Coulomb excitation   1981Mc06,1977Ro08

Type	Author	History Citation	Literature Cutoff Date
Full Evaluation	C. W. Reich	NDS 113, 2537 (2012)	1-Mar-2012

Additional information 1.

B(E2) and B(E3) values and related matrix elements are primarily from 1981Mc06 and secondarily from 1977Ro08, 1977Fi01, 1977Wo02, and 1964Al25. Others: 1960El07, 1961Go09, 1964De07, 1965Yo04, and 1993Su16.

Level half-lives are from 1977Ke06, 1972Wa29, 1975Wa15 (these same values are in 1977Si18), 1959Bi10, and 1967Wo06. Others: 1962Af01, 1972Ru07 (results replaced by those in 1972Wa29).

Experimental methods for B(E2) and B(E3):

1960El07: Coul. ex. with E(p) and E(d)=4.5 MeV. Scattered particles measured in magnetic spectrograph. Report B(E2) to first 2^+ state.

1960Na13: Coul. ex. with E(α)=14, 17, and 20 MeV. No results.

1961Go09: Coul. ex. with E(p)=1.8, 2.8, and 3.2 MeV. Measured thick-target γ yields. Report B(E2) to first 2^+ state.

1962Af01: Coul. ex. with E(^{14}N) 50 MeV. Measured scattered ^{14}N in Si detector and γ in NaI(Tl). See 2^+ and 4^+, but no results given.

1964Al25: Coul. ex. with E(^{14}N)=37 MeV. Measured γ's in coincidence with scattered ^{14}N. Report β(E2;2+$\rightarrow$4$^+$).

1964De07: Coul. ex.

1965Yo04: Coul. ex. with E(^{16}O)=43.5 MeV on enriched (97.01%) target. Measured γ's in coincidence with scattered ^{16}O. Report B(E2) to 2^+ members of γ- and β^- vibrational bands.

1974HaXZ: See 1977Ro08 for published version.

1977Fi01: Coul. ex. with E(α)=11.2-12.0 MeV on enriched (93.58%) target. Measured scattered α's in Si detector with FWHM=18 keV. Report reduced E2 and E4 matrix elements to first 2^+ and 4^+ states, respectively, and associated deformation parameters.

1977Gu09: Calculation of B(E2).

1977Ro08: Coul. ex. with E(α)=11-17 MeV on enriched (>99%) target. Measured scattered α's in magnetic spectrometer. Report four B(E2) values and one B(E3) value. See 1977Ro26.

1977Ro26: Coul. ex. with E(α)=11.5, 12.0, and 12.5 MeV on enriched (>99%) target. Measured scattered α's in magnetic spectrometer. Report reduced matrix elements to first 2^+ and 4^+ states and deduce model-dependent charge deformation parameters.

1977Wo02: Coul. ex. with E(α)=11.8 MeV on enriched (93.6%) target. Measured scattered α's in Si detector with FWHM=19 keV. Deduce reduced matrix elements to first 2^+ and 4^+ states and charge deformation parameters.

1991St01: Natural Gd target. E(^{58}Ni)=160 MeV. Measured simultaneously transient-field precessions for levels in the g.s. bands of ^{156}Gd, ^{158}Gd and ^{160}Gd. Deduced g factors of first 2^+, 4^+ and 6^+ states of ^{156}Gd.

1981Mc06: Enriched (93.58%) ^{156}Gd target. Eα=13.5 MeV. Thick-target yields of γ's measured with Ge(Li) detector at $0°$ and $90°$.

1993Su16: Multiple Coul. ex. with E(^{32}S)=118 MeV. γ radiation detected by 20 BGO Compton-suppressed Ge detectors in the Nordball system in coincidence with the backscattered particles. Report B(E2) and B(E3) values to the first four excited 2^+ states and the first three excited 3^- states.

2011Su15: (Some of the same authors as 1993Su16.) Multiple Coulomb excitation using ^{32}S and ^{58}Ni beams on enriched (93.58% ^{156}Gd) metallic target, 1.0 mg/cm^2 thick. E(^{32}S)=118 MeV and E(^{58}Ni)=225 MeV. γ radiation detected using the NORDBALL array of 20 BGO-shielded Compton-suppressed Ge detectors placed in four rings at polar angles of $37.5°$, $79.2°$, $100.8°$ and $142.6°$ with respect to the beam axis. Scattered ions were detected in five position-sensitive detectors, each consisting of seven Si strips. Measured Eγ, particle-γ-γ coincidences, angular correlations. Extend data on bands previously seen in Coul. ex. to higher spins. Deduce matrix elements using a GOSIA analysis.

