Adopted Levels, Gammas

History

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

Q(β^-)=−381.6 *20*; S(n)=6821 *3*; S(p)=4727.1 *15*; Q(α)=5149.9 *8* 2021Wa16
S(2n)=12615.1 *28*, S(2p)=11844 *12* (2021Wa16).

First identification of ^{231}Pa nuclide is generally accredited to L. Meitner, Zeitschrift fur Elektrochemie und angewandte physikalische Chemie 24, 11-12, 169 (1918), starting with pitchblende without uranium or radium, and isolating both the mother isotope ^{231}Pa and its α-daughter ^{227}Ac. 2013Fr03 mention the identification of ^{231}Pa, as a parent of ^{227}Ac, to O. Hahn and L. Meitner, Z. Physik 19, 208 (1918), where half-life was estimated to be between 1200 y and 180,000 y; and also to an earlier indirect evidence of ^{231}Pa in a paper by F. Soddy and J.A. Cranston, Proc. Roy. Soc. (London), A94, 384 (1918), where half-life was estimated to be >10,000 y. 1931Cu01 evaluation adopted half-life of 32,000 y from 1930Gr01, with the citation of the following earlier references: A.v. Grosse, Ber. Chem. Ges. 61, 233 (1928); Naturwiss. 15, 766 (1927); Nature 120, 621 (1927); O. Hahn and A.v. Grosse, Z. Physik 48, 600 (1928), $T_{1/2}$=20,200 y; O. Hahn and E. Walling, Naturwiss. 15, 803 (1928); E. Walling, Dissertation (Berlin, 1928), $T_{1/2}$=20.760 y. Most current half-life measurement of 32,570 y *130* is reported by 2020Je01, a result from collaboration of independent measurements at six different laboratories.

Application of ^{231}Pa as described in N.E. Holden et al., Pure Appl. Chem. 90, 1833 (2018),"^{231}Pa is a natural radiogenic isotope produced by alpha decay of ^{235}U to ^{231}Th, followed by beta emission to form ^{231}Pa. Although its behavior in the environment as a transient member of the U-series decay chain may be complex, measurements and modeling of ^{231}Pa in relation to the isotopes of uranium and thorium have been used in a variety of geochronologic applications on time scales of 103 to 105 years. Studies include movement of water masses and particles in the oceans, rates of magma melting and movement beneath volcanoes, and ages of carbonate mineral deposits, including corals, in relation to climate change".

1966Cr15:

Theoretical calculations: consult the NSR database (www.nndc.bnl.gov/nsr) for 115 primary references, 97 dealing with half-lives of α and cluster decays and other aspects of radioactive decays, and 19 with nuclear structure calculations. Some of these references are listed in 'document' records in this dataset, which can be accessed through on-line ENSDF database at www.nndc.bnl.gov/ensdf/.

Additional information 1.

^{231}Pa Levels

^{231}Pa presents K=1/2 rotational bands with opposite parity and decoupling parameters with very close absolute values, as well as enhanced E1 γ-ray transitions between parity-doublet band levels. These are typical features of nuclei with large stable octupole deformations. However, ^{231}Pa has a small β_3 deformation parameter of 0.02. Consequently, the characteristic features mentioned before have been explained by using large octupole-phonon components in the low-lying states. Extensive calculations of level energies and B(E1) reduced transition probabilities using the quasiparticle-plus-phonon model (QPM) have produced acceptable agreement between theory and experiment (1996Le01).

The even-parity states in ^{231}Pa are members of rotational bands that are strongly mixed by the Coriolis interaction. This mixing affects level energies as well as α, β, and γ-ray transition probabilities. Comprehensive Coriolis calculations have explained distortions in rotational band level spacings (which includes the unusual inversion of the 84$^-$ (5/2$^+$), 102- (3/2$^+$), and 101-keV (7/2$^+$) states in the 3/2[651] rotational band). These calculations also produced values for γ-ray, β^- (^{231}Th β^- decay), and α-particle (^{235}Np α decay) transition probabilities between these states (1975Ho14, 1973Br12). The agreement between experimental results and calculated values have confirmed the rotational band assignments presented here. Band assignments are from Coulomb excitation, (p,2nγ), (α,t), and ^{231}U ε decay (2003Wu03,1996Le01,1975Er01,1973Br12).

Cross Reference (XREF) Flags

A	^{231}Th β^- decay (25.57 h)	F	^{231}Pa(p,p′)
B	^{231}U ε decay (4.2 d)	G	^{231}Pa(d,d′)
C	^{235}Np α decay (396.1 d)	H	Coulomb excitation
D	^{230}Th(α,t)	I	^{232}Th(p,2nγ)
E	^{231}Pa(γ,γ):Mossbauer		

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Adopted Levels, Gammas (continued)

^{231}Pa Levels (continued)

E(level)[†]	J^{π}[#]	$T_{1/2}$[‡]	XREF	Comments
0.0[@]	3/2−	32570 y *130*	ABCDEFGHI	%α=100; %SF≤3×10^{-10} (1952Se67) μ=1.99 *2* (1961Ax01,2019StZV) Q=−1.72 *5* (1978Fr28,2021StZZ) %^{24}Ne/%α=13.4×10^{-12} *17* track-recording glass detector used by 1992Pr05. Others: 1985Sa40, 1986Tr10. %^{24}Ne/%^{23}F≈1347. One track identified by 1992Pr05 as probably ^{23}F was observed, %^{23}F/%α=9.9×10^{-15} (1995Ar33). J^{π}: spin from electron paramagnetic resonance (1961Ax01,1960Ky01); and optical spectroscopy (1961Ri06,1934Sc04). Parity from 183.5γ E1 from J^{π}=5/2^{+}. The following suggests a 1/2[530] Nilsson orbital configuration: 1) experimental decoupling parameter a(exp.)=−1.5 compares with theoretical value a(theory)=−1.8 (1977Ch27). 2) Same ground state Nilsson configuration in ^{233}Pa. 3) ^{230}Th(α,t) experimental spectroscopic factors are consistent with a 1/2[530] configuration assignment. 4) μ=1.99 *2* (2019StZV) agrees with theoretical value of 2.25 for 1/2-1/2[530] Nilsson orbital (1982Li02). μ: electromagnetic double resonance (ENDOR) (1961Ax01); value of 2.01 *2* in 1961Ax01 is given as 1.99 *2* in 2019StZV evaluation. Q: estimated by 1978Fr28 from B(E2) for 58.6 level, not a measured quadrupole moment. $T_{1/2}$: from 2020Je01, determination of average (by power-moderated mean (PMM) method of S. Pomme and J.D. Keightley, Metrologia, 52, S17-26 (2015)) ^{231}Pa activity concentration measured independently at six metrology laboratories using a variety of methods: 4π α liquid scintillation counting, triple to double coincidence ratio (TDCR), CIEMAT/NIST, 4π α liquid scintillation-γ(NaI) coincidence counting, 4π(PC) αγ-coin counting, α counting at a defined solid angle at the following labs: NPL-Teddington, JRC-Geel, LNE-LNHB-Gif-sur-Yvette, NIM-Beijing, NRC-Ottawa, and PTB-Braunschweig; while atom concentration of the material was measured at LLNL-Livermore by isotope dilution mass spectrometry (IDMS), using ^{233}Pa as a tracer. Others: 32765 y *110* (1969Ro33, calorimetry method, value of 32713 y *110* increased by 52 y due to change in Q(α) from 5140 to 5149.9 *8*); 32340 y *115* (1968Br04, radiometric method, with quoted uncertainty of 230 y at 95% confidence level); 32647 y *260* (1961Ki05, calorimetry method, value of 32480 y *260* increased by 167 y, due to change in the Adopted decay scheme); 34300 y *300* (1949Va02, radiometric method); 32800 y (cited by 1968Br04 from unpublished work of J. Fleggenheimer and A.G. Maddock); 32000 y *3200* (cited by 2020Je01 from measurement by A.v. Grosse, Naturwiss. 20, 505 (1932)). Weighted average of values from 2020Je01, 1969Ro33, 1968Br04 and 1961Ki05 is 32570 y *100*, while PMM method (used in 2020Je01) gives 32570 y *98*. $T_{1/2}$(SF)≥1.1×10^{16} y (1952Se67) (11 fission events observed).
9.183[@] *18*	1/2−		ABCD FGHI	XREF: D(12).
58.5696[@] *24*	7/2−	274 ps *10*	ABCD FGHI	$T_{1/2}$: from β^- decay, (25.6γ)(ce(L) for 58.6γ)(t) (1975Ho14). Other: 281 ps *17*, deduced from B(E2) in Coulomb excitation.
77.692[@] *17*	5/2−		AB D FGHI	
84.2152[a] *20*	5/2+	45.1 ns *13*	ABC E HI	Q=+0.7 *2* (1978Fr28,2021StZZ) $T_{1/2}$: from β^- decay, (β(84γ ce)(t)) (1975Ho14). Others: 43.7 ns *5* (1972Mc29, a time interval distribution method); 41 ns *4* (1955St88, (25.6γ)β(t) and (84.2γ)β(t)). Q: Mossbauer effect (1978Fr28), deduced from measured Q(84.2 level)/Q(g.s.)=−0.4 *1*, and estimated Q(g.s.)=−1.72 *5*. J^{π}: 25.6γ E1 to 7/2−, 84.2γ E1 to 3/2−. HF=3.1 from ^{235}Np α decay suggests strong mixing with 5/2^{+}, 5/2[642] level at 183.5 keV.

