ)), 1.8 *6* (coin with ce(L2)(207γ)). Iγ(50°)/Iγ(90°)=1.21 *7* (1992De51, γ unplaced).
224.0 *4*		392.5	9/2$^+$	168.7	11/2$^-$		Iγ=4.0 *12* (coin with ce(L2)(110γ)).
224.2 *9*		929.3	21/2$^+$	705.0	(17/2$^+$)		Iγ=0.8 *3* (coin with ce(L2)(160γ)), 0.4 *1* (coin with ce(L2)(207γ)).
232.9[‡] *2*	2.8 *1*	344.78	11/2$^-$	111.87	9/2$^+$		Eγ=233.5 *4* in 1996Le01, unplaced. Iγ=3.2 *9* (coin with ce(L2)(110γ)), 1.0 *3* (coin with ce(L2)(160γ)), 0.6 *2* (coin with ce(L2)(207γ)).
235.8[b‡] *2*	0.96[b] *10*	320.22	3/2$^-$	84.17	5/2$^+$		I_γ: total intensity of 1.3 *1* between the placements from 320 and 425 levels divided by evaluators from Iγ(236γ)/Iγ(217γ)=0.233 *9* in the Adopted Levels, Gammas dataset.
235.8[b‡] *2*	0.34[b] *10*	424.7	13/2$^-$	189.0	(13/2$^+$)		I_γ: 1.3 *1*−0.96 *10*.
236.5 *5*		787.4	(21/2$^-$)	550.9	(17/2$^-$)		Iγ=4 *1* (coin with ce(L2)(59γ)), 3.3 *10* (coin with ce(L2)(160γ)), 1.7 *5* (coin with ce(L2)(207γ)).
[x]238.4[‡] *4*	0.4 *2*						
240.2 *5*		317.9	3/2$^+$	77.68	5/2$^-$		Iγ=40 *4* (coin with ce(L2)(59γ)), <0.4 (coin with ce(L2)(110γ)), <0.4 (coin with ce(L2)(160γ)), 1.2 *4* (coin with ce(L2)(207γ)).
249.9 *3*		785.5	23/2$^-$	535.6	19/2$^-$		Iγ=3.4 *10* (coin with ce(L2)(110γ)), 1.8 *6* (coin with ce(L2)(160γ)), 1.8 *6* (coin with ce(L2)(207γ)).
250.2[a‡] *3*	2.4[a] *1*	351.93	5/2$^-$	102.269	3/2$^+$		
250.2[a‡] *3*	2.4[a] *1*	351.93	5/2$^-$	101.408	7/2$^+$		
253.2[‡] *2*	2.30 *5*	424.7	13/2$^-$	171.50	11/2$^+$		Eγ=253.2 *3* in 1996Le01, unplaced. Iγ=25 *3* (coin with ce(L2)(59γ)), <0.4 (coin with

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^{232}Th(p,2nγ) 1996Le01,2003Wu03 (continued)

γ(^{231}Pa) (continued)

