$^{215}_{83}$Bi $_{132}$

1 Decay Scheme

Bi-215 ground state ($J^\pi = (9/2^-)$) decays 100 % by beta-minus emission to various excited levels and the ground state of Po-215.
Le bismuth 215 se désintègre à 100 % par émissions bêta moins vers des états excités et le niveau fondamental du polonium 215.

2 Nuclear Data

$T_{1/2}$(^{215}Bi)	:	7,6	(2)	min
$T_{1/2}$(^{215}Po)	:	1,781	(4)	10^{-3} s
Q^-(^{215}Bi)	:	2189	(15)	keV

2.1 β^- Transitions

	Energy keV	Probability × 100	Nature	lg ft
$\beta^-_{0,18}$	790 (15)	2,8 (1)	[1st forbidden non-unique]	6
$\beta^-_{0,17}$	895 (15)	2,0 (2)	[1st forbidden non-unique]	6,34
$\beta^-_{0,16}$	1013 (15)	0,2 (1)	[1st forbidden non-unique]	7,5
$\beta^-_{0,14}$	1111 (15)	0,7 (1)	[1st forbidden non-unique]	7,1
$\beta^-_{0,9}$	1354 (15)	1,5 (1)	[1st forbidden non-unique]	7,1
$\beta^-_{0,6}$	1512 (15)	0,5 (1)	[1st forbidden non-unique]	7,8
$\beta^-_{0,5}$	1581 (15)	0,7 (1)	(1st forbidden non-unique)	7,7
$\beta^-_{0,4}$	1671 (15)	0,3 (2)	(1st forbidden non-unique)	8,1
$\beta^-_{0,3}$	1787 (15)	0,5 (1)	(1st forbidden unique)	9
$\beta^-_{0,2}$	1895 (15)	30 (6)	(1st forbidden non-unique)	6,35
$\beta^-_{0,0}$	2189 (15)	61 (6)	(1st forbidden non-unique)	6,28

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{3,1}$(Po)	130,58 (1)	0,0505 (12)	M1+26,5%E2	3,19 (16)	0,94 (4)	0,234 (10)	4,44 (13)
$\gamma_{4,2}$(Po)	224,04 (7)	0,044 (7)	E2	0,1296 (19)	0,1407 (20)	0,0370 (6)	0,319 (5)
$\gamma_{1,0}$(Po)	271,228 (10)	2,34 (10)	M1+94%E2	0,111 (6)	0,0668 (11)	0,0173 (3)	0,201 (7)
$\gamma_{2,0}$(Po)	293,56 (4)	32 (2)	M1+50%E2	0,25 (4)	0,062 (4)	0,0152 (7)	0,34 (5)
$\gamma_{6,2}$(Po)	383,10 (8)	0,14 (7)					
$\gamma_{3,0}$(Po)	401,81 (1)	0,50 (8)	E2	0,0351 (5)	0,01528 (22)	0,00390 (6)	0,0555 (8)
$\gamma_{6,1}$(Po)	405,43 (7)	0,006 (1)					
$\gamma_{4,0}$(Po)	517,60 (6)	1,10 (8)	M1+50%E2	0,058 (9)	0,0115 (11)	0,00277 (24)	0,073 (10)
$\gamma_{9,2}$(Po)	541,76 (22)	0,21 (7)					
$\gamma_{9,1}$(Po)	564,09 (22)	0,67 (7)					
$\gamma_{5,0}$(Po)	608,30 (7)	0,67 (7)	(M1 + E2)				
$\gamma_{6,0}$(Po)	676,66 (7)	0,40 (7)					
$\gamma_{17,4}$(Po)	776,9 (1)	0,81 (14)					
$\gamma_{14,2}$(Po)	784 (2)	0,33 (7)					
$\gamma_{14,1}$(Po)	806,4 (20)	0,40 (7)					
$\gamma_{9,0}$(Po)	835,32 (22)	0,62 (7)					
$\gamma_{16,1}$(Po)	905 (2)	0,21 (7)					
$\gamma_{17,1}$(Po)	1023,3 (1)	0,62 (7)					
$\gamma_{18,2}$(Po)	1105,2 (4)	1,50 (7)					
$\gamma_{18,1}$(Po)	1127,6 (4)	0,48 (7)					
$\gamma_{17,0}$(Po)	1294,5 (1)	0,62 (7)					
$\gamma_{18,0}$(Po)	1398,8 (4)	0,81 (7)					

3 Atomic Data

3.1 Po

ω_K : 0,965 (4)
$\bar{\omega}_L$: 0,403 (16)
n_{KL} : 0,807 (5)

3.1.1 X Radiations

		Energy keV		Relative probability
X_K				
	$K\alpha_2$	76,864		60
	$K\alpha_1$	79,293		100
	$K\beta_3$	89,256	}	
	$K\beta_1$	89,807	}	
	$K\beta_5''$	90,363	}	34
	$K\beta_2$	92,263	}	
	$K\beta_4$	92,618	}	10,7
	$KO_{2,3}$	92,983	}	

		Energy keV	Relative probability
X_L			
	$L\ell$	9,658	
	$L\alpha$	11,016 – 11,13	
	$L\eta$	12,085	
	$L\beta$	12,823 – 13,778	
	$L\gamma$	15,742 – 16,213	

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	58,978 – 65,205	100
KLX	71,902 – 79,289	58
KXY	84,8 – 93,1	8,5
Auger L	5,434 – 10,934	3080

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e_{AL}	(Po)	5,434 - 10,934	4,0 (4)
e_{AK}	(Po)		0,22 (5)
	KLL	58,978 - 65,205	}
	KLX	71,902 - 79,289	}
	KXY	84,8 - 93,1	}
$ec_{1,0\ K}$	(Po)	178,13 (1)	0,22 (1)
$ec_{2,0\ K}$	(Po)	200,46 (4)	6,0 (4)
$ec_{1,0\ L}$	(Po)	254,30 - 257,42	0,13 (1)
$ec_{2,0\ L}$	(Po)	276,63 - 279,75	1,5 (1)
$ec_{2,0\ M+}$	(Po)	289,41 - 293,56	0,7 (1)
$\beta^-_{0,18}$	max:	790 (15)	2,8 (1)
$\beta^-_{0,18}$	avg:	249 (6)	

		Energy keV		Electrons per 100 disint.
$\beta^-_{0,17}$	max:	895	(15)	2,0 (2)
$\beta^-_{0,17}$	avg:	287	(6)	
$\beta^-_{0,16}$	max:	1013	(15)	0,2 (1)
$\beta^-_{0,16}$	avg:	332	(6)	
$\beta^-_{0,14}$	max:	1111	(15)	0,7 (1)
$\beta^-_{0,14}$	avg:	370	(6)	
$\beta^-_{0,9}$	max:	1354	(15)	1,5 (1)
$\beta^-_{0,9}$	avg:	465	(6)	
$\beta^-_{0,6}$	max:	1512	(15)	0,5 (1)
$\beta^-_{0,6}$	avg:	528	(6)	
$\beta^-_{0,5}$	max:	1581	(15)	0,7 (1)
$\beta^-_{0,5}$	avg:	556	(6)	
$\beta^-_{0,4}$	max:	1671	(15)	0,3 (2)
$\beta^-_{0,4}$	avg:	593	(6)	
$\beta^-_{0,3}$	max:	1787	(15)	0,5 (1)
$\beta^-_{0,3}$	avg:	619	(6)	
$\beta^-_{0,2}$	max:	1895	(15)	30 (6)
$\beta^-_{0,2}$	avg:	685	(6)	
$\beta^-_{0,0}$	max:	2189	(15)	61 (6)
$\beta^-_{0,0}$	avg:	808	(6)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.	
XL	(Po)	9,658 — 16,213		2,7 (3)	
$XK\alpha_2$	(Po)	76,864		1,8 (3)	} $K\alpha$
$XK\alpha_1$	(Po)	79,293		3,0 (5)	}
$XK\beta_3$	(Po)	89,256	}		
$XK\beta_1$	(Po)	89,807	}	1,02 (16)	$K'\beta_1$
$XK\beta_5''$	(Po)	90,363	}		
$XK\beta_2$	(Po)	92,263	}		
$XK\beta_4$	(Po)	92,618	}	0,32 (5)	$K'\beta_2$
$XKO_{2,3}$	(Po)	92,983	}		