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Adopted Levels, Gammas (continued)

^{231}Pa Levels (continued)

E(level)[†]	J$^{\pi}$[#]	T$_{1/2}$[‡]	XREF	Comments
101.408[a] *4*	7/2$^+$	0.7 ns *2*	ABCd HI	XREF: d(105). T$_{1/2}$: combined for 101.4+102.3 levels (1975Ho14, β^- decay).
102.2685[a] *21*	3/2$^+$	0.7 ns *2*	ABCd HI	XREF: d(105). J$^{\pi}$: 102.3γ (E1) to 3/2$^-$, 18.1γ M1+E2 to 5/2$^+$, 93.0γ to 1/2$^-$. T$_{1/2}$: combined for 101.4+102.3 levels (1975Ho14, β^- decay).
111.648[a] *12*	(9/2$^+$)		A CD FGHI	XREF: D(117)G(109.2).
134 *5*	(11/2$^+$)		D	
168.77[@] *5*	11/2$^-$	154 ps *12*	CD FGHI	XREF: D(172). T$_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) and γ branching ratio for 110.2γ.
171.74[a] *11*	(11/2$^+$)		HI	
174.160[b] *5*	(5/2$^-$)		ABC HI	XREF: C(?). J$^{\pi}$: 89.9γ (E1) to 5/2$^+$, 165.0γ to 1/2$^-$, 115.6γ to 7/2$^-$, 72.8γ to 7/2$^+$.
183.4954[c] *25*	5/2$^+$	≤0.19 ns	ABC HI	J$^{\pi}$: Favored α decay (HF=2.9) from 5/2$^+$, π5/2[642] parent ^{235}Np strongly suggests 5/2$^+$, π5/2[642] for 183.5 level in ^{231}Pa. T$_{1/2}$: from β^- decay, β(ce(M) for 81.2γ+82.1γ)(t) (1975Ho14).
189.14[a] *8*	(13/2$^+$)		D HI	
193.21[@] *11*	(9/2$^-$)	13.6 ps *19*	FGHI	T$_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) and γ branching ratio for 115.5γ.
218.244[b] *13*	(7/2$^-$)		A D HI	XREF: D(214).
247.320[c] *6*	7/2$^+$		A C HI	
273.717[&] *15*	(1/2$^+$)		B FGH	J$^{\pi}$: γ rays to 1/2$^-$, 3/2$^-$ and 3/2$^+$. Upper limits of γ-intensities and ratio of intensities of [E1] transitions to the ground-state band support spin of 1/2$^+$. With this level assigned as the bandhead, energies of the higher members of the rotational band are in agreement.
274.96[b] *17*	(9/2$^-$)		D HI	XREF: D(272).
287 *3*			D	In (α,t), this level was assigned as bandhead of π1/2[400] band, but in later studies using γ-ray data from reactions, a 273.7 level was assigned as bandhead of π1/2[400]+π1/2[660] mixed configuration. It should be noted that π1/2[400] band assignment to two levels in (α,t) seemed tentative, based only on level energies.
296.6 *4*			FG	
300.98[a] *11*	(15/2$^+$)	82 ps *20*	H	T$_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) and γ branching ratio for 129.2.
304.7[c] *3*	(9/2$^+$)		C HI	
311.78[&] *17*	(5/2$^+$)	0.12 ns *+17−6*	GH	T$_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E1) and γ branching ratio for 253.3γ.
316.83[a] *9*	(17/2$^+$)	77 ps *+27−18*	H	T$_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) and γ branching ratio for 127.7γ.
317.94[&] *4*	(3/2$^+$)	0.07 ns *+11−3*	AB D FGHI	T$_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E1) and γ branching ratio for 308.8γ.
320.208[d] *20*	3/2$^-$		AB HI	J$^{\pi}$: 311.0γ M1+E2 to 1/2$^-$; $\gamma\gamma(\theta)$ in ^{231}Th β^- decay (1975Ho14).
328.88[@] *7*	(15/2$^-$)	74 ps *7*	FGHI	T$_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) and γ branching ratio for 160.1γ.
344.55[b] *19*	(11/2$^-$)		D HI	XREF: D(340).
351.69[@] *11*	(13/2$^-$)	10 ps *+11−7*	FGHI	T$_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) and γ branching ratio for 158.5γ.
351.85[d] *4*	(5/2$^-$)		A HI	
391.92[&] *17*	(9/2$^+$)	94 ps *+58−39*	D FGHI	XREF: D(385)F(395.7).

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Adopted Levels, Gammas (continued)

^{231}Pa Levels (continued)

E(level)[†]	J$^{\pi}$[#]	$T_{1/2}$[‡]	XREF	Comments
				$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E1) and γ branching ratio for 333.5γ.
395.92[d] *12*	(7/2$^-$)		D HI	XREF: D(393).
406.14[c] *19*	(11/2$^+$)		HI	
408.68[&] *19*	(7/2$^+$)	0.05 ns *+10−3*	FGHI	XREF: F(411.4)G(411.1). $T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E1) and γ branching ratio for 330.9γ.
424.94[b] *20*	(13/2$^-$)		FGHI	XREF: F(422.7).
443.0 *5*			D FG	
450.62[d] *14*	(9/2$^-$)		D HI	XREF: D(455).
487.62[a] *13*	(19/2$^+$)	21 ps *4*	H	$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) and γ branching ratio for 186.6γ.
494.80[a] *10*	(21/2$^+$)	31 ps *11*	H	$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) and γ branching ratio for 177.96γ.
507 *3*			D	
513.5 *12*			D G	XREF: D(518).
520.54[b] *22*	(15/2$^-$)		HI	
525.35[&] *14*	(13/2$^+$)	54 ps *+33−25*	HI	$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E1) and γ branching ratio for 356.3γ.
535.77[@] *8*	(19/2$^-$)	30.4 ps *21*	GHI	$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) and γ branching ratio for 206.88γ.
543.07[&] *19*	(11/2$^+$)	43 ps *+78−24*	HI	$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E1) and γ branching ratio for 349.5γ.
551.50[@] *11*	(17/2$^-$)	23.4 ps *15*	GHI	$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) and γ branching ratio for 199.8γ.
567.5 *5*			D G	XREF: D(575).
583.5 *8*			D G	XREF: D(590).
604.25[e] *15*	(3/2$^-$)		D HI	J$^{\pi}$: γ to 5/2$^+$; possible γ to 3/2$^-$. This level as bandhead of π3/2[521] was proposed in (α,t) based on a comparison of experimental spectroscopic factor with DWBA calculation for 7/2$^-$ member at 676 keV.
632.21[e] *17*	(5/2$^-$)		D GHI	J$^{\pi}$: γ rays to (5/2$^-$) and 3/2$^-$; band member.
678.1[e] *3*	(7/2$^-$)		D HI	J$^{\pi}$: γ to (5/2$^-$); comparison of experimental spectroscopic factor with DWBA analysis in (α,t).
700 *3*			D	
705.34[&] *16*	(17/2$^+$)	34 ps *14*	HI	$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E1) and γ branching ratio for 376.4γ.
716.74[&] *19*	(15/2$^+$)	37 ps *13*	H	$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E1) and γ branching ratio for 365.4γ.
721.41[a] *13*	(25/2$^+$)	30 ps *+30−6*	H	$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) for 226.6γ.
728.38[a] *24*	(23/2$^+$)	6.9 ps *15*	H	$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) and γ branching ratio for 240.9γ.
734.2[e] *4*	(9/2$^-$)		HI	J$^{\pi}$: γ to (7/2$^-$); band member.
750 *2*			D	
785.59[@] *11*	(23/2$^-$)	13.5 ps *8*	gHI	XREF: g(788.1). $T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) and γ branching ratio for 249.8γ.
788.05[@] *12*	(21/2$^-$)	19.3 ps *16*	gHI	XREF: g(788.1). $T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) and γ branching ratio for 236.58γ.
801[e] *3*	(11/2$^-$)		D	

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Adopted Levels, Gammas (continued)

^{231}Pa Levels (continued)

E(level)[†]	J^{π}[#]	$T_{1/2}$[‡]	XREF	Comments
815 *3*			D	
857.3 *10*			G	
874.0 *6*			G	
901.6 *8*			G	
917.6 *12*			G	
929.55[&] *23*	(21/2$^+$)		HI	
946.0[&] *5*	(19/2$^+$)		GH	
967.9 *6*			G	
993.88[a] *21*	(29/2$^+$)		H	
1019.2[a] *4*	(27/2$^+$)	6 ps *+11−4*	GH	$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(M1) and γ branching ratio for 298.0γ.
1048.4 *6*			G	
1057.11[@] *14*	(25/2$^-$)	10.2 ps *18*	H	$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) and γ branching ratio for 269.1γ.
1074.31[@] *17*	(27/2$^-$)	6.2 ps *+13−9*	H	$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) and γ branching ratio for 288.7γ.
1086.4 *6*			G	
1136.8 *5*			G	
1158.5 *10*			G	
1190.0 *15*			G	
1196.2[&] *4*	(23/2$^+$)		H	
1221.3 *8*			G	
1307.8[a] *4*	(33/2$^+$)		H	
1355.5[@] *3*	(29/2$^-$)	6.8 ps *+7−17*	H	$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) and γ branching ratio for 298.6γ.
1357.5[a] *5*	(31/2$^+$)		H	
1398.15[@] *22*	(31/2$^-$)	3.1 ps *+11−6*	H	$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E2) and γ branching ratio for 323.8γ.
1660.4[a] *5*	(37/2$^+$)		H	
1683.2[@] *5*	(33/2$^-$)		H	
1754.2[@] *4*	(35/2$^-$)	1.2 ps *+19−7*	H	$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E1) and γ branching ratio for 446.9γ.
2040.4[@] *9*	(37/2$^-$)		H	
2139.3[@] *5*	(39/2$^-$)	1.2 ps *+32−8*	H	$T_{1/2}$: from Coulomb excitation, deduced by evaluators from B(E1) and γ branching ratio for 479.0γ.

[†] From least-squares fit to Eγ data. Reduced χ^2=0.79, with only two Eγ values deviating slightly, between 2 and 3 σ.
[‡] From ^{231}Th β^- decay, unless otherwise specified.
[#] From γ-ray multipolarities and rotational band structures. Individual arguments for spin and parity assignments are given for rotational bandheads.
[@] Band(A): π1/2[530].
[&] Band(B): π1/2[400]+π1/2[660].
[a] Band(C): π3/2[651].
[b] Band(D): π5/2[512].
[c] Band(E): π5/2[642].
[d] Band(F): π3/2[532].
[e] Band(G): π3/2[521].

Adopted Levels, Gammas (continued)

$\gamma(^{231}Pa)$

Gamma-ray transition probabilities are from Coulomb excitation, unless otherwise indicated.

