^{213}Bi - Comments on evaluation of the decay data

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This evaluation was completed in 2006. Literature available by January 2006 was included.

1. Decay Scheme

^{213}Bi disintegrates 97.91 (3) % by β^- emission to levels in ^{213}Po and 2.09 (3) % through α decay to ^{209}Tl. ^{213}Bi ground state has $J^\pi = 9/2^-$ (1992Ak01).

The ^{213}Bi β^- decay scheme was built from the γ-γ coincidence measurements of 1998Ar03 and 2000Gr35. The ^{213}Bi α decay scheme was built from the α–γ coincidence measurements of 1964Gr11, the singles α- particle measurements of 1997Ch53 and γ-γ coincidence measurements of 1998Ar03.

The decay branching ratios have been deduced by the evaluator using the absolute photon intensity (96.58 (10), 1991Ma16) adopted for the 465 keV γ-ray from ^{209}Tl β^- decay and measured absolute intensity (2.022 (26), 1986He06) of the same γ-ray following the ^{213}Bi α decay. Our recommended α decay branching ratio is I_α = 2.09 (3) %, thus I_{β^-} = 97.91 (3) %.

The three values of the ^{213}Bi α decay branching ratio found in the literature are presented in Table 1. The corresponding β^- branching ratios are: I_{β^-} = 97.84 (11) %, (deduced by 1964Gr11); I_{β^-} = 97.91 (3) %, (deduced from the measurements of 1986He06); I_{β^-} = 97.80 (3) %, measured in equilibrium with ^{213}Po by 1997Ch53.

Table 1: Measured and recommended branching ratio for ^{213}Bi α decay.

I_α (%)	References	Comments
2.16 (11)	1964Gr11	Deduced from measured I_α
2.09 (3)	1986He06	Deduced from the P_γ(465 keV) from ^{209}Tl following ^{213}Bi α decay and measured value by 1986He06
2.20 (3)	1997Ch53	Measured in equilibrium with ^{213}Po
2.15 (4)		LWM
2.09 (3)		Recommended

The recommended Q(α) value of 5983 (6) keV and Q(β^-) values of 1423 (5) keV in Audi(2003Au03) agrees with the Q(α) value of 5979 (2) keV and Q(β^-) values of 1422 (6) keV, calculated by the evaluator (using program RADLST) from average radiation energies. This agreement supports the completeness and correctness of the decay scheme.

2. Nuclear Data

The Q values are from the 2003Au03 evaluation.
Level energies have been obtained from a least-squares fit to γ-ray energies (GTOL computer code). Spin and parities are from 1992Ak01, 1998Ar03 and 2000Gr35.
The measured and recommended ^{213}Bi half-life values are listed in Table 2.

Table 2: Measured half-life values of ^{213}Bi and recommended value

$T_{1/2}$ (min)	References	Measurement method
46	1947En03	
47 (1)	1950Ha52	Alpha pulse analyzer, 9 $T_{1/2}$
46 (1)	1964Gr11	
45.59 (6)	1973Po16	ZnS(Ag), weighted average of 2 sources, 8 $T_{1/2}$
46.2 (4)		Unweighted mean (except 1947En03)
45.60 (6)		LWM (except 1947En03), χ^2 = 1.07
45.59 (6)	Recommended value	From 1973Po16

The half-life weighted average has been calculated by LWM program. The recommended value is taken from the measurement of 1973Po16.

2.1 β⁻ transitions

The maximum energies of the β⁻ transitions in the decay of ^{213}Bi have been deduced from the Q value (2003Au03) and the level energies.

The adopted β⁻ transition probabilities and the associated uncertainties were deduced from the γ-ray transition probability balance at each level of the decay scheme. Measured and adopted β⁻ transition probabilities are given in table 3.

Table 3: Measured and adopted probabilities (%) of β⁻ transitions

Level energy (keV)	1955Ma61	1968Va17	**Adopted value**
0		65 (3)	**66.2 (4)**
292.8			**0.21 (9)**
440.4	32	35 (3)	**30.8 (4)**
600.8			**0.002 5 (19)**
868			**0.012 9 (6)**
1003.6			**0.064 8 (23)**
1045.6			**0.020 (4)**
1100.2			**0.595 (17)**
1119.4			**0.060 8 (20)**
1328.2			**0.0014 (2)**

The values of *lg ft* and average β⁻ energies have been calculated with the program LOGFT.

2.2 γ-ray Transitions

The γ-ray transition probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients.

Multipolarities and mixing ratios of γ-ray transitions are from 2000Gr35, 1977Vy02 and 1969DzZZ.

The internal conversion coefficients (ICC) and their associated uncertainties for γ-ray transitions have been obtained using the BrIcc computer program, which uses the "Frozen Orbital" approximation (2002Ba85). Experimental and theoretical conversion coefficients are compared in Table 4.

