^{231}U ε decay (4.2 d) 1994Br36,1996Le01

History

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

Parent: ^{231}U: E=0.0; J$^{\pi}$=(5/2^{-}); $T_{1/2}$=4.2 d *1*; Q(ε)=381.6 *20*; %ε decay=100.0
^{231}U-J$^{\pi}$,$T_{1/2}$: From ^{231}U Adopted Levels.
^{231}U-Q(ε): From 2021Wa16.
^{231}U-%ε decay: %ε≈100 for ^{231}U ε decay.
1994Br36: ^{231}U activity was produced via the electron capture decay of ^{231}Np, which was formed in the ^{233}U(p,3n) reaction with 49-MeV protons. The recoiling reaction products of ^{231}Np were chemically separated from their ^{231}U daughter nuclei. Measured Eγ, Iγ, E(ce), I(ce), γγ-coin using HPGe detector for γ rays, pin diode for conversion electrons. Main contaminants were ^{237}U and ^{117m}Sn. Deduced conversion coefficients, γ-ray multipolarities.
1996Le01: ^{231}U activity produced by ^{232}Th(α,5n), E=52 MeV and mass separated. Measured Eγ, Iγ using HPGe detector. Main contaminant was ^{231}Th, produced in ^{232}Th(α,α′n) reaction.
1961Ho29, 1957Ho07: data from private communications from J.M. Hollander listed in 1978LeZA (Table of Isotopes).
Evaluators′ note: the decay scheme seems fairly complete, except for lack of spectral information for 9.18 and 77.69-keV γ transitions.

^{231}Pa Levels

E(level)†	J$^{\pi}$‡	$T_{1/2}$‡	Comments
0.0	3/2^{-}	32570 y *130*	
9.186 *20*	1/2^{-}		
58.570 *3*	7/2^{-}	274 ps *10*	
77.69 *4*	5/2^{-}		
84.2150 *20*	5/2^{+}	45.1 ns *13*	
101.409 *4*	7/2^{+}	0.7 ns *2*	$T_{1/2}$: combined for 101.4+102.3 levels (1975Ho14, ^{231}Th β^{-} decay).
102.2687 *22*	3/2^{+}	0.7 ns *2*	$T_{1/2}$: combined for 101.4+102.3 levels (1975Ho14, ^{231}Th β^{-} decay).
174.160 *5*	(5/2^{-})		
183.496 *3*	5/2^{+}	≤0.19 ns	
273.719 *16*	(1/2^{+})		
317.94 *5*	(3/2^{+})	0.07 ns *+11−3*	
320.207 *22*	3/2^{-}		

† Deduced from least-squares fit to Eγ values.
‡ From the Adopted Levels.

ε radiations

E(decay)	E(level)	Iε†	Log *ft*	Comments
(61.4 *20*)	320.207	0.53 *10*	6.3 *1*	εL=0.603 *7*; εM+=0.397 *7*
(63.7 *20*)	317.94	0.0028 *3*	8.6 *1*	εL=0.610 *7*; εM+=0.390 *7*
(107.9 *20*)	273.719	0.13 *3*	7.5^{1u} *1*	εL=0.6777 *16*; εM+=0.3223 *16*
(198.1 *20*)	183.496	0.14 *7*	8.4 *2*	εK=0.460 *7*; εL=0.384 *5*; εM+=0.1554 *20*
(207.4 *20*)	174.160	0.06 *3*	8.8 *2*	εK=0.487 *6*; εL=0.366 *4*; εM+=0.1469 *18*
(279.3 *20*)	102.2687	59 *23*	6.2 *2*	εK=0.6073 *21*; εL=0.2837 *15*; εM+=0.1089 *7*
(297.4 *20*)	84.2150	44 *23*	6.4 *2*	εK=0.6245 *18*; εL=0.2719 *12*; εM+=0.1036 *6*
(303.9 *20*)	77.69	0.52 *8*	8.4 *1*	εK=0.6300 *17*; εL=0.2681 *12*; εM+=0.1019 *5*

† Absolute intensity per 100 decays.

