Coulomb excitation 1989Ku23

Type	Author	History Citation	Literature Cutoff Date
Full Evaluation	C. Morse	NDS 197,259 (2024).	26-Sep-2023

$(\gamma)(\gamma)(\theta)$ was measured by 1989Ku23.

The level scheme is mainly that of 1989Ku23 which is based on the level scheme constructed in earlier Coulomb-excitation studies by 1984Ge03, except where otherwise noted.

See 1971Fo17, 1971Mc21, 1973Be44, 1977Mi11 for discussions, and for deduced quadrupole and hexadecapole deformation parameters.

1989Ku23: Coulomb excitation of ^{230}Th by ^{32}S, ^{84}Kr, and ^{142}Nd projectiles at the Munich tandem accelerator using three coaxial Ge(Li) detectors. Scattered projectiles were detected with gas-proportional counters. Measured E_γ, I_γ.

^{230}Th Levels

E(level)†	Jπ†	$T_{1/2}$	Comments
0.0‡	0^+		
53.20‡ *2*	2^+	0.352 ns *5*	B(E2)↑=8.06 *11* (1973Be44) Other measurements: B(E2)=11.1 *17*; ε(L12)B(E2)=4.4, (L1+L2/L3)=1.10 *15* (1961Re02). $T_{1/2}$: Deduced by evaluator from B(E2)=8.06 *11*, α=228.
174.10‡ *3*	4^+		
356.6‡ *5*	6^+		
508.16# *5*	1^-		
571.77# *10*	3^-		B(E3)↑=0.64 *6* (1974Mc15)
594.1‡ *5*	8^+		
634.9@ *1*	0^+		
677.6@ *1*	2^+	15 ps *2*	B(E2)↑=0.046 *6* (1974Mc15) $T_{1/2}$: Deduced by evaluator from B(E2)=0.046 *6* and branching(677γ)=0.35 *3* (see ^{230}Th adopted γ properties).
686.7#	5^-		
769.6@	4^+		
781.37& *5*	2^+	3.3 ps *5*	B(E2)↑=0.123 *13* (1974Mc15) $T_{1/2}$: Deduced by evaluator from B(E2)=0.123 *13* and branching(781γ)=0.43 *3* (see ^{230}Th Adopted Gammas).
825.8& *2*	3^+		
852.4#	7^-		
879.7‡	10^+		
883.6&	4^+		
951.94a *5*	1^-		
972.69a	2^-		
1009.7b *1*	2^+	≥0.8 ps	B(E2)↑≤0.084 *13* (1974Mc15) 1009- and 1012-keV levels were unresolved in experiment by 1974Mc15. If the excitation of 3-, 1012-keV level is taken as negligible, then B(E2)=0.084 *13* (1974Mc15). $T_{1/2}$: Deduced by evaluator from B(E2)≤0.097 and branching(1009γ)=0.29 *6* (see ^{230}Th Adopted Gammas). B(E2)=0.084 *13* yields $T_{1/2}$=0.93 ps *24*.
1012.5a *2*	3^-		B(E3)↑≤0.50 *7* (1974Mc15)
1040.0&	6^+		
1052.6b	3^+		
1065.6#	9^-		
1079.26c *10*	2^-		
1108.2b	4^+		

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Coulomb excitation 1989Ku23 (continued)

^{230}Th Levels (continued)

E(level)†	Jπ†	E(level)†	Jπ†	E(level)†	Jπ†	E(level)†	Jπ†
1109.0[a]	(5⁻)	1251.4[&]	8⁺	1949[#]	15⁻	2850[‡]	20⁺
1127.85[c] *10*	3⁻	1321.9[#]	11⁻	1971.5[‡]	16⁺	3125?[#]	(21⁻)
1178.6[b]	5⁺	1520.4[&]	10⁺	2313[#]	17⁻	3325[‡]	22⁺
1196.8[c]	(4⁻)	1572.9[‡]	14⁺	2397.8[‡]	18⁺	3812?[‡]	(24⁺)
1207.8[‡]	12⁺	1617.5[#]	13⁻	2706[#]	19⁻		

† Adopted values.
‡ Band(A): K=0⁺ g.s. rotational band.
# Band(B): K=0⁻ octupole-vibrational band.
@ Band(C): K=0⁺ β-vibrational band.
& Band(D): K=2⁺ γ-vibrational band.
a Band(E): K=1⁻ band.
b Band(F): K=2⁺ band.
c Band(G): K=2⁻ band.