Other measurements: 1974HaXZ (see 1977Ro08), and 1984Gu22.

Experimental methods for $T_{1/2}$ measurements:

1959Bi10: Coul. ex. with E(p)=2.8 MeV. Measured $T_{1/2}$ from pulse-γ coincidences.

1967Wo06: Coul. ex. with protons, E(p) not given. Measured $T_{1/2}$ and g-factor for first-excited 2^+ state.

1972Ru07: Coul. ex. with E(^{35}Cl)=100 MeV. Measured $T_{1/2}$ by Doppler-shift recoil-distance method. Results replaced by those of 1972Wa29.

1972Wa29: Coul. ex. with E(^{35}Cl)=80 MeV. Measured $T_{1/2}$ by Doppler-shift recoil-distance method. Results replace those of 1972Ru07.

1975Wa15: Coul. ex. with E(^{35}Cl)=135 MeV. Measured $T_{1/2}$ by Doppler-broadened lineshape method. Same results appear in

Coulomb excitation   1981Mc06,1977Ro08 (continued)

1977Si18.
1977Ke06: Coul. ex. with E(^{56}Fe)=232 MeV and E(^{84}Kr)=348 MeV. Measured T$_{1/2}$ by Doppler-broadened lineshape method.
1977Si18: Coul. ex. with E(^{35}Cl)=132-143 MeV. Measured T$_{1/2}$ by Doppler-broadened lineshape method. Same results appear in
1975Wa15.

<div align="center">^{156}Gd Levels</div>

E(level)[†]	J[π][#]	T$_{1/2}$[@]	Comments
0[&]	0$^+$		
89[‡][&]	2$^+$	2.20 ns *10*	B(E2)↑=4.62 *2*; g=0.39 *7*
			B(E2)↑: Weighted average of 4.63 *2* (1977Fi01), 4.57 *5* (1977Ro08; if the matrix element in 1977Ro26 is used, B(E2)=4.56 *3*) and 4.59 *9* (1977Wo02). Others: 4.57 *25* (1960El07); 4.2 *4* (1961Go09); and 4.16 (1993Su16).
			g: From 1991St01. Their data were normalized to g=0.387 *4* for the 89 level, as given by 1989Ra17.
			T$_{1/2}$: Weighted average of 2.05 ns *10* (1959Bi10) and 2.28 ns *6* (1967Wo06).
288[‡][&]	4$^+$	114 ps *2*	B(E4)↑=0.23 *3*; g=0.39 *4*
			g: From 1991St01. Their data were normalized to g=0.387 *4* for the 89 level, as given by 1989Ra17.
			B(E4)↑: Computed from the E4 matrix element=0.48 *3* eb^2. This value is a weighted average of 0.50 *4* (1977Fi01), 0.42 *8* (1977Ro26), and 0.41 *+12−18* (1977Wo02), all in eb^2.
			B(E2)↑: B(E2,2+→4$^+$)=2.58 (1964Al25).
			T$_{1/2}$: From 1972Wa29. Other: 114 ps (1962Af01).
584[‡][&]	6$^+$	15.8 ps *4*	g=0.36 *7*
			g: From 1991St01. Their data were normalized to g=0.387 *4* for the 89 level, as given by 1989Ra17.
			T$_{1/2}$: From 1972Wa29. Other: 17.6 ps *24* (1975Wa15 and 1977Si18).
964[&]	8$^+$	4.32 ps *23*	T$_{1/2}$: Weighted average of 4.26 ps *34* (1977Ke06) and 4.4 ps *3* (1977Si18). 1975Wa15 give the same value as that of 1977Si18, but with a smaller uncertainty.
1052[a]	0$^+$		E(level): From 2011Su15.
1128[a]	2$^+$	1.59 ps *11*	B(E2)↑=0.0158 *9*
			B(E2)↑: From 1981Mc06. Others: 0.013 *4* (1977Ro08); 0.07 *3* (1965Yo04); and 0.036 (1993Su16).
			T$_{1/2}$: Computed from B(E2) and the adopted γ branching.
1155[b]	2$^+$	0.568 ps *19*	B(E2)↑=0.117 *4*
			B(E2)↑: Weighted average of 0.120 *4* (1977Ro08) and 0.111 *6* (1981Mc06). Others: <0.24 (1960Na13); 0.06 *2* (1965Yo04); and 0.073 (1993Su16).
			T$_{1/2}$: Computed from B(E2) and the adopted γ branching.
1243[d]	1$^-$		
1258[‡][c]	2$^+$	1.54 ps *15*	B(E2)↑=0.0077 *7*
			B(E2)↑: From 1981Mc06. Others: <0.008 (1977Ro08); 0.00828 (1993Su16). The evaluator has associated this latter value with the 1258 level.
			T$_{1/2}$: Computed from B(E2) and the adopted γ branching.
1276[‡][d]	3$^-$	0.075 ps *15*	B(E3)↑=0.171 *7*
			B(E3)↑: From 1981Mc06. Others: 0.16 *4* (1977Ro08); 0.036 (1993Su16).
			T$_{1/2}$: Computed from the B(E1) values reported by 1981Mc06 for the two deexciting γ's.
1297[a]	4$^+$		
1356[b]	4$^+$		
1406[d]	5$^-$		
1415[&]	10$^+$	1.90 ps *8*	T$_{1/2}$: Weighted average of 1.94 ps *12* (1977Ke06) and 1.86 ps *11* (1975Wa15 and 1977Si18).
1462[c]	4$^+$		
1538[‡][e]	3$^-$		B(E3)↑=0.038
			B(E3)↑: From 1993Su16. Other:<0.013 (1981Mc06).
1541[a]	6$^+$		

