^{216}Po – Comments on evaluation of decay data by A. L. Nichols

Evaluated: July/August 2001
Re-evaluated: January 2004 and May 2010

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

A simple decay scheme was derived from the gamma-ray studies of 1977Ku15, with an absolute emission probability of 0.0019 (3) % for the single 804.9-keV gamma ray. This value and theoretical internal conversion coefficients were used to calculate the alpha-particle emission probabilities. Alpha-particle and gamma-ray studies are required to confirm the validity of the proposed decay scheme.

Nuclear Data

The ^{228}Th decay chain is important in quantifying the environmental impact of the decay of naturally-occurring ^{232}Th.

Half-life

The recommended half-life is the weighted mean of three somewhat elderly measurements (1911Mo01, 1942Wa04 and 1963Di05) and a more recent study (2003Da24). Further measurements are merited to determine this value with greater confidence.

(a). 1911Mo11 used an air jet to transport and separate the positively-charged activity from an actinium-228 source by passage along a flow tube to a negatively-charged rotating disk that subsequently presented the deposited material in turn to two ionization chambers. The half-life of Po-216 (thorium A) was determined from the fall in activity on the collection plate during the time taken to rotate the disk with plate from one ionization chamber to the other. Unexpected irregularities were occasionally observed, but were never resolved, and no effort was made to identify possible impurities.

(b). 1942Wa04 adopted a coincidence circuit linked to a Geiger counter to determine the time interval between the disintegration of parent Rn-220 and Po-216; contamination was identified with the unwanted presence of Ra-224.

(c). 1963Di05 used a Si-surface detector to obtain a parent-daughter decay curve analysed in terms of Po-216 decay and the background, as shown in the relevant figure. Impurities were not considered in the analyses of the decay curves, and were effectively assumed to be negligible. The uncertainty is quoted as only being statistical, with no assessment having been made of the systematic component.

(d). 2003Da24 carried out time-amplitude analyses of the alpha spectra accumulated by means of $^{116}CdWO_4$ crystal scintillators in preparation for their ββ-decay studies. Data processing involved pulse shape definitions based on Gaussian functions in which impurities were assumed to be negligible.

There is no evidence of any change in the half-life of ^{216}Po on extreme cooling of alpha-active ^{224}Ra samples and decay products within a metallic environment (2007St23). Sources were held at temperatures at and below 1 kelvin for periods of several days, and exhibited an upper limit of change in the alpha-decay half-lives of the order of 1 %.

Reference	Half-life (s)
1911Mo01	0.145 (15)
1942Wa04	0.158 (8)
1963Di05	0.145 (2)*
2003Da24	0.144 (8)
Recommended value	0.148 (4)

* Uncertainty adjusted to ± 0.006 to reduce weighting below 50 %.

Alpha Particles

Energies

Alpha-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 2005Br03 and Q-value of 6906.3 keV (2003Au03) were used to determine the energies and uncertainties of the alpha-particle transitions to the first excited and ground states of Pb-212, while allowing for the significant recoil components.

Emission Probabilities

Both alpha-particle emission probabilities were derived from the weighted mean emission probability of the single gamma transition and theoretical internal conversion coefficients. A hindrance factor (HF) of 1.00 for the 6778.4-keV alpha-particle emission yields $r_0(^{212}Pb)$ of 1.5408 (9) fm which was adopted in the equivalent calculation of the HF for the other alpha-particle emission (1998Ak04).

Alpha-particle emission probabilities per 100 disintegrations of ^{216}Po, and hindrance factors.

E_α(keV)	P_α		HF
	1962Wa28	Recommended values*	
5988.6 (10)	0.0021 (4)	0.0019 (3)	35
6778.6 (5)	~ 100	99.9981 (3)	1.00

* Recommended emission probabilities derived from evaluated gamma-ray emission probability and theoretical internal conversion coefficients.

Gamma Ray

Energy

The single gamma-ray energy was based on the nuclear level energy of 804.9 (5) keV from 2005Br03.

