Coulomb excitation **2007Ha05,2002Ha54,1982Ha25**

History

Type	Author	Citation	Literature Cutoff Date
Full Evaluation	E. Achterberg, O. A. Capurro, G. V. Marti	NDS 110, 1473 (2009)	31-May-2008

2007Ha05,2006Ha04: Reported results from two experiments: a) Coulomb excitation using a 650 MeV ^{136}Xe beam on an 89% enriched ^{178}Hf target. Detection of projectile and target particles using the Rochester PPAC array (CHICO), and of γ rays with the GAMMASPHERE detector system. Confirmed and extended the level scheme shown in 2002Ha54. Extracted information for reduced transition matrix elements coupling various excited bands and the g.s. band. Provided half-lives, B(E2) values, and other parameters. b) Coulomb excitation using a 858-MeV beam of $^{178}Hf^{24+}$ implanted into a target of natural Ta, to study excitation of levels in the band above the 16^+ isomeric state in ^{178}Hf.

2002Ha54: Coulomb excitation of a 89% enriched ^{178}Hf target using a beam of 650 MeV ^{136}Xe. The GAMMASPHERE detector array was used to observe γ rays, in coincidence with the Rochester 4π PPAC array (CHICO), which recorded the particle kinematics. Doppler-shift corrections were applied to improve γ-ray energy resolution.

1982Ha25: Coulomb excitation of ^{178}Hf targets (enriched to 95%) with a 384 MeV beam of ^{86}Kr, and a 594 MeV beam of ^{136}Xe, using SuperHILAC. Ge(Li) detectors at 0 and 90°, for γ rays, in coincidence with backscattered heavy ions. A second experiment used a thin ^{178}Hf target and ^{136}Xe projectiles at 628, 652 and 682 MeV, detecting coincidences between scattered ^{136}Xe particles and Hf recoils using 2D position sensitive avalanche counters. Established levels with $J^\pi=10^+$ to 16^+ (possibly 18^+) in the g.s. band and determined half-lives for the five states from 6^+ to 14^+ of the g.s. band.

1977Ro08: Coulomb excitation with an E=11-17 MeV α-particle beam on >99% enriched ^{178}Hf targets. Observed scattered α's at θ=90°, deduced B(E2) values.

Other: 1996Lu07,1996De11,2001Na13.

^{178}Hf Levels

The level scheme is from 2007Ha05. Exceptions are noted in the Comments column. For extensive discussions regarding g.s. and excited band configurations, K-mixing, fitting of reduced matrix elements to observed yields for transitions connecting various bands, estimates of B(QL) values and other parameters, see 2007Ha05 and references quoted therein.

E(level)	J^π[#]	$T_{1/2}$[†]	Comments
0.0[@]	0^+		Q_0=6.86 eb *4* (2007Ha05). Charge and nuclear deformation parameters: β_2^c=0.295, β_4^c=−0.166 *18*, β_2^n=0.291 *19*, β_4^n=−0.103 *4* (1988Ne07). Other: $\beta_2\approx$0.25 (2007Ha05).
93.3[@] *8*	2^+	1.494 ns *23*	g=0.237 *14* from precession measurements on Coulomb excited ^{178}Hf nuclei recoiling into liquid Ga (1968Be04). B(E2)↑=4.86 *5* (1977Ro08).
306.5[@] *10*	4^+		
632.1[@] *11*	6^+	11.2[‡] ps *6*	
1058.4[@] *12*	8^+	2.77[‡] ps *6*	
1147.2[d] *13*	8^-	4.0 s *2*	
1174.7[a] *8*	2^+	0.62 ps *2*	This state was identified as the J=2 bandhead of the $K^\pi=2^+$ γ vibrational band (1971Va06). B(E2)↑=0.115 *4* (1977Ro08). Other: 0.10 *8* (1971Va06). Q_0=7.0 eb *3* (2007Ha05).
1267.8[a] *12*	3^+		
1276.0 *10*	2^+	0.49 ps *+15−10*	E(level): from 1971Va06. $T_{1/2}$: from 2002Ro15. B(E2)↑=0.022 *5* (2002Ro15).
1323	3^-		E(level): from 1977Ro08. B(E3)↑=0.053 *10* (1977Ro08).
1364.2[d] *15*	9^-		
1384.3[a] *10*	4^+		
1496.0 *10*	2^+	0.9 ps *2*	E(level): from 1971Va06.