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{3,1}$(Po)	130,58 (1)	0,0093 (10)
$\gamma_{4,2}$(Po)	224,04 (7)	0,033 (5)
$\gamma_{1,0}$(Po)	271,228 (10)	1,95 (7)
$\gamma_{2,0}$(Po)	293,56 (4)	23,8 (9)
$\gamma_{6,2}$(Po)	383,10 (8)	0,14 (7)
$\gamma_{3,0}$(Po)	401,81 (1)	0,48 (7)
$\gamma_{6,1}$(Po)	405,43 (7)	0,006 (1)
$\gamma_{4,0}$(Po)	517,60 (6)	1,02 (8)
$\gamma_{9,2}$(Po)	541,76 (22)	0,21 (7)
$\gamma_{9,1}$(Po)	564,09 (22)	0,67 (7)
$\gamma_{5,0}$(Po)	608,30 (7)	0,67 (7)
$\gamma_{6,0}$(Po)	676,66 (7)	0,40 (7)
$\gamma_{17,4}$(Po)	776,9 (1)	0,81 (14)
$\gamma_{14,2}$(Po)	784 (2)	0,33 (7)
$\gamma_{14,1}$(Po)	806,4 (20)	0,40 (7)
$\gamma_{9,0}$(Po)	835,32 (22)	0,62 (7)
$\gamma_{16,1}$(Po)	905 (2)	0,21 (7)
$\gamma_{17,1}$(Po)	1023,3 (1)	0,62 (7)
$\gamma_{18,2}$(Po)	1105,2 (4)	1,50 (7)
$\gamma_{18,1}$(Po)	1127,6 (4)	0,48 (7)
$\gamma_{17,0}$(Po)	1294,5 (1)	0,62 (7)
$\gamma_{18,0}$(Po)	1398,8 (4)	0,81 (7)

6 Main Production Modes

U – 235 (4n + 3) decay chain

Th – 232(p,x)Bi – 215

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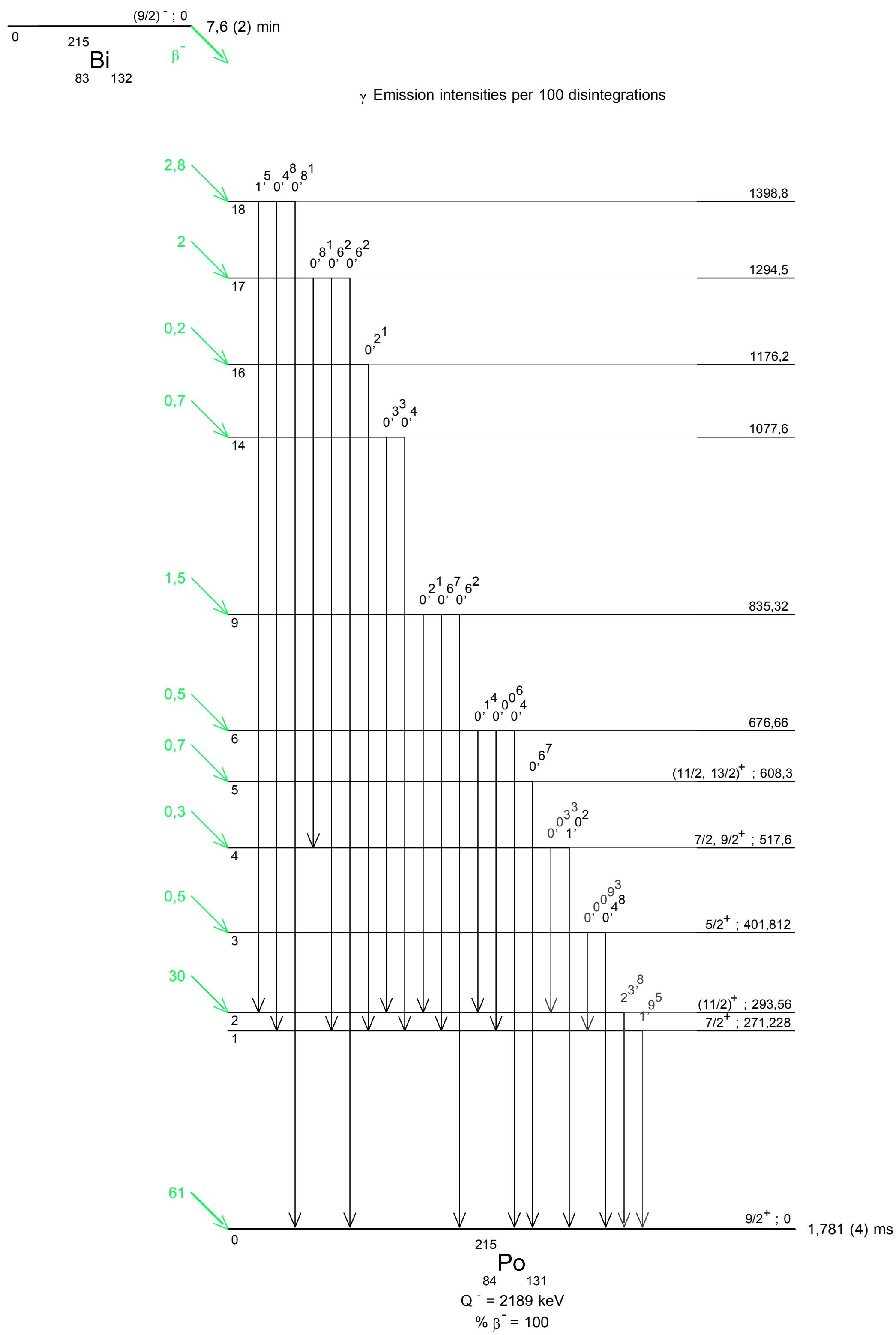
(9/2)⁻ ; 0
7,6 (2) min
215 Bi 83 132
γ Emission intensities per 100 disintegrations
1398,8
1294,5
1176,2
1077,6
835,32
676,66
(11/2, 13/2)+ ; 608,3
7/2, 9/2+ ; 517,6
5/2+ ; 401,812
(11/2)+ ; 293,56
7/2+ ; 271,228
9/2+ ; 0
1,781 (4) ms
215 Po 84 131
Q⁻ = 2189 keV
% β⁻ = 100

^{215}Bi – Comments on evaluation of decay data by A. L. Nichols and F. G. Kondev

Evaluated: June 2011

Evaluation Procedure

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

The ^{215}Bi ground state (J^{π} = (9/2^{-})) decays 100 % by β^{-} emission to various excited levels and the ground state of ^{215}Po. A reasonably complex but inadequate decay scheme has been constructed primarily from the gamma-ray measurements of Kurpeta *et al.* (2003Ku26) in which 19 distinct gamma-ray emissions were identified with the β^{-} decay of ^{215}Bi. Although these authors assessed that there is no direct beta decay to the ground state of ^{215}Po, their reported absolute emission probabilities for the gamma rays populating the ground state are in conflict with this proposal.

Direct β^{-} feeding to the ground state of daughter ^{215}Po has not been satisfactorily determined. Therefore, the evaluators resorted to comparisons with the β^{-} decay of other odd-even Bi radionuclides (^{213}Bi) and β^{-}-decay theory in order to define the β^{-} and γ emission probabilities in absolute terms. Further studies are required to clarify and define more clearly the ^{215}Bi decay scheme, particularly with respect to the absolute gamma-ray emission probabilities and quantification of direct β^{-} feeding to the ground state of daughter ^{215}Po.

Nuclear Data

^{215}Bi is part of the (4n + 3) naturally-occurring decay chain, and of relevance in quantifying the environmental impact of ^{235}U and decay-chain products. Specific radionuclides in this decay chain are noteworthy because of their decay characteristics (^{215}Po, ^{211}Bi and ^{211}Po alpha decay).

Half-life

^{215}Bi was first observed by 1953Hy83, and assigned a half-life of (8 ± 2) min. However, the recommended half-life is the weighted mean of three more recent measurements (1965Nu03, 1989Bu09 and 1990Ru02).

Reference	Half-life (min)
1965Nu03	7.4 (6)
1989Bu09	7.5 (4)
1990Ru02	7.7 (2)
Recommended value	7.6 (2)

^{215}Po half-life of 1.781 (4) millisecond was adopted from the evaluation of Browne (2001Br31).

Q value

Q^{-} of 2189 (15) keV was adopted from the evaluated tabulations of Audi *et al.* (2003Au03).