Emission Probability

The absolute emission probability of the 804.9 (5)-keV gamma ray was determined from the measurement of 1977Ku15, adjusted for the change from 3.95 % (0.0395) to 4.12 % (0.0412) of P_γ(240.986 keV) of ^{224}Ra (as adopted from an equivalent DDEP evaluation of ^{224}Ra decay data, dated April 2010).

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Published gamma-ray emission probabilities per 100 disintegrations of ^{216}Po.

E_γ (keV)	P_γ
	1977Ku15¶
804.9 (5)	0.0018 (3)

¶ Absolute value in measurements that include P_γ(240.986 keV) of 3.95 % for ^{224}Ra.

Absolute gamma-ray emission probabilities per 100 disintegrations of ^{216}Po.

E_γ (keV)	P_γ^{abs}	
	1977Ku15†	**Recommended value**
804.9 (5)	0.0019 (3)	0.0019 (3)

† Adjusted with respect to evaluated P_γ(240.986 keV) of 4.12 (4) % (0.0412 (4)) for ^{224}Ra, as adopted from an equivalent DDEP evaluation of ^{224}Ra decay data (dated April 2010).

<u>Multipolarity and Internal Conversion Coefficients</u>

The decay scheme specified by 2005Br03 and 2007Wu02 has been used to define the multipolarity of the gamma transition on the basis of the assumed spins and parities of the two nuclear levels. Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibedi *et al*. (2008Ki07), based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45).

Gamma-ray emission: multipolarity and theoretical internal conversion coefficients (frozen orbital approximation).

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{total}
804.9 (5)	[E2]	0.007 99 (12)	0.001 732 (25)	0.000 548 (8)	0.010 27 (15)

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the x-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{216}Po.

			Energy (keV)	Photons per 100 disint.
XL		(Pb)	9.184 – 15.216	5.9 (6) x 10^{-6}
	XL_l	(Pb)	9.184	2.7 (3) x 10^{-6}
	XL_α	(Pb)	10.450 – 10.551	2.53 (24) x 10^{-6}
	XL_η	(Pb)	11.349	4.9 (5) x 10^{-7}
	XL_β	(Pb)	12.142 – 13.015	4.7 (7) x 10^{-8}
	XL_γ	(Pb)	14.765 – 15.216	1.42 (18) x 10^{-7}
XK_α	$XK_{\alpha2}$	(Pb)	72.8049	4.3 (7) x 10^{-6}
	$XK_{\alpha1}$	(Pb)	74.9700	7.2 (12) x 10^{-6}
$XK'_{\beta1}$	$XK_{\beta3}$	(Pb)	84.451	)
	$XK_{\beta1}$	(Pb)	84.937	) 2.4 (4) x 10^{-6}
	$XK_{\beta5}''$	(Pb)	85.470	)
$XK'_{\beta2}$	$XK_{\beta2}$	(Pb)	87.238	)
	$XK_{\beta4}$	(Pb)	87.580	) 7.4 (12) x 10^{-7}
	$XKO_{2,3}$	(Pb)	87.911	)

Electron energies were determined from electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

Data Consistency

A Q_α-value of 6906.3 (5) keV has been adopted from the atomic mass evaluation of Audi *et al.* (2003Au03) while in the course of formulating the decay scheme of ^{216}Po. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{216}Po alpha-decay process (i.e. α, electron, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 6906.3\ (5)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al*. is (0.000 ± 0.010) %, which supports the derivation of a highly consistent decay scheme.