$\gamma(^{230}Th)$

E_γ†	I_γ‡	E_i(level)	J_i^π	E_f	J_f^π	Mult.	α&	Comments
53.20 *2*		53.20	2⁺	0.0	0⁺	E2	227.9 *32*	α(L)=166.8 *24*; α(M)=45.7 *6*; α(N)=12.22 *17*; α(O)=2.72 *4*; α(P)=0.448 *6*; α(Q)=0.001240 *17* E_γ: from Adopted Gammas. Eγ=53.4 was measured by 1961Re02. Mult.: (L1+L2)/L3=1.10 *5* (1961Re02). See also ^{230}Pa ε decay.
x86.5	171 *30*							
x89.3	152 *21*							
x93.1	154 *14*							
x100.6	22 *10*							
x105.2	77 *11*							
x109.0	84 *11*							
114.9	28 *9*	686.7	5⁻	571.77	3⁻			
120.9	1637 *20*	174.10	4⁺	53.20	2⁺			
x127.5	15 *7*							
146.7[b]		781.37	2⁺	634.9	0⁺			Iγ(146.7γ)=13 *6* was measured by 1989Ku23 and assigned this γ ray as a transition from the 2⁺ state of the γ-vibrational band to the 0⁺ β-vibrational state (146.7-keV photon is not listed in 1984Ge03). Nonobservation of a 146.6-keV photon in ^{230}Pa ε decay and in ^{230}Ac β⁻ decay implies that the 146.6-keV transition could be a doublet, and its component deexciting the 781-keV level is possibly weak.
x152.8	20 *7*							
x157.9	≈6							
165.7	11 *9*	852.4	7⁻	686.7	5⁻			
182.5	4116 *77*	356.6	6⁺	174.10	4⁺			E=182.8 *2* measured by 1983Ha31.
x184.9	91 *14*							
x187.5	≈7							
x203.2	12 *7*							
205.9	16 *8*	883.6	4⁺	677.6	2⁺			

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Coulomb excitation 1989Ku23 (continued)

$\gamma(^{230}Th)$ (continued)

E_γ[†]	I_γ[‡]	E_i(level)	J_i^π	E_f	J_f^π	Comments
213.2	30 *6*	1065.6	9^-	852.4	7^-	
[x]215.3	13 *6*					
237.5	1138 *14*	594.1	8^+	356.6	6^+	E=237.2 *2* measured by 1983Ha31.
[x]247.4	8 *5*					
256.3[#]		1321.9	11^-	1065.6	9^-	
258.3	56 *6*	852.4	7^-	594.1	8^+	
[x]279.6	10 *5*					
285.6	150 *5*	879.7	10^+	594.1	8^+	
[x]289.7	14 *4*					
295.6[#]		1617.5	13^-	1321.9	11^-	
[x]297.2	12 *4*					
313.0	12 *4*	1520.4	10^+	1207.8	12^+	
[x]322.5	13 *4*					
328.1	17 *3*	1207.8	12^+	879.7	10^+	
330.1	80 *5*	686.7	5^-	356.6	6^+	
331[#]		1949	15^-	1617.5	13^-	
[x]342.1	6 *4*					
[x]359.2	5 *4*					
364[#]		2313	17^-	1949	15^-	
365.1[#]		1572.9	14^+	1207.8	12^+	
376[#b]		1949	15^-	1572.9	14^+	
380.1	≤5	951.94	1^-	571.77	3^-	Iγ=2.1 *5* from Iγ(380γ)/Iγ(951γ)=0.0104 *20*, measured in ^{230}Pa ε decay.
[x]383.4	≤5					
393[#]		2706	19^-	2313	17^-	
397.7	88 *6*	571.77	3^-	174.10	4^+	
398.6[#]		1971.5	16^+	1572.9	14^+	
[x]404.5	8 *4*					
409.7[#]		1617.5	13^-	1207.8	12^+	
413.0	≤5	769.6	4^+	356.6	6^+	
[x]416.9	13 *5*					
419[#b]		3125?	(21^-)	2706	19^-	
[x]422.6	21 *6*					
426.3[#]		2397.8	18^+	1971.5	16^+	
[x]430.1	11 *5*					
440.8		1012.5	3^-	571.77	3^-	From Iγ(440γ)/Iγ(959γ)=0.25 *10*, as measured in ^{230}Pa ε decay, Iγ(440.8γ deexciting 1012.6 level)≤1.25; Iγ(440.8γ)=11 *5* is listed in 1989Ku23.
442.2[#]		1321.9	11^-	879.7	10^+	
443.7	22 *5*	951.94	1^-	508.16	1^-	
452[#]		2850	20^+	2397.8	18^+	
455.0	255 *10*	508.16	1^-	53.20	2^+	
[x]460.0[@]						Iγ(460.0γ)/Iγ(182.5γ)=72 *10*/4116 *37* (1984Ge03). This γ ray was tentatively placed by 1984Ge03 between the 2^- (K=1) state at 972.8 keV and the 1^- (K=0) state at 508.2 keV. Its intensity relative to the 919.5γ (transition from the 2^- state to the 2^+ of g.s. band) is stronger than it would be expected for such a transition.
471.5	60 *6*	1065.6	9^-	594.1	8^+	
475[#]		3325	22^+	2850	20^+	
487[#b]		3812?	(24^+)	3325	22^+	
495.8	185 *9*	852.4	7^-	356.6	6^+	