E_i(level)	J^π_i	E_γ[†]	I_γ[†]	E_f	J^π_f	Mult.[†#]	δ[†]	α[c]	$I_{(\gamma+ce)}$	Comments
9.183	1/2⁻	(9.183)		0.0	3/2⁻				100	B(E2)(W.u.)=333 *+38−36* E_γ: from level-energy difference.
58.5696	7/2⁻	58.5700 *24*	100	0.0	3/2⁻	E2		155.5 *22*		B(E2)(W.u.)=227 *9* α(L)=113.6 *16*; α(M)=31.3 *5* α(N)=8.43 *12*; α(O)=1.90 *3*; α(P)=0.306 *5*; α(Q)=0.000818 *12* B(E2)(W.u.) from $T_{1/2}$=274 ps *10*. Other: 222 *+13−11* from Coulomb excitation.
77.692	5/2⁻	(19.1)		58.5696	7/2⁻					
		68.5 *1*	100 *5*	9.183	1/2⁻	E2		73.3 *10*		B(E2)(W.u.)=127 *+52−28* α(L)=53.5 *9*; α(M)=14.76 *24* α(N)=3.98 *7*; α(O)=0.898 *14*; α(P)=0.1448 *23*; α(Q)=0.000423 *7*
		77.6[‡] *2*	72 *12*	0.0	3/2⁻	[M1+E2]		25 *16*		B(E2)(W.u.)=71 *6*
84.2152	5/2⁺	25.65 *2*	202 *3*	58.5696	7/2⁻	E1		4.37 *6*		B(E1)(W.u.)=3.37×10⁻⁵ *13* α(L)=3.26 *5*; α(M)=0.843 *12* α(N)=0.219 *4*; α(O)=0.0471 *7*; α(P)=0.00673 *10*; α(Q)=0.000196 *3* B(E1)(W.u.) from $T_{1/2}$=45.1 ns *13* and γ-branching ratio. Other: 3.1×10⁻⁵ *+5−2* from Coulomb excitation.
		84.2140 *22*	100	0.0	3/2⁻	E1		2.17 *21*		B(E1)(W.u.)=4.45×10⁻⁷ *+28−25* α(L)=0.1434 *20*; α(M)=0.0350 *5* α(N)=0.00925 *13*; α(O)=0.00212 *3*; α(P)=0.000359 *5*; α(Q)=1.694×10⁻⁵ *24* α: experimental value of anomalous conversion coefficient (1975Ho14). B(E1)(W.u.) from $T_{1/2}$=45.1 ns *13* and γ-branching ratio. Other: 9.1×10⁻⁷ *+39−66* from Coulomb excitation.
101.408	7/2⁺	17.195 *21*	46×10¹ *16*	84.2152	5/2⁺	(M1)		166 *3*		α(L)=1.4; α(M)=122.6 *18*; α(N)=32.7 *5*; α(O)=7.75 *12*; α(P)=1.505 *22*; α(Q)=0.144 *2*
		42.81 *5*	100.0 *23*	58.5696	7/2⁻	[E1]		1.136 *16*		α(L)=0.854 *13*; α(M)=0.213 *4* α(N)=0.0558 *9*; α(O)=0.01240 *19*; α(P)=0.00194 *3*; α(Q)=7.08×10⁻⁵ *11*
102.2685	3/2⁺	18.055 *18*	21 *8*	84.2152	5/2⁺	M1+E2	0.040 *+18−0*	218 *28*		α(L)=45 *15*; α(M)=128 *8* α(N)=34 *2*; α(O)=8.1 *4*; α(P)=1.55 *5*; α(Q)=0.124 *1*
		93.02 *4*	10.6 *12*	9.183	1/2⁻	(E1)		0.1463 *21*		α(L)=0.1103 *16*; α(M)=0.0269 *4*

Adopted Levels, Gammas (continued)

γ(^{231}Pa) (continued)

E_i(level)	J_i^π	E_γ[†]	I_γ[†]	E_f	J_f^π	Mult.[†#]	δ[†]	α[c]	Comments
									α(N)=0.00711 *10*; α(O)=0.001633 *23*; α(P)=0.000279 *4*; α(Q)=1.363×10^{-5} *20*
102.2685	3/2$^+$	102.2700 *24*	100 *3*	0.0	3/2$^-$	(E1)		0.1141 *16*	α(L)=0.0860 *12*; α(M)=0.0210 *3* α(N)=0.00554 *8*; α(O)=0.001276 *18*; α(P)=0.000220 *3*; α(Q)=1.107×10^{-5} *16*
111.648	(9/2$^+$)	53.2[a] *8*	100[a]	58.5696	7/2$^-$	[E1]		0.64 *3*	α(L)=0.483 *21*; α(M)=0.119 *6* α(N)=0.0313 *14*; α(O)=0.0070 *3*; α(P)=0.00114 *5*; α(Q)=4.53×10^{-5} *16*
168.77	11/2$^-$	57.2[a] *2*	7.8[a] *7*	111.648	(9/2$^+$)	[E1]		0.529 *8*	B(E1)(W.u.)=5.5×10^{-5} *+14−9* α(L)=0.398 *6*; α(M)=0.0982 *14* α(N)=0.0258 *4*; α(O)=0.00583 *9*; α(P)=0.000950 *14*; α(Q)=3.89×10^{-5} *6*
		110.20[‡] *5*	100[a] *5*	58.5696	7/2$^-$	(E2)[@]		7.80 *11*	B(E2)(W.u.)=301 *24* α(L)=5.70 *9*; α(M)=1.573 *23* α(N)=0.424 *7*; α(O)=0.0960 *14*; α(P)=0.01559 *23*; α(Q)=6.92×10^{-5} *10*
171.74	(11/2$^+$)	60.3[a] *3*	100[a] *22*	111.648	(9/2$^+$)	[M1]		18.3 *4*	B(M1)(W.u.)=0.0047 *+19−16*
		70.4[a] *3*	25[a] *7*	101.408	7/2$^+$	[E2]		64.3 *16*	
174.160	(5/2$^-$)	72.7510 *29*	25.5 *7*	101.408	7/2$^+$	[E1]		0.280 *4*	α(L)=0.211 *3*; α(M)=0.0517 *8* α(N)=0.01363 *19*; α(O)=0.00310 *5*; α(P)=0.000519 *8*; α(Q)=2.33×10^{-5} *4*
		89.95 *2*	100 *3*	84.2152	5/2$^+$	(E1)		0.1598 *23*	α(L)=0.1205 *17*; α(M)=0.0294 *5* α(N)=0.00777 *11*; α(O)=0.001782 *25*; α(P)=0.000304 *5*; α(Q)=1.467×10^{-5} *21*
		115.63 *3*	0.10 *3*	58.5696	7/2$^-$	[M1+E2]		10 *4*	α(K)=5 *6*; α(L)=3.3 *13*; α(M)=0.9 *4* α(N)=0.24 *11*; α(O)=0.055 *23*; α(P)=0.009 *4*; α(Q)=0.00028 *23*
		165.00 *5*	0.35 *1*	9.183	1/2$^-$	[E2]		1.464 *21*	α(K)=0.209 *3*; α(L)=0.917 *13*; α(M)=0.252 *4* α(N)=0.0681 *10*; α(O)=0.01545 *22*; α(P)=0.00254 *4*; α(Q)=1.96×10^{-5} *3*
		174.15 *2*	1.79 *7*	0.0	3/2$^-$	[M1+E2]		2.7 *15*	α(K)=1.8 *16*; α(L)=0.68 *4*; α(M)=0.177 *22* α(N)=0.048 *6*; α(O)=0.0111 *11*; α(P)=0.00196 *6*; α(Q)=9.E−5 *7*
183.4954	5/2$^+$	81.2280 *21*	100 *4*	102.2685	3/2$^+$	M1(+E2)	0.00 *8*	7.66 *20*	α(L)=5.78 *14*; α(M)=1.40 *4* α(N)=0.374 *11*; α(O)=0.0898 *24*; α(P)=0.0172 *4*; α(Q)=0.001422 *22*
		82.0870 *22*	46.6 *23*	101.408	7/2$^+$	M1(+E2)	0.04 *6*	7.47 *23*	α(L)=5.63 *17*; α(M)=1.36 *5* α(N)=0.365 *12*; α(O)=0.088 *3*; α(P)=0.0167 *5*; α(Q)=0.001377 *22*
		99.2780 *36*	14.9 *8*	84.2152	5/2$^+$	M1+E2	0.35 *7*	5.2 *4*	α(L)=3.9 *3*; α(M)=0.97 *8* α(N)=0.261 *20*; α(O)=0.062 *5*; α(P)=0.0113 *7*; α(Q)=0.00072 *3*
		105.79 *3*	0.89 *8*	77.692	5/2$^-$	[E1]		0.1043 *15*	α(L)=0.0787 *11*; α(M)=0.0192 *3*

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Adopted Levels, Gammas (continued)

γ(^{231}Pa) (continued)

E$_i$(level)	J$^\pi_i$	E$_\gamma$[†]	I$_\gamma$[†]	E$_f$	J$^\pi_f$	Mult.[†#]	δ[†]	α[c]	Comments
									α(N)=0.00507 8; α(O)=0.001168 17; α(P)=0.000202 3; α(Q)=1.027×10^{-5} 15
183.4954	5/2$^+$	124.927 18	6.62 15	58.5696	7/2$^-$	(E1)		0.294 4	α(K)=0.226 4; α(L)=0.0511 8; α(M)=0.01241 18 α(N)=0.00329 5; α(O)=0.000761 11; α(P)=0.0001331 19; α(Q)=7.12×10^{-6} 10
		183.489 20	3.77 15	0.0	3/2$^-$	(E1)		0.1181 17	α(K)=0.0928 13; α(L)=0.0191 3; α(M)=0.00463 7 α(N)=0.001228 18; α(O)=0.000287 4; α(P)=5.13×10^{-5} 8; α(Q)=3.05×10^{-6} 5
189.14	(13/2$^+$)	77.6[a] 2	100[a]	111.648	(9/2$^+$)	[E2]		40.5 8	
193.21	(9/2$^-$)	(24.3)	44 9	168.77	11/2$^-$	[M1]		270 40	B(M1)(W.u.)=0.35 +9−5 γ implied from Coulomb excitation.
		81.6[a] 4	88[a] 31	111.648	(9/2$^+$)	[E1]		0.207 4	B(E1)(W.u.)=2.2×10^{-5} +8−7
		91.4[a] 6	25×10^1[a] 19	101.408	7/2$^+$	[E1]		0.153 4	α(L)=0.1142 16; α(M)=0.0279 4 α(N)=0.00737 11; α(O)=0.001690 24; α(P)=0.000289 4; α(Q)=1.403×10^{-5} 20
		115.5[‡] 2	100[a] 13	77.692	5/2$^-$	[E2]		6.49 12	B(E2)(W.u.)=180 +8−9
		134.4[‡] 2	75[a] 19	58.5696	7/2$^-$	(E2+M1)	4.0 9	3.7 2	B(E2)(W.u.)=25 5; B(M1)(W.u.)=0.0009 +4−3
218.244	(7/2$^-$)	44.08 17	2.9 11	174.160	(5/2$^-$)	[M1+E2]		3.3×10^2 29	α(L)=2.4×10^2 21; α(M)=66 58 α(N)=18 16; α(O)=4.0 35; α(P)=0.65 55; α(Q)=0.0057 29
		106.61 3	70 3	111.648	(9/2$^+$)	[E1]		0.1023 14	α(L)=0.0772 11; α(M)=0.0188 3 α(N)=0.00497 7; α(O)=0.001145 16; α(P)=0.000198 3; α(Q)=1.010×10^{-5} 15
		116.83 2	89 5	101.408	7/2$^+$	(E1)		0.342 5	α(K)=0.262 4; α(L)=0.0608 9; α(M)=0.01478 21 α(N)=0.00391 6; α(O)=0.000904 13; α(P)=0.0001574 22; α(Q)=8.26×10^{-6} 12
		134.03 2	100.0 27	84.2152	5/2$^+$	(E1)		0.249 4	α(K)=0.192 3; α(L)=0.0426 6; α(M)=0.01033 15 α(N)=0.00274 4; α(O)=0.000635 9; α(P)=0.0001116 16; α(Q)=6.10×10^{-6} 9
		140.54 4	2.90 26	77.692	5/2$^-$	[M1+E2]		5.3 25	α(K)=3 3; α(L)=1.5 4; α(M)=0.40 12 α(N)=0.11 4; α(O)=0.025 7; α(P)=0.0043 9; α(Q)=0.00016 13
247.320	7/2$^+$	63.86 3	14.6 26	183.4954	5/2$^+$	M1+E2	0.6 3	39 16	α(L)=28 12; α(M)=7.5 33 α(N)=2.03 88; α(O)=0.47 20; α(P)=0.079 31; α(Q)=0.0023 5
		73.0 1	4.3 17	174.160	(5/2$^-$)	[E1]		0.277	
		135.670 11	51.1 17	111.648	(9/2$^+$)	M1(+E2)	0.1 +4−1	8.5 10	α(K)=6.7 13; α(L)=1.32 17; α(M)=0.32 6 α(N)=0.086 15; α(O)=0.021 4; α(P)=0.0039 5; α(Q)=0.00032 6
		145.06 4	3.73 26	102.2685	3/2$^+$	(E2)		2.46 4	α(K)=0.237 4; α(L)=1.627 23; α(M)=0.448 7 α(N)=0.1209 17; α(O)=0.0274 4; α(P)=0.00448 7; α(Q)=2.86×10^{-5} 4
		145.94 2	20.6 9	101.408	7/2$^+$	M1+E2	0.78 24	5.2 7	α(K)=3.5 8; α(L)=1.26 8; α(M)=0.32 3 α(N)=0.087 8; α(O)=0.0204 16; α(P)=0.00362 19;

