^{140}Ba - Comments on evaluation of decay data
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The first DDEP evaluation of ^{140}Ba decay data was done by R. Helmer in 2003 (2004BeZQ). The current evaluation has been completed in March 2015 with a literature cut-off by the same date. The main changes compared to the DDEP initial evaluation are due to new publications: 2014Un01 (half-life), 2012Wa38 (Q-value), 2008Ki07 (theoretical internal conversion coefficients).

1. DECAY SCHEME

The structure of the adopted decay scheme of ^{140}Ba is based on the ENSDF evaluation by N. Nica (2007Ni07). ^{140}Ba disintegrates by β^- emission via ^{140}La excited levels. The level scheme is incomplete. There are 34 reported levels in ^{140}La below the β^- decay energy, so some levels in addition to the six reported here may be weakly populated in this decay.

2. NUCLEAR DATA

Q^- value is from 2012 mass evaluation by Wang *et al.* (2012Wa38).

The recommended half-life of ^{140}Ba is based on the experimental results given in Table 1.

Table 1. Experimental values of the ^{140}Ba half-life (in days)

N	Author(s) and year	Reference	$T_{1/2}$ (d)	Method and comments
1	Simonet *et al.* (1965)	1965Si17	12.80 (5)	NaI detector
2	Baba *et al.* (1971)	1971Ba28	12.789 (20)	β counting, proportional counter; original uncertainty is 0.006
3	Debertin *et al.* (1982)	1982DeYX	12.746 (10)	4πγ ionization chamber; *omitted* as superseded by 5
4	Hoppes *et al.* (1982)	1982HoZJ	12.753 (2)	4πγ ionization chamber; *omitted* as superseded by 7
5	Walz *et al*. (1983)	1983Wa26	12.739 (22)	Ge(Li) spectrometer
6	Walz *et al*. (1983)	1983Wa26	12.751 (5)	4πγ ionization chamber
7	Unterweger *et al.*	1992Un01, 2002Un02	12.7527 (23)	4πγ ionization chamber; *omitted* as superseded by 8
8	Fitzgerald (2012)	2012Fi12	12.7525 (23)	4πγ ionization chamber; *omitted* as superseded by 9
9	Unterweger and Fitzgerald (2014)	2014Un01	12.753 (12)	4πγ ionization chamber
	Recommended value		**12.753 (5)**	LWM

The value of 1971Ba28 disagrees with all of the later values, so the evaluators increased its uncertainty from 0.006 to 0.020 (see, also 2004BeZR). The values from 1982DeYX, 1982HoZJ, 1992Un01 and 2002Un02, and 2012Fi12 were not used because they were replaced ultimately by later results of the same laboratory.

The unweighted average of the remained five values is 12.766 (12) d. The weighted average is 12.753 d. The LWEIGHT computer program has chosen the weighted average with the internal uncertainty of 0.0044 d. The external uncertainty is 0.0048 d. The ratio of the reduced χ^2 / $(\chi^2)_{crit}$ is 1.17/3.30. The smallest experimental uncertainty is 0.005 d.

The recommended value of ^{140}Ba half-life is **12.753 (5) days**. It can be compared with earlier evaluations of 12.753 (4) (2004BeZR) and 12.7527 (23) (2007Ni07). The latter value has just been taken from 1992Un01 and 2002Un02, later superseded.

2.1. Beta Transitions

The energies of β^- transitions have been obtained using the Q^- value and the ^{140}La level energies. The probabilities of β^--transitions $P_{\beta-}$ have been deduced from the P(γ+ce) balance at each level of ^{140}La. The level energies, spins and parities of ^{140}La (Table 2) are taken from 2007Ni07 (Adopted Levels).

Table 2. ^{140}La levels populated in ^{140}Ba β^--decay

Level	Energy (keV)	Spin and parity	Half-life	$P_{\beta-}$ (%)
0	0	3-	1.67858 (21) d	**≤ 0.000 01**
1	29.9641 (6)	2-	0.25 ns	**25.6 (42)**
2	43.884 (18)	1-	0.52 ns	**35.6 (31)**
3	63.1790 (7)	4-		**< 0.000 000 01**
4	162.6591 (19)	2-	< 0.01 ns	**4.14 (31)**
5	467.63 (3)	1-	< 7.7 ns	**9.71 (12)**
6	581.106 (18)	0-		**24.94 (50)**

The limits for the very weak β^- branches to the ground state and the excited level with energy 63 keV of ^{140}La are estimated from the log *ft* systematics. The β^- transition to the ground state is a non-unique 3rd forbidden transition for which the log *ft* systematics of 1998Si17 list only one non-unique 3rd forbidden β^- decay and it has a log *ft* of 17.5. If we assume that this class of decays all have log *ft* >15, the corresponding I_{β^-} is < 1×10^{-5} %. Similarly, the β^- transition to the excited level with energy 63 keV is unique 3rd forbidden for which 1973Ra10 lists log *ft* values of 18.1 and 20.9.

(The corresponding log *ft* values in 1998Si17 are 20.7 and 21.4). If we assume that this class has log *ft*>18, I_{β^-} is < 10^{-8} %.

2.2. Gamma Transitions and Internal Conversion Coefficients

The multipolarities and mixing ratios δ are from the adopted data in the ENSDF evaluation (2007Ni07). Gamma-ray transition probabilities have been deduced from their gamma-ray emission probabilities and the total ICC(s). The adopted ICC(s) are obtained by using the theoretical values with the BrIcc computer program, accepting the "frozen orbital (no hole)" approximation (2008Ki07).