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Coulomb excitation 1989Ku23 (continued)

$\gamma(^{230}Th)$ (continued)

E_γ[†]	I_γ[‡]	E_i(level)	J_i^π	E_f	J_f^π	Comments
503.4	31 *5*	677.6	2^+	174.10	4^+	
508.2[a]	201[a] *11*	508.16	1^-	0.0	0^+	Iγ(508.2γ)=205 *10* is listed in 1989Ku23 for the doublet. The deduced Iγ(508γ deexciting 1079-keV level)=4 *2*, yields Iγ(508.2γ deexciting 508-keV level)/Iγ(455γ)=201 *11*/255 *10*=0.79 *6* in Coulomb excitation; however, 0.57 *6* was deduced in ^{230}Pa ε decay.
508.2[a]	4[a] *2*	1079.26	2^-	571.77	3^-	I_γ: from Iγ(508γ)/Iγ(1026γ)=0.15 *8*, as determined in ^{230}Pa ε decay.
512.6	145 *8*	686.7	5^-	174.10	4^+	
[x]515.8	27 *7*					
518.6	122 *8*	571.77	3^-	53.20	2^+	
[x]521.6	12 *5*					
527.0	17 *4*	883.6	4^+	356.6	6^+	
537.0	≤5	1109.0	(5^-)	571.77	3^-	
[x]553.1	23 *6*					
556.0	≤5	1127.85	3^-	571.77	3^-	
[x]562.5	9 *5*					
[x]566.0	15 *6*					
571.1	≈6	1079.26	2^-	508.16	1^-	From Iγ(571γ)/Iγ(1026γ)=0.74 *4*, measured in ^{230}Th decay, Iγ(571.1γ) is expected to be 19 *8*.
[x]575.2	28 *6*					
581.6	105 *9*	634.9	0^+	53.20	2^+	
595.5	9 *6*	769.6	4^+	174.10	4^+	
[x]600.2	15 *6*					
607.3	≤5	781.37	2^+	174.10	4^+	Iγ(607γ)/Iγ(728γ)=0.026 *12* was measured in ^{230}Pa ε decay; this ratio is ≤0.013 here.
[x]608.4	13 *6*					
624.3	53 *7*	677.6	2^+	53.20	2^+	Iγ(624γ)/Iγ(677γ)=1.36 *25* here; 0.90 *30* was measured in ^{230}Pa ε decay.
640.7	9 *5*	1520.4	10^+	879.7	10^+	
[x]648.7	13 *5*					
651.7	22 *6*	825.8	3^+	174.10	4^+	Iγ(651γ)/Iγ(772γ)=0.41 *13* in 1989Ku23, 0.28 *12* in 1984Ge03, in 0.17 *6* from ^{230}Pa ε decay.
657.3	16 *6*	1251.4	8^+	594.1	8^+	
[x]667.7	15 *6*					
677.5	39 *5*	677.6	2^+	0.0	0^+	
683.4	125 *8*	1040.0	6^+	356.6	6^+	
[x]687.2	18 *6*					
709.5	268 *11*	883.6	4^+	174.10	4^+	
716.4	11 *4*	769.6	4^+	53.20	2^+	
728.2	408 *13*	781.37	2^+	53.20	2^+	
[x]749.7	45 *7*					
[x]753.9[@]						Iγ(753.9γ)/Iγ(182.5γ)=44 *8*/4116 *37* (1984Ge03). This γ ray was placed by 1984Ge03 between the J^π=5$^-$, K=1 state at 1109.0 keV and the 6^+ of the g.s. band. A relative photon intensity of ≤4 would be expected from the Alaga rule: Iγ(753γ to 6^+)/Iγ(935γ to 4^+)=0.83.
[x]761.4	13 *6*					
772.6	54 *7*	825.8	3^+	53.20	2^+	
[x]776.6	17 *7*					
781.4	238 *11*	781.37	2^+	0.0	0^+	
[x]789.3	10 *6*					
[x]798.7	17 *6*					The 798.7-keV transition was placed by 1989Ku23 between the 2^- state at 972.8 keV and the 4^+ state at 174.1 keV, which would require the 798.7γ to be an M2 transition.
[x]803.7	19 *6*					
[x]811.3	16 *5*					

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Coulomb excitation 1989Ku23 (continued)

$\gamma(^{230}Th)$ (continued)