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Coulomb excitation 2007Ha05,2002Ha54,1982Ha25 (continued)

^{178}Hf Levels (continued)

E(level)	J^{π}[#]	$T_{1/2}$[†]	Comments
			B(E2)↑=0.013 *4* (1977Ro08). Other: 0.01 (1971Va06).
1513.9[b] *10*	4^+	62 ps	Q_0=6.6 eb *3* (2007Ha05). $T_{1/2}$: from 2007Ha05.
1532.6[a] *12*	5^+		
1554.0[c] *11*	6^+	77.5 ns *7*	
1570.7[@] *13*	10^+	1.03[‡] ps *4*	
1601.3[d] *15*	10^-		Iγ(E2)/Iγ(M1)=2.2 *3* (2007Ha05),
1640.8[b] *16*	5^+		
1691.2[a] *11*	6^+		
1742.0[c] *13*	7^+		
1791.0[b] *12*	6^+		
1859.0[d] *16*	11^-		g_K-g_R=0.12 *7* (2007Ha05).
1889.6[a] *14*	7^+		
1939.3[e] *18*	10^-		
1951.8[b] *19*	7^+		
1952.0[c] *13*	8^+		
2083.0[a] *13*	8^+		
2136.8[d] *17*	12^-		
2150.1[@] *15*	12^+	0.56[‡] ps *2*	
2155.1[b] *13*	8^+		
2183.9[c] *14*	9^+		
2202.0[e] *19*	11^-		
2315.5[a] *14*	9^+		
2348.8[b] *21*	9^+		
2433.0[d] *19*	13^-		
2434.2[c] *15*	10^+		
2440.6[&] *15*	(10^+)		
2446.4[f] *17*	16^+	31 y *1*	Q_0=8.2 *11* (1996Lu07).
2484.0[e] *19*	12^-		
2538.3[a] *14*	10^+		
2604.9[b] *14*	10^+		
2701.5[c] *16*	11^+		
2748.8[d] *20*	14^-		
2777.1[@] *16*	14^+	0.33[‡] ps *7*	
2797.5[a] *17*	11^+		
2803.8[f] *18*	17^+		
2826.8[b] *24*	11^+		
2942.4[&] *15*	(12^+)		
2988.2[c] *16*	12^+		
3053.2[a] *15*	12^+		
3084.0[d] *21*	15^-		
3100[e]	14^-		
3135.9[b] *17*	12^+		
3181.8[f] *20*	18^+		
3283.9[c] *17*	13^+		
3335.5[a] *20*	13^+		
3379[b] *3*	13^+		
3435.4[@] *18*	16^+		

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Coulomb excitation 2007Ha05,2002Ha54,1982Ha25 (continued)

^{178}Hf Levels (continued)

E(level)	Jπ#	E(level)	Jπ#	E(level)	Jπ#	E(level)	Jπ#
3522.2[&] *16*	(14+)	3741.9[b] *20*	14+	3997.1?[b]	15+	4417.9[b] *23*	16+
3579.8[f] *23*	19+	3902?[c]	15+	4119.9[@] *20*	18+	4837.9[@] *23*	20+
3594.0[c] *18*	14+	3927.5?[a] *22*	15+	4179.2[&] *17*	(16+)	4838?[&]	(18+)
3625.2[a] *18*	14+	3996.8[f] *25*	20+	4250?[a]	16+	5154?[b]	18+

† From adopted values, except as indicated.
‡ From 1982Ha25.
# From adopted band member pattern (2007Ha05).
@ Band(A): $K^\pi=0^+$ g.s. rotational band.
& Band(B): Band "A" (2007Ha05).
a Band(C): $K^\pi=2^+$ gamma band.
b Band(D): $K^\pi=4^+$ band.
c Band(E): $K^\pi=6^+$ isomer band. Average $g_K=1.04$ *3*, $g_K-g_R=0.56$ *2* (2007Ha05). The configuration is almost pure $\pi(7/2^+[404])\pi(5/2^+[402])$ (2007Ha05).
d Band(F): $K^\pi=8^-$ isomer band. Configuration proposed as predominantly $\nu(7/2^-[514])\nu(9/2^+[624])$ (2007Ha05). $g_K-g_R=0.51$ *5* (2007Ha05).
e Band(G): 2nd $K^\pi=8^-$ band. The proposed configuration is $\pi(9/2^-[514])\pi(7/2^+[404])$ (2007Ha05). $g_K-g_R=0.32$ *4* (2007Ha05).
f Band(H): $K^\pi=16^+$ isomer band. The adopted configuration is a 4-qp structure given by $\nu(7/2^-[514])+\nu(9/2^+[624])+\pi(7/2^+[404])+\pi(9/2^-[514])$ (1977Kh01), which is interpreted as a combination of those for the two 8^- states.

$\gamma(^{178}Hf)$

Additional information 1.