Table 4: Comparison of the calculated and measured conversion coefficients

E_γ (keV)	Multipolarity	Mixing ratio	α(theory)	α(exp.) 2000Gr35
147.7	E2		α_T = 1.453, α_K = 0.31, α_L = 0.85	α_K = 0.33 (14)
292.8	M1+E2	1.2 (+11 -8)	α_T = 0.3, α_K = 0.22, α_L = 0.06	α_K = 0.20 (5)
323.7	E2+M1	1.26 (16)	α_T = 0.178, α_K = 0.134, α_L = 0.03	α_K = 0.131 (15)
440.44	M1		α_T = 0.179, α_K = 0.146	α_K = 0.13 (2)

2.3 α Transitions

1997Ch53 measured the upper limit for intensity of the E_α(868 keV level) = 5018 keV, and the value is < 10^{-4}. But this measurement did not support the assumption that the 868 keV level is excited in ^{209}TI by the ^{213}Bi α decay. Thus the 868 keV level is not considered here.

Measured energies of alpha particles are listed in table 5. The measured values are in good agreement with the calculated results from Q_α(2003Au03) and the level energies. Our recommended values are from 1964Gr11.

Table 5: Measured and recommended values of α-particle energies (in keV) from ^{213}Bi α decay

1947En02	1964Gr11	1967Dz02	Deduced	Recommended
	5549 (10)		5553 (6)	5549 (10)
5860 (30)	5869 (10)	5870 (6)	5871 (6)	5869 (10)

Experimental and recommended α-particle relative intensities to 100 % α decay are listed in Table 6. Our recommended α-particle relative intensities are deduced from the calculated results of the γ transition probability balance. These calculated results are in good agreement with the measured relative intensities of 1964Gr11 and 1997Ch53.

Table 6: Experimental, recommended α-particle relative intensities to 100 % α decay

E_α(keV)	I_α(%)		
	1964Gr11	1997Ch53	Recommended
5549 (10)	7.4 (14)	6.8 (1)	8.9 (2)
5869 (10)	92.6 (14)	93.2 (14)	91.1 (14)

The recommended α-particle emission intensities are the relative intensities values recommended in table 6 multiplied by 0.0209 (3).

3. Atomic data

Atomic fluorescence yields (ω_K,ϖ_L, ϖ_M, η_{KL} and η_{LM}) are from Schönfeld (1996Sc06).

The X-ray and Auger electron emission intensities have been deduced from γ-ray and conversion electron data by using the computer code RADLST. Measured and calculated X-ray emission intensities are compared in Table 7.

Table 7: Comparison of the calculated and measured X-ray emission intensities

	1972Dz14	Adopted (deduced)
$K_{\alpha1}$	1.6 (2)	1.6 (3)
$K_{\alpha2}$	0.93 (12)	0.99 (15)

The deduced KX-ray emission intensities agree with the measured value of 1972Dz14, thus confirming the completeness of the decay scheme.

4. Electron Emissions.

The conversion electron emission probabilities have been deduced from γ-ray transition data.

5. Photon Emissions

5.1 γ-ray energy values

The measurements of the γ- ray energy value of ^{213}Bi are listed in Table 8 associated with their LWM average value. The recommended values are taken from the LWM of the measurements of 1977Vy02, 1981Di14, 1989Ko26, 1998Ar03 and 2000Gr35, or from 1998Ar03 in the case of only one energy measurement (402.8 keV, 884.6 keV, 886.66 keV, 897.0 keV and 1328.2 keV).

Table 8: Measured and recommended values of γ-ray energy (in keV) for ^{213}Bi

1977Vy02	**1981Di14**	**1989Ko26**	**1998Ar03**	**2000Gr35**	**Recommended**
		147.63 (8)	147.66 (5)	147.7 (1)	147.70 (4)
292.86 (10)	292.85 (2)	292.80 (1)	292.76 (5)	292.81 (1)	292.80 (1)
323.81 (5)	323.7 (2)	323.71 (3)	323.69 (5)	323.80 (4)	323.70 (2)
			402.8 (3)		402.8 (3)
440.42 (2)	440.4 (2)	440.46 (1)	440.43 (5)	440.44 (1)	440.44 (1)
			574.8 (3)	575.2 (5)	574.9 (3)
			600.7 (3)	601.0 (2)	600.9 (2)
			604.9 (3)	604.94 (21)	604.93 (17)
			646.03 (9)	646.0 (1)	646.0 (1)
659.81 (10)	659.7 (2)	659.8 (1)	659.77 (5)	659.74 (2)	659.75 (2)
		710.8 (1)	710.81 (21)	710.82 (3)	710.82 (3)
807.36 (4)	807.3 (2)	807.36 (1)	807.38 (5)	807.37 (1)	807.37 (1)
		826.8 (2)	826.47 (6)	826.59 (5)	826.55 (4)