Beta particles

Energies

All beta-particle energies were calculated from the structural details of the proposed decay scheme. A combination of nuclear level energies recommended by 2001Br31 and derived from 2003Ku26, and a Q-value of 2189 (15) keV (2003Au03) were used to determine the energies and uncertainties of the beta-particle emissions to the various levels.

Adopted nuclear levels of ^{215}Po: Energy, J^{π} and origins (2001Br31, 2003Ku26).

Nuclear level	Nuclear level energy (keV)	J^{π}	Origins
0	0.0	9/2 +	**^{215}Bi β^- decay**, ^{219}Rn α decay
1	271.228 ± 0.010	7/2 +	**^{215}Bi β^- decay**, ^{219}Rn α decay
2	293.56 ± 0.04	11/2 +	**^{215}Bi β^- decay**, ^{219}Rn α decay
3	401.812 ± 0.010	5/2 +	**^{215}Bi β^- decay**, ^{219}Rn α decay
4	517.60 ± 0.06	7/2 +, 9/2 +	**^{215}Bi β^- decay**, ^{219}Rn α decay
5	608.30 ± 0.07	(11/2 +, 13/2 +)	**^{215}Bi β^- decay**, ^{219}Rn α decay
6	676.66 ± 0.07		**^{215}Bi β^- decay**, ^{219}Rn α decay
7	708.1 ± 0.5		^{219}Rn α decay
8	732.7 ± 0.4		^{219}Rn α decay
9	835.32 ± 0.22		**^{215}Bi β^- decay**, ^{219}Rn α decay
10	877.2 ± 0.6		^{219}Rn α decay
11	891.1 ± 0.3		^{219}Rn α decay
12	930 ± 1		^{219}Rn α decay
13	1073.7 ± 0.4	(5/2 +)	^{219}Rn α decay
14	1077.6 ± 2.0*		**^{215}Bi β^- decay**
15	1094.2 ± 1.0		^{219}Rn α decay
16	1176.2 ± 2.0*		**^{215}Bi β^- decay**
17	1294.5 ± 0.1*		**^{215}Bi β^- decay**
18	1398.8 ± 0.4*		**^{215}Bi β^- decay**

* Calculated from the energies of the depopulating gamma rays (2003Ku26), and the lower-energy nuclear levels that they populate.

Emission Probabilities

Direct beta-particle feeding to the ground state of ^{215}Po has not been unambiguously defined from the various γ-ray measurements. Under these circumstances, a systematic assessment of the appropriate properties of odd-even Bi nuclides in the vicinity of ^{215}Bi has been undertaken to explore whether a reasonable approximation can be made of beta decay directly to the ground state of ^{215}Po (1991Ma16, 2001Br31, 2003Ak06, 2004Br45, 2007Ba19).

(a) Spin and parity of ^{215}Bi

Nuclide	^{209}Bi	^{211}Bi	^{213}Bi	^{215}Bi	^{217}Bi
β^- decay	stable	0.28 %	97.91 %	100 %	100 %
Direct β^- decay to ground state	–	0.28 %	65.9 %	?	?
α decay	stable	99.72 %	2.09 %	–	–
Spin and parity	$9/2^-$	$9/2^-$	$9/2^-$	$(9/2^-)$	?
Spin and parity of Po ground state	$1/2^-$	$9/2^+$	$9/2^+$	$9/2^+$	$(11/2^+)$

Spins and parities of $9/2^-$ are well defined for ^{209,211,213}Bi, and can be similarly assigned with reasonable confidence as $(9/2^-)$ for ^{215}Bi.

(b) Direct beta-particle feeding of ^{215}Bi to the ground state of ^{215}Po

Population-depopulation balances have been calculated on the basis of the relative emission probabilities of the gamma rays (see below) in order to derive relative beta-particle emission probabilities to all of the excited nuclear levels of ^{215}Po.

The β^- decay of ^{215}Bi was assumed to occur primarily via first forbidden non-unique transitions to the ground state ($9/2^+$) and 293.56-keV nuclear level ($11/2^+$) of ^{215}Po. The preparation of recommended decay-data files for DDEP necessitates the formulation of decay schemes that are based on absolute emission and transition probabilities that frequently encompass well-defined normalization factors in conjunction with accurate relative emission probabilities and various other nuclear parameters (e.g. internal conversion coefficients). This ideal situation cannot be achieved for ^{215}Bi because of existing inadequacies in the measured data. Therefore, the main β^- branches populate the 293.56-keV nuclear level and ground state of ^{215}Po, and their important emission probabilities have been derived somewhat unusually through application of the fifth-power law of β^- decay (1933Sa01, 1955Ev23, 1963KaZZ).

A general approximation has been formulated for the ratio of allowed beta-particle emission probabilities, based on the observation that the mean life (τ) for partial β^- decay is inversely proportional to the fifth power of the β^- end-point energy (1955Ev23, 1963KaZZ):

$$\frac{1}{\tau_\beta} \propto [(M(Z) - M(Z \pm 1)c^2)]^5$$

where

$$\tau_\beta = \frac{\tau_{exp}}{P_\beta} \quad \text{and} \quad \tau_{exp} \text{ is the lifetime of the parent nuclide.}$$

Therefore

$$\frac{1}{\tau_\beta} \sim (E_\beta)^5$$

This approximation has been applied to the major first-forbidden non-unique beta-particle emissions of ^{215}Bi directly to the ground state of ^{215}Po (($9/2^-$) → $9/2^+$)

$$\frac{1}{\tau_{0,0}} \sim (E_{\beta_{0,0}})^5 \qquad (1)$$

and to the 293.56-keV nuclear level of ^{215}Po (($9/2^-$) → $11/2^+$)

$$\frac{1}{\tau_{0,2}} \sim (E_{\beta_{0,2}})^5 \qquad (2)$$

Combining equations (1) and (2):

$$\frac{\tau_{0,2}}{\tau_{0,0}} = \frac{P_{\beta_{0,0}}}{P_{\beta_{0,2}}} \sim \left(\frac{E_{\beta_{0,0}}}{E_{\beta_{0,2}}}\right)^5 = \left[\frac{2189(15)}{1895(15)}\right]^5 = 1.155^5 \sim 2.055$$

where $P_{\beta_{0,0}}$ and $P_{\beta_{0,2}}$ are the β-particle emission probabilities to the ground state and 293.56-keV nuclear level, respectively.

The proposed decay scheme, recommended relative emission probabilities of the gamma rays and α_{total} have been used to determine a $P^{rel}_{\beta_{0,2}}$ value of 125 (7) by the appropriate summation of the measured gamma population/depopulation of the 293.56-keV nuclear level. Therefore:

$$P^{rel}_{\beta_{0,0}} \sim 2.055 \times 125\,(7) = 257\,(14)$$

with an uncertainty assigned in a somewhat arbitrary manner on the basis of the uncertainty derived for $P^{rel}_{\beta_{0,2}}$.

The normalization factor (*NF*) for the relative emission probabilities of both the β^- particles and γ rays has been determined from the total βγ transitions populating the ground state of ^{215}Po directly:

$$P^{rel}_{\beta_{0,0}} \times NF + \sum P^{rel}_{\gamma}(1 + \alpha_{total}) \times NF = 100$$

$$257\,(14) \times NF + [164\,(7) \times NF] = 100$$

$$NF = 100/421\,(16) = 0.238\,(9)$$

Both P^{abs}_{β} to the ground state and 293.56-keV nuclear level of ^{215}Po were simply calculated from their P^{rel}_{β} values and *NF*, and are coupled together on the basis of crude estimates of their uncertainties (i.e. arbitrary uncertainty of 20 % assigned to the value of $P_{\beta^-_{0,2}}$):

$P^{abs}_{\beta_{0,2}}$ of 30 (6) %

and $P^{abs}_{\beta_{0,0}}$ of 61 (6) %.

These data should be treated with a high degree of caution. Their derivation also impacts significantly on the quantification of the other beta-particle emission probabilities.

Apart from the beta-particle emission directly to the ground state of ^{215}Po, the relative emission probabilities of all of the other beta-particle decays were calculated from population-depopulation balances of the relative gamma transition probabilities, as derived from the relative gamma-ray emission probabilities and internal conversion coefficients determined from the frozen orbital approximation of Kibédi *et al*. (2008Ki07) based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45). Direct beta population of the 271.228-keV nuclear level of ^{215}Po was calculated to be zero from the calculation of the known gamma transition probabilities populating and depopulating this particular excited state ((9/2$^-$) to 7/2$^+$ (1st forbidden non-unique)).