Coulomb excitation   1981Mc06,1977Ro08 (continued)

<u>^{156}Gd Levels (continued)</u>

E(level)[†]	J$^{\pi}$[#]	T$_{1/2}$[@]	Comments
1633[d]	7$^-$		
1642[b]	6$^+$		
1765[c]	6$^+$		
1849[a]	8$^+$		
1923[&]	12$^+$	1.1 ps 1	T$_{1/2}$: From 1977Ke06.
1957[d]	9$^-$		
2010[b]	8$^+$		
2135[c]	(8$^+$)		
2220[a]	10$^+$		
2359[d]	11$^-$		
2442[b]	10$^+$		
2474[&]	14$^+$		
2650[a]	(12$^+$)		
2828[d]	13$^-$		
2957[b]	(12$^+$)		
3057[&]	16$^+$		
3134[a]	(14$^+$)		
3346[d]	15$^-$		
3671[&]	18$^+$		

[†] From 2011Su15, unless noted otherwise.
[‡] Nominal value, from the adopted values.
[#] From the adopted values. Population of these levels in Coul. ex. provides useful information regarding regarding their make-up and band structure.
[@] Values given here are from Coul. ex. only. All results are given in the ^{156}Gd Adopted Levels.
[&] Band(A): K$^{\pi}$=0$^+$ g.s. band.
[a] Band(B): First excited K$^{\pi}$=0$^+$ band. Extraction of matrix elements from GOSIA analysis suggests a change in make-up of this band near J=10 (2011Su15).
[b] Band(C): γ-vibrational band, α=0 branch. Extraction of matrix elements from GOSIA analysis suggests a change in make-up of this band near J=10 (2011Su15).
[c] Band(D): K$^{\pi}$=0$^+$ band.
[d] Band(E): K$^{\pi}$=1$^-$ octupole-vibrational band.
[e] Band(F): K$^{\pi}$=0$^-$ octupole-vibrational band.

<u>γ(^{156}Gd)</u>

E$_{\gamma}$[†]	I$_{\gamma}$[#@]	E$_i$(level)	J$^{\pi}_i$	E$_f$	J$^{\pi}_f$	Comments
89[‡]	100	89	2$^+$	0	0$^+$	
199[‡]		288	4$^+$	89	2$^+$	
242		1541	6$^+$	1297	4$^+$	Shown on the level scheme of 2011Su15, but no other information is available on this γ. γ is shown as questionable in the adopted values.
288		1642	6$^+$	1356	4$^+$	I$_{\gamma}$: Iγ(288γ)/Iγ(1354γ)=0.161 14.
296[‡]		584	6$^+$	288	4$^+$	
367		2010	8$^+$	1642	6$^+$	I$_{\gamma}$: Iγ(367γ)/Iγ(1045γ)=0.200 27.
380[‡]		964	8$^+$	584	6$^+$	

Continued on next page (footnotes at end of table)