E_γ[†]	I_γ[‡]	E_i(level)	J_i^π	E_f	J_f^π	Comments
822.0	17 *5*	1178.6	5^+	356.6	6^+	
[x]827.3	31 *7*					
830.4	97 *8*	883.6	4^+	53.20	2^+	
836.2	34 *7*	1009.7	2^+	174.10	4^+	Iγ(836γ)/Iγ(956γ)=0.052 *20* from ^{230}Pa ε decay; this ratio is 0.29 *8* in 1989Ku23.
[x]842.7	34 *8*					
[x]851.4	21 *10*					
[x]855.4	12 *9*					
[x]861.5	≤5					
865.9	40 *9*	1040.0	6^+	174.10	4^+	
[x]872.3	15 *9*					
879.0	27 *10*	1052.6	3^+	174.10	4^+	
[x]886.9	30 *10*					
894.8	10 *7*	1251.4	8^+	356.6	6^+	
898.7	32 *11*	951.94	1^-	53.20	2^+	
[x]908.4	28 *11*					
[x]914.2	26 *11*					
919.6	≤5	972.69	2^-	53.20	2^+	
926.3	27 *11*	1520.4	10^+	594.1	8^+	
934.0	26 *12*	1108.2	4^+	174.10	4^+	
935.0	≤5	1109.0	(5^-)	174.10	4^+	
[x]940.5	≈10					
951.9	203 *26*	951.94	1^-	0.0	0^+	
956.6	118 *17*	1009.7	2^+	53.20	2^+	
959.4	≤5	1012.5	3^-	53.20	2^+	
[x]966.6	18 *16*					
[x]970.2	≈15					
[x]975.6	57 *15*					
[x]984.2	≈11					
[x]992.0						
1000.0	21 *10*	1052.6	3^+	53.20	2^+	
1009.8	43 *10*	1009.7	2^+	0.0	0^+	Iγ(1009γ)/Iγ(956γ)=0.68 *15* was measured in ^{230}Pa ε decay; this ratio is 0.36 *10* in 1989Ku23.
1022.7	26 *10*	1196.8	(4^-)	174.10	4^+	
1026.1	26 *10*	1079.26	2^-	53.20	2^+	
[x]1037.0	40 *11*					
[x]1048.1	24 *10*					
1055.0	44 *11*	1108.2	4^+	53.20	2^+	
[x]1062.5	31 *12*					
[x]1069.3	19 *11*					
1074.6	33 *14*	1127.85	3^-	53.20	2^+	
[x]1081.2	26 *16*					
[x]1089.9	17 *14*					
[x]1094.3	≈13					
[x]1100.5	≈12					
[x]1111.3	≈11					
[x]1121.7	≈9					
[x]1126.8	23 *13*					
[x]1150.9	≈6					
[x]1155.6	≈6					
[x]1160.4	11					
[x]1170.4[@]						Iγ(1170.4γ)/Iγ(182.5γ)=31 *7*/4116 *37* (1984Ge03).
[x]1184.4[@]						Iγ(1184.4γ)/Iγ(182.5γ)=24 *6*/4116 *37* (1984Ge03).
[x]1188.9[@]						Iγ(1188.9γ)/Iγ(182.5γ)=30 *7*/4116 *37* (1984Ge03).

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Coulomb excitation 1989Ku23 (continued)

$\gamma(^{230}Th)$ (continued)

E_γ [†]	E_i(level)	Comments
[x]1313.1[@]		Iγ(1313.1γ)/Iγ(182.5γ)=16 *5*/4116 *37* (1984Ge03).
[x]1323.0[@]		Iγ(1323.0γ)/Iγ(182.5γ)=39 *8*/4116 *37* (1984Ge03).

[†] From 1989Ku23, unless noted otherwise.
[‡] Relative experimental photon intensities (1989Ku23) in (^{32}S,^{32}S′γ) experiment in coincidence with ^{32}S ions scattered into the angle intervals of $60°\leq\theta\leq105°$ and $-105°\leq\theta\leq-160°$. The stronger lines were corrected for the angular correlations. The dependence of the γ-ray intensity on the scattering angle (therefore, impact parameter) was utilized for identifying multipolarities. Measured intensities of γ rays coincident with ^{32}S scattered into $50°\leq\theta\leq150°$ and $162°\leq\theta\leq172°$ were listed in 1984Ge03. For approximate comparison with Iγ′s in 1989Ku23, the relative intensities of 1984Ge03 have been renormalized to Iγ(182.5γ)=4116 and given in comments.
[#] Transition is not listed in table of 1989Ku23; it is assumed to be observed in ^{142}Nd and/or ^{84}Kr bombardments; Eγ is taken from authors′ drawing.
[@] From 1984Ge03; transition was not listed in 1989Ku23. See 1984Ge03 for additional γ rays for which no assignments were made.
[&] Additional information 1.
[a] Multiply placed with intensity suitably divided.
[b] Placement of transition in the level scheme is uncertain.
[x] γ ray not placed in level scheme.