3. ATOMIC DATA

The atomic data (fluorescence yields, X-ray energies and relative probabilities, and Auger electrons energies and relative probabilities) have been deduced by using the SAISINUC software.

4. ELECTRON EMISSIONS

The energies of the conversion electrons have been obtained from the gamma-ray transition energies and the electron binding energies. The absolute emission probabilities of the conversion electrons have been deduced using recommended Pγ and ICC values. The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

β– average energies have been calculated using the LOGFT computer program.

5. PHOTON EMISSIONS

5.1. X-ray Emissions

The absolute emission probabilities of La KX- and LX- rays have been calculated using the EMISSION computer program. These probabilities are compared below with the experimental values deduced from the intensities measured relative to the 537-keV gamma ray intensity.

	1991Ch05	1982Ad02	1969Ka33	**Adopted**
LX	13.3 (6)	8 (2)		**13.7 (4)**
Kα	0.73 (3)	1.6 (1)	2.5 (5)	**1.566 (25)**
Kβ	0.36 (3)	0.39 (4)	< 0.49 (7)	**0.378 (8)**

5.2. Gamma ray emissions

The evaluated energies of gamma rays in ^{140}La are the energies of the gamma transitions minus the recoil energy.

The measured relative intensities and the adopted values obtained with the LWEIGHT program are listed in Table 4. Many values have been scaled from their original normalizations (2004BeZR). All the values of 1966Mo16 were omitted since they do not have uncertainties. For γ29.9, γ113.6, γ132.7, γ162.7, and γ304.9, the smallest uncertainties have been used in the adopted values.

Table 4. Experimental and adopted relative gamma-ray intensities in decay of ^{140}Ba

γ-ray energy (keV)	1991Ch05	1990Me03	1982Ad02	1977Ge12	1977De34	1976Li06	1975Ha50	1970Ke09	1969Ka33	**Adopted**
13.9	4.69 (12)	5.0 (7)	4.9 (6)						7.2 (25)	**4.71 (12)**
29.9	58.4 (10)	61.0 (40)	60 (3)					55 (8)	72 (12)*	**58.6 (10)**
43.8	0.054 (7)		< 0.007					< 0.005		
63.1		0.000 12 (6)								**0.000 12 (6)**
99.4		0.000 08 (5)								**0.000 08 (5)**
113.4	0.072 (6)	0.066 (5)	0.077 (16)					0.074 (8)		**0.070 (5)**
118.7	0.25 (1)	0.250 (3)	0.27 (3)				1.56 (16)*	0.28 (3)	0.21 (2)	**0.248 (7)**
132.6	0.81 (2)	0.83 (2)	0.90 (8)				2.14 (31)*	0.84 (5)	0.83 (7)	**0.82 (2)**
162.6	25.3 (3)	25.45 (29)	28.0 (8)	26.4 (8)	25.5 (3)	25.9 (7)	27.6 (16)	25.1 (10)	28.4 (9)	**26.4 (10)**
304.9	17.54 (15)	17.6 (2)	17.8 (5)	17.67 (18)	17.63 (21)	18.5 (7)*	17.9 (19)	17.2 (7)	17.3 (7)	**17.60 (15)**
418.4		0.015 (1)	< 0.04							
423.7	12.65 (12)	12.7 (1)	12.8 (5)	12.73 (14)	12.92 (16)	13.0 (6)	14.8 (12)*	12.7 (5)	12.8 (6)	**12.73 (12)**
437.6	7.91 (8)	7.91 (4)	7.80 (25)	7.82 (9)	7.91 (16)	8.5 (5)*	8.9 (4)*	7.8 (3)	7.8 (4)	**7.89 (4)**
467.7	0.29 (3)	< 0.002	< 0.01							
537.2	100 (1)	100.0 (3)	100	100.0 (10)	100.0 (9)	100.0 (23)	100.0 (23)	100.0 (20)	100	**100**
551.1	0.028 (4)	0.0128 (8)	0.027 (9)							**0.020 (8)**
848.9			0.02							

* These values have been rejected by the LWEIGHT computer program based on the Chauvenet's criterion.

These relative emission probabilities have been scaled by **0.246 (5)**. This scaling factor has been obtained from the transition intensity balance to the ground state of ^{140}La assuming that the probability of the beta transition to the ground state is $< 1\times10^{-5}$ % (see sect.2.1).

The following normalization factors have been experimentally found: 0.2439 (22) (1977De34), 0.257 (6) (1975Ha50) and 0.236 (5) (1976Li06). In 1977De34 the normalization factor is based on the measured γ -emission rates for five lines and the source activity by 1977De34. Two other factors were determined for the 1596 keV line from ^{140}La decay. The discrepancy between the latter two values is 9 % and may result from difficulties in determining the efficiency at 1596 keV line where there is a lack of efficiency calibration lines. If the three values are averaged, the weighted mean is dominated by the 1977De34 value and is 0.2441 (22) with the internal uncertainty of 0.0019 and the external uncertainty of 0.0036, $\chi^2 / (\chi^2)_{crit} = 3.6/4.6$.

6. ENERGY CONSERVATION

The total average energy of 1040 (60) keV, for one disintegration, calculated from the current evaluated data corresponds to the available energy of 1048 (8) keV (Q^-) from the mass tables (2012Wa38) confirming the consistency of the decay scheme and the reliability of this evaluation.

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