Coulomb excitation   1981Mc06,1977Ro08 (continued)

$\gamma(^{156}$Gd) (continued)

E$_\gamma$[†]	I$_\gamma$[#@]	E$_i$(level)	J$_i^\pi$	E$_f$	J$_f^\pi$	Comments
432		2442	10$^+$	2010	8$^+$	I$_\gamma$: Iγ(432γ)/Iγ(1027γ)=1.00 6.
451[‡]		1415	10$^+$	964	8$^+$	
508[‡]		1923	12$^+$	1415	10$^+$	
513		2957	(12$^+$)	2442	10$^+$	I$_\gamma$: Iγ(513γ)/Iγ(1034γ)=1.00 28.
551[‡]		2474	14$^+$	1923	12$^+$	
583[‡]		3057	16$^+$	2474	14$^+$	
614[‡]		3671	18$^+$	3057	16$^+$	
659.0 4	0.10 1	3134	(14$^+$)	2474	14$^+$	
726.9 6	0.30 2	2650	(12$^+$)	1923	12$^+$	
804.3 3	0.60 3	2220	10$^+$	1415	10$^+$	
872		3346	15$^-$	2474	14$^+$	
877		1462	4$^+$	584	6$^+$	
882 7	0.20 3	1849	8$^+$	964	8$^+$	
905		2828	13$^-$	1923	12$^+$	
944		2359	11$^-$	1415	10$^+$	
956.2 5	0.8 1	1541	6$^+$	584	6$^+$	
963		1052	0$^+$	89	2$^+$	
971		1258	2$^+$	288	4$^+$	
993		1957	9$^-$	964	8$^+$	
1009.5 2	1.9 1	1297	4$^+$	288	4$^+$	
1027		2442	10$^+$	1415	10$^+$	
1034		2957	(12$^+$)	1923	12$^+$	
1039 4	0.6 5	1128	2$^+$	89	2$^+$	
1045		2010	8$^+$	964	8$^+$	
1049		1633	7$^-$	584	6$^+$	
1058		1642	6$^+$	584	6$^+$	I$_\gamma$: Iγ(1058γ)/Iγ(1354γ)=2.32 18.
1066		1155	2$^+$	89	2$^+$	
1067		1356	4$^+$	288	4$^+$	
1118		1406	5$^-$	288	4$^+$	
1154		1243	1$^-$	89	2$^+$	
1171		2135	(8$^+$)	964	8$^+$	
1174		1462	4$^+$	288	4$^+$	
1181		1765	6$^+$	584	6$^+$	
1211.0 9	0.10 2	3134	(14$^+$)	1923	12$^+$	
1235.0 5	0.30 3	2650	(12$^+$)	1415	10$^+$	
1252.6 5	1.7 1	1541	6$^+$	288	4$^+$	
1255.6 6	0.30 5	2220	10$^+$	964	8$^+$	
1265.4 5	0.6 1	1849	8$^+$	584	6$^+$	
1267		1356	4$^+$	89	2$^+$	
1354		1642	6$^+$	288	4$^+$	
1426		2010	8$^+$	584	6$^+$	I$_\gamma$: Iγ(1426γ)/Iγ(1045γ)=0.400 32.
1478		2442	10$^+$	964	8$^+$	I$_\gamma$: Iγ(1478γ)/Iγ(1027γ)=0.88 13.