Eγ[†]	Iγ[@]	Ei(level)	J^π_i	Ef	J^π_f	Mult.[&]	Comments
							ce(L2)(110γ)), 1.2 *4* (coin with ce(L2)(160γ)), 1.4 *4* (coin with ce(L2)(207γ)).
[x]255.3 *2*							Iγ=20 *4* (coin with ce(L2)(59γ)), 31.5 *32* (coin with ce(L2)(110γ)), 6.5 *20* (coin with ce(L2)(160γ)), <0.4 (coin with ce(L2)(207γ)). Iγ(50°)/Iγ(90°)=1.46 *15* (1992De51).
[x]259.8 *8*							Iγ=32 *3* (coin with ce(L2)(59γ)).
267.8[‡] *2*	1.60 *7*	351.93	5/2⁻	84.17	5/2⁺		
[x]271.0 *4*							Iγ=1.2 *4* (coin with ce(L2)(207γ)).
[x]274.6 *4*							Iγ=4.3 *13* (coin with ce(L2)(110γ)), <0.4 (coin with ce(L2)(160γ)).
279.1[‡] *2*	1.46 *7*	450.57	9/2⁻	171.50	11/2⁺		
280.6[‡] *3*	0.5 *2*	632.25	(5/2⁻)	351.93	5/2⁻		
284.1[a‡] *2*	0.9[a] *1*	395.98	7/2⁻	111.87	9/2⁺		
284.1[a‡] *2*	0.9[a] *1*	604.30	(3/2⁻)	320.22	3/2⁻		
294.5[a‡] *2*	0.9[a] *1*	395.98	7/2⁻	101.408	7/2⁺		
294.5[a‡] *2*	0.9[a] *1*	406.35	(11/2⁺)	111.87	9/2⁺		
311.9[a‡] *2*	2.1[a] *1*	395.98	7/2⁻	84.17	5/2⁺		
311.9[a‡] *2*	2.1[a] *1*	632.25	(5/2⁻)	320.22	3/2⁻		
[x]321.7 *6*						(E1)	Iγ=6.4 *19* (coin with ce(L2)(110γ)), <0.4 (coin with ce(L2)(207γ)).
326.2[‡] *3*	1.0 *2*	678.1	(7/2⁻)	351.93	5/2⁻		
331.4[‡] *2*	0.8 *1*	520.4	(15/2⁻)	189.0	(13/2⁺)		
332.0 *9*		409.7	7/2⁺	77.68	5/2⁻		Iγ=3.6 *11* (coin with ce(L2)(110γ)), 1.4 *4* (coin with ce(L2)(160γ)).
333.8 *3*		392.5	9/2⁺	58.6	7/2⁻		Iγ=100 *10* (coin with ce(L2)(59γ)).
338.3[a‡] *3*	0.5[a] *2*	450.57	9/2⁻	111.87	9/2⁺		
338.3[a‡] *3*	0.5[a] *2*	734.3	(9/2⁻)	395.98	7/2⁻		
349.2 *5*		542.4	11/2⁺	193.2	9/2⁻		Iγ<0.4 (coin with ce(L2)(110γ)), <0.4 (coin with ce(L2)(160γ)), 0.9 *3* (coin with ce(L2)(207γ)).
349.3[‡] *2*	2.3 *1*	450.57	9/2⁻	101.408	7/2⁺		
356.4 *2*		525.2	13/2⁺	168.7	11/2⁻	(E1)	Iγ=68 *7* (coin with ce(L2)(59γ)), 67 *7* (coin with ce(L2)(110γ)). Iγ(50°)/Iγ(90°)=1.22 *7* (1992De51, γ unplaced).
[x]365.4 *4*							Iγ=54 *5* (coin with ce(L2)(59γ)).
376.4 *3*		705.0	(17/2⁺)	328.6	15/2⁻	(E1)	Iγ=21 *2* (coin with ce(L2)(59γ)), 22.0 *22* (coin with ce(L2)(110γ)), 21.4 *22* (coin with ce(L2)(160γ)). Iγ(50°)/Iγ(90°)=1.50 *8* (1992De51, γ unplaced).
393.8 *5*		929.3	21/2⁺	535.6	19/2⁻		Iγ=1.6 *5* (coin with ce(L2)(110γ)), 2.4 *7* (coin with ce(L2)(160γ)), 1.2 *4* (coin with ce(L2)(207γ)).
[x]403.9[‡] *2*	1.4 *1*						
[x]406.2[‡] *2*	1.1 *1*						
[x]415.6 *3*							Iγ=20 *4* (coin with ce(L2)(59γ)), 32.7 *33* (coin with ce(L2)(110γ)), 1.4 *4* (coin with ce(L2)(160γ)). Iγ(50°)/Iγ(90°)=1.05 *10* (1992De51).
420.7[‡] *2*	1.3 *1*	604.30	(3/2⁻)	183.58	5/2⁺		
[x]459.6 *5*							Iγ=10.2 *31* (coin with ce(L2)(110γ)), 9.2 *28* (coin with ce(L2)(160γ)). Iγ(50°)/Iγ(90°)=1.38 *18* (1992De51).
[x]564.6 *5*							10.2 *31* (coin with ce(L2)(110γ)).