E_γ†	E_i(level)	J_i^π	E_f	J_f^π	Mult.	α#	Comments
(13 *3*)	2446.4	16+	2433.0	13−	[E3]		
(40)	1554.0	6+	1513.9	4+	[E2]	211	B(E2)(W.u.)=1.03 *7* (2007Ha05).
89	1147.2	8−	1058.4	8+			E_γ: from adopted gammas. Transition not seen in 2007Ha05.
93	93.3	2+	0.0	0+			
170	1554.0	6+	1384.3	4+	[E2]	0.500	B(E2)(W.u.)=0.018 *3* (2007Ha05).
188	1742.0	7+	1554.0	6+			
210	1952.0	8+	1742.0	7+			
213	306.5	4+	93.3	2+			
217	1364.2	9−	1147.2	8−			
232	2183.9	9+	1952.0	8+			
238	1601.3	10−	1364.2	9−			
246	1513.9	4+	1267.8	3+			
250	2434.2	10+	2183.9	9+			
258	1859.0	11−	1601.3	10−			
265	1532.6	5+	1267.8	3+			
267	2701.5	11+	2434.2	10+			
277	1791.0	6+	1513.9	4+			
278[&]	2136.8	12−	1859.0	11−			
287	2988.2	12+	2701.5	11+			
292[&]	2083.0	8+	1791.0	6+			
296	3283.9	13+	2988.2	12+			

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Coulomb excitation 2007Ha05,2002Ha54,1982Ha25 (continued)

$\gamma(^{178}Hf)$ (continued)

E_γ[†]	E_i(level)	J_i^π	E_f	J_f^π	Mult.	α[#]	Comments
298[&]	2433.0	13^-	2136.8	12^-			
307	1691.2	6^+	1384.3	4^+			
307[&]	3902?	15^+	3594.0	14^+			
310	2446.4	16^+	2136.8	12^-			E_γ: from adopted values.
310	3594.0	14^+	3283.9	13^+			
311	1951.8	7^+	1640.8	5^+			
325.6[‡]	632.1	6^+	306.5	4^+			
338	1939.3	10^-	1601.3	10^-			
339	1513.9	4^+	1174.7	2^+			
343	2202.0	11^-	1859.0	11^-			
357	1889.6	7^+	1532.6	5^+			
357.4 *3*	2803.8	17^+	2446.4	16^+			E_γ: from 1996Lu07. Other: 356.5 *4* (1996De11).
364	2155.1	8^+	1791.0	6^+			
373	1640.8	5^+	1267.8	3^+			
378	3181.8	18^+	2803.8	17^+			
392	2083.0	8^+	1691.2	6^+			
397	2348.8	9^+	1951.8	7^+			
398	1952.0	8^+	1554.0	6^+			
398	3579.8	19^+	3181.8	18^+			
407	1554.0	6^+	1147.2	8^-	[M2]	0.281	B(M2)(W.u.)=0.020 *3* (2007Ha05).
417	3996.8	20^+	3579.8	19^+			
426	2315.5	9^+	1889.6	7^+			
426.4[‡]	1058.4	8^+	632.1	6^+			
442	2183.9	9^+	1742.0	7^+			
450	2604.9	10^+	2155.1	8^+			
454	1601.3	10^-	1147.2	8^-			
455	2538.3	10^+	2083.0	8^+			
478	2826.8	11^+	2348.8	9^+			
482	2434.2	10^+	1952.0	8^+			
482	2797.5	11^+	2315.5	9^+			
494	1859.0	11^-	1364.2	9^-			
502	2942.4	(12^+)	2440.6	(10^+)			
512.4[‡]	1570.7	10^+	1058.4	8^+			
514	3053.2	12^+	2538.3	10^+			
518	2701.5	11^+	2183.9	9^+			
531	3135.9	12^+	2604.9	10^+			
536	2136.8	12^-	1601.3	10^-			
538	3335.5	13^+	2797.5	11^+			
552	3379	13^+	2826.8	11^+			
554	2988.2	12^+	2434.2	10^+			
572	3625.2	14^+	3053.2	12^+			
574	2433.0	13^-	1859.0	11^-			
579.7[‡]	2150.1	12^+	1570.7	10^+			
580	3522.2	(14^+)	2942.4	(12^+)			
582	3283.9	13^+	2701.5	11^+			
587	2446.4	16^+	1859.0	11^-			E_γ: from adopted values.
592	3927.5?	15^+	3335.5	13^+			
600[&]	2202.0	11^-	1601.3	10^-			
606	3594.0	14^+	2988.2	12^+			
606	3741.9	14^+	3135.9	12^+			
612	2748.8	14^-	2136.8	12^-			
618[&]	3902?	15^+	3283.9	13^+			
618[&]	3997.1?	15^+	3379	13^+			

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Coulomb excitation **2007Ha05,2002Ha54,1982Ha25 (continued)**

$\gamma(^{178}Hf)$ (continued)

