^{133}Ba - Comments on evaluation of decay data

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This evaluation was done in May 1999, and revised in April 2000. The literature available by April 2000 was included. The half-life was revised in January 2004 using new references available by 2004.

1. Decay Scheme

Since ^{133}Ba has spin and parity $1/2^+$, it decays primarily by allowed ε branches to the $1/2^+$ and $3/2^+$ levels at 437 and 383 keV. As to the intensities of the other possible ε branches to the levels at 0, 81 and 161 keV they can be estimated from log *ft* systematics. From that of 1998Si17, one expects the log *ft* of the unique 2nd forbidden decay to the ground state to be greater than 13.9 which corresponds to a branch of less than 0.0005%. Similarly, the log *ft* of the 2nd forbidden decays to the 81- and 161-keV levels are expected to be greater than 10.6 which corresponds to branches of less than 0.7% and 0.3%, respectively. Our evaluations for these two branches from the gamma intensity balance agree very well with this expectation (see section 2.1)

From the measured γ-ray emission probabilities and the internal conversion coefficients, the intensity balances at the 81- and 161 keV levels give branching to these levels of 0.0(16) % and 0.11(18)%, respectively.

Therefore, all of these unobserved β branches can be considered negligible.

For comparison see also the evaluations made by R. B. Firestone (1990Fi03), A. L.Nichols (1993Nichols) and Shaheen Rab (1995Ra12) as well as the analysis by F. E. Chukreev (1992Chukreev).

Q value is from Audi and Wapstra (1995Au04).

The ^{133}Ba half-life values available from 1961 are, in days:

3908(73)	1961Wy01	
2849(37)	1968La10	Rejected, large deviation from mean
3894(44)	1968Re04	
3781(15)	1970Wa19	Rejected, revised in 1983Wa26
3981(37)	1972Em01	Rejected by Chauvenet's criterion
4127(260)	1973Ll01	Rejected by Chauvenet's criterion
3850(55)	1979HaYC	
3785(27)	1980RuZY	
3848.0(11)	1980Ho17	
3828(11)	1982HoZJ	Rejected, revised in 1992Un01
3885.9(43)	1983Ki08	
3842(18)	1983Wa26	
3853.6(36)	1992Un01	Rejected, revised in 2002Un02
3848.9(7)	1997Ma75	
3854.7(28)	2002Un02	
3840.5(65)	2003Schrader	
3849.7(22)	Mean value	

The values before 1961 were struck off due to their large uncertainties (more then 1 year).

The values of 1970Wa19, 1982HoZJ and 1992Un01 had been omitted since they have been replaced by later values from the same group when the data set of the thirteen remained values was formed.

Then the value of 1968La10 (7.8±0.1 y) was omitted on statistical considerations because of a great contribution into the χ^2 value (27 σ from adopted value).

Use of the LWEIGHT computer program on the remaining twelve half-life values led to subsequent omitting outliers of 1973Ll01 and then 1972Em01 by Chauvenet's criterion. The uncertainty of 1997Ma75 was increased to 0.98 days to adjust weights according to the Limitation of Relative

Statistical Weight method. In consequence the LWEIGHT program chose the weighted average of 3849.7 days and external uncertainty of 2.2 days.

It should be noted that in the weighted average of the two values of 1980Ho17 and 1997Ma75 have altogether 90% of the relative weight. Since these two values agree, any weighted average will be about 3849 days that differs slightly from an unweighted average of about 3856 days.

The adopted value for the ^{133}Ba half-life is 3849.7(22) in days and 10,540(6) in years.

2.1. Electron Capture Transitions

The energies of the electron capture, ε , transitions have been calculated from the Q value and the level energies deduced from gamma transition energies (see also 1995Ra12) .

The electron capture probabilities $\varepsilon_{0,4}$ and $\varepsilon_{0,3}$ have been calculated from the intensity balance for the 437 level and the 384 level, respectively, using the evaluated $P_{\gamma+ce}$ values. Similarly, the electron capture probabilities $\varepsilon_{0,2}$ and $\varepsilon_{0,1}$ are obtained from the intensity balance for 161 and 81 keV levels respectively, as (0.11±0,18) and (0.0±1.6) per 100 disintegrations. Hence the upper limits for them are ($P\varepsilon_{0,2}$ < 0.3) and ($P\varepsilon_{0,1}$ < 2) per 100 disintegrations. However the upper limit for $\varepsilon_{0,1}$ can be decreased with use of the correlation of $P\varepsilon_{0,1} = 100 - P\varepsilon_{0,4} - P\varepsilon_{0,3} - P\varepsilon_{0,2} = 0.0(7)$, i.e. , $P\varepsilon_{0,1} < 0.7$ per 100 disintegrations.