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$\gamma(^{231}Pa)$ (continued)

E_i(level)	J_i^π	E_γ†	I_γ†	E_f	J_f^π	Mult.†#	δ†	αc	Comments
									α(Q)=0.00017 *4*
		163.1010 *54*	100 *4*	84.2152	5/2+	M1(+E2)	0.0 *3*	5.1 *3*	α(K)=4.0 *4*; α(L)=0.776 *19*; α(M)=0.187 *7* α(N)=0.0502 *19*; α(O)=0.0120 *4*; α(P)=0.00230 *5*; α(Q)=0.000190 *15*
		169.65 *3*	0.86 *4*	77.692	5/2−	[E1]		0.1421 *20*	α(K)=0.1113 *16*; α(L)=0.0233 *4*; α(M)=0.00564 *8* α(N)=0.001497 *21*; α(O)=0.000349 *5*; α(P)=6.22×10^{-5} *9*; α(Q)=3.63×10^{-6} *5*
		188.76 *2*	2.10 *9*	58.5696	7/2−	[E1]		0.1105 *16*	α(K)=0.0869 *13*; α(L)=0.01782 *25*; α(M)=0.00431 *6*

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Adopted Levels, Gammas (continued)

$\gamma(^{231}Pa)$ (continued)

E_i(level)	J^π_i	E_γ[†]	I_γ[†]	E_f	J^π_f	Mult.[†#]	δ[†]	α[c]	Comments
									α(N)=0.001144 *16*; α(O)=0.000267 *4*; α(P)=4.79×10^{-5} *7*; α(Q)=2.87×10^{-6} *4*
273.717	(1/2$^+$)	171.43[&] *3*	32[&] *3*	102.2685	3/2$^+$	[M1+E2]		2.8 *16*	
		189.5[&]	≤0.8[&]	84.2152	5/2$^+$				
		196.0[&e]	≤0.8[&]	77.692	5/2$^-$				γ to 5/2$^-$ is not likely.
		264.55[&] *2*	45[&] *4*	9.183	1/2$^-$	[E1]		0.0506 *7*	
		273.71[&] *2*	100[&] *5*	0.0	3/2$^-$	[E1]		0.0469 *7*	
274.96	(9/2$^-$)	100.4[‡] *8*	20 *6*	174.160	(5/2$^-$)	[E2]		12.0 *5*	I$_\gamma$: weighted average of 25 *6* in (p,2nγ) and 14 *7* in Coul. ex.
		163.5[‡] *3*	44.2[b] *28*	111.648	(9/2$^+$)	[E1]		0.155 *2*	I$_\gamma$: 86 *21* in Coul. ex.
		173.5[‡] *2*	100.0[b] *16*	101.408	7/2$^+$	[E1]		0.135 *2*	
300.98	(15/2$^+$)	111.8[a] *2*	81[a] *8*	189.14	(13/2$^+$)	[M1]		3.04 *4*	B(M1)(W.u.)=0.0063 *+15−24*
		129.2[a] *1*	100[a] *9*	171.74	(11/2$^+$)	[E2]		4.00 *6*	B(E2)(W.u.)=276 *+98−36*
304.7	(9/2$^+$)	121.1[‡] *8*	50[b] *25*	183.4954	5/2$^+$				
		203.3[‡] *3*	100[b] *25*	101.408	7/2$^+$				
311.78	(5/2$^+$)	253.3[a] *2*	100[a] *13*	58.5696	7/2$^-$	[E1]		0.0559 *8*	B(E1)(W.u.)=6.0×10^{-5} *+44−33*
		311.6[a] *3*	47[a] *6*	0.0	3/2$^-$	(E1)[@]		0.0351 *5*	B(E1)(W.u.)=1.2×10^{-5} *+12−6*
316.83	(17/2$^+$)	(15.9)	1.7[a] *3*	300.98	(15/2$^+$)	[M1]		230 *50*	B(M1)(W.u.)=0.129 *+20−10* γ implied from Coulomb excitation.
		127.7[a] *1*	100[a] *8*	189.14	(13/2$^+$)	[E2]		4.21 *6*	B(E2)(W.u.)=286 *+37−46*
317.94	(3/2$^+$)	240.27 *5*	70 *8*	77.692	5/2$^-$	[E1]		0.0630 *9*	
		308.78 *7*	100 *13*	9.183	1/2$^-$	[E1]		0.0358 *5*	B(E1)(W.u.)=1.9×10^{-5} *+17−11*
		317.87 *8*	23 *5*	0.0	3/2$^-$	[E1]		0.0336 *5*	B(E1)(W.u.)=2.1×10^{-5} *13*
320.208	3/2$^-$	136.75 *7*	11.0 *5*	183.4954	5/2$^+$	[E1]		0.237 *3*	α(K)=0.184 *3*; α(L)=0.0404 *6*; α(M)=0.00981 *14* α(N)=0.00260 *4*; α(O)=0.000603 *9*; α(P)=0.0001061 *15*; α(Q)=5.83×10^{-6} *9* I$_\gamma$: 20.7 *20* in (p,2nγ).
		217.94 *3*	100.0 *17*	102.2685	3/2$^+$	E1		0.0789 *11*	
		236.04 *6*	23.3 *10*	84.2152	5/2$^+$	[E1]		0.0657 *9*	I$_\gamma$: 31.7 *24* in (p,2nγ).
		242.51 *4*	2.10 *10*	77.692	5/2$^-$	[M1+E2]		1.0 *7*	α(K)=0.7 *6*; α(L)=0.22 *4*; α(M)=0.055 *7* α(N)=0.0147 *17*; α(O)=0.0035 *5*; α(P)=0.00062 *13*; α(Q)=3.E−5 *3*
		311.00 *5*	7.8 *3*	9.183	1/2$^-$	M1(+E2)	0.7 *9*	0.61 *27*	α(K)=0.43 *25*; α(L)=0.103 *25*; α(M)=0.026 *6* α(N)=0.0069 *14*; α(O)=0.0016 *4*; α(P)=0.00030 *8*; α(Q)=2.0×10^{-5} *11*
		320.15 *8*	0.40 *10*	0.0	3/2$^-$	[M1+E2]		0.5 *3*	α(K)=0.3 *3*; α(L)=0.09 *3*; α(M)=0.022 *6* α(N)=0.0059 *17*; α(O)=0.0014 *5*; α(P)=0.00026 *9*; α(Q)=1.6×10^{-5} *13*
328.88	(15/2$^-$)	139.75[‡] *5*	18.0[a] *4*	189.14	(13/2$^+$)	[E1]		0.225 *3*	B(E1)(W.u.)=6.3×10^{-5} *+3−1*

Adopted Levels, Gammas (continued)

γ(^{231}Pa) (continued)