E_γ [†]	E_i(level)	J_i^π	E_f	J_f^π	Mult.	α [#]	Comments
625	2484.0	12^-	1859.0	11^-			
625[&]	4250?	16^+	3625.2	14^+			
626.9[‡]	2777.1	14^+	2150.1	12^+			
651	3084.0	15^-	2433.0	13^-			
657	4179.2	(16^+)	3522.2	(14^+)			
658.6[‡]	3435.4	16^+	2777.1	14^+			
659[&]	4838?	(18^+)	4179.2	(16^+)			
666[&]	3100	14^-	2433.0	13^-			
676	4417.9	16^+	3741.9	14^+			
684.4[‡]	4119.9	18^+	3435.4	16^+			
718	4837.9	20^+	4119.9	18^+			
737[&] *2*	5154?	18^+	4417.9	16^+			E_γ: from 1996De11.
744	4179.2	(16^+)	3435.4	16^+			
745	3522.2	(14^+)	2777.1	14^+			
792	2942.4	(12^+)	2150.1	12^+			
870	2440.6	(10^+)	1570.7	10^+			
904	3053.2	12^+	2150.1	12^+			
922	1554.0	6^+	632.1	6^+	[E2]	0.00483	B(E2)(W.u.)=8.6×10^{-5} *6* (2007Ha05).
967	2538.3	10^+	1570.7	10^+			
985[&]	3135.9	12^+	2150.1	12^+			
1024	2083.0	8^+	1058.4	8^+			
1034	2604.9	10^+	1570.7	10^+			
1059	1691.2	6^+	632.1	6^+			
1078	1384.3	4^+	306.5	4^+			
1081	1174.7	2^+	93.3	2^+	E2(+M1)	0.0052 *17*	δ= −32, from angular correlations (1971Va06), indicating an almost pure E2 transition.
1097	2155.1	8^+	1058.4	8^+			
1159	1791.0	6^+	632.1	6^+			
1174[&]	1267.8	3^+	93.3	2^+			
1175	1174.7	2^+	0.0	0^+			B(E2)(W.u.)=4.0 *3* (2002Ha54). Other: 3.9 *1* (1977Ro08).
1207	1513.9	4^+	306.5	4^+			
1226	1532.6	5^+	306.5	4^+			
1227[&]	2797.5	11^+	1570.7	10^+			
1247	1554.0	6^+	306.5	4^+	[E2]	0.00265	B(E2)(W.u.)=1.16×10^{-5} *9* (2007Ha05).
1257	2315.5	9^+	1058.4	8^+			
1276	1276.0	2^+	0.0	0^+			
1291	1384.3	4^+	93.3	2^+			
1372[@]	2942.4	(12^+)	1570.7	10^+			
1372[@]	3522.2	(14^+)	2150.1	12^+			
1382[&]	2440.6	(10^+)	1058.4	8^+			
1385	1691.2	6^+	306.5	4^+			
1402	4179.2	(16^+)	2777.1	14^+			
1421	1513.9	4^+	93.3	2^+			B(E2)(W.u.)=0.0022 *2* (2002Ha54).
1475[&]	3625.2	14^+	2150.1	12^+			
1479[&]	2538.3	10^+	1058.4	8^+			
1481[&]	3053.2	12^+	1570.7	10^+			
1496	1496.0	2^+	0.0	0^+			E_γ: from 1971Va06.

[†] Transition energies are from 2007Ha05 unless noted otherwise.

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Coulomb excitation **2007Ha05,2002Ha54,1982Ha25** **(continued)**

$\gamma(^{178}Hf)$ (continued)