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^{232}Th(p,2nγ) 1996Le01,2003Wu03 (continued)

γ(^{231}Pa) (continued)

[†] From 1996Le01, unless otherwise stated.
[‡] From 2003Wu03.
[#] Rounded value from the Adopted Levels, Gammas dataset.
[@] From coincidence with 84.2-keV ce(L1) (2003Wu03). Intensities in coin with ce(L2)(111γ), ce(L2)(207γ), ce(L2)(160γ), and ce(L2)(59γ) from 1996Le01 are listed in comments. 1992De51 give a general statement for uncertainty, 10% for strong lines and 30% for weak lines. Evaluators assign 10% for Iγ>20, 20% for Iγ=10-20, and 30% for Iγ<10.
[&] From ce and $\gamma(\theta)$ data (1996Le01,1992De51). Authors give definite assignments, but as full details of the ce measurements are not available, evaluators assign these in parentheses.
[a] Multiply placed with undivided intensity.
[b] Multiply placed with intensity suitably divided.
[x] γ ray not placed in level scheme.

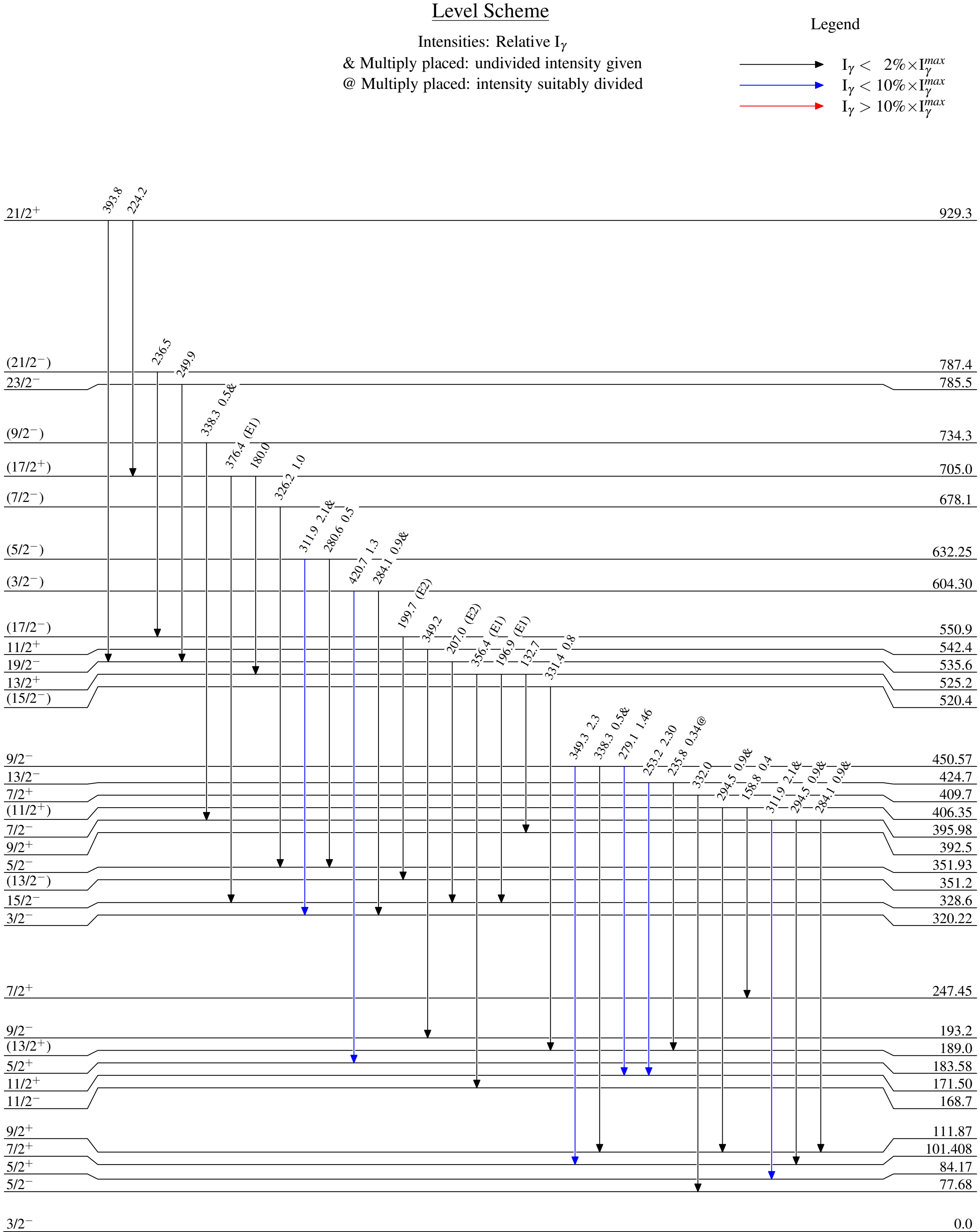
^{232}Th(p,2nγ) 1996Le01,2003Wu03

Level Scheme

Intensities: Relative I_γ

& Multiply placed: undivided intensity given

@ Multiply placed: intensity suitably divided



$^{231}_{91}Pa_{140}$

^{232}Th(p,2nγ) 1996Le01,2003Wu03

Level Scheme (continued)