[†] From 2011Su15, unless noted otherwise.
[‡] Nominal value, from the adopted values.
[#] Listed values are those of 2011Su15, from GOSIA analysis of particle-γ-γ data.
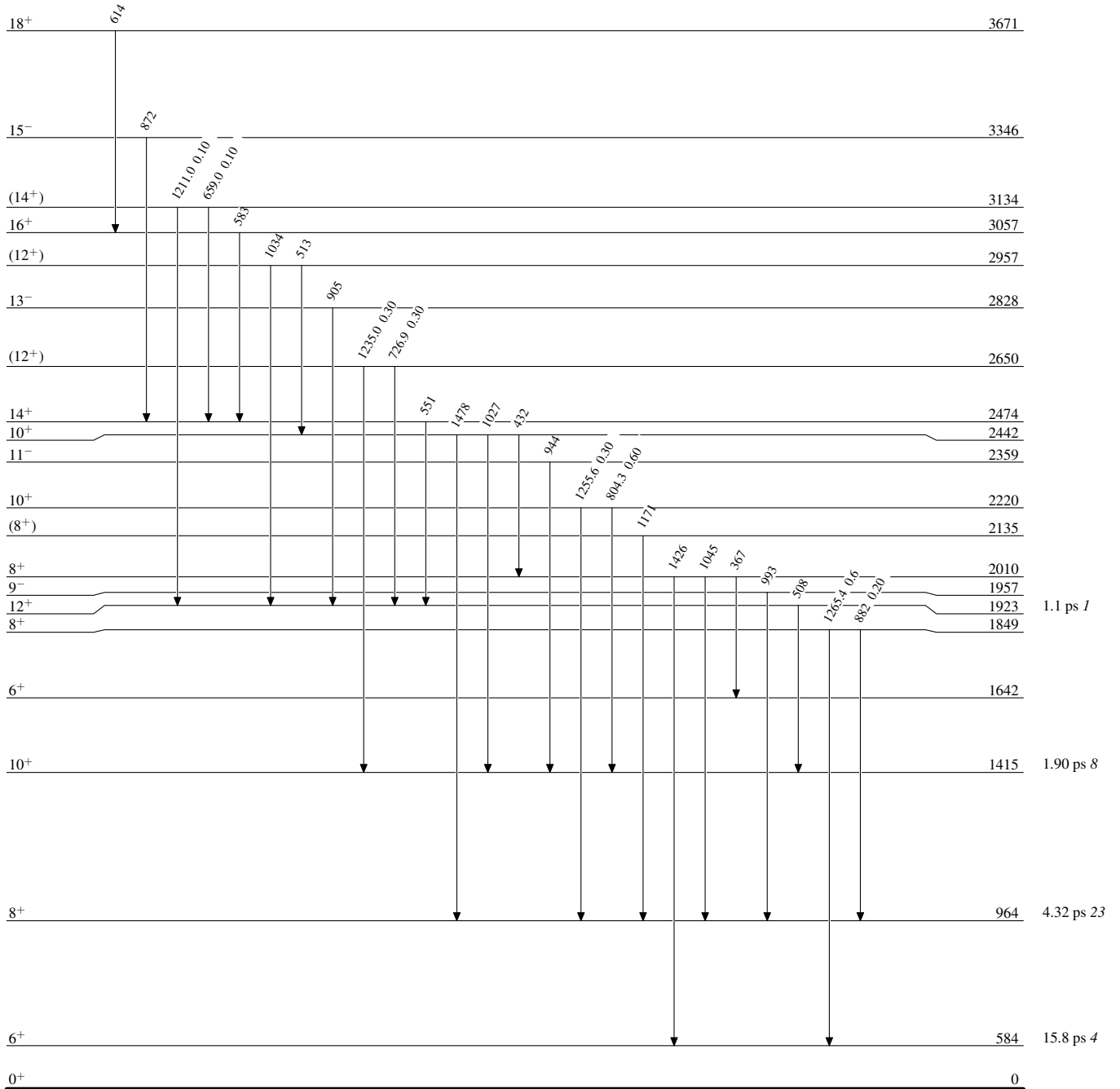[@] Values relative to Iγ(89γ)=100.

Coulomb excitation   1981Mc06,1977Ro08

<u>Level Scheme</u>

Intensities: Type not specified

Legend

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

18^+		3671
15^-		3346
(14^+)		3134
16^+		3057
(12^+)		2957
13^-		2828
(12^+)		2650
14^+		2474
10^+		2442
11^-		2359
10^+		2220
(8^+)		2135
8^+		2010
9^-		1957
12^+	1.1 ps 1	1923
8^+		1849
6^+		1642
10^+	1.90 ps 8	1415
8^+	4.32 ps 23	964
6^+	15.8 ps 4	584
0^+		0