γ(^{231}Pa)

Iγ normalization: From a relative K x ray intensity of 780 *28* (1994Br36), a theoretical εK/ε=0.59 (1977Ba48), and a K-fluorescence yield of 0.970 *4* (1996Sc06) the total number of atomic vacancies produced by the electron capture process and the Iγ normalization factor become 1362 *66* and 0.073 *4*, respectively. The total number of atomic vacancies also agrees with the total relative γ-ray transition intensity (photons plus electrons) of 1350 *70* to the ground and 9.2-keV levels. This result is consistent with the absence of any appreciable electron-capture decays to these levels.

Measured energies and intensities of Pa x-rays relative to 100 for the 84.21-keV γ ray from ^{231}U ε decay (1994Br36):

Pa $K_{\alpha2}$: 92.3 keV *1*, relative intensity=238 *14* (1994Br36).

Pa $K_{\alpha1}$: 95.8 keV *1*, relative intensity=382 *22* (1994Br36).

Pa $K_{\beta3}$: 107.5 keV *2*, relative intensity=34.6 *28* (1994Br36).

Pa $K_{\beta1}$: 108.3 keV *2*, relative intensity=78 *6* (1994Br36).

Pa $K_{\beta2}$: 111.4 keV *2*, relative intensity=37.6 *26* (1994Br36).

Pa O_{23}: 112.2 keV *2*, relative intensity=9.2 *12* (1994Br36).

Experimental Pa K x ray intensities: 17.5% *10* ($K\alpha_2$ x ray), 28.1% 16 ($K\alpha_1$ x ray), and 11.8% *6* (Kβ x ray) compare with 17.85% *8* ($K\alpha_2$ x ray), 28.73% *12* (Kβ x ray), respectively, calculated by evaluators (using the computer program RADLST) from γ-ray intensities, K-conversion coefficients and K-electron capture probabilities presented here, using a K-fluorescence yield of 0.970 *4* (1996Sc06). This agreement shows that most γ rays with energies greater than 112.6 keV (the K-binding in Pa) have accurate intensities and correct multipolarities, and that K-electron capture probabilities are also correct.

Q(β^-)=381.6 keV *20* (2021Wa16) compares with a total average radiation energy of 350 keV, calculated by evaluators using the computer program RADLST. The small discrepancy between these values is probably due to low-energy γ rays (i.e., 9.2-, 17.2-, and 19.1-keV transitions) not included in the calculation because their intensities are unknown. These results support the consistency and completeness of the decay scheme.

E_γ [†]	I_γ [‡b]	E_i(level)	J^π_i	E_f	J^π_f	Mult. [a]	δ [a]	α [c]	$I_{(\gamma+ce)}$ [b]	Comments
(9.183)		9.186	1/2⁻	0.0	3/2⁻				8.8 *3*	E_γ: from the Adopted Gammas. $I_{(\gamma+ce)}$: from transition intensity balance at 9.19 level, assuming no direct ε feeding to the 9.19 level, as expected from ΔJ^π=(2), Δπ=(no).
(17.195 *21*)	≤0.014	101.409	7/2⁺	84.2150	5/2⁺	(M1)		166 *3*	≤2.3	%Iγ≤0.0010 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* $I_{(\gamma+ce)}$: from I(γ+ce)≤2.3 for 82.087γ from 183.4 level. I_γ: from I(γ+ce) and α(theory).
(18.055 *18*)	3.6[&] *13*	102.2687	3/2⁺	84.2150	5/2⁺	M1+E2	0.040 *+18−0*	218 *28*		%Iγ=0.26 *10* 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*
25.65 *2*	200[@] *12*	84.2150	5/2⁺	58.570	7/2⁻	E1		4.37 *6*		%Iγ=14.6 *12* M1/M3=0.38; M2/M3=0.61; M4/M3=0.38; M5/M3=0.38 (1961Ho29)

γ(^{231}Pa) (continued)