The P_K, P_L and P_M values for transitions $\varepsilon_{0,4}$ and $\varepsilon_{0,3}$ to the 437 keV and 384 keV levels, respectively, have been computed from the tables of Schönfeld (1998Sc28).

The available experimental P_K values are:

	$P_K(\varepsilon_{0,4})$	$P_K(\varepsilon_{0,3})$	$P_K(\varepsilon_{0,2})$	$P_K(\varepsilon_{0,1})$
1968Na16	0.68(5)			
1972Sc08	0.72(4)	0.80(7)		
1974Da09	0.76(6)	0.87(14)		
1975Ni07	0.75(10)			
1983Si17	0.75(4)	0.80(4)	0.92(13)	0.95(6)
1983Si22	0.71(11)	0.79(5)		
1988BeYQ	0.78(4)			
1990Da11	0.76(4)			
1990Bh01	0.730(12)	0.81(3)	0.91(7)	0.94(6)
1992Sa28	0.65(3)	0.74(4)	0.79(3)	0.88(4)
adopted	0.672(5)	0.7734(21)	0.79(3)	0.88(4)

Most of these values were obtained in 1974-1990 using the method of the X-, gamma-ray sum peak measurements. The results exceed the theoretical P_K values for the allowed $\varepsilon_{0,4}$, $\varepsilon_{0,3}$ - transitions and depend also on adopted conversion coefficients α_K and fluorescence yield ω_K.

The new measurement results obtained in 1992 agree better with the adopted values of P_K. Hence for P_K of the 2nd forbidden transitions $\varepsilon_{0,2}$, $\varepsilon_{0,1}$ we have adopted the values of 1992Sa28 (as the expression in 1998Sc28 do not apply to 2nd forbidden transitions).

2.2. Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of gamma transitions are the energies of gamma rays with adding the recoil energy .

The probabilities of gamma transitions $P_{\gamma+ce}$ have been computed using the evaluated absolute gamma-ray emission probabilities and the total internal conversion coefficients (ICC). The ICC have been evaluated using the information of the multipolarity admixture coefficients from 1977Kr13, 1980Kr22 and 1995Ra12 and the theoretical values from 1978Ro22.

3. Atomic Data

3.1. Fluorescence yields

The fluorescence yields are taken from 1996Sc06 (Schonfeld and Janβen).

3.2. X Radiations

The X-ray energies are based on the wave lengths in the compilation of 1967Be65 (Bearden). The relative KX-ray emission Kβ/Kα and $K\alpha_2/K\alpha_1$ probabilities are taken from 1996Sc06. In order to calculate the $K\beta'_1/K\alpha_1$ and $K\beta'_2/K\alpha_1$ ratios the value of $K\beta'_2/K\beta'_1$ measured in 1989Ma60 (0,2525(23)) has been adopted.

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins).

The ratios P(KLX)/P(KLL) and P(KLY)/P(KLL) are taken from 1996Sc06.

4. Photon Emissions

4.1. X-Ray Emissions

The total absolute emission probability of KX-rays (P_{XK}) has been computed using the adopted value of ω_K, the evaluated total absolute emission probability of K conversion electrons (Pce_K) and the electron capture ($P\varepsilon_K$). The absolute emission probabilities of the KX-ray components have been computed from P_{XK} using the relative probabilities from 1996Sc06 and 1989Ma60 for $K\beta'_2/K\beta'_1$ and 1996Sc06 for all others.

The measured values of the total absolute emission probability of KX-rays ($P_{XK}\times100$) are given below in comparison with the calculated (adopted) value:

1972Sc08	1977Sc31	1989Egorov	Adopted
123.1(17)	117.4(22)	119.7(11)	119.7(13)

The total absolute emission probability of LX-rays has been computed using total absolute sums Pce_L, Pce_K, $P\varepsilon_K$, $P\varepsilon_L$ and atomic data of section 3 (ω_K, ϖ_L, n_{KL}).