Coulomb excitation 1989Ku23

Level Scheme

Intensities: Relative I_γ

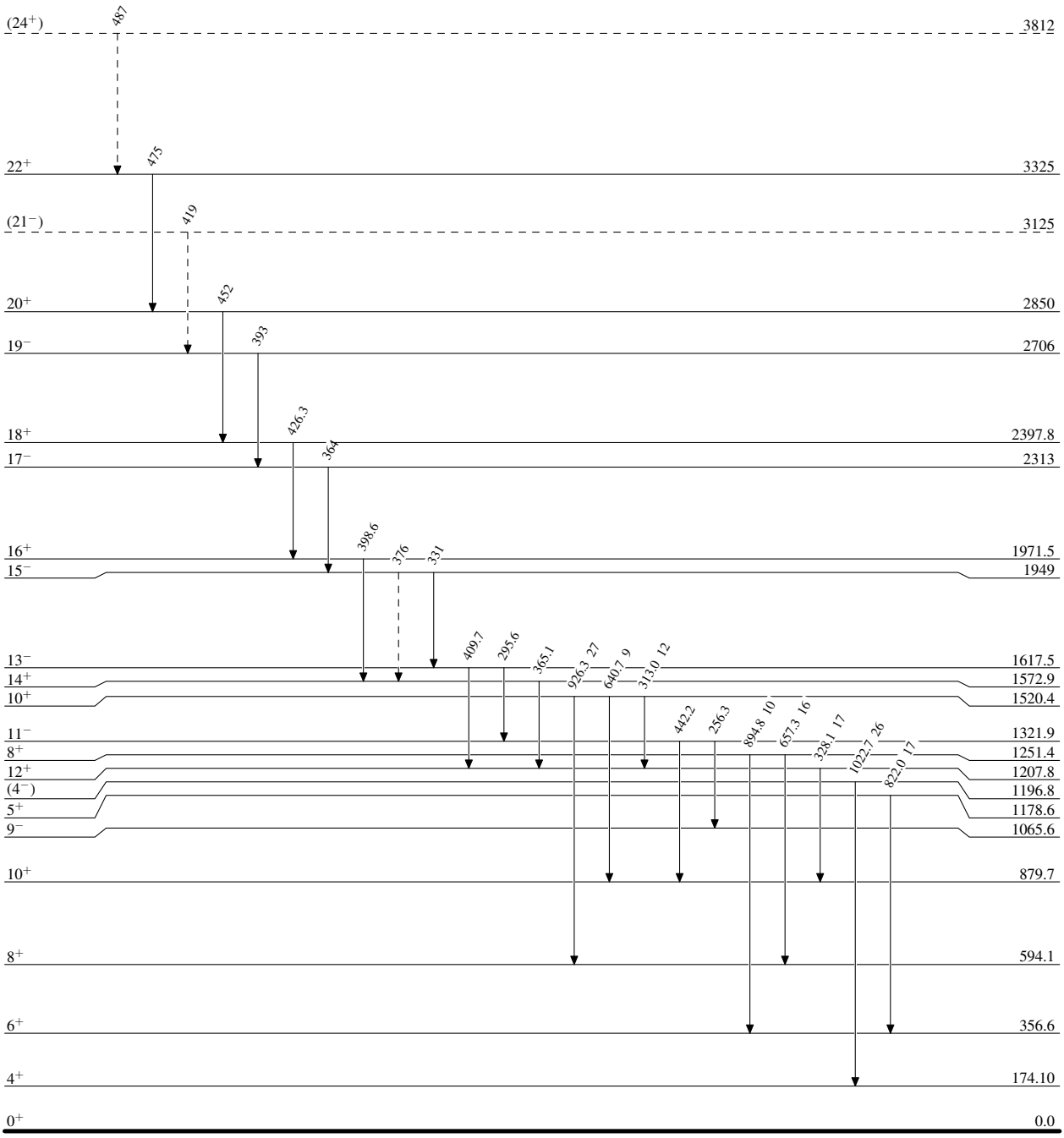
Legend

$I_\gamma < 2\% \times I_\gamma^{max}$

$I_\gamma < 10\% \times I_\gamma^{max}$

$I_\gamma > 10\% \times I_\gamma^{max}$

γ Decay (Uncertain)