E_γ [†]	I_γ [‡b]	E_i(level)	J^π_i	E_f	J^π_f	Mult. [a]	δ [a]	α [c]	Comments
									α(L)=3.25 *5*; α(M)=0.842 *13* α(N)=0.219 *4*; α(O)=0.0471 *7*; α(P)=0.00673 *10*; α(Q)=0.000196 *3* E_γ: other: 25.65 *4* (1994Br36).
58.5700 *24*	6.8[@] *4*	58.570	7/2⁻	0.0	3/2⁻	E2		155.5 *22*	%Iγ=0.50 *4* α(L1)exp+α(L2)exp=64 *8*; α(L3)exp=49 *6*; α(M)exp=36 *5*; α(N)exp=10 *2* (1994Br36) 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* E_γ: other: 58.55 *4* (1994Br36). I_γ: 6.4 *4* in 1994Br36 is adjusted by evaluators to 6.8 *4* to obtain transition intensity balance at 58.57 level, with no direct ε feeding to this level. Ice(L1+L2)=205 *21*, Ice(L3)=156 *16*, Ice(M)=116 *12*, Ice(N)=31 *3* (1994Br36). Other: 1961Ho29. Additional information 1.
68.5 *1*	0.079	77.69	5/2⁻	9.186	1/2⁻	E2		73.3 *10*	%Iγ=0.00577 α(L)=53.5 *8*; α(M)=14.76 *21* α(N)=3.98 *6*; α(O)=0.898 *13*; α(P)=0.1448 *21*; α(Q)=0.000423 *6* Additional information 2. I_γ: from 1961Ho29, cited by 1994Br36, where Iγ is deduced from relative conversion electron intensity and α(theory) for E2.
(72.7510 *29*)	0.15[&] *8*	174.160	(5/2⁻)	101.409	7/2⁺	[E1]		0.280 *4*	%Iγ=0.011 *6* α(L)=0.211 *3*; α(M)=0.0517 *8* α(N)=0.01363 *20*; α(O)=0.00310 *5*; α(P)=0.000519 *8*; α(Q)=2.33×10⁻⁵ *4*
(77.69)	0.057	77.69	5/2⁻	0.0	3/2⁻	[M1+E2]		24 *16*	%Iγ=0.00416 α(L)=18 *12*; α(M)=5 *4* α(N)=1.3 *9*; α(O)=0.30 *20*; α(P)=0.05 *3*; α(Q)=0.0009 *7* E_γ: from level-energy difference.
81.2280 *21*	≤0.32	183.496	5/2⁺	102.2687	3/2⁺	M1(+E2)	0.00 *8*	7.66 *20*	%Iγ≤0.0234 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* I_γ: from 1996Le01. Other: Iγ=0.19, Ice(L1)=0.51 (1961Ho29, cited by 1994Br36).
82.0870 *22*	≤0.26	183.496	5/2⁺	101.409	7/2⁺	M1(+E2)	0.04 *6*	7.47 *23*	%Iγ≤0.019 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* I_γ: from 1996Le01. Other: Iγ=0.26, Ice(L1)=0.73 (1961Ho29, cited by 1994Br36).

γ(^{231}Pa) (continued)