E_i(level)	J_i^π	E_γ[†]	I_γ[†]	E_f	J_f^π	Mult.[†#]	δ[†]	α[c]	Comments
									α(K)=0.1744 25; α(L)=0.0382 6; α(M)=0.00927 13 α(N)=0.00246 4; α(O)=0.000570 8; α(P)=0.0001004 15; α(Q)=5.55×10^{-6} 8 Other B(E1)(W.u.)=10.2×10^{-5} +14−3, deduced from branching ratios.
328.88	(15/2$^-$)	160.13[‡] 5	100[a] 6	168.77	11/2$^-$	(E2)[@]		1.651 23	B(E2)(W.u.)=299 +21−22 α(K)=0.216 3; α(L)=1.048 15; α(M)=0.288 5 α(N)=0.0778 12; α(O)=0.0176 3; α(P)=0.00290 5; α(Q)=2.14×10^{-5} 3
344.55	(11/2$^-$)	126.3[‡] 5	21[b] 7	218.244	(7/2$^-$)				
		232.9[‡] 2	100[b] 4	111.648	(9/2$^+$)				
351.69	(13/2$^-$)	(22.8)	7[a] 5	328.88	(15/2$^-$)	[M1]		320 22	B(M1)(W.u.)=0.35 +21−5 γ implied from Coulomb excitation.
		158.5[a] 3	100[a] 14	193.21	(9/2$^-$)	[E2]		1.72 3	B(E2)(W.u.)=272 +111−60
		162.4[a] 5	9.5[a] 48	189.14	(13/2$^+$)	[E1]		0.1577 25	B(E1)(W.u.)=3.3×10^{-5} 17
		180.0[a] 2	22[a] 3	171.74	(11/2$^+$)	[E1]		0.1236 17	B(E1)(W.u.)=7.8×10^{-5} +16−12 α(K)=0.0970 14; α(L)=0.0201 3; α(M)=0.00486 7 α(N)=0.001289 18; α(O)=0.000301 5; α(P)=5.38×10^{-5} 8; α(Q)=3.18×10^{-6} 5
		183.3[‡] 2	11.4[a] 19	168.77	11/2$^-$	[M1+E2]	1.1 +12−7	2.2 11	B(E2)(W.u.)=6.1 +29−41; B(M1)(W.u.)=0.00056 +62−34
351.85	(5/2$^-$)	249.60 7	55 5	102.2685	3/2$^+$	[E1]		0.0578 8	
		250.45 7	46 5	101.408	7/2$^+$	[E1]		0.0573 8	
		267.72 9	100 7	84.2152	5/2$^+$	[E1]		0.0493 7	
		274.10 10	2.3 9	77.692	5/2$^-$	[M1+E2]		0.71 48	α(K)=0.5 5; α(L)=0.14 4; α(M)=0.036 7 α(N)=0.0098 19; α(O)=0.0023 5; α(P)=0.00042 12; α(Q)=2.5×10^{-5} 20
		351.80 10	4.6 9	0.0	3/2$^-$	[M1+E2]		0.35 25	α(K)=0.26 21; α(L)=0.066 25; α(M)=0.016 6 α(N)=0.0044 14; α(O)=0.0010 4; α(P)=0.00019 8; α(Q)=1.2×10^{-5} 10
391.92	(9/2$^+$)	(80.2)	4.4 22	311.78	(5/2$^+$)	[E2]		34.6 12	B(E2)(W.u.)=264 +150−29 γ implied from Coulomb excitation.
		222.5[‡] 3	4.0 12	168.77	11/2$^-$	[E1]		0.0752 11	B(E1)(W.u.)=4.7×10^{-5} +11−12
		333.6[‡] 2	100 10	58.5696	7/2$^-$	[E1]		0.0303 4	B(E1)(W.u.)=1.9×10^{-5} +3−4
395.92	(7/2$^-$)	284.1[d‡] 2		111.648	(9/2$^+$)				Iγ=43 5 in (p,2nγ) for a double placement. Iγ(284γ)/Iγ(294γ)=0.5 2 in Coul. ex. where each γ is doubly placed.
		294.5[d‡] 2		101.408	7/2$^+$				Iγ=43 5 in (p,2nγ) for a double placement.
		311.9[d‡] 2		84.2152	5/2$^+$				Iγ=100 5 in (p,2nγ) for a double placement, Iγ not available in Coul. ex.

Adopted Levels, Gammas (continued)

γ(^{231}Pa) (continued)

E_i(level)	J^π_i	E_γ[†]	I_γ[†]	E_f	J^π_f	Mult.[†#]	α[c]	Comments
406.14	(11/2$^+$)	158.8[‡] 5	100 50	247.320	7/2$^+$			
		294.5[d‡] 2		111.648	(9/2$^+$)			Iγ=225 25 in (p,2nγ) and 200 67 in Coul. ex. for double placement.
408.68	(7/2$^+$)	(90.7)	7[a] 6	317.94	(3/2$^+$)	[E2]	19.4 6	B(E2)(W.u.)=238 +125−179 γ implied from Coulomb excitation.
		215.5[a] 2	59[a] 18	193.21	(9/2$^-$)	[E1]	0.0809 11	
		330.9[‡] 3	100[a] 13	77.692	5/2$^-$	[E1]	0.0308 4	B(E1)(W.u.)=3.4×10^{-5} +12−19
424.94	(13/2$^-$)	235.8[‡] 2	15[b] 5	189.14	(13/2$^+$)			
		253.2[‡] 4	100.0[b] 22	171.74	(11/2$^+$)			
450.62	(9/2$^-$)	279.1[‡] 2	63[b] 3	171.74	(11/2$^+$)			
		338.3[d‡] 3	[b]	111.648	(9/2$^+$)			Iγ: <30 for double placement in (p,2nγ).
		349.3[‡] 2	100[b] 4	101.408	7/2$^+$			
487.62	(19/2$^+$)	171.0[a] 2	55[a] 4	316.83	(17/2$^+$)	[M1]	4.42 6	B(M1)(W.u.)=0.016 +3−6 Other B(M1)(W.u.)=0.043 6 from branching ratios.
		186.6[a] 1	100[a] 4	300.98	(15/2$^+$)	[E2]	0.910 13	B(E2)(W.u.)=295 38
494.80	(21/2$^+$)	(7.2)	0.085[a] 25	487.62	(19/2$^+$)	[M1]	2.4×10^3 6	B(M1)(W.u.)=0.406 +36−31 γ implied from Coulomb excitation.
		177.96[a] 6	100[a] 4	316.83	(17/2$^+$)	[E2]	1.090 15	B(E2)(W.u.)=301 +58−39
520.54	(15/2$^-$)	331.4[‡] 2	100	189.14	(13/2$^+$)			
525.35	(13/2$^+$)	132.7[‡] 9	50[a] 25	391.92	(9/2$^+$)	[E2]	3.52 5	B(E2)(W.u.)=297 +144−60 Iγ: from Coulomb excitation.
		196.8[‡] 2	54[a] 11	328.88	(15/2$^-$)	(E1)[@]	0.1002 14	α(K)=0.0789 12; α(L)=0.01606 23; α(M)=0.00388 6 α(N)=0.001031 15; α(O)=0.000241 4; α(P)=4.33×10^{-5} 7; α(Q)=2.62×10^{-6} 4
		356.3[‡] 2	100[a] 9	168.77	11/2$^-$	(E1)[@]	0.0263 4	B(E1)(W.u.)=1.9×10^{-5} +6−4 Eγ: weighted average of values from Coul. ex. and (p,2nγ).
535.77	(19/2$^-$)	(48.2)	1.6[a] 8	487.62	(19/2$^+$)	[E1]	0.83 5	B(E1)(W.u.)=3.3×10^{-4} +33−12 γ implied from Coulomb excitation.
		206.88[‡] 5	100[a] 5	328.88	(15/2$^-$)	(E2)[@]	0.619 9	B(E2)(W.u.)=308 +18−16 α(K)=0.1475 21; α(L)=0.343 5; α(M)=0.0940 14 α(N)=0.0254 4; α(O)=0.00577 9; α(P)=0.000956 14; α(Q)=1.058×10^{-5} 15
		218.93[a] 6	22.9[a] 5	316.83	(17/2$^+$)	[E1]	0.0780 11	B(E1)(W.u.)=7.5×10^{-5} 4
543.07	(11/2$^+$)	(134.2)	30[a] 22	408.68	(7/2$^+$)	[E2]	3.41 8	B(E2)(W.u.)=277 +143−127 γ implied from Coulomb excitation.
		349.5[‡] 2	100[a] 13	193.21	(9/2$^-$)	[E1]	0.0270 4	B(E1)(W.u.)=4.1×10^{-5} +14−20
551.50	(17/2$^-$)	(15.8)	0.39[a] 3	535.77	(19/2$^-$)	[M1]	235 24	B(M1)(W.u.)=0.347 +12−31 γ implied from Coulomb excitation.
		199.82[‡] 6	100[a] 4	351.69	(13/2$^-$)	(E2)[@]	0.704 10	B(E2)(W.u.)=328 +14−13

γ(^{231}Pa) (continued)

E_i(level)	J^π_i	E_γ[†]	I_γ[†]	E_f	J^π_f	Mult.[†#]	δ[†]	α[c]	Comments
									α(K)=0.1568 *22*; α(L)=0.400 *6*; α(M)=0.1096 *16* α(N)=0.0296 *5*; α(O)=0.00672 *10*; α(P)=0.001113 *16*; α(Q)=1.162×10^{-5} *17*
551.50	(17/2$^-$)	223.0[a] *3*	2.5[a] *7*	328.88	(15/2$^-$)	[M1+E2]	1.3 *+21−7*	1.1 *6*	B(E2)(W.u.)=4.6 *+22−24*; B(M1)(W.u.)=0.00045 *+56−34*
		234.5[a] *5*	1.1[a] *4*	316.83	(17/2$^+$)	[E1]		0.0670 *10*	B(E1)(W.u.)=8.2×10^{-5} *21* Other B(E1)(W.u.)=4.5×10^{-5} *+29−21* from branching ratios.
		250.5[a] *2*	4.1[a] *4*	300.98	(15/2$^+$)	[E1]		0.0573 *8*	B(E1)(W.u.)=1.3×10^{-5} *+9−7*
604.25	(3/2$^-$)	284.1[d‡] *2*		320.208	3/2$^-$				Iγ=69 *11* in (p,2nγ) and 12 *4* in Coul. ex. for a doubly placed γ. Crude estimate is <40 from the two values.
		420.7[‡] *2*	100[b] *8*	183.4954	5/2$^+$				
632.21	(5/2$^-$)	280.6[‡] *3*	100[b] *40*	351.85	(5/2$^-$)				
		311.9[d‡] *2*	[b]	320.208	3/2$^-$				Iγ=420 *20* in (p,2nγ) for a double placement, Iγ not available in Coul. ex.
678.1	(7/2$^-$)	326.2[‡] *3*	100	351.85	(5/2$^-$)				
705.34	(17/2$^+$)	180.0[‡] *2*	90[a] *41*	525.35	(13/2$^+$)	[E2]			B(E2)(W.u.)=305 *+176−130*
		376.4[‡] *2*	100[a] *10*	328.88	(15/2$^-$)	(E1)[@]		0.0234 *3*	B(E1)(W.u.)=3.5×10^{-5} *+11−6*
716.74	(15/2$^+$)	173.3[a] *2*	120[a] *55*	543.07	(11/2$^+$)	[E2]			B(E2)(W.u.)=303 *+205−54*
		365.4[a] *2*	100[a] *15*	351.69	(13/2$^-$)	[E1]			B(E1)(W.u.)=2.7×10^{-5} *6*
721.41	(25/2$^+$)	226.6[a] *1*	100[a]	494.80	(21/2$^+$)	[E2]			B(E2)(W.u.)=261 *+60−130*
728.38	(23/2$^+$)	233.2[a] *5*	88[a] *10*	494.80	(21/2$^+$)	[M1]			B(M1)(W.u.)=0.112 *+22−17*
		240.9[a] *5*	100[a] *10*	487.62	(19/2$^+$)	[E2]			B(E2)(W.u.)=307 *+60−69*
734.2	(9/2$^-$)	338.3[d‡] *3*	100	395.92	(7/2$^-$)				
785.59	(23/2$^-$)	(57.2)	0.090[a] *23*	728.38	(23/2$^+$)	[E1]		0.53 *3*	B(E1)(W.u.)=4.1×10^{-5} *+8−12* γ implied from Coulomb excitation.
		249.8[‡] *1*	100.0[a] *25*	535.77	(19/2$^-$)	[E2]			B(E2)(W.u.)=327 *+19−20*
		290.8[a] *2*	23.7[a] *7*	494.80	(21/2$^+$)	[E1]		0.0409 *6*	B(E1)(W.u.)=8.4×10^{-5} *+4−3*
788.05	(21/2$^-$)	236.58[‡] *8*	100.0[a] *28*	551.50	(17/2$^-$)	[E2]			B(E2)(W.u.)=310 *23*
		252.1[a] *5*	3.3[a] *11*	535.77	(19/2$^-$)	[M1]			B(M1)(W.u.)=0.0020 *+10−8*
		293.1[a] *5*	1.5[a] *7*	494.80	(21/2$^+$)	[E1]			B(E1)(W.u.)=6.6×10^{-5} *+41−29*
		300.5[a] *3*	3.3[a] *4*	487.62	(19/2$^+$)	[E1]		0.0381 *5*	B(E1)(W.u.)=1.5×10^{-5} *+10−8*
929.55	(21/2$^+$)	224.2[‡] *2*	33[b] *12*	705.34	(17/2$^+$)				Branching ratios for 224γ and 394γ from γ(ce)-coin data in (p,2nγ) listed in comments in that dataset.
		393.8[‡] *5*	100[b] *30*	535.77	(19/2$^-$)				
946.0	(19/2$^+$)	(228.9)	100[a] *52*	716.74	(15/2$^+$)	[E2]		0.432 *6*	B(E2)(W.u.)=314 *+162−57* γ implied from Coulomb excitation.
		394.5[a] *4*	37[a] *7*	551.50	(17/2$^-$)	[E1]			B(E1)(W.u.)=4.4×10^{-5} *+9−12*
993.88	(29/2$^+$)	272.5[a] *2*	100[a]	721.41	(25/2$^+$)	[E2]		0.241 *4*	