Beta-particle emission probabilities per 100 disintegrations of ^{215}Bi, transition type and log *ft*.

E_β(keV)	P_β Recommended value	transition type[‡]	log *ft*[#]
790 (15)	2.8 (1)[*]	[1st forbidden non-unique]	6.00
895 (15)	2.0 (2)[*]	[1st forbidden non-unique]	6.34
1013 (15)	0.2 (1)[*]	[1st forbidden non-unique]	7.5
1111 (15)	0.7 (1)[*]	[1st forbidden non-unique]	7.1
1354 (15)	1.5 (1)[*]	[1st forbidden non-unique]	7.10
1512 (15)	0.5 (1)[*]	[1st forbidden non-unique]	7.8
1581 (15)	0.7 (1)[*]	(1st forbidden non-unique)	7.7
1671 (15)	0.3 (2)[*]	(1st forbidden non-unique)	8.1
1787 (15)	0.5 (1)[*]	(1st forbidden unique)	9.0
1895 (15)	30 (6)[*†]	(1st forbidden non-unique)	6.35
1918 (15)	−	(1st forbidden non-unique)	−
2189 (15)	61 (6)[†]	(1st forbidden non-unique)	6.28
	Σ 100 (8)		

[*] Recommended absolute β^- emission probabilities derived from the relative gamma-ray emission probabilities, normalization factor of 0.238 (9), and theoretical internal conversion coefficients.
[†] Absolute emission probabilities calculated from fifth-power relationship of β^- end-point energies, with an arbitrary estimated uncertainty of 20 % assigned to the 1895-keV β^- emission probability.
[‡] Transition types within square brackets [] are not based on any spin-parity assignments – they have been assumed to be first forbidden non-unique as observed for the majority of the higher-energy β^- transitions.
[#] Log *ft* values calculated on the assumption of first forbidden non-unique transitions, apart from the 1787-keV beta emission (defined as most likely to be first forbidden unique).

The observed systematics of the two principle emissions in β^- decay for odd-even nuclides has been used in a quantitative manner to derive beta-particle emission probabilities in absolute terms. This approach is both approximate and of highly questionable merit – under these unsatisfactory circumstances, further experimental studies are required to determine direct β^- feeding to the ground state of daughter ^{215}Po with good accuracy.

Gamma rays

Energies

All gamma-ray transition energies were calculated from the structural details of the proposed decay scheme derived from 2001Br01 and 2003Ku26. The lower-energy nuclear level energies of 2001Br31 were adopted, along with higher-energy nuclear levels calculated from the gamma-ray studies of 2003Ku26. These data were subsequently used to re-determine the energies and associated uncertainties of the gamma-ray transitions between the various populated-depopulated levels.

Emission Probabilities

The only known experimental studies of relevance in defining the decay scheme of ^{215}Bi are the measurements by Ruchowska *et al.* (1990Ru02) in which the emission probabilities of seven gamma-ray transitions were quantified in terms of Pγ(293.56 keV) of 1000 (redefined as 100 %), and the more extensive studies of Kurpeta *et al.* (2003Ku26) in which the emission probabilities of 19 gamma-ray transitions were quantified.

Table 3 and Fig. 6 of 2003Ku26 contain highly questionable absolute β-particle and γ-ray emission probabilities. While the resulting γ-ray transition probabilities populating the ^{215}Po ground state directly sum to only 57.6 %, no direct β^- decay is advocated to achieve a correct summation of 100 %. Private communications between Kurpeta (Institute of Experimental Physics, Warsaw University) and Kondev (ANL), April 2011, have clarified the caption of Table 3: γ intensities listed in this table are relative and not absolute (defined erroneously as %

per decay). Therefore, these γ-ray emission probabilities have been re-defined as relative to Pγ(293.56 keV) of 100 %.

A number of unobserved low-intensity gamma rays have also been introduced by considering the equivalent gamma-ray studies of the α decay of ^{219}Rn – this process results in the introduction of the 130.58-, 224.04- and 405.43-keV gamma transitions, each with relative emission probabilities of less than 0.15 %.

Gamma-ray emission probabilities: as published, and relative to P_γ(293.56 keV) of 100 %.

E_γ (keV)	P_γ^{rel}			
	1990Ru02	2003Ku26† as published	adjusted	Recommended value*
130.58 (1)	–	–	–	0.039(4)‡
224.04 (7)	–	–	–	0.14 (2)‡
271.228 (10)	5.5 (5)	2.9 (1)	8.2 (3)	8.2 (3)
293.56 (4)	100 (7)	35.2 (11)	100 (3)	100 (3)
383.10 (8)	–	0.2 (1)	0.6 (3)	0.6 (3)
401.81 (1)	1.0 (4)	0.7 (1)	2.0 (3)	2.0 (3)
405.43 (7)	–	–	–	0.024 (4)‡
517.60 (6)	1.9 (3)	1.5 (1)	4.3 (3)	4.3 (3)
541.76 (22)	–	0.3 (1)	0.9 (3)	0.9 (3)
564.09 (22)	1.3 (3)	1.0 (1)	2.8 (3)	2.8 (3)
608.30 (7)	–	1.0 (1)	2.8 (3)	2.8 (3)
676.66 (7)	0.6 (2)	0.6 (1)	1.7 (3)	1.7 (3)
776.9 (1)	–	1.2 (2)	3.4 (6)	3.4 (6)
784 (2)	–	0.5 (1)	1.4 (3)	1.4 (3)
806.4 (20)	–	0.6 (1)	1.7 (3)	1.7 (3)
835.32 (22)	1.4 (3)	0.9 (1)	2.6 (3)	2.6 (3)
905 (2)	–	0.3 (1)	0.9 (3)	0.9 (3)
1023.3 (1)	–	0.9 (1)	2.6 (3)	2.6 (3)
1105.2 (4)	–	2.2 (1)	6.3 (3)	6.3 (3)
1127.6 (4)	–	0.7 (1)	2.0 (3)	2.0 (3)
1294.5 (1)	–	0.9 (1)	2.6 (3)	2.6 (3)
1398.8 (4)	–	1.2 (1)	3.4 (3)	3.4 (3)

† Published as absolute emission probabilities of doubtful overall pedigree (transition probabilities directly populating the ^{215}Po ground state only sum to 57.6 %, while direct β^- decay of zero is advocated); J. Kurpeta (Institute of Experimental Physics, Warsaw University), private communication to F.G. Kondev (ANL), 27 April 2011, concerning caption of Table 3 (2003Ku26): γ intensities are relative and not % per decay – therefore, emission probabilities have been adjusted to be relative to Pγ(293.56 keV) of 100 %.

* Recommended data biased completely towards the more extensive measurements of 2003Ku26.

‡ Derived from equivalent γ-ray measurements of ^{219}Rn α decay.

Major disagreements are observed between the emission probability measurements of 1990Ru02 and 2003Ku26 that negate the merit of any form of weighted-mean analysis. Under these circumstances, the more comprehensive data of 2003Ku26 have been adopted relative to Pγ(293.56 keV) of 100 %.

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

The decay scheme specified by 2001Br31 has been used to define the multipolarity of specific gamma transitions on the basis of the known spins and parities of the nuclear levels. Thus, the 224.04- and 401.81-keV gamma-ray emissions are adjudged to be E2 transitions. Multipolarity mixing ratios for the 130.58- and 271.228-keV gamma transitions of 0.60 (6) and 4.0 (4), respectively, were derived from the K/L and L sub-shell conversion-electron ratios determined by Davidson and Connor (1970Da09), while the 293.56- and 517.60-keV gamma-ray emissions were arbitrarily assigned mixing ratios of 1.0 (2) (i.e. 50 % M1 + 50 % E2). Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al*. (2008Ki07), based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45).

Gamma-ray emissions: multipolarities and theoretical internal conversion coefficients (frozen orbital approximation).