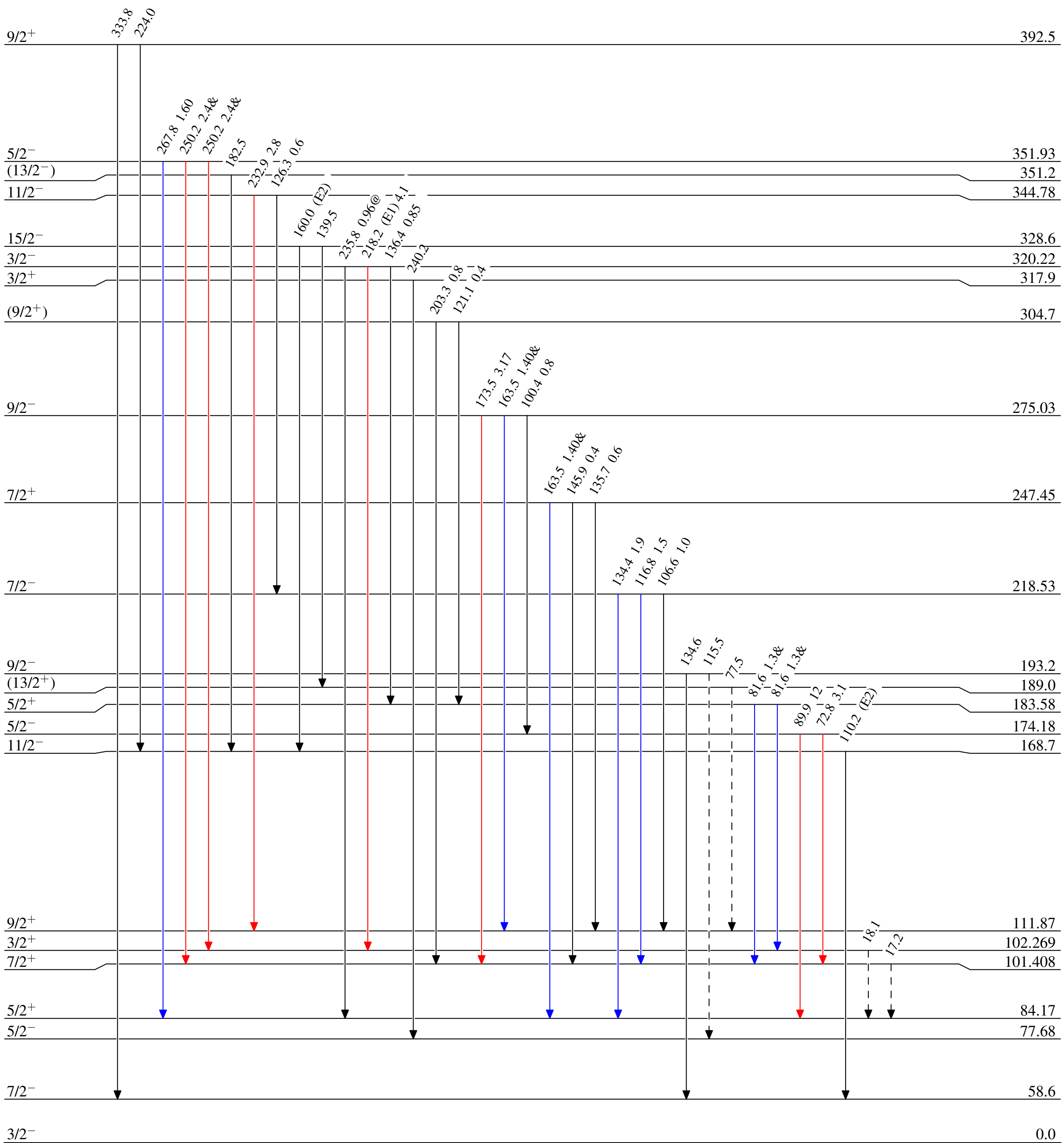
Intensities: Relative I_γ

& Multiply placed: undivided intensity given

@ Multiply placed: intensity suitably divided

Legend

- $I_\gamma < 2\% \times I_\gamma^{max}$
- $I_\gamma < 10\% \times I_\gamma^{max}$
- $I_\gamma > 10\% \times I_\gamma^{max}$
