^{226}Ra α decay (1603 y) 2017Ma22,1963Ba62,1971Lo19

History

Type	Author	Citation	Literature Cutoff Date
Full Evaluation	Balraj Singh, M. S. Basunia, Jun Chen et al. ,	NDS 192,315 (2023)	25-Sep-2023

Parent: ^{226}Ra: E=0.0; J$^{\pi}$=0^{+}; $T_{1/2}$=1603 y *8*; Q(α)=4870.70 *25*; %α decay=100

^{226}Ra-$T_{1/2}$: unweighted average of 1599 y *7* (1966Ra13, uncertainty for 3σ), 1577 y *9* (1959Go80,1958Go75), 1602 y *8* (1959Ma12), 1617 y *12* (1956Se10), 1622 y *13* (1949Ko01). Weighted average is 1599 y *3*, but with reduced χ^2=2.87, somewhat larger than critical χ^2=2.37 at 95% confidence level.

^{226}Ra-Q(α): From 2021Wa16.

Dataset by Balraj Singh, S. Basunia, and IAEA-ICTP workshop participants: S. Basu and S.S. Nayak.

2017Ma22: precise measurements of α emission probabilities for the main branches from α decay of ^{226}Ra. Independent measurements were carried out at Joint Research Centre (JRC) in Geel, and Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas (CIEMAT) in Madrid, and different spectral analysis and deconvolution techniques were used. Third measurement was also carried out at Laboratoire National Henri Becquerel (LNHB) in Saclay, but results from this experiment were not used in the final recommended values due to inherent problems with the counting and analysis methods. The ^{226}Ra source was about 20-50 Bq strength, electrodeposited as an active 2 cm diameter onto stainless steel disks of 2.5 cm diameter and 1 mm thickness. The detector system was a set of two PIPS detectors and a magnet system to deflect away the conversion electrons. FWHM=20 keV for α-particle spectrum.

2018Ma11: measured absolute Iγ(186) and Rn x rays from α decay of ^{226}Ra using HPGe detectors and standard Czech Metrology Institute (CMI) sources.

1989Po03: measured $\alpha\gamma(\theta)$.

1974Or02, 1970Or02: measured $\alpha\gamma(\theta$,H).

1971Lo19: measured Eγ, Iγ, $\gamma\gamma$-coin.

1968Bi08: measured (^{226}Ra α)(^{222}Rn α)(θ); deduced isotropic angular correlation.

1960Be25: measured half-life of 186 level by $\alpha\gamma$(t).

1960St20, 1956Ha71: measured Eγ, Iγ.

1954Ro06, 1954Mi53: measured $\alpha\gamma(\theta)$.

1942Ka01: measured Eβ, Iβ.

Measurements of decay constants in search of variation of decay constant of ^{222}Rn using ^{226}Ra→^{222}Rn decay in equilibrium: Additional information 1.

2018St04: measured decay constant of ^{222}Rn using ^{226}Ra→^{222}Rn decay in equilibrium at the Geological Survey of Israel. Authors claimed effect of solar and cosmic neutrinos on the half-life of ^{222}Rn based on their measurements.

2019Po13, 2018Po01, 2016Po08, 2016Sc08: measurement of decay constant of ^{222}Rn from ^{226}Ra→^{222}Rn decay in equilibrium at JRC-Geel and PTB-Braunschweig using ionization chambers, gamma-ray spectrometers and an alpha spectrometer, did not confirm any variations in the decay constant from extra-terrestrial sources such as solar and cosmic neutrinos proposed by 2018St04, rather the reported variations were ascribed to terrestrial sources on the experimental apparatus such as from solar irradiance, rainfall and weather conditions.

2018Be08: measurement of decay constant of ^{222}Rn from ^{226}Ra→^{222}Rn decay in equilibrium at Gran-Sasso underground laboratory using γ-ray spectroscopic techniques did not show any significant variations in the decay constant.

2017Sc08, and V. Milian-Sanchez et al, Nucl. Instr. & Meth. A828, 210 (2010): measurement of decay constant of ^{222}Rn from ^{226}Ra→^{222}Rn decay in equilibrium; ascribed observed variation in decay constant to correlations with space weather.