E_γ[†]	I_γ[‡b]	E_i(level)	J^π_i	E_f	J^π_f	Mult.[a]	δ[a]	α[c]	Comments
84.2140 *22*	100[@] *6*	84.2150	5/2$^+$	0.0	3/2$^-$	E1		2.17 *21*	%Iγ=7.3 *6* α(L1)exp+α(L2)exp=1.7 *1*; α(M)exp=0.48 *4*; α(N)exp=0.34 *3* (1994Br36) α(M1)exp=0.34; α(M2)exp=0.21; α(M3)exp=0.009; α(N1)exp=0.17 (1961Ho29) E_γ: other: 84.23 *7* (1994Br36). Ice(L1+L2)=83 *1*, Ice(M)=24 *1*, Ice(N)=17 *1* (1994Br36). Other: 1961Ho29. Additional information 3. Total conversion coefficient from ce data in ^{231}Th β^- decay. Other: 2.6 *1* from summed conversion coefficients in 1994Br36. Transition is anomalously converted (1960As02). See also 2008Go10. α(O1)exp=0.031 (1961Ho29).
89.95 *2*	0.58[#] *32*	174.160	(5/2$^-$)	84.2150	5/2$^+$	(E1)		0.1598 *23*	%Iγ=0.042 *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*
(93.02 *4*)	1.8[&] *2*	102.2687	3/2$^+$	9.186	1/2$^-$	(E1)		0.1463 *21*	%Iγ=0.131 *16* α(L)=0.1103 *16*; α(M)=0.0269 *4* α(N)=0.00711 *10*; α(O)=0.001633 *23*; α(P)=0.000279 *4*; α(Q)=1.363×10^{-5} *20*
(99.2780 *36*)	≤0.050[&]	183.496	5/2$^+$	84.2150	5/2$^+$	M1+E2	0.35 *7*	5.2 *4*	%Iγ≤0.00365 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*
102.2700 *24*	17.2[@] *10*	102.2687	3/2$^+$	0.0	3/2$^-$	(E1)		0.1141 *16*	%Iγ=1.26 *10* α(L)=0.0860 *13*; α(M)=0.0209 *3* α(N)=0.00554 *8*; α(O)=0.001275 *19*; α(P)=0.000220 *4*; α(Q)=1.106×10^{-5} *16* E_γ: other: 102.3 *1* (1994Br36).
136.75 *7*	0.57[#] *5*	320.207	3/2$^-$	183.496	5/2$^+$	[E1]		0.237 *3*	%Iγ=0.042 *4* 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*
171.43[#] *3*	0.200[#] *16*	273.719	(1/2$^+$)	102.2687	3/2$^+$	[M1+E2]		2.8 *16*	%Iγ=0.0146 *14* α(K)=1.8 *17*; α(L)=0.72 *6*; α(M)=0.19 *3* α(N)=0.051 *7*; α(O)=0.0118 *14*; α(P)=0.00207 *8*; α(Q)=9.E−5 *8*
(189.5)	≤0.0053[#]	273.719	(1/2$^+$)	84.2150	5/2$^+$				%Iγ≤0.00039 E_γ: from level-energy difference.

From ENSDF

$^{231}_{91}$Pa$_{140}$-4

γ(^{231}Pa) (continued)