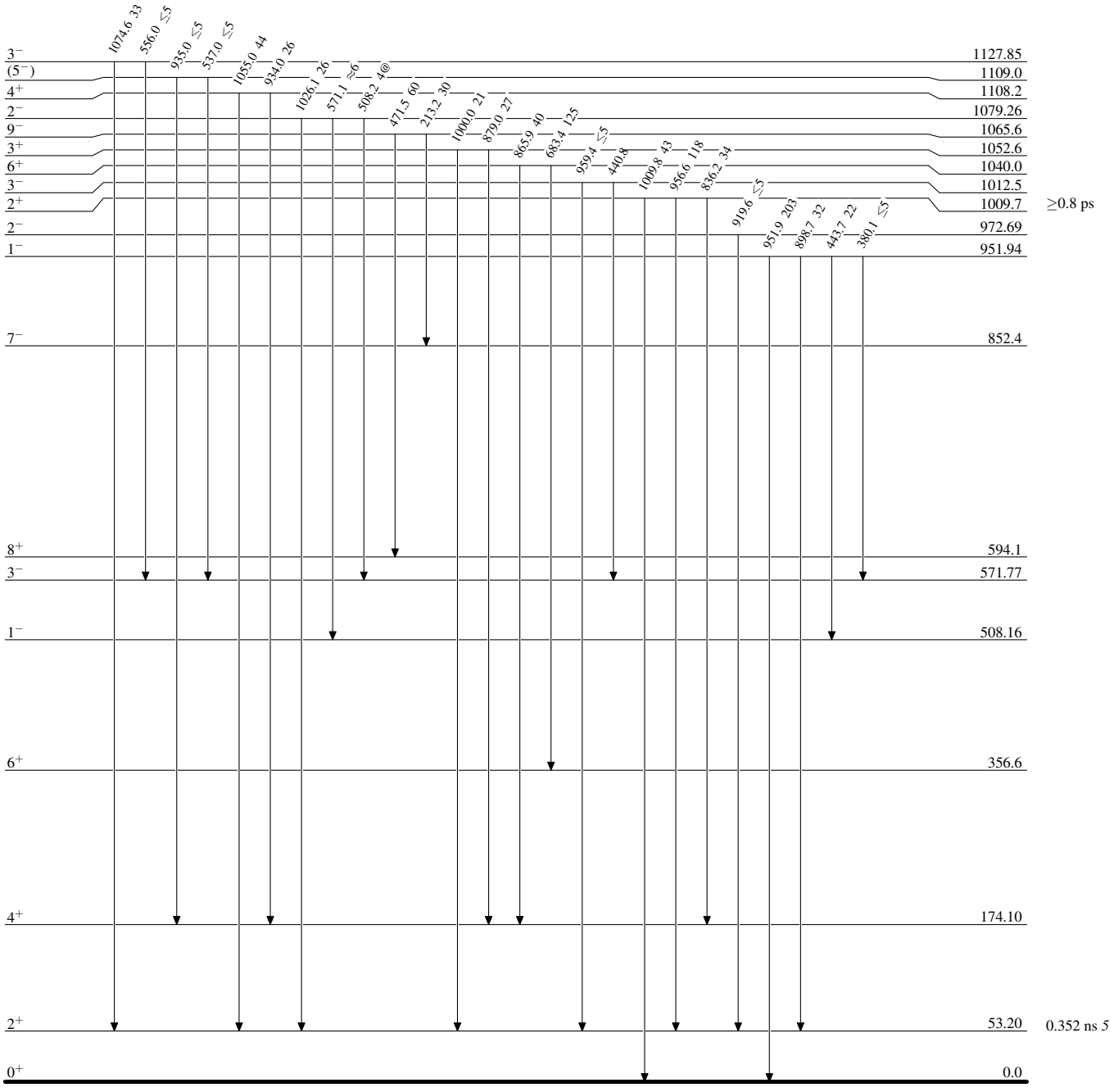
$^{230}_{90}Th_{140}$

Coulomb excitation 1989Ku23

Level Scheme (continued)

Intensities: Relative I_γ
@ Multiply placed: intensity suitably divided

Legend
$I_\gamma < 2\% \times I_\gamma^{max}$
$I_\gamma < 10\% \times I_\gamma^{max}$
$I_\gamma > 10\% \times I_\gamma^{max}$