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	α_{total}
130.58 (1)	73.5%M1 + 26.5%E2 δ = 0.60(6)	3.19 (16)	0.94 (4)	0.31	4.44 (13)
224.04 (7)	(E2)	0.1296 (19)	0.1407 (20)	0.0487	0.319 (5)
271.228 (10)	6%M1 + 94%E2 δ = 4.0(4)	0.111 (6)	0.0668 (11)	0.0232	0.201 (7)
293.56 (4)	(50%M1 + 50%E2) δ = 1.0(2)	0.25 (4)	0.062 (4)	0.028	0.34 (5)
383.10 (8)	–	–	–	–	–
401.81 (1)	E2	0.0351 (5)	0.01528 (22)	0.00512	0.0555 (8)
405.43 (7)	–	–	–	–	–
517.60 (6)	50%M1 + 50%E2 δ = 1.0(2)	0.058 (9)	0.0115 (11)	0.0035	0.073 (10)
541.76 (22)	–	–	–	–	–
564.09 (22)	–	–	–	–	–
608.30 (7)	(M1 + E2)	–	–	–	–
676.66 (7)	–	–	–	–	–
776.9 (1)	–	–	–	–	–
784 (2)	–	–	–	–	–
806.4 (20)	–	–	–	–	–
835.32 (22)	–	–	–	–	–
905 (2)	–	–	–	–	–
1023.3 (1)	–	–	–	–	–
1105.2 (4)	–	–	–	–	–
1127.6 (4)	–	–	–	–	–
1294.5 (1)	–	–	–	–	–
1398.8 (4)	–	–	–	–	–

While a decay scheme has been formulated from the gamma-ray emission probability measurements of Kurpeta *et al.* (2003Ku26), further studies are required to determine the absolute and relative gamma-ray emission probabilities and also quantify any direct β^- feeding to the ground state of daughter ^{215}Po with much greater confidence. Such work would assist greatly to remove the severe doubts associated with the proposed decay scheme.

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 ^{215}Bi.

			Energy (keV)	Photons per 100 disint.
XL		(Po)	9.658 – 16.213	2.7 (3)
	XL_l	(Po)	9.658	0.065 (8)
	XL_α	(Po)	11.016 – 11.130	1.20 (13)
	XL_η	(Po)	12.085	0.022 (3)
	XL_β	(Po)	12.823 – 13.778	1.18 (11)
	XL_γ	(Po)	15.742 – 16.213	0.24 (2)
XK_α	$XK_{\alpha 2}$	(Po)	76.864 (4)	1.8 (3)
	$XK_{\alpha 1}$	(Po)	79.293 (5)	3.0 (5)
$XK'_{\beta 1}$	$XK_{\beta 3}$	(Po)	89.256	} 1.02 (16)
	$XK_{\beta 1}$	(Po)	89.807	
	$XK''_{\beta 5}$	(Po)	90.363	
$XK'_{\beta 2}$	$XK_{\beta 2}$	(Po)	92.263	} 0.32 (5)
	$XK_{\beta 4}$	(Po)	92.618	
	$XKO_{2,3}$	(Po)	92.983	

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_β-value of 2189 (15) keV has been adopted from the atomic mass evaluation of Audi *et al.* (2003Au03) while in the course of formulating the decay scheme of ^{215}Bi. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{215}Bi beta-decay process (i.e. β^-, conversion electrons, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 2190\ (170)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al.* is (0 ± 8) %, which supports the derivation of a highly consistent decay scheme with a large variant.

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$^{215}_{84}$Po $_{131}$

1 Decay Scheme

Po-215 decays 100 % by alpha transitions to Pb-211 and 2.3(2) $\times 10^{-4}$ by beta- emission to At215.
Le polonium 215 se désintègre par émissions alpha principalement vers le niveau fondamental du plomb 211. Il existe un faible branchement bêta moins vers l'astate 215.

2 Nuclear Data

$T_{1/2}$(^{215}Po)	:	1,781	(4)	10^{-3} s
$T_{1/2}$(^{215}At)	:	0,10	(2)	10^{-3} s
$T_{1/2}$(^{211}Pb)	:	36,1	(2)	min
Q^{α}(^{215}Po)	:	7526,3	(8)	keV
Q^{-}(^{215}Po)	:	715	(7)	keV

2.1 α Transitions

	Energy keV	Probability × 100	F
$\alpha_{0,7}$	6632 (3)	0,0003	365
$\alpha_{0,6}$	6711 (3)	0,0020 (6)	109
$\alpha_{0,5}$	6793 (3)	0,0008 (3)	550
$\alpha_{0,4}$	6883 (3)	0,0008 (3)	1170
$\alpha_{0,3}$	6928 (3)	0,0016 (5)	8500
$\alpha_{0,2}$	6942 (3)	0,0004 (2)	3800
$\alpha_{0,1}$	7087,4 (8)	0,06 (2)	82
$\alpha_{0,0}$	7526,3 (8)	99,934 (20)	1,34

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{7,2}$(Pb)	310 (4)						
$\gamma_{1,0}$(Pb)	438,9 (2)	0,06 (2)	E2	0,0275 (4)	0,00984 (14)	0,00247 (4)	0,0405 (6)
$\gamma_{2,0}$(Pb)	584 (3)						
$\gamma_{3,0}$(Pb)	598 (3)						
$\gamma_{4,0}$(Pb)	643 (3)		(M1+E2)	0,029 (17)	0,0054 (23)	0,0013 (6)	0,036 (20)
$\gamma_{5,0}$(Pb)	733 (3)						
$\gamma_{6,0}$(Pb)	815 (3)						
$\gamma_{7,0}$(Pb)	894 (3)						

3 Atomic Data

3.1 Pb

ω_K : 0,963 (4)
$\bar{\omega}_L$: 0,379 (15)
n_{KL} : 0,811 (5)

3.1.1 X Radiations

		Energy keV		Relative probability
X_K				
	$K\alpha_2$	72,8049		59,5
	$K\alpha_1$	74,97		100
	$K\beta_3$	84,451	}	
	$K\beta_1$	84,937	}	
	$K\beta_5''$	85,47	}	34,18
	$K\beta_2$	87,238	}	
	$K\beta_4$	87,58	}	10,32
	$KO_{2,3}$	87,911	}	
X_L				
	$L\ell$	9,186		
	$L\alpha$	10,4495 – 10,5512		
	$L\eta$	11,3495		
	$L\beta$	12,1443 – 13,3763		
	$L\gamma$	14,3078 – 15,2169		

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	56,028 – 61,669	100
KLX	68,181 – 74,969	55,8
KXY	80,3 – 88,0	7,78
Auger L	5,33 – 15,82	

4 α Emissions

	Energy keV	Probability × 100
$\alpha_{0,7}$	6509 (3)	0,0003
$\alpha_{0,6}$	6586 (3)	0,0020 (6)
$\alpha_{0,5}$	6667 (3)	0,0008 (3)
$\alpha_{0,4}$	6755 (3)	0,0008 (3)
$\alpha_{0,3}$	6799 (3)	0,0016 (5)
$\alpha_{0,2}$	6813 (3)	0,0004 (2)
$\alpha_{0,1}$	6955,4 (8)	0,06 (2)
$\alpha_{0,0}$	7386,1 (8)	99,934 (20)

5 Electron Emissions

		Energy keV		Electrons per 100 disint.
e_{AL}	(Pb)	5,33 - 15,82		0,00115 (14)
e_{AK}	(Pb)			0,000059 (21)
	KLL	56,028 - 61,669	}	
	KLX	68,181 - 74,969	}	
	KXY	80,3 - 88,0	}	
$ec_{1,0\ K}$	(Pb)	350,9 (2)		0,0016 (5)
$ec_{1,0\ L}$	(Pb)	423,0 - 425,9		0,00057 (19)
$ec_{1,0\ M}$	(Pb)	435,0 - 436,4		0,000143 (47)

6 Photon Emissions

6.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.	
XL	(Pb)	9,186 — 15,2169		0,00071 (12)	
$XK\alpha_2$	(Pb)	72,8049		0,00045 (15)	} $K\alpha$
$XK\alpha_1$	(Pb)	74,97		0,00075 (25)	}
$XK\beta_3$	(Pb)	84,451	}		
$XK\beta_1$	(Pb)	84,937	}	0,00026 (9)	$K'\beta_1$
$XK\beta_5''$	(Pb)	85,47	}		
$XK\beta_2$	(Pb)	87,238	}		
$XK\beta_4$	(Pb)	87,58	}	0,000078 (26)	$K'\beta_2$
$XKO_{2,3}$	(Pb)	87,911	}		

6.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}$(Pb)	438,9 (2)	0,058 (19)