E_γ[†]	I_γ[‡b]	E_i(level)	J_i^π	E_f	J_f^π	Mult.[a]	δ[a]	α[c]	Comments
(196.0)	≤0.0053[#]	273.719	(1/2$^+$)	77.69	5/2$^-$				%Iγ≤0.00039 γ to 5/2$^-$ is unlikely. E_γ: from level-energy difference.
217.94 *3*	4.1 *11*	320.207	3/2$^-$	102.2687	3/2$^+$	[E1]		0.0789 *11*	%Iγ=0.30 *8* α(K)=0.0624 *9*; α(L)=0.01249 *18*; α(M)=0.00301 *5* α(N)=0.000801 *12*; α(O)=0.000188 *3*; α(P)=3.39×10^{-5} *5*; α(Q)=2.10×10^{-6} *3* E_γ: other: 217.9 *2* (1994Br36). Energy is from 1994Br36. Iγ is a unweighted average of discrepant values: 5.26 *3* (1996Le01) and 3.0 *4* (1994Br36).
236.04 *6*	1.22[#] *6*	320.207	3/2$^-$	84.2150	5/2$^+$	[E1]		0.0657 *9*	%Iγ=0.089 *7* α(K)=0.0521 *8*; α(L)=0.01028 *15*; α(M)=0.00248 *4* α(N)=0.000659 *10*; α(O)=0.0001545 *22*; α(P)=2.80×10^{-5} *4*; α(Q)=1.770×10^{-6} *25*
240.27 *5*	0.0132[#] *16*	317.94	(3/2$^+$)	77.69	5/2$^-$	[E1]		0.0630 *9*	%Iγ=0.00096 *13* α(K)=0.0500 *7*; α(L)=0.00984 *14*; α(M)=0.00237 *4* α(N)=0.000631 *9*; α(O)=0.0001480 *21*; α(P)=2.68×10^{-5} *4*; α(Q)=1.703×10^{-6} *24* E_γ: other: 240.3 *2* (1996Le01).
242.51 *4*	0.111[#] *11*	320.207	3/2$^-$	77.69	5/2$^-$	[M1+E2]		1.01 *66*	%Iγ=0.0081 *9* α(K)=0.72 *61*; 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)=3.5×10^{-5} *28*
264.55[#] *2*	0.279[#] *26*	273.719	(1/2$^+$)	9.186	1/2$^-$	[E1]		0.0506 *7*	%Iγ=0.0204 *22* α(K)=0.0403 *6*; α(L)=0.00781 *11*; α(M)=0.00188 *3* α(N)=0.000500 *7*; α(O)=0.0001176 *17*; α(P)=2.14×10^{-5} *3*; α(Q)=1.389×10^{-6} *20*
273.71[#] *2*	0.621[#] *32*	273.719	(1/2$^+$)	0.0	3/2$^-$	[E1]		0.0469 *7*	%Iγ=0.0453 *34* α(K)=0.0373 *6*; α(L)=0.00721 *10*; α(M)=0.001735 *25* α(N)=0.000461 *7*; α(O)=0.0001085 *16*; α(P)=1.98×10^{-5} *3*; α(Q)=1.292×10^{-6} *18*
308.78 *7*	0.0195[#] *21*	317.94	(3/2$^+$)	9.186	1/2$^-$	[E1]		0.0358 *5*	%Iγ=0.00142 *17* α(K)=0.0287 *4*; α(L)=0.00544 *8*; α(M)=0.001307 *19* α(N)=0.000348 *5*; α(O)=8.19×10^{-5} *12*; α(P)=1.501×10^{-5} *22*; α(Q)=1.006×10^{-6} *15* E_γ: other: 308.7 *2* (1996Le01).
311.00 *5*	0.37[#] *5*	320.207	3/2$^-$	9.186	1/2$^-$	M1(+E2)	0.7 *9*	0.61 *27*	%Iγ=0.027 *4* α(K)=0.47 *24*; α(L)=0.107 *24*; α(M)=0.026 *5* α(N)=0.0071 *14*; α(O)=0.0017 *4*; α(P)=0.00031 *8*; α(Q)=2.2×10^{-5} *11*

$^{231}_{91}Pa_{140}$-5

γ(^{231}Pa) (continued)

E_γ[†]	I_γ[‡b]	E_i(level)	J^π_i	E_f	J^π_f	Mult.[a]	α[c]	Comments
317.87 *8*	0.0042[#] *16*	317.94	(3/2$^+$)	0.0	3/2$^-$	[E1]	0.0336 *5*	%Iγ=0.00031 *12* α(K)=0.0269 *4*; α(L)=0.00509 *8*; α(M)=0.001223 *18* α(N)=0.000325 *5*; α(O)=7.67×10^{-5} *11*; α(P)=1.406×10^{-5} *20*; α(Q)=9.48×10^{-7} *14* E_γ: other: 317.7 *3* (1996Le01).
320.15 *8*	0.0158 *16*	320.207	3/2$^-$	0.0	3/2$^-$	[M1+E2]	0.46 *32*	%Iγ=0.00115 *13* α(K)=0.34 *28*; α(L)=0.088 *29*; α(M)=0.0221 *61* α(N)=0.0059 *17*; α(O)=0.00140 *41*; α(P)=2.57×10^{-4} *89*; α(Q)=1.6×10^{-5} *13*

† From the Adopted Gammas, which are mostly from ^{231}Th β^- decay, unless otherwise indicated.

‡ Relative intensities listed in 1994Br36 and 1996Le01 are normalized to 100 for the 84.21-keV γ ray from a level of this energy.

From 1996Le01.

@ From 1994Br36.

& Deduced from the γ-branching ratios in Adopted Gammas, which are mostly from ^{231}Th β^- decay.

a From the Adopted Gammas, unless otherwise stated.

b For absolute intensity per 100 decays, multiply by 0.073 *4*.

c 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.

^{231}U ε decay (4.2 d) 1994Br36,1996Le01

Decay Scheme