$^{231}_{91}$Pa$_{140}$-13

$\gamma(^{231}Pa)$ (continued)

E_i(level)	J^π_i	E_γ[†]	I_γ[†]	E_f	J^π_f	Mult.[†#]	α[c]	Comments
1019.2	(27/2+)	290.8[a] 3	100[a] 17	728.38	(23/2+)	[E2]	0.196 3	
		298.0[a] 5	33[a] 17	721.41	(25/2+)	[M1]		B(M1)(W.u.)=0.045 +28−23
1057.11	(25/2−)	269.1[a] 1	100[a] 3	788.05	(21/2−)	[E2]		B(E2)(W.u.)=322 +50−30
		271.4[a] 3	6.7[a] 21	785.59	(23/2−)	[M1]		B(M1)(W.u.)=0.0084 +28−23
		328.7[a] 3	6.2[a] 26	728.38	(23/2+)	[E1]	0.0313 5	B(E1)(W.u.)=3.7×10^{-5} 16
1074.31	(27/2−)	(17.2)	0.11[a] 6	1057.11	(25/2−)	[M1]	183 17	B(M1)(W.u.)=0.28 +34−4 γ implied from Coulomb excitation.
		288.7[a] 2	100[a] 3	785.59	(23/2−)	[E2]	0.201 3	B(E2)(W.u.)=324 +27−37
		352.8[a] 2	25.7[a] 14	721.41	(25/2+)	[E1]	0.0268 4	B(E1)(W.u.)=1.1×10^{-4} +0−4 Other B(E1)(W.u.)=1.9×10^{-4} +3−2 from branching ratios.
1196.2	(23/2+)	408.1[a] 3	100[a]	788.05	(21/2−)			
1307.8	(33/2+)	314.2[a] 3	100[a]	993.88	(29/2+)	[E2]	0.155 2	
1355.5	(29/2−)	280.6[a] 5	4[a] 2	1074.31	(27/2−)	[M1]		B(M1)(W.u.)=0.0052 +57−16 Other B(M1)(W.u.)=0.009 +6−5 from branching ratios.
		298.6[a] 3	100[a] 4	1057.11	(25/2−)	[E2]		B(E2)(W.u.)=330 +31−114
1357.5	(31/2+)	338.3[da] 3	100[a]	1019.2	(27/2+)			
1398.15	(31/2−)	(42.6)	0.54[a] 30	1355.5	(29/2−)	[M1]	50.7 20	B(M1)(W.u.)=0.28 +6−15 γ implied from Coulomb excitation.
		323.8[a] 2	100[a] 9	1074.31	(27/2−)	[E2]		B(E2)(W.u.)=322 +31−52
		404.2[a] 2	46[a] 6	993.88	(29/2+)	[E1]	0.0201 3	B(E1)(W.u.)=4.1×10^{-4} 6
1660.4	(37/2+)	352.6[a] 5	100[a]	1307.8	(33/2+)	[E2]	0.1110 16	
1683.2	(33/2−)	327.7[a] 3	100[a]	1355.5	(29/2−)	[E2]	0.137 2	
1754.2	(35/2−)	355.8[a] 3	100[a] 33	1398.15	(31/2−)	[E2]	0.1080 15	B(E2)(W.u.)=0.03 +76−0
		446.9[a] 5	33[a] 11	1307.8	(33/2+)	[E1]	0.0164 2	B(E1)(W.u.)=3.7×10^{-4} 16
2040.4	(37/2−)	357.2[a] 8	100[a]	1683.2	(33/2−)	[E2]	0.1070 15	
2139.3	(39/2−)	385.1[a] 3	100[a] 40	1754.2	(35/2−)	[E2]	0.0870 12	B(E2)(W.u.)=32×10^{1} +128−30 B(E2)(W.u.) from level $T_{1/2}$ and γ-branching ratio. Note: upper limit exceeds RUL=1000 for E2.
		479.0[a] 6	100[a] 60	1660.4	(37/2+)	[E1]	0.0142 2	B(E1)(W.u.)=6.6×10^{-4} +54−41

[†] From ^{231}Th β^- decay, unless otherwise specified.

[‡] From Coulomb excitation and/or (p,2nγ).

[#] From conversion electron data in ^{231}Th β^- decay, unless otherwise specified.

[@] From ce and $\gamma(\theta)$ in (p,2nγ), assignment treated as tentative by the evaluators, as no details of ce data are available.

[&] From ^{231}U ε decay.

[a] From Coul. Ex. only.

[b] From (p,2nγ).

[c] Total theoretical internal conversion coefficients, calculated using the BrIcc code (2008Ki07) with Frozen orbital approximation based on γ-ray energies,

γ(^{231}Pa) (continued)

assigned multipolarities, and mixing ratios, unless otherwise specified.

[d] Multiply placed.

[e] Placement of transition in the level scheme is uncertain.

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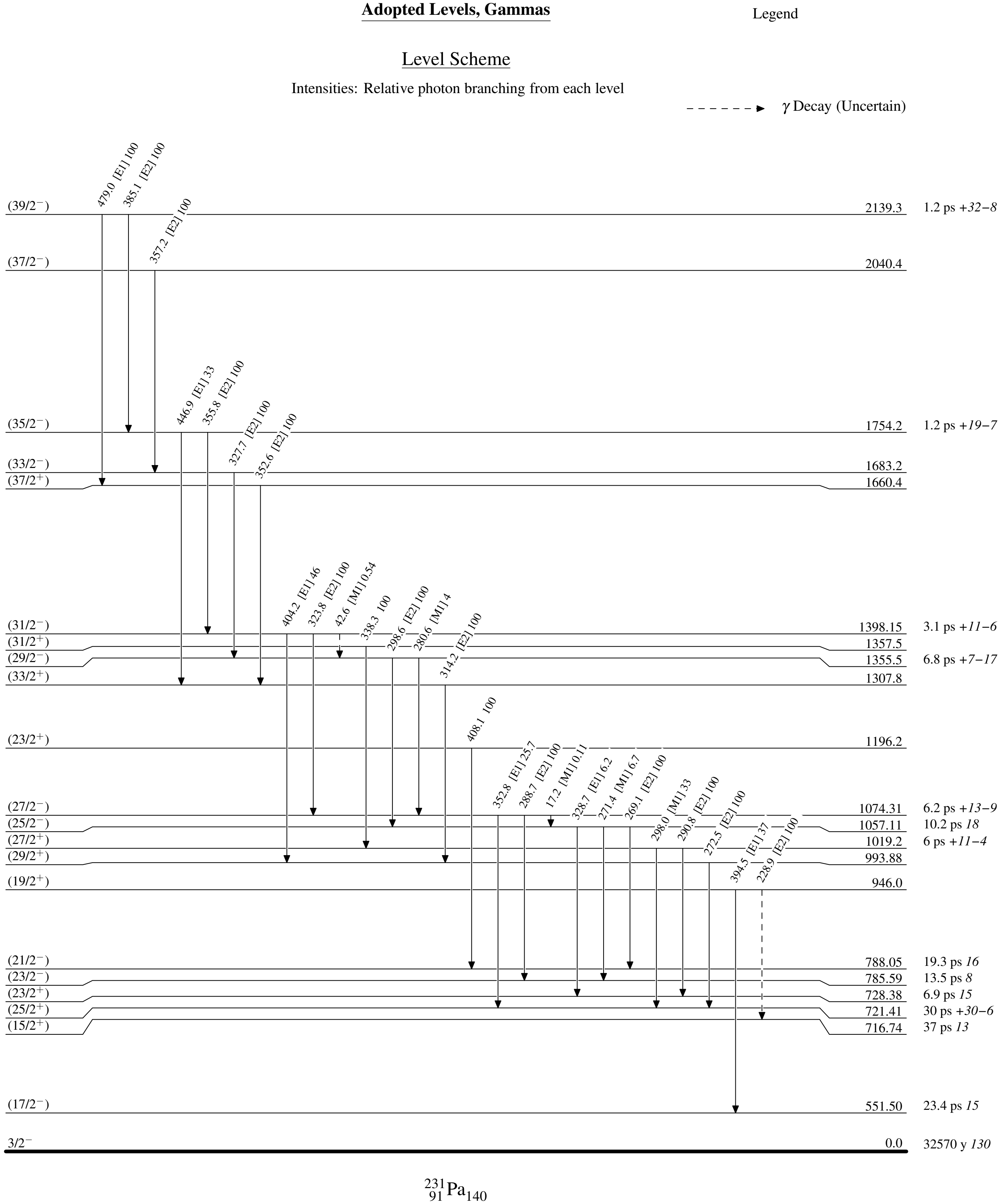
Adopted Levels, Gammas