7 Main Production Modes

U – 235 decay chain

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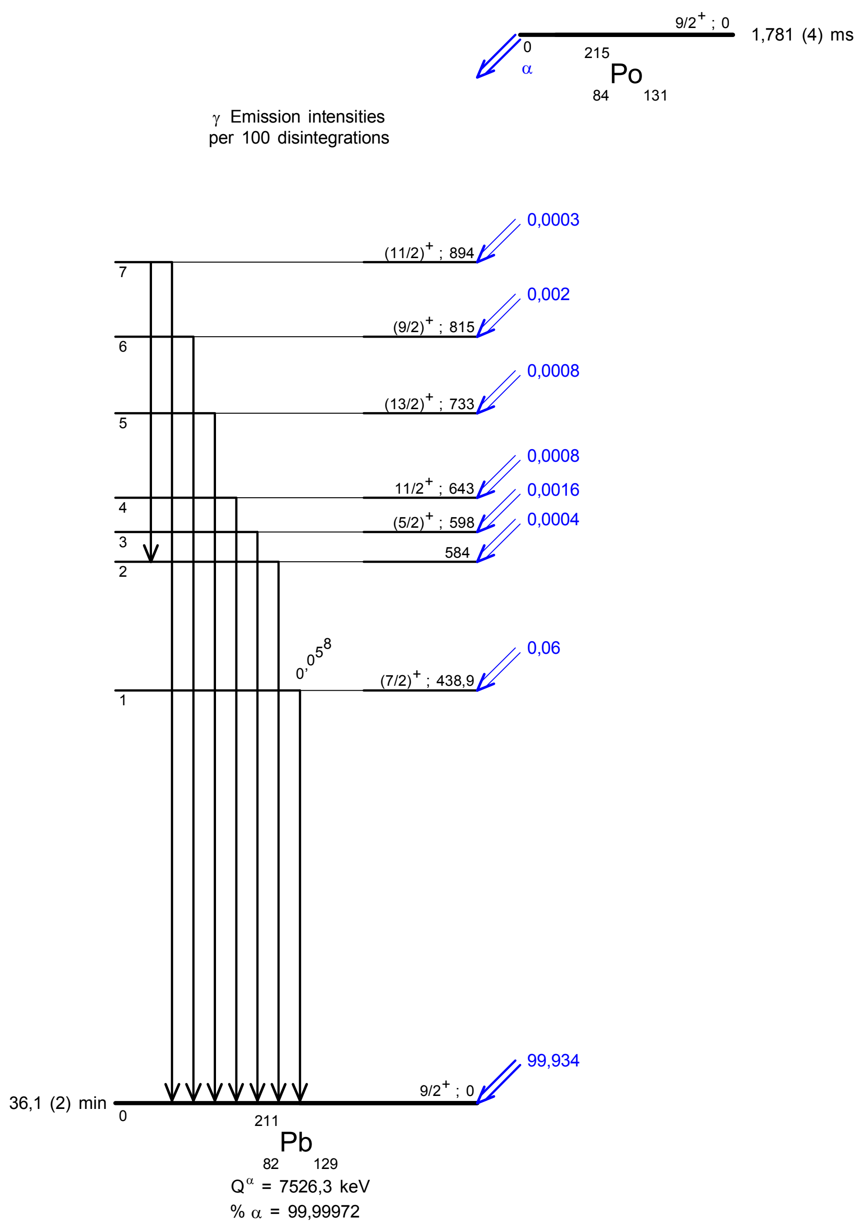
9/2+ ; 0
1,781 (4) ms
0
α
215
Po
84
131
γ Emission intensities
per 100 disintegrations
0,0003
(11/2)+ ; 894
0,002
(9/2)+ ; 815
0,0008
(13/2)+ ; 733
0,0008
11/2+ ; 643
0,0016
(5/2)+ ; 598
0,0004
584
7
6
5
4
3
2
1
0,058
0,06
(7/2)+ ; 438,9
99,934
9/2+ ; 0
36,1 (2) min
0
211
Pb
82
129
Qα = 7526,3 keV
% α = 99,99972

^{215}Po -Comments on evaluation of decay data by V.P. Chechev

This evaluation was done in November 2010 with a literature cut-off by the same date.

1. DECAY SCHEME

^{215}Po decays 100 % to levels of ^{211}Pb by emission of α particles and 2.3 (2) × 10^{-4} % to ^{215}At by emission of β^- particles. The structure of the adopted scheme of ^{215}Po decay is based on the experiment of 1998Li53 and the evaluation by E. Browne (2004Br45). The existence of the alpha-particle group with energy of 6950 keV, reported in 1962Wa18, 1971Gr17, was not confirmed in 1998Li53 and the relevant ^{211}Pb level of 447 keV was omitted in this evaluation. Similarly, the questionable ^{211}Pb level of 762 keV, determined by the alpha-particle group with energy of 6636 keV and intensity of ~ 3 × 10^{-4} %, has not been adopted.

The decay scheme of ^{215}Po is not completed as only approximate information is available for weak gamma transitions following α decay, their gamma-ray emission probabilities and multipolarities have not been determined, and, in fact, the ^{211}Pb levels were deduced only from measurements of alpha-particle groups. In respect of ^{215}Po β^- decay, the β^- - spectrum has not been measured and a fine structure of β^- decay is unknown.

The current evaluated data are supported by the agreement between Q(calculated) = 7526.2 (22) keV, deduced from the calculated average energies of all emissions, and Q(α) = 7526.3 (8) keV, adopted from 2003Au03. Percentage deviation of Q(calculated) from the Q(α) of Audi *et al*. (2003Au03) is (0.0 ± 0.3) %.

2. NUCLEAR DATA

Q(α) and Q(β^-) values are from Audi et al. (2003Au03).

The ^{215}Po half-life is based on the experimental results given in Table 1.

Table 1. Experimental values of ^{215}Po half-life

Reference	Author(s)	Half-life (ms)	Method
1942Wa04	Ward	1.83 (4)	Observations with a single Geiger counter
1961Vo06	Volkov et al.	1.778 (5)	Measurements with ionization alpha-spectrometer equipped by time analyzer
1971Er02	Erlik et al.	1.785 (10)	Time interval analyzer method
1971Er02	Erlik et al.	1.784 (8)	Multichannel delay coincidence method

The set of the four experimental values is consistent. The weighted average for this data set is 1.781 with the internal uncertainty of 0.0039 and an external uncertainty of 0.0033 ($\chi^2/\nu = 0.72$).

The recommended value of the ^{215}**Po half-life** is **1.781 (4) ms**.

β^- branching of 2.3 (2) × 10^{-4} % was adopted from the measurement of 1950Av61. With this value the α branching is obtained to be 99.999 77 (2) %.

2.1. Alpha Transitions

The alpha transition energies have been obtained from the Q(α) value and ^{211}Pb level energies given in Table 2 from 2004Br45. The uncertainties in the energies of levels 2 - 7 have been adopted ± 3 keV taking into account the average discrepancy of experimental and calculated alpha-particle energies (Table 3) and as provided by uncertainties of gamma ray energies from 1998Li53 ≥ 1.0 keV for all γ rays, except for γ438.9 keV.

Table 2. ^{211}Pb levels populated in ^{215}Po α-decay

Level	Energy (keV)	Spin and parity	Half-life	Probability of α- transition (%)
0	0.0	9/2+	36.1(4) min	99.934 (20)
1	438.9 (2)	(7/2)+		0.06 (2)
2	584 (3)			4 (2) × 10^{-4}
3	598 (3)	(5/2+)		1.6 (5) × 10^{-3}
4	643 (3)	11/2+		8 (3) × 10^{-4}
5	733 (3)	(13/2+)		8 (3) × 10^{-4}
6	815 (3)	(9/2+)		2.0 (6) × 10^{-3}
7	894 (3)	(11/2+)		3 × 10^{-4}

The alpha transitions in ^{215}Po decay were observed in a number of works by study of an ^{223}Ra alpha emitting source (1962Wa18, 1965Va10, 1970Da09, 1998Li53). In 1962Wa18 the ^{215}Po alpha spectrum was measured with magnetic spectrometer. In 1965Va10 the coincidence of $\gamma_{1,0}$ (438.9 keV)-gamma ray with $\alpha_{0,1}$ (6.95 MeV) was observed. In 1970Da09 the alpha transition probability (P(α)) was measured for $\alpha_{0,1}$ (6.95 MeV)-transition. Most accurate and detailed data were obtained by 1998Li53 with use of α–γ coincidences. These measurement results have been adopted for the recommended P(α) and compared in Table 3 with other available poor experimental data.