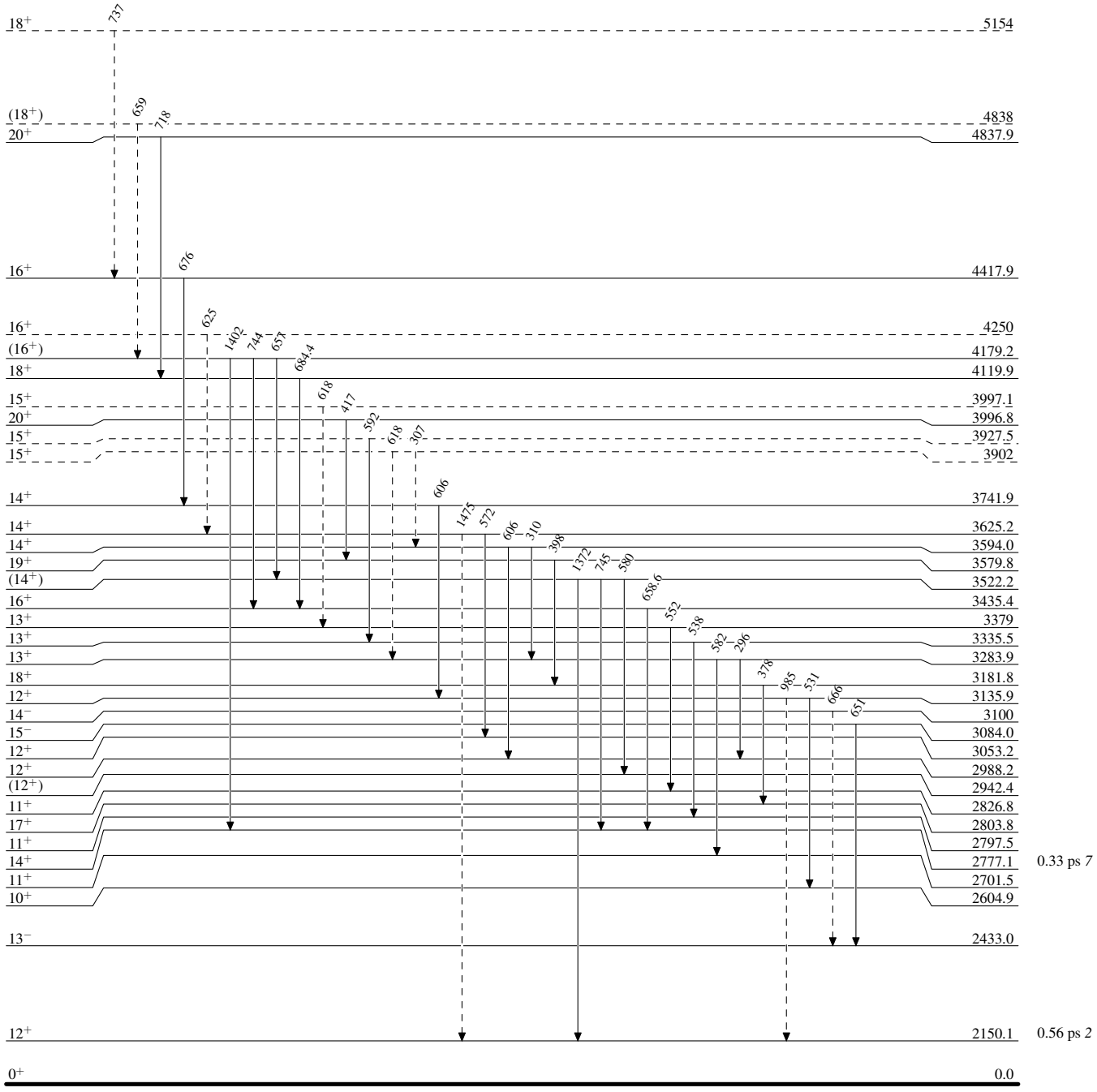
‡ From 1982Ha25.
# Total theoretical internal conversion coefficients, calculated using the BrIcc code (2008Ki07) with Frozen orbital approximation based on γ-ray energies, assigned multipolarities, and mixing ratios, unless otherwise specified.
@ Multiply placed.
& Placement of transition in the level scheme is uncertain.

Coulomb excitation 2007Ha05,2002Ha54,1982Ha25

Legend

Level Scheme

γ Decay (Uncertain)