- γ Decay (Uncertain)



$^{231}_{91}Pa_{140}$

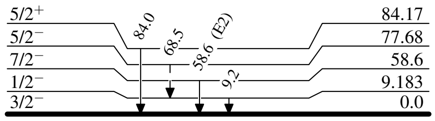
^{232}Th(p,2nγ) 1996Le01,2003Wu03

Level Scheme (continued)

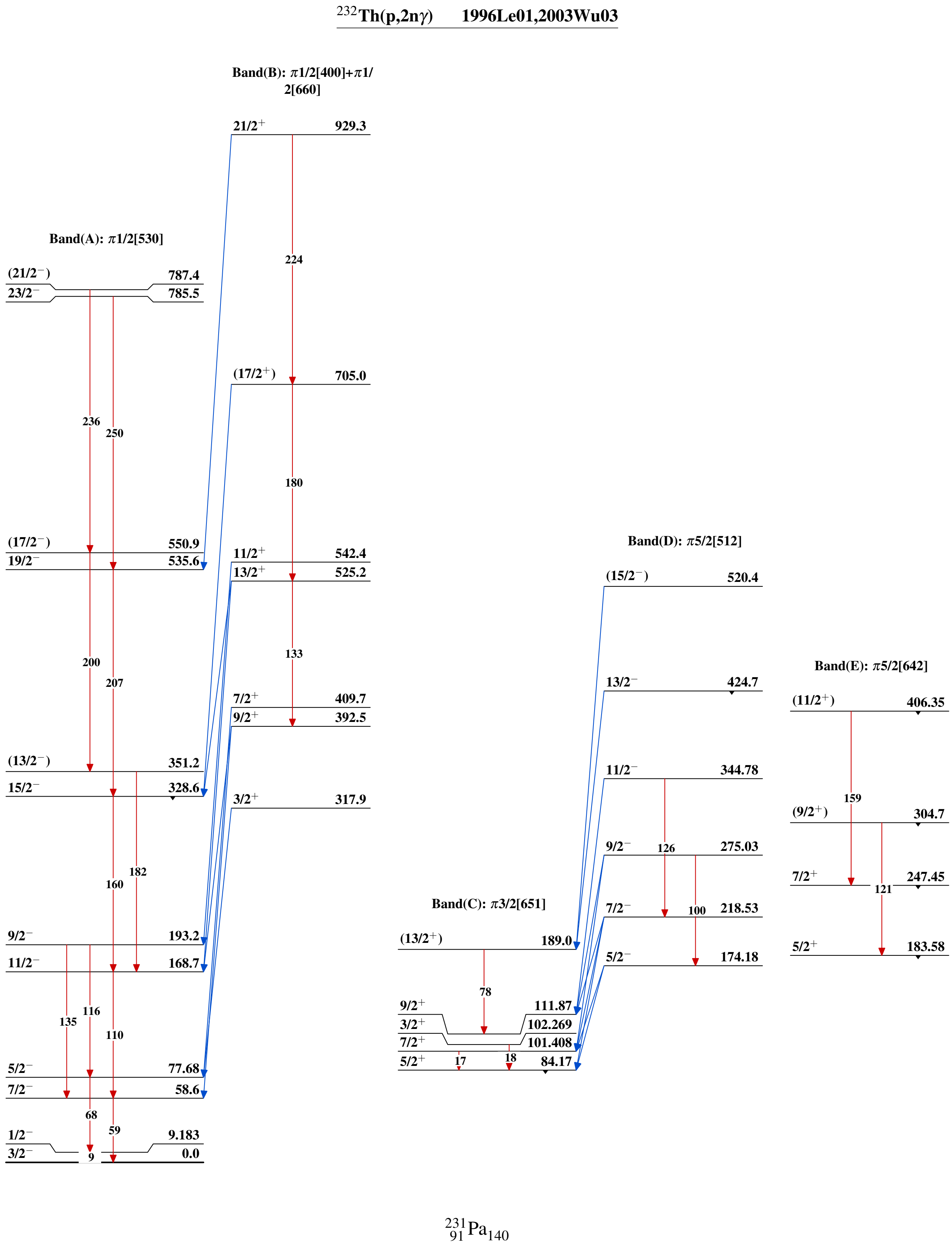
Intensities: Relative I_γ
& Multiply placed: undivided intensity given
@ Multiply placed: intensity suitably divided