Level Scheme

Intensities: Relative photon branching from each level

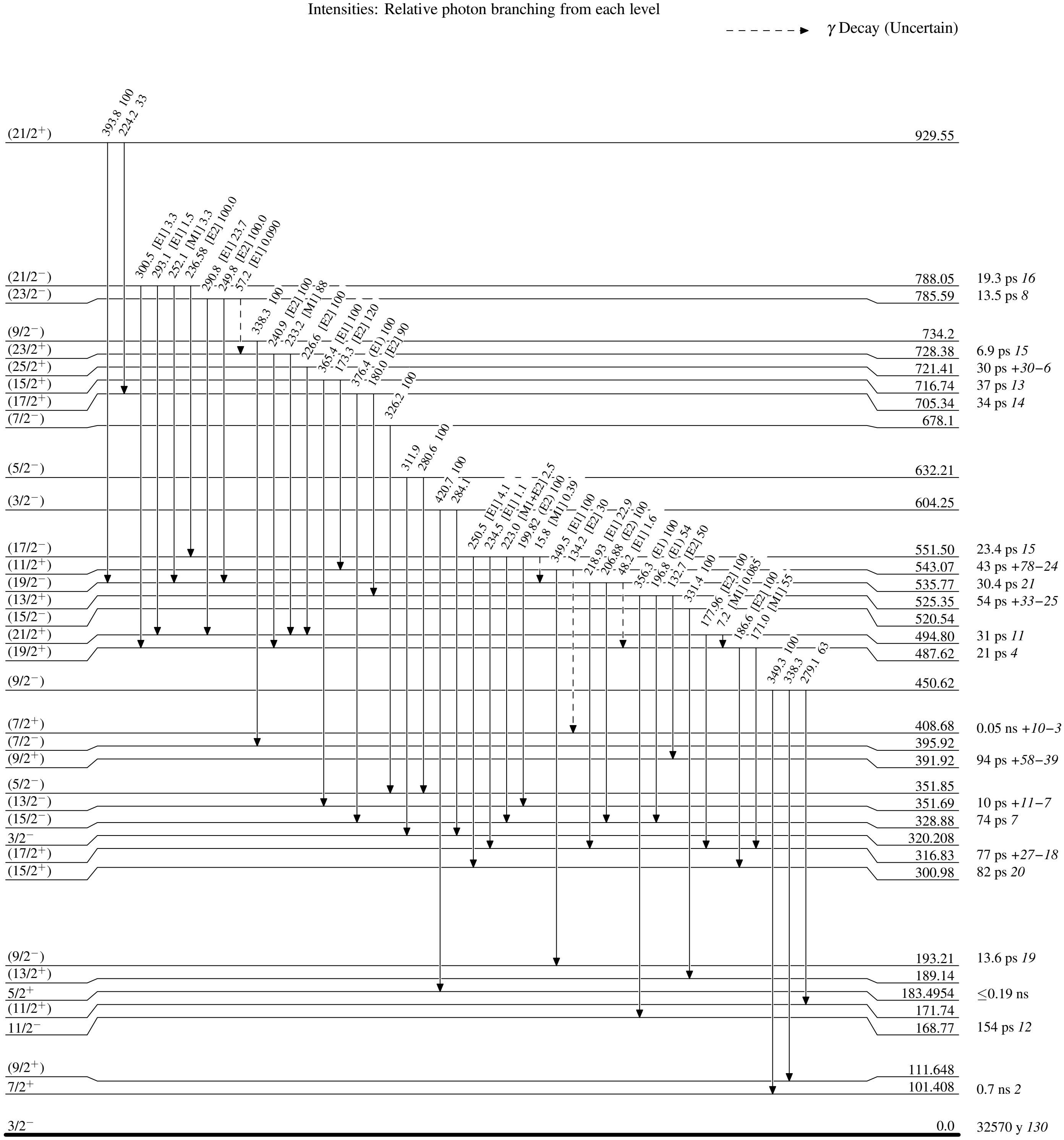


Adopted Levels, Gammas

Legend

Level Scheme (continued)

Intensities: Relative photon branching from each level



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

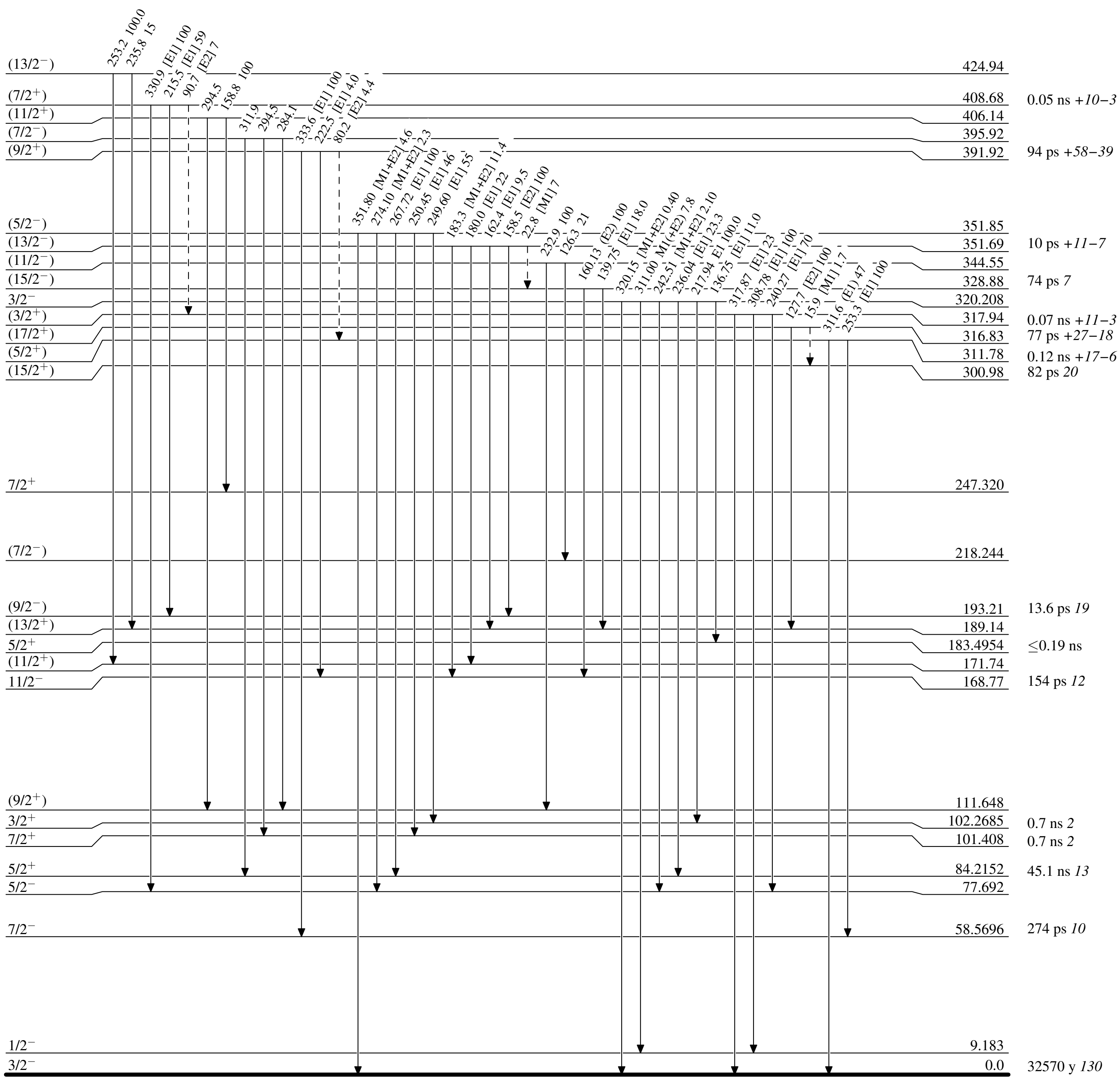
Adopted Levels, Gammas

Legend

Level Scheme (continued)

Intensities: Relative photon branching from each level

- - - - - -► γ Decay (Uncertain)