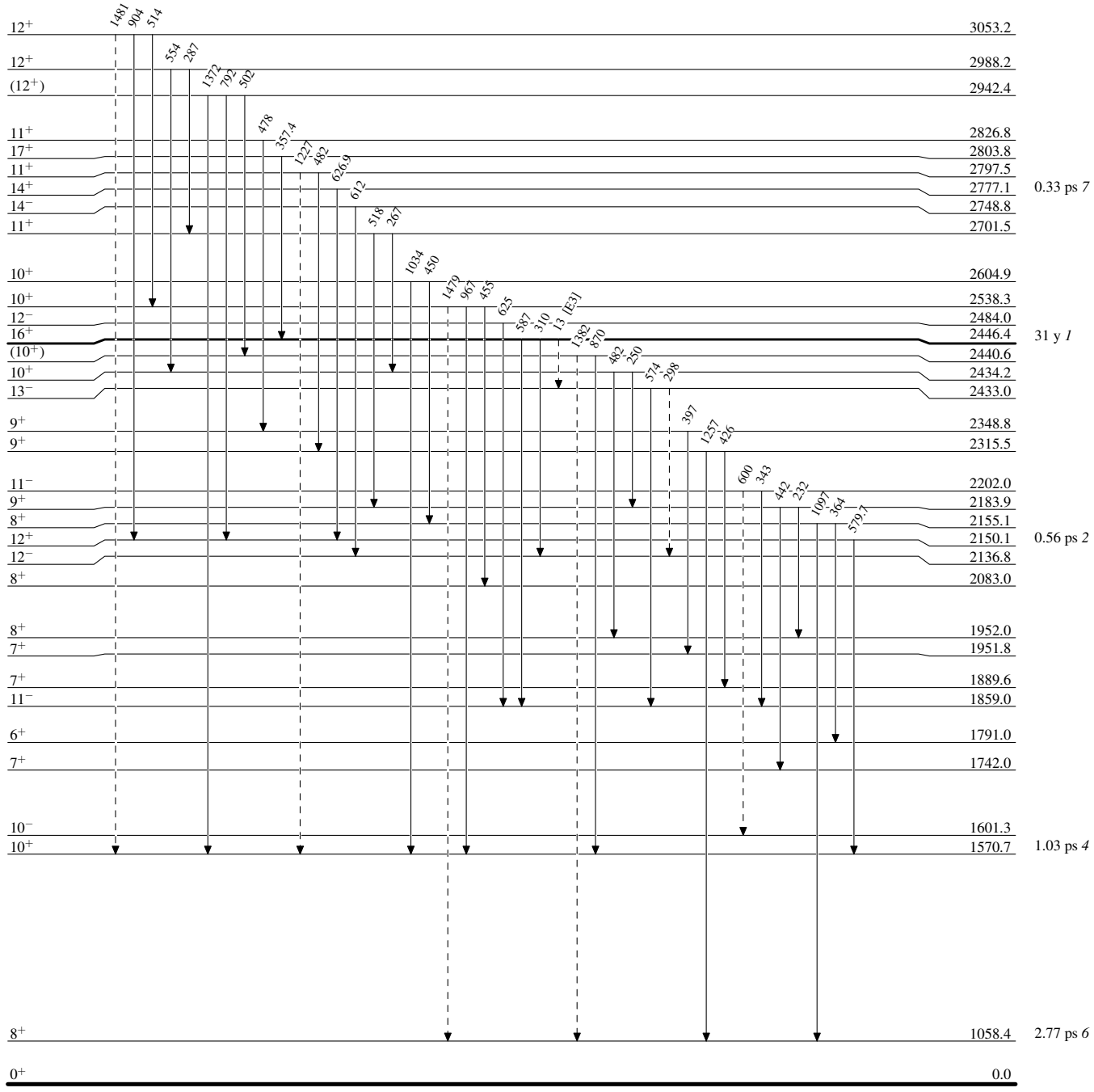
$^{178}_{72}Hf_{106}$

Coulomb excitation 2007Ha05,2002Ha54,1982Ha25

Legend

Level Scheme (continued)

γ Decay (Uncertain)