Legend

γ Decay (Uncertain)

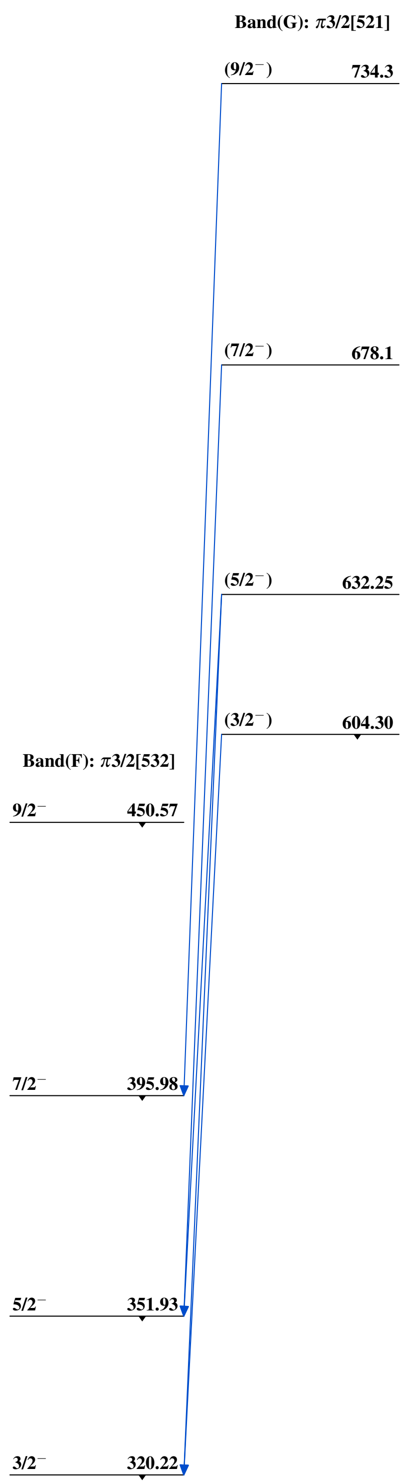


$^{231}_{91}Pa_{140}$



232Th(p,2nγ) 1996Le01,2003Wu03
Band(A): π1/2[530]
Band(B): π1/2[400]+π1/2[660]
Band(C): π3/2[651]
Band(D): π5/2[512]
Band(E): π5/2[642]
21/2+ 929.3
(21/2−) 787.4
23/2− 785.5
(17/2+) 705.0
(17/2−) 550.9
19/2− 535.6
11/2+ 542.4
13/2+ 525.2
(15/2−) 520.4
13/2− 424.7
7/2+ 409.7
9/2+ 392.5
(11/2+) 406.35
(13/2−) 351.2
15/2− 328.6
3/2+ 317.9
11/2− 344.78
(9/2+) 304.7
9/2− 275.03
7/2+ 247.45
7/2− 218.53
9/2− 193.2
(13/2+) 189.0
5/2+ 183.58
5/2− 174.18
11/2− 168.7
9/2+ 111.87
3/2+ 102.269
7/2+ 101.408
5/2+ 84.17
5/2− 77.68
7/2− 58.6
1/2− 9.183
3/2− 0.0
224
236
250
180
200
207
133
182
160
159
126
100
121
78
135
116
110
17
18
68
59
9
231 91 Pa 140

^{232}Th(p,2nγ) 1996Le01,2003Wu03 (continued)



$^{231}_{91}Pa_{140}$