Table 3. Experimental ^{215}Po alpha transition probability values (P(α))

α-particle energy (keV)	1962Wa18	1970Da09	1998Li53
7386	100		99.93
6955	≈ 0.056	≈ 0.1	0.06 (2)
6813			4 (2) × 10^{-4}
6799			1.6 (5) × 10^{-3}
6755			8 (3) × 10^{-4}
6667			8 (3) × 10^{-4}
6586			2.0 (6) × 10^{-3}
6509			~ 3 × 10^{-4}

The accurate $P(\alpha_{0,0})$ value has been deduced from $\Sigma P(\alpha_{0,i})$ = 99.999 77 (2) %, (i = 0, 1,...7) and, the individual adopted $P(\alpha_{0,i})$, (i = 1 – 7).

The α decay hindrance factors were calculated using the ALPHAD computer program from the ENSDF evaluation package with r_0 (^{211}Pb) = 1.5393 fm (2004Br45).

2.2. Gamma Transitions and Internal Conversion Coefficients

Information on the gamma-ray transition probabilities and the gamma-ray multipolarities is not available, except for γ438.9 keV (1968Br17, 1970Da09, 1998Li53, see §6.2.2). The gamma-ray transition probability $P_{\gamma+ce}$ ($\gamma_{1,0}$ - 438.9 keV) was then deduced from the probability balance: $P(\alpha_{0,1}) = P_{\gamma+ce}$ ($\gamma_{1,0}$ - 438.9 keV). The multipolarity of this gamma-ray transition has been adopted as being E2. In 1998Li53 a multipolarity higher than a pure E2 was reported from the relative intensity P(KX) / P_γ (438.9 keV) = 0.034 (10), then it was noted that a small amount of M1 cannot be ruled out.

ICCs have been interpolated using the BrIcc computer program, version v2.2a, data set BriccFO (2008Ki07).

3. ATOMIC DATA

The fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities are from the SAISINUC software.

4. ALPHA EMISSIONS

The energy of the alpha-particle group $\alpha_{0,0}$ that populates the ^{211}Pb ground state is the absolute measurement result from 1971Gr17 adjusted in 1991Ry01 for change in calibration standards: $E(\alpha_{0,0})$ = 7386.1 (8) keV. Latter coincides with the value deduced by the evaluator from the adopted Q(α) taking into account the recoil energy for ^{211}Pb.

The energy of alpha-particle group $\alpha_{0,1}$ of 6955.4 (8) keV has been deduced from the Q(α) value taking into account the level energy of 439.8 (2) keV and the recoil energy for ^{211}Pb. The above value of $E(\alpha_{0,1})$ can be compared to the measured $E(\alpha_{0,1})$ of 6956.7 keV (without uncertainty) by 1962Wa18, 1971Gr17 and of 6954 (3) keV by 1998Li53 with adjustement adopted in 2004Br45.

The energies of remaining alpha-particle groups have been deduced from Q(α) and the relevant ^{211}Pb level energies. In Table 4 the deduced (recommended) E(α) are compared with the experimental values from the measurements of 1998Li53 adjusted in 2004Br45 to the adopted $E(\alpha_{0,0})$= 7386.1 (8) keV.

Table 4. Experimental and deduced (recommended) ^{215}Po alpha-particle energies (E(α))

Level	Level energy (keV)	α-transition energy	Experimental E(α) (1998Li53) [a]	Deduced E(α) (recommended)
0	0.0	7526.3 (8)	7386.1 (8)	7386.1 (8)
1	438.9 (2)	7087.4 (10)	6954 (3)	6955.4 (8)
2	584 (3)	6942 (3)	6819 (15)	6813 (3)
3	598 (3)	6928 (3)	6803 (8)	6799 (3)
4	643 (3)	6883 (3)	6754 (10)	6755 (3)

Level	Level energy (keV)	α-transition energy	Experimental E(α) (1998Li53) [a]	Deduced E(α) (recommended)
5	733 (3)	6793 (3)	6671 (10)	6667 (3)
6	815 (3)	6711 (3)	6589 (8)	6586 (3)
7	894 (3)	6632 (3)	6519 (20)	6509 (3)

[a] E(α) have been adjusted to the adopted E($\alpha_{0,0}$) = 7386.1 (8) keV.

5. ELECTRON EMISSIONS

The energies of the conversion electrons for the γ438.9 keV transition have been obtained from the gamma-ray transition energy and the atomic electron binding energies.

The emission probabilities of the conversion electrons have been deduced using the P_γ and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

6. PHOTON EMISSIONS

6.1 X - Ray emissions

The absolute emission probabilities of Pb KX- and LX-rays were calculated using the EMISSION computer program. The total emission probability of Pb KX-rays in decay of ^{215}Po was determined relatively to $P_\gamma(\gamma_{1,0}$ - 438.9 keV) (1998Li53). The experimental P(KX)/$P_\gamma(\gamma_{1,0}$ - 438.9 keV) = 0.034 (10) agrees with the value of 0.029 (14) calculated with the EMISSION code.

The agreement between measured and calculated KX-ray emission probabilities supports the recommended γ-ray emission probability and assigned multipolarity for $\gamma_{1,0}$ - 438.9 keV.

6.2. Gamma emissions

6.2.1. Gamma ray energies

The gamma-ray energies (E_γ) have been taken from the measurements of 1998Li53. The uncertainties on the gamma-ray energies higher than 500 keV have been assumed being ± 3 keV (see section **2.1**). Other measurements of E ($\gamma_{1,0}$ - 438.9 keV) are reported in 1968Br17 (438.7 (3) keV) and in 1970Da09 (438.9 keV – without uncertainty).

6.2.2. Gamma ray emission probabilities

There is no available information on the gamma-ray emission probabilities, except for P(γ438.9 keV): 0.048 (5) % (1968Br17) and 0.064 (2) % (1970Da09). These discrepant values do not conflict with the recommended value of P(γ438.9 keV) = 0.058 (19) % deduced by the evaluator from the alpha transition probability P($\alpha_{0,1}$) = 0.06 (2) % and total internal conversion coefficient α_T = 0.0405 (6) under the assumption of E2 multipolarity.

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$^{215}_{85}\mathrm{At}_{130}$

1 Decay Scheme

At-215 decays 100% to levels of Bi-211 by emission of alpha-particles.
L'astate 215 se désintègre par émissions alpha essentiellement vers le niveau fondamental du bismuth 211.

2 Nuclear Data

$T_{1/2}(^{215}\mathrm{At})$	:	0,10	(2)	10^{-3} s
$T_{1/2}(^{211}\mathrm{Bi})$	:	2,15	(2)	min
$Q^{\alpha}(^{215}\mathrm{At})$	:	8178	(4)	keV

2.1 α Transitions

	Energy keV	Probability × 100	F
$\alpha_{0,1}$	7773 (4)	0,05 (2)	390
$\alpha_{0,0}$	8178 (4)	99,95 (2)	2,8

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{1,0}$(Bi)	404,854 (9)	0,05 (2)	M1+E2	0,095 (7)	0,0206 (8)	0,00498 (17)	0,122 (8)

3 Atomic Data

3.1 Bi

ω_K	:	0,964	(4)
$\bar{\omega}_L$	:	0,391	(16)
n_{KL}	:	0,809	(5)

3.1.1 X Radiations

		Energy keV		Relative probability
X_K				
	$K\alpha_2$	74,8157		59,77
	$K\alpha_1$	77,1088		100
	$K\beta_3$	86,835	}	
	$K\beta_1$	87,344	}	
	$K\beta_5''$	87,862	}	34,25
	$K\beta_2$	89,732	}	
	$K\beta_4$	90,074	}	10,49
	$KO_{2,3}$	90,421	}	
X_L				
	$L\ell$	9,4207		
	$L\alpha$	10,7308 – 10,8387		
	$L\eta$	11,7127		
	$L\beta$	12,4814 – 13,8066		
	$L\gamma$	14,7735 – 15,7084		

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	57,491 – 63,419	100
KLX	70,025 – 77,105	56
KXY	82,53 – 90,52	7,84
Auger L	5,42 – 16,34	

4 α Emissions

	Energy keV	alpha per 100 disint.
$\alpha_{0,1}$	7628 (4)	0,05 (2)
$\alpha_{0,0}$	8026 (4)	99,95 (2)