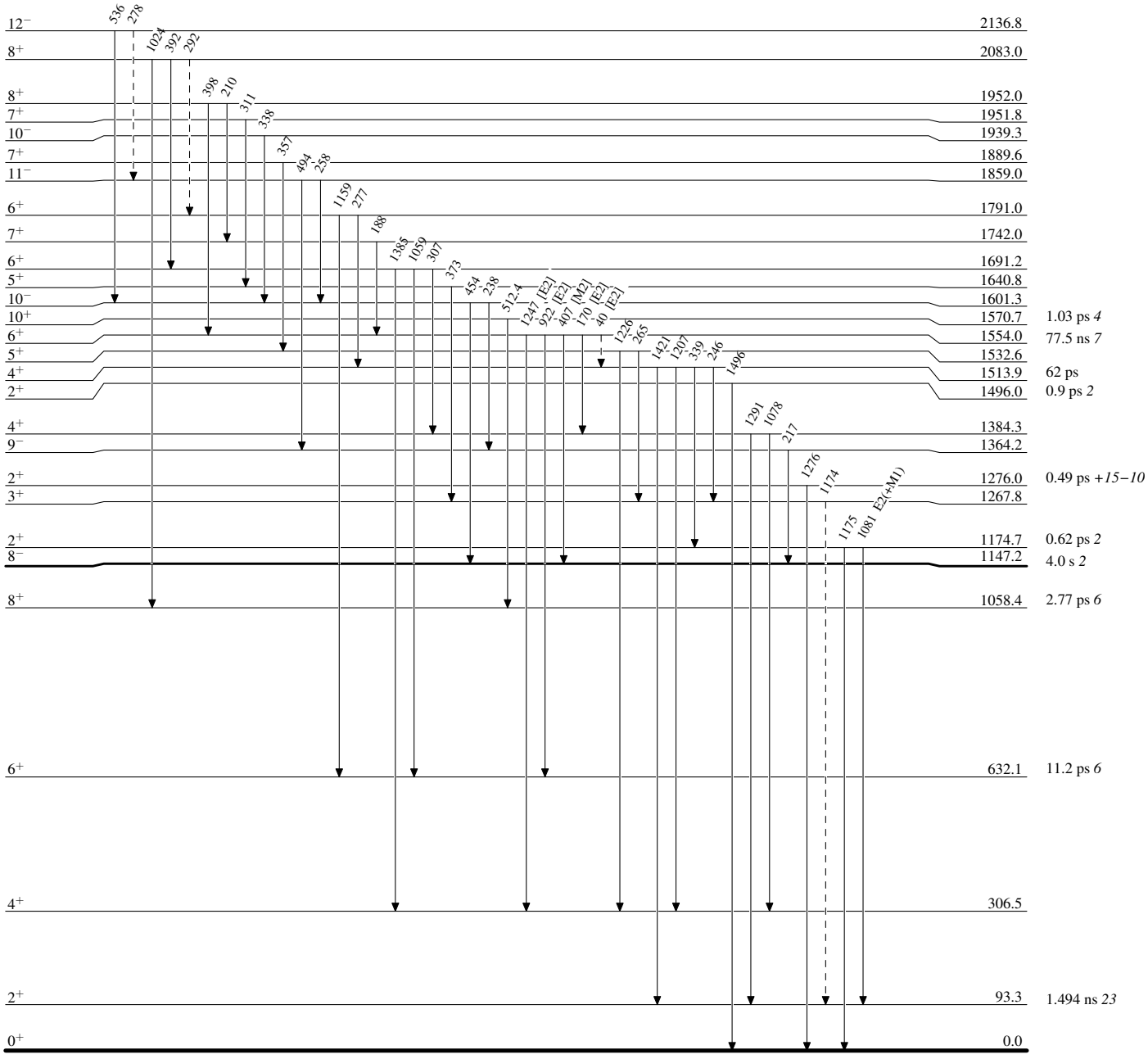
$^{178}_{72}Hf_{106}$

Legend

Coulomb excitation 2007Ha05,2002Ha54,1982Ha25

Level Scheme (continued)

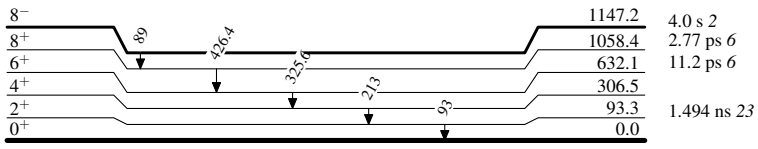
- - - - - - ► γ Decay (Uncertain)



$^{178}_{72}Hf_{106}$

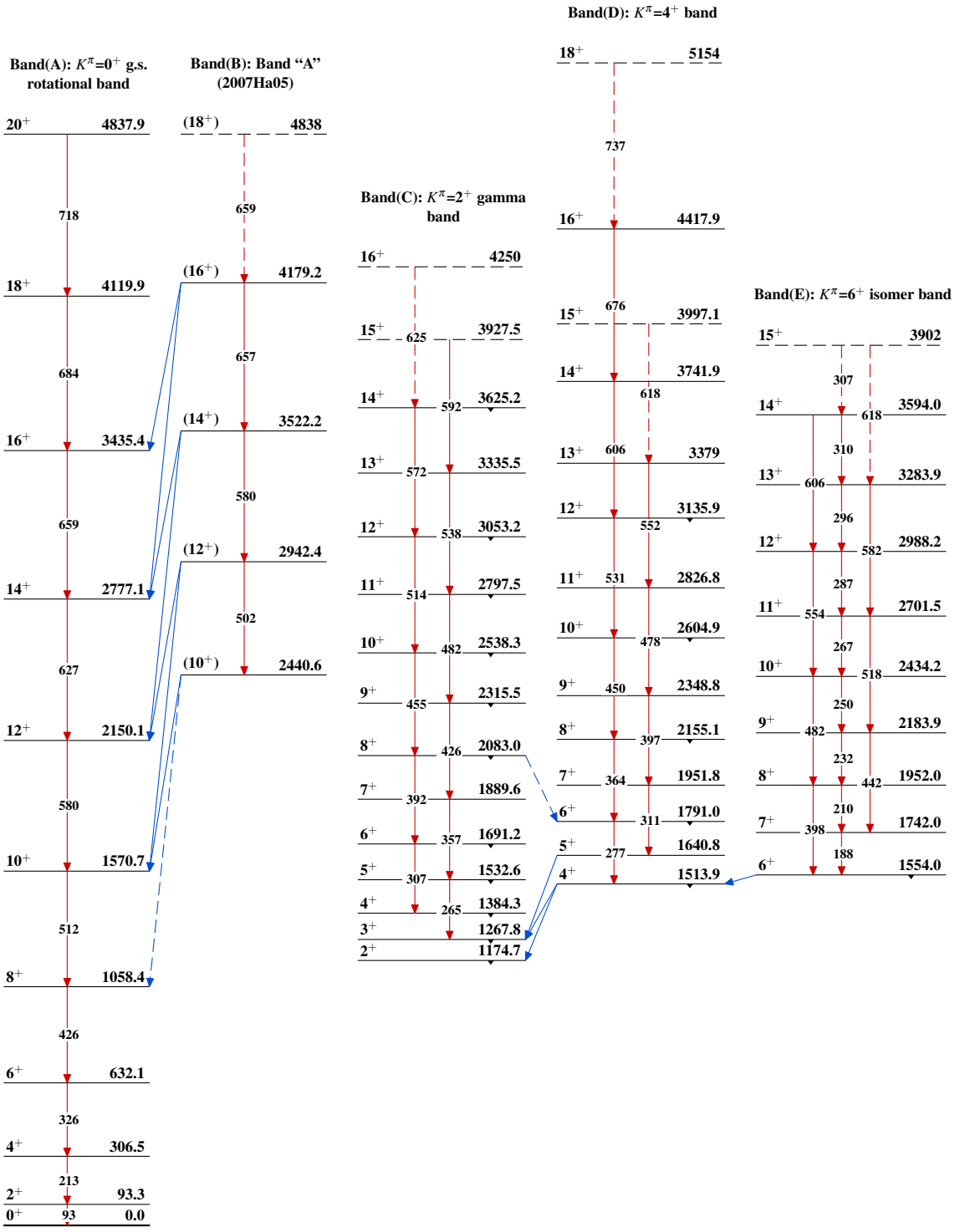
Coulomb excitation 2007Ha05,2002Ha54,1982Ha25