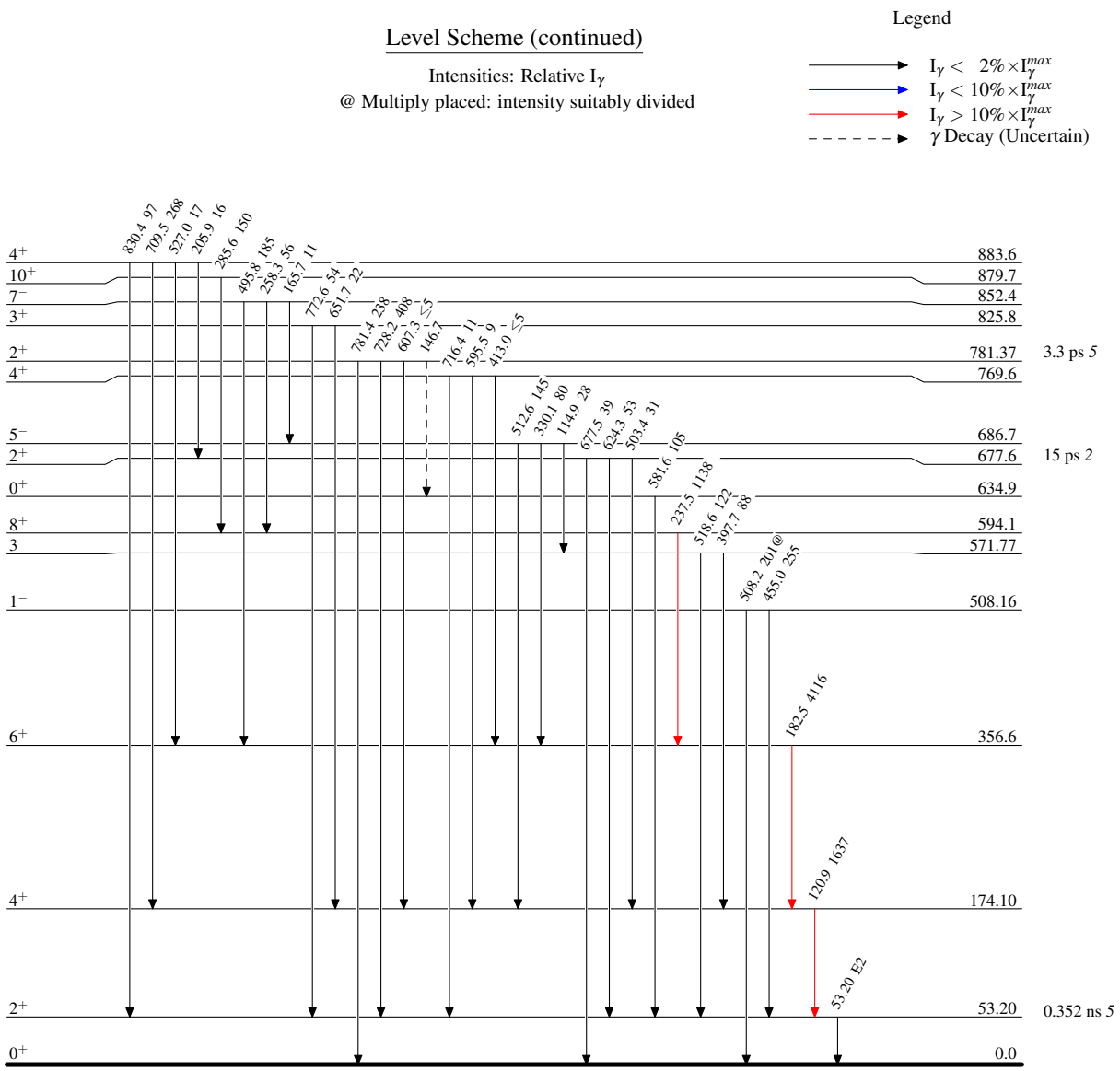
$^{230}_{90}Th_{140}$

Coulomb excitation 1989Ku23

Level Scheme (continued)