5 Electron Emissions

		Energy keV		Electrons per 100 disint.
e_{AL}	(Bi)	5,42 - 16,34		0,0027 (5)
e_{AK}	(Bi)			0,00015 (7)
	KLL	57,491 - 63,419	}	
	KLX	70,025 - 77,105	}	
	KXY	82,53 - 90,52	}	
$ec_{1,0\ T}$	(Bi)	314,328 - 404,830		0,0055 (22)
$ec_{1,0\ K}$	(Bi)	314,328 (9)		0,0043 (17)
$ec_{1,0\ L}$	(Bi)	388,466 - 391,435		0,00093 (37)
$ec_{1,0\ M}$	(Bi)	400,855 - 402,274		0,00022 (9)
$ec_{1,0\ N}$	(Bi)	403,916 - 404,697		0,000057 (23)

6 Photon Emissions

6.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.	
XL	(Bi)	9,4207 — 15,7084		0,0017 (4)	
$XK\alpha_2$	(Bi)	74,8157		0,0012 (5)	} $K\alpha$
$XK\alpha_1$	(Bi)	77,1088		0,0020 (9)	}
$XK\beta_3$	(Bi)	86,835	}		
$XK\beta_1$	(Bi)	87,344	}	0,00069 (28)	$K'\beta_1$
$XK\beta_5''$	(Bi)	87,862	}		

		Energy keV		Photons per 100 disint.	
XKβ_2	(Bi)	89,732	}		
XKβ_4	(Bi)	90,074	}	0,00021 (9)	K$'\beta_2$
XKO$_{2,3}$	(Bi)	90,421	}		

6.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}$(Bi)	404,853 (9)	0,045 (18)

7 Main Production Modes

U – 235 decay chain

$$\begin{cases} \text{Th} - 232(\text{p, 6n})\text{Pa} - 227 \\ \text{Pa} - 227(\alpha) -> \text{Ac} - 223(\alpha) -> \text{Fr} - 219(\alpha) -> \text{At} - 215 \end{cases}$$

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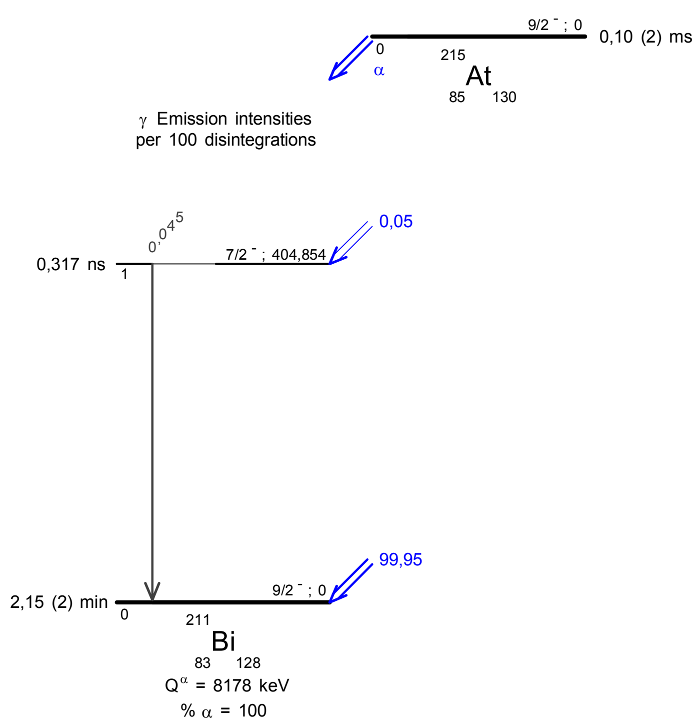
9/2 - ; 0
0,10 (2) ms
0
α
215
At
85 130
γ Emission intensities
per 100 disintegrations
0,045
0,05
0,317 ns
1
7/2 - ; 404,854
99,95
2,15 (2) min
9/2 - ; 0
0
211
Bi
83 128
Qα = 8178 keV
% α = 100

^{215}At -Comments on evaluation of decay data
by V.P. Chechev

This evaluation was done in December 2010 with a literature cut-off by the same date.

1. DECAY SCHEME

^{215}At decays 100 % to levels of ^{211}Bi by emission of α particles. The adopted ^{211}Bi levels populated in the ^{215}At decay are based on the experiment of 1966Gr07 and the evaluation by Browne (2004Br45).

The decay scheme of ^{215}At seems to be incomplete as the alpha decays to higher levels in daughter ^{211}Bi, which are known from the β^- decay of ^{211}Pb (see ^{211}Bi Adopted Levels, Gammas of 2004Br45), are not observed yet.

The current evaluated data are supported by the agreement between Q(calculated) = 8178 (5) keV, deduced from the calculated average energies of all emissions, and Q(α) = 8178 (4) keV, adopted from 2003Au03.

2. NUCLEAR DATA

Q(α) is from 2003Au03 where this value has been deduced from the measurement of α-particle energy E($\alpha_{0,0}$) = 8026 (4) keV by 1982Bo04 recommended in 1991Ry01.

The ^{215}At half-life of 0.10 (2) ms is from the single measurement of 1951Me10.

2.1. Alpha Transitions

The alpha transition energies have been obtained from the Q(α) value and ^{211}Bi level energies given in Table 1 from ^{211}Bi Adopted Levels, Gammas of 2004Br45.

Table 1. ^{211}Bi levels populated in ^{215}At α-decay

Level	Energy (keV)	Spin and parity	Half-life	Probability of α-transition (%)
0	0.0	9/2–	2.14 (2) min	99.95 (2)
1	404.854 (9)	7/2–	0.317 (11) ns	0.05 (2)

The alpha transition probability P ($\alpha_{0,1}$) is from the measurement of 1966Gr07 by means of α–γ coincidence technique with surface-barrier semi-conductor and NaI(Tl) detectors. The accurate P($\alpha_{0,0}$) value has been deduced from the expression of P($\alpha_{0,0}$) + P($\alpha_{0,1}$) = 100 %.

The α decay hindrance factors have been calculated using the ALPHAD computer program from the ENSDF evaluation package with r_0 (^{211}Pb) = 1.5443 fm (2004Br45).

2.2. Gamma Transitions and Internal Conversion Coefficients

The 405-keV gamma-ray transition probability has been deduced from the intensity balance at the 405-keV level using the adopted alpha transition probability P($\alpha_{0,1}$) and total internal conversion coefficient (ICC) α_T for $\gamma_{1,0}$ (405 keV). The multipolarity (M1+E2) and E2/M1 mixing ratio (δ) of -1.1 (1) have been taken from 2004Br45. These are based on the measurements of conversion electrons in ^{211}Pb β^- decay and $\gamma(\theta)$ measurements with polarized ^{211}Bi nuclei. ICCs α_T, α_K, α_L, α_M have been interpolated using the BrIcc computer program, version v2.2a, data set BrIccFO (2008Ki07).

3. ATOMIC DATA

The fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities are from the SAISINUC software.

4. ALPHA EMISSIONS

The energy of alpha-particle group $\alpha_{0,0}$ that populates the ^{211}Bi ground state is the measured value from 1982Bo04 recommended in 1991Ry01. In 1966Gr07 the measured value of 8.00 (1) MeV was reported.

The energy of alpha-particle group $\alpha_{0,1}$ of 7628 (4) keV has been deduced from the Q(α) value taking into account the level energy of 404.854 (9) keV and the recoil energy for ^{211}Bi. The above value of E($\alpha_{0,1}$) can be compared to the value of 7626 (15) keV as measured by 1966Gr07 and adjusted by the evaluator to the adopted E($\alpha_{0,0}$) = 8026 (4) keV (the original value of 1966Gr07 is 7.60 (1) MeV).

The earlier measured energy of α–emission in the decay of ^{215}At is 8.00 (2) MeV (1951Me10).

5. ELECTRON EMISSIONS

The energies of the conversion electrons for $\gamma_{1,0}$ (405 keV) have been obtained from the gamma-ray transition energy and the atomic electron binding energies.

The emission probabilities of the conversion electrons have been deduced using the P_γ and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

6. PHOTON EMISSIONS

6.1 X - Ray emissions

The absolute emission probabilities of Pb KX- and LX-rays were calculated using the EMISSION computer program.

6.2. Gamma emissions

6.2.1. Gamma ray energies

The 405-keV gamma-ray energy has been adopted from the 405-keV level energy. In 1966Gr07 this energy was obtained from the ^{215}At α decay as ≈ 404 keV.

6.2.2. Gamma ray emission probabilities

The 405-keV gamma-ray emission probability has been deduced from the alpha transition probability P($\alpha_{0,1}$) = 0.05 (2) % and total internal conversion coefficient α_T = 0.122 (8).

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