2012Th04: measurement of decay constant of ^{222}Rn from ^{226}Ra→^{222}Rn decay in equilibrium as a function of temperature of the source material using γ-ray spectroscopic techniques, and reported apparent variation in activity with temperature.

^{222}Rn Levels

E(level)†	J$^{\pi}$‡	$T_{1/2}$‡	Comments
0.0	0^{+}	3.8222 d *9*	
186.206 *13*	2^{+}	0.32 ns *2*	
448.48 *5*	4^{+}	52.5 ps *+44−23*	J$^{\pi}$: spin from α(262γ)(θ) (1989Po03), with rejection of J=0, 1, 2 and 3.
600.73 *4*	1^{-}	0.7 ps *+11−5*	J$^{\pi}$: spin from α(415γ)(θ) and α(601γ)(θ) (1989Po03), with rejection of J=2 and 3.
635.57 *8*	3^{-}	≈0.4 ns	J$^{\pi}$: spin from α(449γ)(θ) (1989Po03), with rejection of J=0, 1, 2 and 4.

Continued on next page (footnotes at end of table)

^{226}Ra α decay (1603 y) 2017Ma22,1963Ba62,1971Lo19 (continued)

^{222}Rn Levels (continued)

† From least-squares fit to Eγ data.
‡ From the Adopted Levels.

α radiations

Eα†	E(level)	Iα‡@	HF#	Comments
4160 *2*	635.57	0.00027 *5*	8.6 *16*	Iα: from 1963Ba62. Other: 0.00027 from γ transition intensities.
4191 *2*	600.73	0.0010 *1*	4.4 *5*	Eα: 4194.4 *3* from level energy and Eα (to g.s.). Iα: from 1963Ba62. Other: 0.00072 from γ transition intensities.
4340 *1*	448.48	0.0059 *15*	10.3 *5*	Iα: from 2017Ma22 (measurements carried out at JRC-Geel, CIEMAT, and LNHB; authors recommend Iα=0.0059 *15* as mean of Iα=0.0067 *20* from JRC-Geel, and 0.0052 *15* from CIEMAT). Individual measurements listed by 2017Ma22 are: 0.005 *2*, 0.006 *1*, 0.0102 *25* at JRC-Geel; 0.0046 *15*, 0.0037 *12* at CIEMAT; and 0.007 *6* at LNHB). Evaluators obtain weighted average of 0.0053 *12* from all the measured values above, except that from LNHB. Other measurement: 0.0065 *3* (1963Ba62). Precise value from 1963Ba62 is not used as various summing effects, as discussed by 2017Ma22, were probably not considered, implying that uncertainty of 0.0003 in 1963Ba62 may be underestimated. Other: 0.0060 *6* from γ transition intensity balance.
4601 *1*	186.206	5.93 *1*	0.857 *6*	Eα: the original energy of 4598 *1* in 1963Ba62 has been increased by 3 keV, as recommended by 1991Ry01, because of a change in the calibration energy. Eα=4601.7 *2* was recommended by 1983Co22 and 1987El01 from measurement of 1958Wa16. Eα=4601.43 *26* from Eα(g.s.)=4784.34 *25* and E(level). Iα: from 2017Ma22, measured Iα=5.917 *10* at JRC-Geel (weighted average of 5.917 *20*, 5.917 *30*, 5.918 *35*, 5.914 *10*, 5.925 *25*); and 5.94 *2* at CIEMAT (extrapolated value of 5.92 *2*, 5.90 *2*, 5.81 *2*, 5.75 *2*). Value measured at LNHB was: 5.51 *4*. Other measurements: 6.16 *3* (2001La14), 5.55 (1963Ba62). Other: 5.97 *7* from γ transition intensity balance.
4784.34 *25*	0.0	94.07 *1*	1.0	Eα: from 1971Gr17. The original energy has been decreased by 0.16 keV, as recommended by 1991Ry01. Other measurements: 1996Wi27, 4781 *1* (1963Ba62). Iα: from 2017Ma22, measured Iα=94.077 *10* at JRC-Geel (weighted average of 94.078 *20*, 94.077 *30*, 94.075 *35*, 94.080 *10*, 94.064 *25*); and 94.06 *2* at CIEMAT (extrapolated value of 94.08 *2*, 94.12 *2*, 94.21 *2*, 94.29 *2*). Value measured at LNHB was: 94.49 *4*. Other measurements: 93.84 *11* (2001La14), 94.45 (1963Ba62). Other: 94.02 *7* from 100−(γ transition intensities feeding the g.s.).