4.2. Gamma-Ray Emissions

The γ-ray energies are taken from the evaluation 2000He14 where the values are deduced on the revised energy scale. For the γ-ray of 81 keV see also the measurement of 1991We08.

The γ-ray absolute emission probabilities have been computed using the evaluated γ-ray relative probabilities and the absolute emission probability for the γ-ray 356 keV of 0.6205(19) measured in 1980Chauvenet, 1983Ch11. This experimental value for the most intensive γ-ray in the decay of ^{133}Ba was obtained as a result of the international intercomparison ICRM -S- 6 (1980Chauvenet). It is more preferable for normalizing of gamma-ray absolute emission probabilities than having been obtained from a ground state intensity balance 0.621(10)-because of uncertainties in multipolarity admixtures (and thus in ICC) as well as possible ambiguity in determination of some spins (see 1992Chukreev).

At the same time the relative gamma ray emission probabilities from ICRM-S-6 measured at the fifteen laboratories are used below in Table 1 equally with other measurements for averaging all the available data (the evaluation technique is given in 2000Ch01). The measurements of ICRM-S-6 have been lettered CRP and deduced from absolute emission probabilities published in 1980Chauvenet excluding an activity uncertainties ~0.2 %.

5. Electron Emissions

The energies of the conversion electrons have been calculated from the gamma-transition energies given in 2.2 and the electron binding energies.

The emission probabilities of the conversion electrons have been calculated using the conversion coefficients given in 2.2. The values of the emission probabilities of K-Auger electrons have been calculated using the transition probabilities given in 2.1 and 2.2, the atomic data given in 3. and the conversion coefficients given in 2.2.

Table 1. The experimental and evaluated values for γ-ray relative emission probabilities

	γ53	γ80	γ81	γ161	γ223	γ276	γ303	γ356	γ384
1967Bl15	3,8(8)	3,8(4)	53(4)	1,1(3)	0,7(3)	11,0(7)†	30(2)	100	14,5(1)
1968Al16	3,3(5)	-	-	1,20(6)†	0,74(6)	12,0(4)†	30,6(9)†	100	14,2(5)
1968Bo04	4,2(2)†	4,0(4)	58,2(15)	1,07(5)	0,78(6)	11,8(3)	29,8(8)	100	14,3(10)
1968Do10	3,2(4)	5,5(7)†	52(7)	0,99(10)	0,72(8)	11,6(8)	29,4(2)	100	14,3(10)
1968No01	3,78(9)	4,9(6)	60(7)	1,21(5)†	0,80(3)†	11,61(17)	29,75(29)	100	14,18(26)
1969Gu15	2,91(5)	4,54(7)	53,7(17)	1,13(15)	-	11,2(3)	29,3(5)	100	14,03(26)†
1972Sc08	3,54(5)	3,9(2)	52,6(10)	1,16(5)	0,74(4)	11,4(3)	30,2(6)	100	14,4(3)
1973In06	-	-	-	0,98(7)	0,76(5)	11,6(5)	29,6(11)	100	14,9(6)†
1973Legrand	-	3,7(4)	56(6)	1,4(2)†	0,66(2)†	11,35(25)	29,4(6)	100	14,3(3)
1973Mc18	-	-	-	-	-	11,43(23)	29,3(6)	100	14,5(3)
1977Ge12	3,0(4)	5,6(15)†	52(4)	1,12(8)	0,85(7)†	11,7(8)	29,87(21)	100	14,4(11)
1977Sc31	3,49(8)	4,29(12)	55,8(16)	0,97(3)	0,73(3)	11,41(16)	29,4(3)	100	14,33(21)
1978He21	3,54(18)	3,1(3)†	49,2(26)	1,08(4)	0,745(25)	11,7(4)	29,8(4)	100	14,36(20)
1978Vylov	3,57(12)	4,16(18)	54,6(17)	0,98(8)	0,71(4)	11,4(3)	28,8(8)†	100	14,3(5)
1980Ro22	-	-	-	1,03(7)	0,72(5)	11,69(16)	29,9(4)	100	14,79(27)†
1983Yo03	-	-	-	1,035(28)	0,756(16)	11,57(7)	29,55(18)	100	14,36(9)
1987Lakshn	2,96(9)	4,67(14)	55,3(16)	-	-	-	-	100	-
1989Da11	3,6(5)	3,7(5)	52,3(7)	1,032(10)	0,713(8)	11,51(8)	29,51(23)	100	13,99(9)†
1990Me15	3,48(7)	3,77(9)	51,2(4)	1,05(3)	0,71(2)	11,3(2)	29,2(3)	100	14,5(2)
1998Hw07	-	-	-	0,950(18)	0,715(10)	11,64(13)	29,31(40)	100	14,52(17)
CRP-1	-	-	-	1,11(9)	0,85(5)†	11,7(4)	29,9(11)	100	14,5(5)
CRP-2	3,56(14)	-	53,1(19)	0,99(4)	0,729(28)	11,7(3)	30,1(9)	100	14,4(5)
CRP-3	3,53(8)	4,20(12)	54,8(12)	1,031(24)	0,69(3)	11,51(14)	29,5(3)	100	14,37(16)
CRP-4	3,53(7)	4,18(11)	54,6(12)	1,037(20)	0,730(22)	11,48(14)	29,5(4)	100	14,41(16)
CRP-5	3,9(7)	4,00(15)	51,5(19)	1,020(27)	0,728(22)	11,5(3)	29,5(9)	100	14,2(5)
CRP-6	3,45(8)	4,73(12)	57,6(14)	1,020(25)	0,728(18)	11,68(28)	29,7(7)	100	14,5(4)
CRP-7	3,56(8)	4,73(12)	58,9(15)	1,070(27)	0,738(18)	11,50(28)	29,6(7)	100	14,3(4)
CRP-8	-	-	-	-	-	11,22(27)	29,3(6)	100	14,53(28)
CRP-9	-	-	-	-	-	11,22(24)	29,3(5)	100	14,26(25)
CRP-10	-	-	-	-	-	11,48(25)	29,3(5)	100	14,20(22)
CRP-11	-	-	-	-	-	11,57(19)	29,4(4)	100	14,34(26)
CRP-12	3,69(18)	4,37(16)	55,3(18)	1,050(19)	0,741(15)	11,53(16)	29,5(4)	100	14,36(20)
CRP-13	2,92(16)	-	-	-	0,75(3)	11,9(4)	30,2(11)	100	14,6(5)
CRP-14	3,53(8)	4,39(11)	55,9(12)	1,015(20)	0,735(10)	11,61(13)	29,6(4)	100	14,34(18)