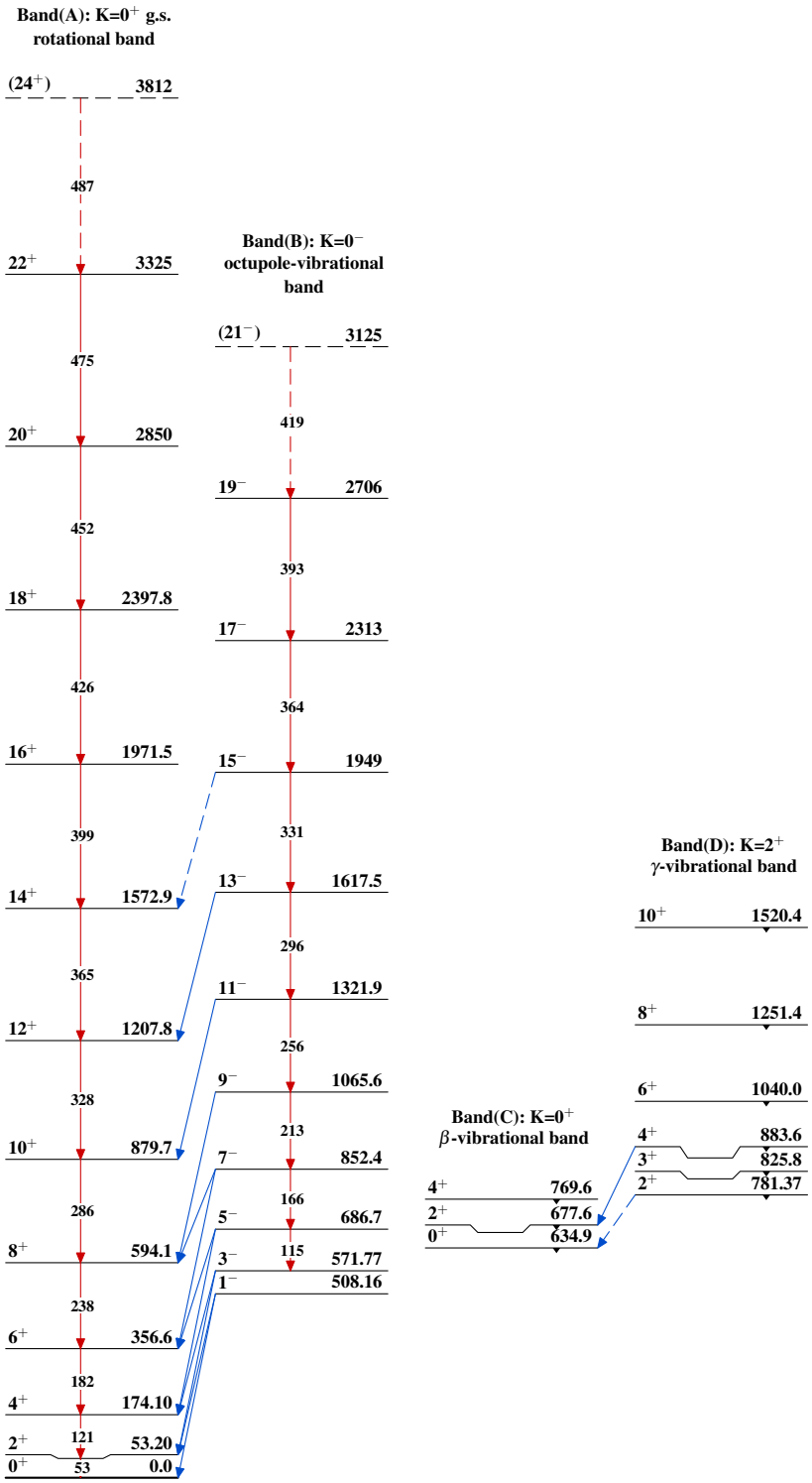
Intensities: Relative I_γ

@ Multiply placed: intensity suitably divided



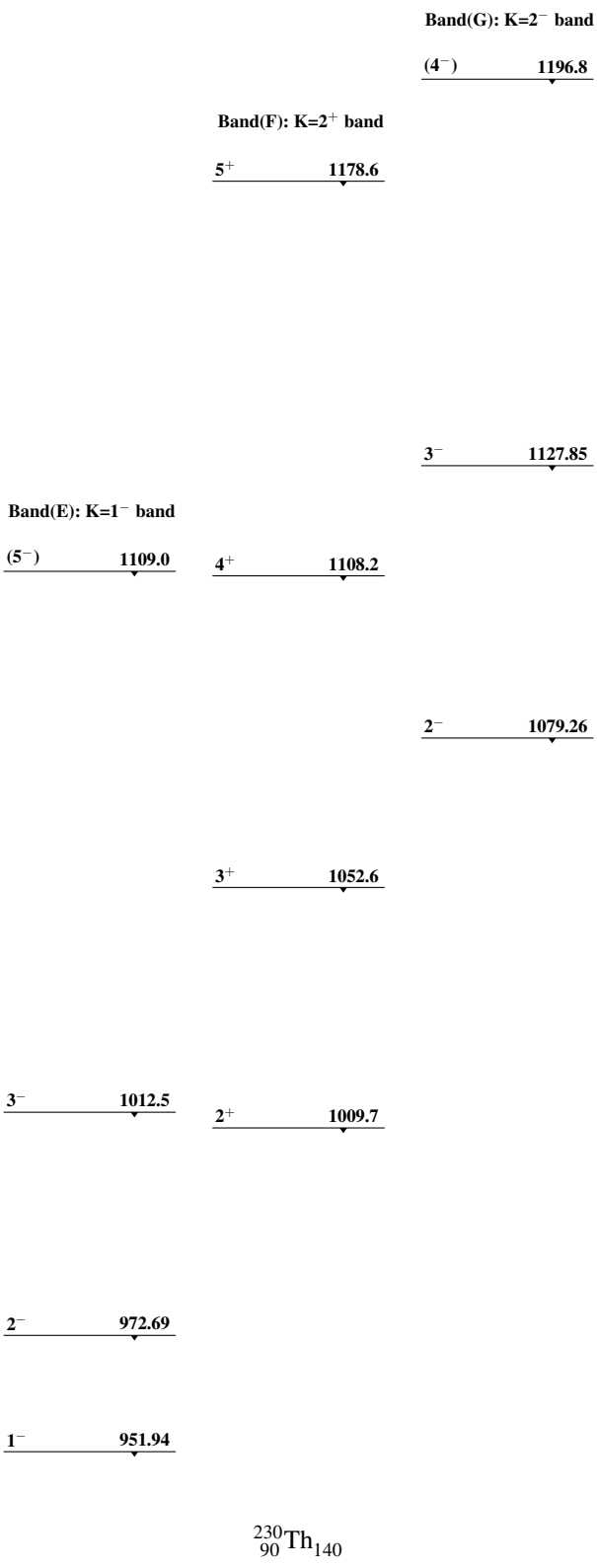
$^{230}_{90}Th_{140}$

Coulomb excitation 1989Ku23



$^{230}_{90}Th_{140}$

Coulomb excitation 1989Ku23 (continued)



$^{230}_{90}Th_{140}$