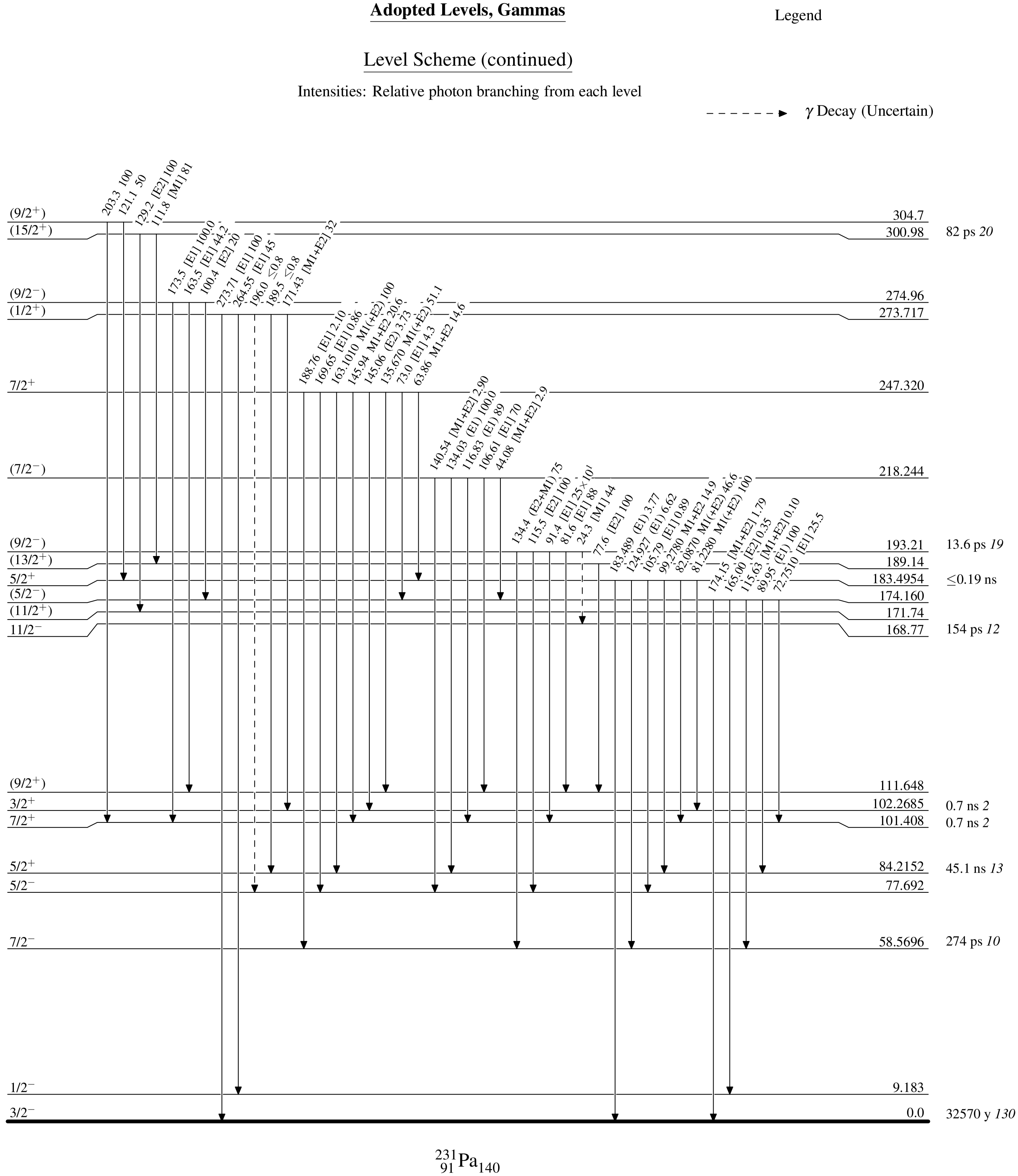


$^{231}_{91}Pa_{140}$

Adopted Levels, Gammas

Level Scheme (continued)

Intensities: Relative photon branching from each level



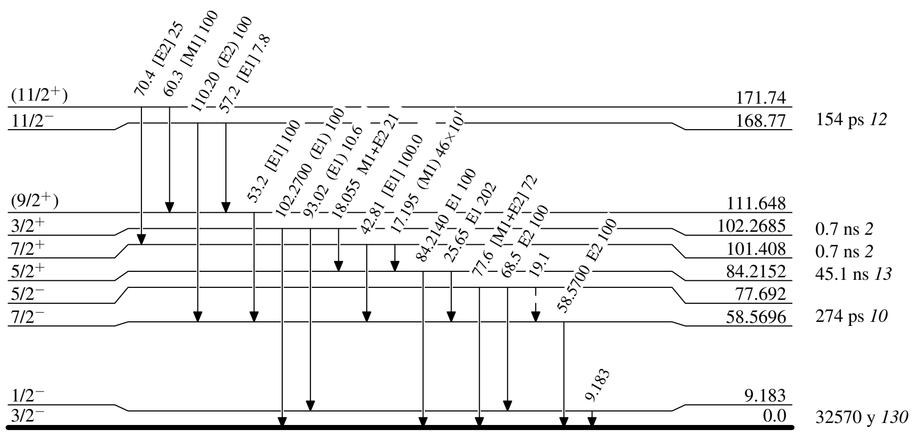
Adopted Levels, Gammas

Legend

Level Scheme (continued)

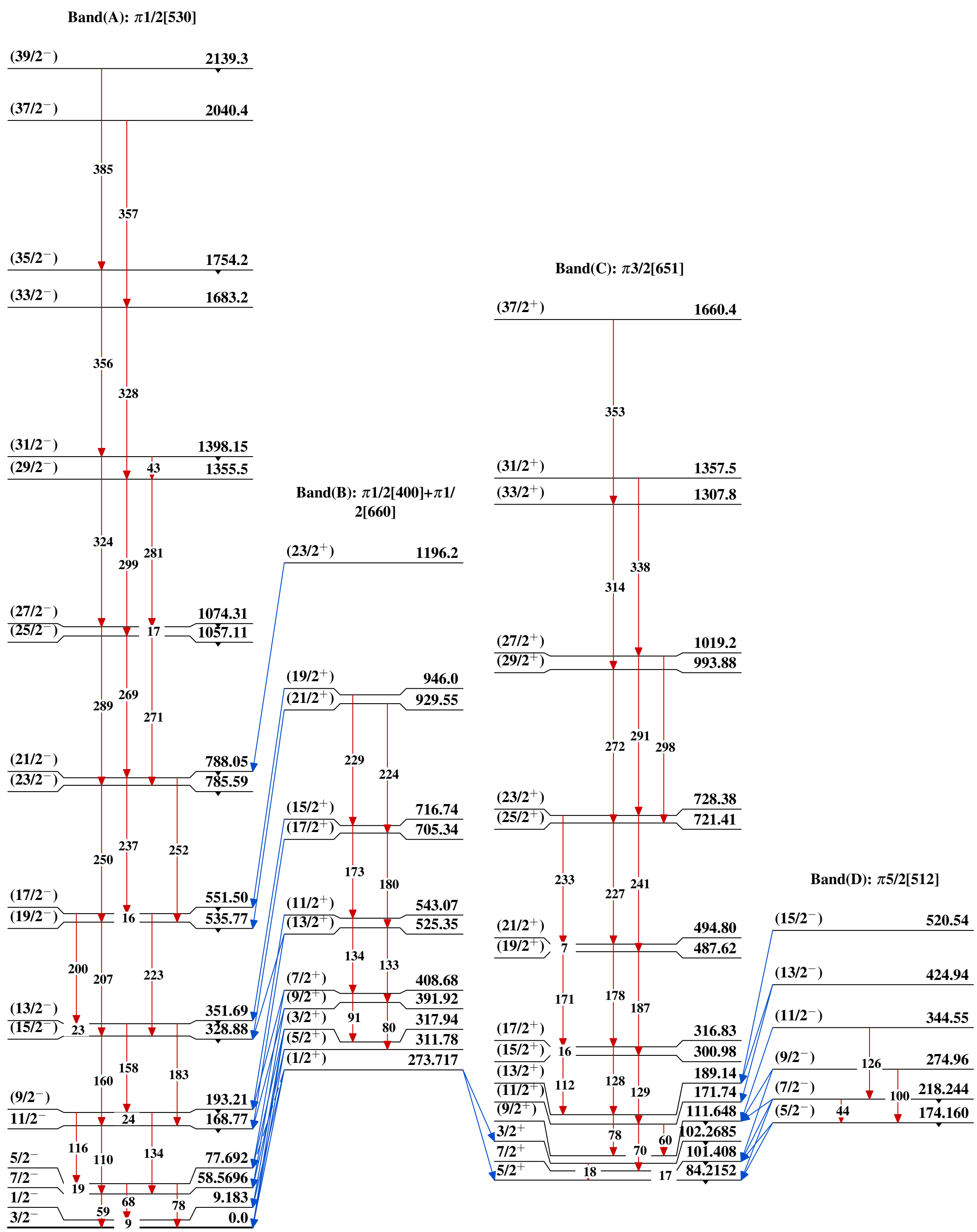
Intensities: Relative photon branching from each level

- - - - - - ► γ Decay (Uncertain)



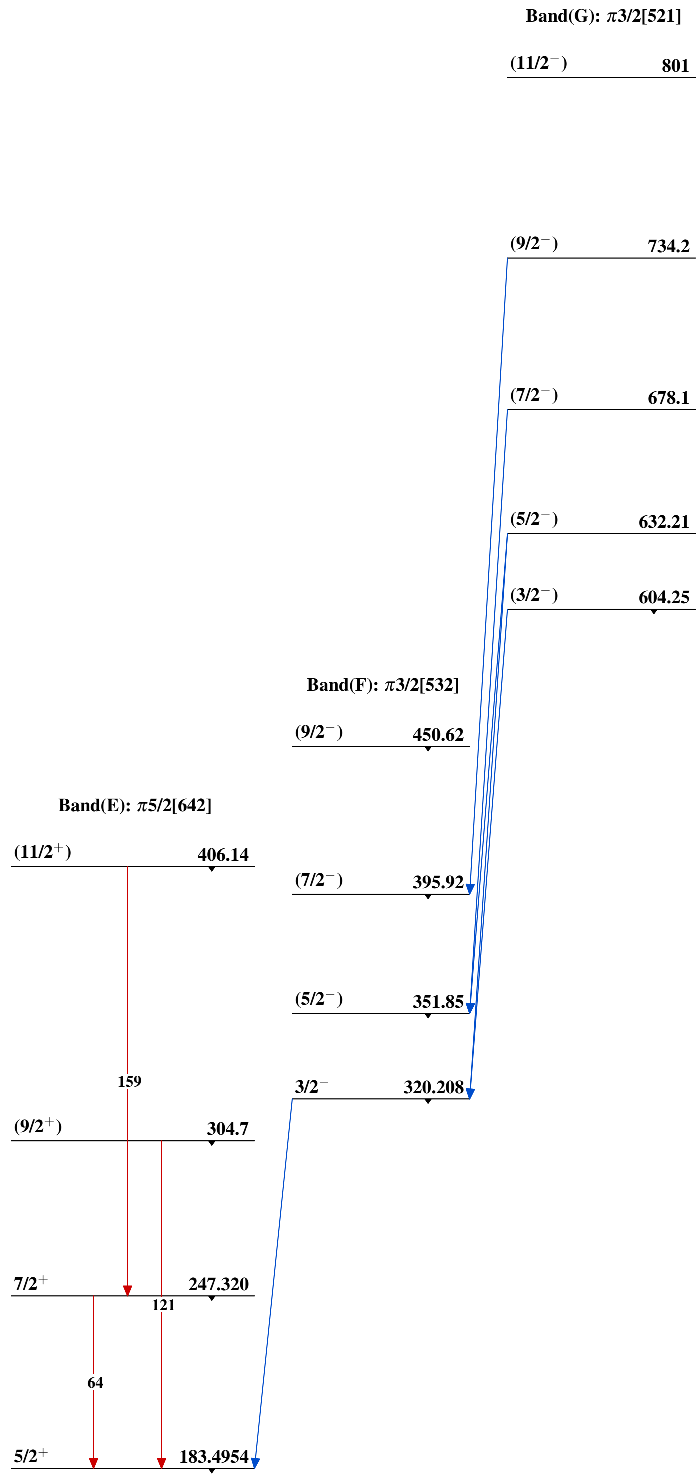
$^{231}_{91}Pa_{140}$

Adopted Levels, Gammas



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

Adopted Levels, Gammas (continued)



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