	γ53	γ80	γ81	γ161	γ223	γ276	γ303	γ356	γ384
CRP-15 CRP-16 CRP-19 CRP-20 CRP-21	3,36(18) 3,26(17) 3,53(5) 3,53(6) 3,62(6)	- - - 4,05(8) 4,15(12)	- - - 55,1(9) 55,8(9)	1,05(4) 1,05(4) 1,063(17) 1,05(5) 1,039(15)	0,758(28) 0,764(26) 0,725(17) 0,72(4) 0,705(11)	11,7(5) 11,7(4) 11,61(12) 11,49(21) 11,57(17)	29,6(10) 29,7(6) 29,7(3) 29,4(6) 29,5(4)	100 100 100 100 100	14,3(4) 14,3(3) 14,53(13) 14,51(22) 14,40(20)
Nunber of input values	27	20	24	29	28	36	36		34
Reduced χ^2	7,21	5,54	4,08	1,68	0,79	0,37	0,29		0,20
Weighted average	3,45	4,27	53,4	1,032	0,726	11,54	29,55		14,41
Internal uncertainty	0,017	0,029	0,23	0,0048	0,0035	0,030	0,064		0,037
External uncertainty	0,046	0,068	0,47	0,0062	0,0031	0,018	0,035		0,016
Adopted value	3,45(5)[a]	4,27(8)[a]	53,1(5)[b]	1,028(8)[c]	0,730(5)[c]	11,54(7)[a]	29,55(18)[a]	100	14,41(9)[a]

† Omitted as outliers

[a] The least uncertainty of experimental values

[b] Adopted value has been changed slightly from the weighted average for a precise ground state intensity balance to get. Such a small change only for one gamma-ray supports the adopted experimental value of 62,05(19) % for the 356 keV γ-ray absolute emission probability and confirms the decay scheme. The adopted uncertainty of 0,5 is external.

[c] Computed using the absolute emission probability measured in 1996Mi26.

In that work a special precise measurements of the absolute emission probabilities only for the two weak 161 and 223 keV gamma-rays were made by using a 4πβ(ppc)-γ(HPGe) coincidence system.

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