Transition labels: 614, 872, 1211.0 0.10, 659.0 0.10, 583, 1034, 513, 905, 1235.0 0.30, 726.9 0.30, 551, 1478, 1027, 432, 944, 1255.6 0.30, 804.3 0.60, 1171, 1426, 1045, 367, 993, 508, 1265.4 0.6, 882 0.20
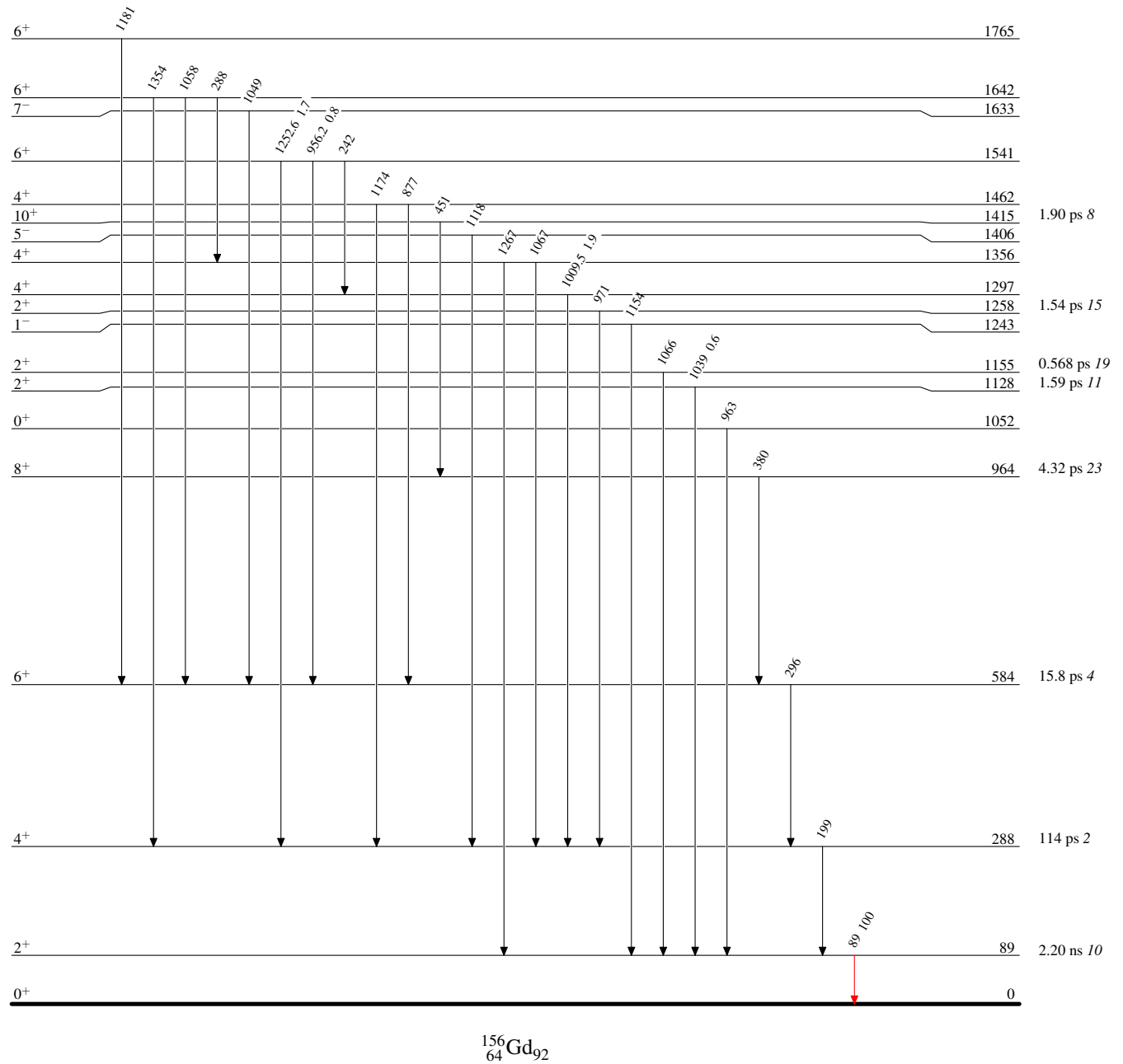
${}^{156}_{64}$Gd${}_{92}$

Coulomb excitation   1981Mc06,1977Ro08

Level Scheme (continued)

Intensities: Type not specified

Legend

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

6+	1765
6+	1642
7−	1633
6+	1541
4+	1462
10+	1415 1.90 ps 8
5−	1406
4+	1356
4+	1297
2+	1258 1.54 ps 15
1−	1243
2+	1155 0.568 ps 19
2+	1128 1.59 ps 11
0+	1052
8+	964 4.32 ps 23
6+	584 15.8 ps 4
4+	288 114 ps 2
2+	89 2.20 ns 10
0+	0

$^{156}_{64}$Gd$_{92}$

Coulomb excitation   1981Mc06,1977Ro08

$^{156}_{64}$Gd$_{92}$