References

1911Mo01 H.G.J. Moseley, K. Fajans, LIX. Radio-Active Products of Short Life, Phil. Mag. 22 (1911) 629-638. [Half-life]

1942Wa04 A.G. Ward, A New Method of Determining Half-Value Periods from Observations with a Single Geiger Counter, Proc. Roy. Soc. (London) 181A (1942) 183-197. [Half-life]

1962Wa28 R.J. Walen, Spectrographie α du Radium 224 et de ses Dérivés, C. R. Acad. Sci. Paris 255 (1962) 1604-1605. [P_α]

1963Di05 H. Diamond, J.E. Gindler, Alpha Half-Lives of ^{216}Po, ^{217}At and ^{218}Rn, J. Inorg. Nucl. Chem. 25 (1963) 143-149. [Half-life]

1977Ku15 W. Kurcewicz, N. Kaffrell, N. Trautmann, A. Plochocki, J. Zylicz, M. Matul, K. Stryczniewicz, Collective States Fed by Weak α-transitions in the ^{232}U Chain, Nucl. Phys. A289 (1977) 1-14. [P_γ]

1977La19 F.P. Larkins, Semiempirical Auger-electron Energies for Elements $10 \leq Z \leq 100$, At. Data Nucl. Data Tables 20 (1977) 311-387. [Auger-electron energies]

1996Sc06 E. Schönfeld, H. Janβen, Evaluation of Atomic Shell Data, Nucl. Instrum. Methods Phys. Res. A369 (1996) 527-533. [X_K, X_L, Auger electrons]

1998Ak04 Y.A. Akovali, Review of alpha-decay data from doubly-even nuclei, Nucl. Data Sheets 84 (1998) 1-114. [alpha decay, r_0 parameters]

1998ScZM E. Schönfeld, G. Rodloff, Tables of the Energies of K-Auger Electrons for Elements with Atomic Numbers in the Range from Z = 11 to Z = 100, PTB Report PTB-6.11-98-1, October 1998. [Auger electrons]

1999ScZX E. Schönfeld, G. Rodloff, Energies and Relative Emission Probabilities of K X-rays for Elements with Atomic Numbers in the Range from Z = 5 to Z = 100, PTB Report PTB-6.11-1999-1, February 1999. [X_K]

2002Ba85 I.M. Band, M.B. Trzhaskovskaya, C.W. Nestor Jr., P.O. Tikkanen, S. Raman, Dirac–Fock Internal Conversion Coefficients, At. Data Nucl. Data Tables 81 (2002) 1-334. [ICC]

2002Ra45 S. Raman, C.W. Nestor Jr., A. Ichihara, M.B. Trzhaskovskaya, How Good are the Internal Conversion Coefficients Now? Phys. Rev. C66 (2002) 044312, 1-23. [ICC]

2003Au03 G. Audi, A.H. Wapstra, C. Thibault, The AME2003 Atomic Mass Evaluation (II). Tables, Graphs and References, Nucl. Phys. A729 (2003) 337-676. [Q-value]

2003Da24 F.A. Danevich, A.Sh. Georgadze, V.V. Kobychev, B.N. Kropivyansky, A.S. Nikolaiko, O.A. Ponkratenko, V.I. Tretyak, S.Yu. Zdesenko, Yu.G. Zdesenko, P.G. Bizzeti, T.F. Fazzini, P.R. Maurenzig, Search for 2β Decay of Cadmium and Tungsten Isotopes: Final Results of the Solotvina Experiment, Phys. Rev. C68 (2003) 035501, 1-12. [Half-life]

2005Br03 E. Browne, Nuclear Data Sheets for A = 212, Nucl. Data Sheets 104 (2005) 427-496. [Nuclear structure, level energies]

2007St23 N.J. Stone, J.R. Stone, M. Lindroos, P. Richards, M. Veskovic, D.A. Williams, On the Absence of Appreciable Half-life Changes in Alpha Emitters Cooled in Metals to 1 Kelvin and Below, Nucl. Phys. A793 (2007) 1-19. [Half-life]

2007Wu02 S.-C. Wu, Nuclear Data Sheets for A = 216, Nucl. Data Sheets 108 (2007) 1057-1092. [Nuclear structure, level energies]

2008Ki07 T. Kibédi, T.W. Burrows, M.B. Trzhaskovskaya, P.M. Davidson, C.W. Nestor Jr., Evaluation of Theoretical Conversion Coefficients using BrIcc, Nucl. Instrum. Methods Phys. Res. A589 (2008) 202-229. [ICC]