† From 1963Ba62, except where otherwise noted. Other measurements: 1958Wa16, 1953Ba29, 1949Ro08. 1991Ry01 evaluation recommended Eα values for 4784.34α and 4601α.
‡ Recommended values in 2017Ma22, based on results from α spectra obtained for five measurements at JRC and four at CIEMAT. Uncertainty budget is explained in detail. The results are compared with those in the Decay Data Evaluation Project (DDEP) (see 2008BeZV: Monographie BIPM-5, Vol.4., Bureau International des Poids et Mesures or consult Saclay's www.nucleide.org/DDEP.htm webpage). Note that recommended values from CIEMAT are from an extrapolation procedure as described in text and Fig. 7 of the paper. Exceptions are noted. Other measurements: 2001La14, 1963Ba62.
# HF(4784α)=1.0 gives $r_0(^{222}Rn)$=1.5397 *3*.
@ Absolute intensity per 100 decays.

γ(^{222}Rn)

Measured absolute x-ray emission probabilities (per 100 decays) (2018Ma11): I(Kα_2)=0.180 *2*, I(Kα_1)=0.299 *3*, I(Kβ_1)=0.105 *1*, I(Kβ_2)=0.033 *1*.
Measured ratios of x-ray emissions (2007Ya02): $K_{\alpha2}/K_{\alpha1}$=0.5837 *21*, $K_{\beta1}/K_{\alpha1}$=0.2165 *33*, K_β/K_α=0.2606 *12*.
Measured absolute x-ray emission probabilities (per 100 decays) (2002De03,2004Mo07): I(Kα_2)=0.159 *40*, I(Kα_1)=0.219 *33*, I(Kβ_1)=0.080 *6*, I(Kβ_2)=0.020 *4*.
Measured absolute x-ray emission probabilities (per 100 decays) (1983Sc13): I(Kα_2)+I(Kα_1)=0.418 *21*, I(Kβ)=0.145 *9*.

E_γ †	I_γ ‡	E_i(level)	J^π_i	E_f	J^π_f	Mult.	α #	$I_{(\gamma+ce)}$ ‡	Comments
(34.81 *16*)	≈6×10^{-8}	635.57	3$^-$	600.73	1$^-$	[E2]	1.30×10^3 *4*	≈0.00008	E_γ: transition was not observed; its energy is from the level scheme. I(γ+ce) from intensity balance at the 635.5 level, assuming negligible I(γ+ce) for the 187.1 transition.
186.211 *13*	3.565 *29*	186.206	2$^+$	0.0	0$^+$	E2	0.677 *9*		α(K)=0.1901 *27*; α(L)=0.360 *5*; α(M)=0.0963 *13* α(N)=0.02509 *35*; α(O)=0.00510 *7*; α(P)=0.000584 *8* E_γ: from 1993Di09 and 1977Zo01. Other measured energies: 186.0 *1* (1969Li10), 185.97 *5* (1971Lo19), 186.196 *12* (1974AlZT), 185.8 *2* (1975Ha31), 186.19 *10* (1976De48), 186.19 *16* (1982Ak03). Earlier measurements: 1951Co15, 1960St20, 1964Ew04. I_γ: weighted average of measured absolute intensity (per 100 decays) of 3.555 *29* by 2018Ma11 (note that authors quote uncertainty of 0.027 in their Table 3); 3.64 *4* (2001La14); 3.59 *6* (1991Li11), 3.50 *5* (1983Ol01); 3.51 *6* (1983Sc13). Other: 3.29 *3* (1983Co22) appears discrepant, although this value agrees with 3.28 *3* from intensity balance at the 186-keV level. Other values: Iγ(186γ)/Iγ(609γ of ^{214}Bi in equilibrium)= 0.07812 *31* (2002De03), 0.0785 *5* (2002MoZP), 0.076 *8* (2000Sa32), 0.0858 *5* (1993Di09), 0.0823 *3* (1983Bu14), 0.092 *10* (1982Ak03), 0.0907 *14* (1982Fa10), 0.076 *4* (1981We18), 0.0900 *11* (1977Zo01), 0.087 *15* (1975Ha31), 0.0820 *12* (1970Mo28), 0.079 *8* (1964Ew04). Iγ(609γ of ^{214}Bi in equilibrium)=45.45% *19* is adopted in ^{214}Bi β^- decay dataset in the ENSDF database (May 2021 update). Other Iγ measurements: 2002MoZP, 1990MoZP, 1976De48, 1974AlZT, 1969Li10, 1969Wa27, 1969Gr33, 1967Ma51. Mult.: from ce ratios measured by 1963Go21, 1955Ju14, 1954Ro05. 1973De50 α(K)=0.200 *9*, α(L)=0.380 *20* were deduced by 1973De50 from I(K x ray)/I(186γ), I(L x ray)/I(186γ).
(187.10 *20*)		635.57	3$^-$	448.48	4$^+$	[E1]	0.1011 *14*		α(K)=0.0809 *12*; α(L)=0.01535 *22*; α(M)=0.00365 *5*