Level Scheme (continued)



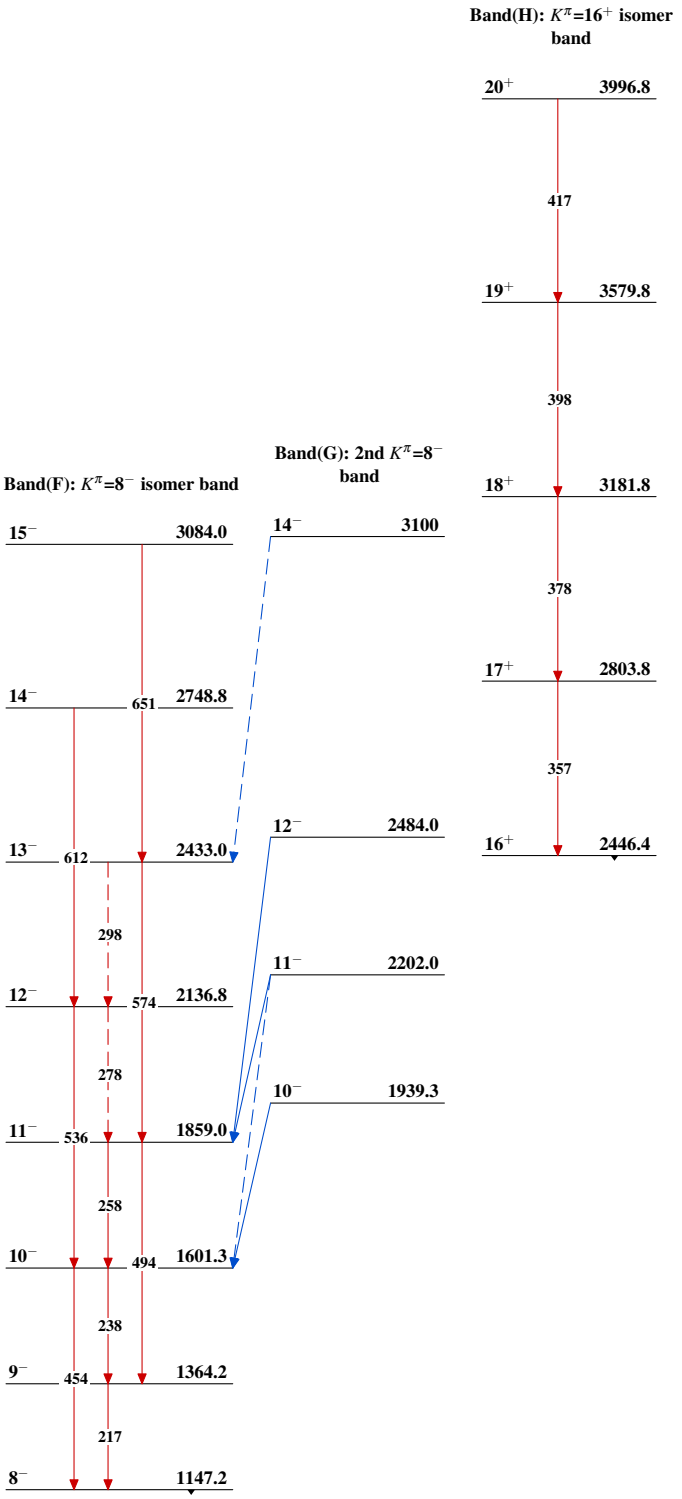
$^{178}_{72}Hf_{106}$

Coulomb excitation 2007Ha05,2002Ha54,1982Ha25



$^{178}_{72}Hf_{106}$

Coulomb excitation 2007Ha05,2002Ha54,1982Ha25 (continued)



$^{178}_{72}Hf_{106}$