1977Vy02	1981Di14	1989Ko26	1998Ar03	2000Gr35	Recommended
		868.0 (2)	867.98 (3)	867.93 (3)	867.96 (2)
			880.2 (3)	880.91 (1)	880.91 (1)
			884.6 (3)		884.6 (3)
			886.66 (14)		886.66 (14)
			897.0 (3)		897.0 (3)
		1003.57 (3)	1003.55 (5)	1003.59 (3)	1003.58 (2)
			1045.70 (9)	1045.10 (40)	1045.67 (8)
1100.14 (6)	1100.1 (2)	1100.16 (2)	1100.12 (5)	1100.18 (2)	1100.16 (1)
1119.60 (14)		1119.4 (1)	1119.29 (5)	1119.50 (4)	1119.42 (8)
			1328.2 (3)		1328.2 (3)

5.2 Relative values of the γ-ray intensities

The measurements of the relative γ-ray intensities of ^{213}Bi α decay and β^- decay are listed in table 9 and table 10, respectively.

For α decay, the recommended values are taken from the LWM average of the measurements of 1989Ko26, 1998Ar03 and 2000Gr35. For β^- decay, the recommended values are taken from the LWM average of the measurements of 1986He06, 1989Ko26, 1998Ar03 and 2000Gr35 (according to the availability of the reported data).

Table 9: Measured and recommended relative γ-ray intensities for ^{213}Bi α decay
(the intensity of the 440.44 keV γ-ray is considered 100)

E_γ (keV)	I_γ						
	1969ArZV	1977Vy02	1981Di14	1989Ko26	1998Ar03	2000Gr35	Recommended
323.70(2)	0.67 (10)	1.12 (8)	0.660 (15)	0.619 (37)	0.567 (46)	0.618 (32)	0.607 (2)

Table 10: Measured and recommended relative γ-ray intensities for ^{213}Bi γ- decay

E (keV)	I γ							
	1969ArZV	1977Vy02	1981Di14	1986He06	1989Ko26	1998Ar03	2000Gr35	Recommended
147.70 (4)					0.0429 (43)	0.0567 (46)	0.087 (32)	0.049 (3)
292.80 (1)	1.81 (14)	2.65 (38)	1.555 (87)	1.644 (27)	1.571 (63)	1.594 (88)	1.58 (4)	1.613 (20)
402.8 (3)						0.00038 (12)		0.00038 (12)
440.44 (1)	100	100	100	100	100	100	100	100
574.9 (3)						0.00241 (65)	0.0099 (39)	0.0026 (6)
600.9 (2)						0.00268 (84)	0.0165 (32)	0.010 (7)
604.93 (17)						0.00192 (69)	0.0091 (24)	0.0055 (17)
646.0 (1)[×]						0.00885 (84)	0.0095 (39)	0.0089 (8)
659.75 (2)	0.19 (10)	0.53 (5)	0.185 (6)		0.1476 (89)	0.1383 (77)	0.173 (12)	0.165 (20)
710.82 (3)					0.0429 (43)	0.0391 (42)	0.0469 (39)	0.043 (2)
807.37 (1)	1.14 (14)	1.59 (5)	1.152 (26)	1.119 (46)	1.048 (42)	0.923 (57)	1.114 (71)	1.10 (5)
826.55 (4)					0.0271 (16)	0.0218 (19)	0.0303 (51)	0.0249 (14)
867.96 (2)					0.0476 (29)	0.0425 (42)	0.0484 (43)	0.0467 (21)
880.91 (1)[×]						0.0111 (38)	0.0165 (16)	0.015 (2)
884.6 (3)[×]						0.00111 (38)		0.0011 (4)
886.66 (14)						0.00391 (73)		0.0039 (7)
897.0 (3)[×]						0.00119 (35)		0.0012 (4)
1003.58 (2)					0.205 (12)	0.192 (19)	0.209 (12)	0.205 (8)
1045.67 (8)						0.069 (12)	0.134 (75)	0.071 (12)
1100.16 (1)	1.05 (14)	1.71 (8)	1.000 (24)		1.095 (44)	0.992 (61)	0.988 (67)	1.016 (19)
1119.42 (8)		0.214 (25)			0.238 (14)	0.192 (12)	0.201 (12)	0.208 (7)
1328.2 (3)						0.0015 (5)		0.0015 (5)

[×]: not placed in level scheme.

5.3 Absolute values of the γ-ray emission probabilities

There is only one measurement of the absolute γ-ray emission probability of the 440.44 keV from ^{213}Bi β^- decay which was measured in equilibrium with ^{229}Th by 1986He06 in 1986. This measurement can be adopted as the normalization factor N, that is, N = 0.261 (3).

The evaluated absolute γ-ray emission probabilities are the relative values evaluated in table 9 and table 10 multiplied by 0.261 (3).

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