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γ(^{222}Rn) (continued)

E_γ †	I_γ ‡	E_i(level)	J_i^π	E_f	J_f^π	Mult.	α #	Comments
								α(N)=0.000941 *13*; α(O)=0.0001996 *28*; α(P)=2.67×10^{-5} *4* E_γ: transition was not observed; its energy is from the level scheme. I(γ+ce)(34.8γ)+I(γ+ce)(187.1γ)=0.00008 from the intensity balance at the 635.5-keV level. Intensity balance at the 448.4-keV level, without the assumption of 187.1γ feeding the 448.4 level is −0.0001 *16*, suggesting negligible intensity of 187.1 transition.
262.27 *5*	0.0050 *5*	448.48	4^+	186.206	2^+	[E2]	0.2093 *29*	α(K)=0.0923 *13*; α(L)=0.0868 *12*; α(M)=0.02294 *32* α(N)=0.00597 *8*; α(O)=0.001225 *17*; α(P)=0.0001446 *20* I_γ: from Iγ(262γ)/Iγ(186γ)=0.0014 *2* (1993Di09,1971Lo19). Other measured ratios: 0.0029 (1960St20), 0.0025 (1956Ha71). I(262γ)=0.0049 *13* from I(4340α)=0.0059 *15* and α(262γ)=0.209; if I(γ+ce) of 187.1γ from the 635 level is negligible.
414.60 *5*	0.00030	600.73	1^-	186.206	2^+	[E1]	0.01628 *23*	α(K)=0.01329 *19*; α(L)=0.002278 *32*; α(M)=0.000537 *8* α(N)=0.0001390 *19*; α(O)=2.99×10^{-5} *4*; α(P)=4.19×10^{-6} *6* I_γ: from Iγ(414.6γ)/Iγ(186γ)=0.000086 (1971Lo19). Other measured ratio: 0.00021 (1960St20).
449.37 *10*	0.00019	635.57	3^-	186.206	2^+	[E1]	0.01373 *19*	α(K)=0.01123 *16*; α(L)=0.001908 *27*; α(M)=0.000449 *6* α(N)=0.0001163 *16*; α(O)=2.509×10^{-5} *35*; α(P)=3.53×10^{-6} *5* I_γ: from Iγ(449γ)/Iγ(186γ)=5.5×10^{-5} (1971Lo19). Other measured ratio: 9×10^{-5} (1960St20).
600.66 *5*	0.00049	600.73	1^-	0.0	0^+	[E1]	0.00762 *11*	α(K)=0.00627 *9*; α(L)=0.001034 *14*; α(M)=0.0002428 *34* α(N)=6.29×10^{-5} *9*; α(O)=1.362×10^{-5} *19*; α(P)=1.936×10^{-6} *27* I_γ: from Iγ(600γ)/Iγ(186γ)=0.00014 (1971Lo19). Other measured ratio: 0.00033 (1960St20).

† From 1971Lo19, except when noted otherwise.

‡ Absolute intensity per 100 decays.

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.

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