^{140}La - Comments on evaluation of decay data by R. G. Helmer

1 Decay scheme

There are many levels in ^{140}Ce below the β^- decay energy of 3762 keV that are not reported in these decay data, so some other levels may be weakly populated. However, all of the known levels (1994Pe19) below 2600 keV are populated in this decay.

If the γ rays from the decay of ^{140}La are used to determine the amount of ^{140}Ba that is present in a sample, a correction must be made for the fact that their decay rates are different. After they have come into "equilibrium," the ^{140}La decay rate is larger by a factor of
$T_{1/2}(^{140}Ba) / [T_{1/2}(^{140}Ba - T_{1/2}(^{140}La)] = 1.1516$ (7), so the deduced amount of ^{140}Ba should be divided by 1.1516.

The J^{π} are from the ^{140}Ce Adopted Levels of the Nuclear Data Sheets (1994Pe19).

2 Nuclear Data

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

The half-life values available are, in hours:

40.224 (20)	1954Ki08	
40.31 (6)	1954Ya02	
40.27 (5)	1957Pe09	
40 (2)	1960Wi10	
40.23 (3)	1965Si17	
40.2 (2)	1967Ka12	
40.2 (2)	1968Re04	
40.272 (7)	1977DeYO,	superseded by 1983Wa26
40.232 (67)	1978Da21	
40.280 (6)	1980Ho17	
40.295 (5)	1980Ol03	
40.279 (17)	1982HoZJ,	superseded by 1992Un01
40.270 (29)	1983Wa26	
40.284 (5)	1989Ab18	
40.293 (12)	1992Un01 and 2002Un02	
40.34 (4)	2002Ad02	
40.284 (4)	Weighted average, adopted	

The adopted value of 40.284 (4) hours, or 1.67850 (17) days, is the weighted average of the fourteen unsuperseded values, the internal uncertainty is 0.0027, and the reduced-χ^2 is 1.88.

2.1 b$^-$ Transitions

The level energies used to compute the β^- transition energies are from a least-squares fit to the γ-ray energies.

The probabilities for the β^- branches are from the balances from the γ-ray transition probabilities at each level.

The β^- branches to the levels at 0, 1903, and 2107 keV are nonunique 3rd forbidden. The log *ft* systematics of 1998Si17 give only one value, 17.5, for this class of β decays. From the data of 1998Si17, it is reasonable to assume a lower limit of log *ft* > 15 for this class. The corresponding $I_{\beta-}$ limits are then < $1. \times 10^{-4}$ % ; < $1. \times 10^{-5}$ %, ; and < $1. \times 10^{-5}$ %, respectively. Although there have been many analyses of the β^- spectrum, only 1966Dz05 has reported a branch to the ground state. Their intensity of 5×10^{-5} % (2) is compatible with the limit from the log *ft* systematics; however, since others have not seen this branch, this value is assumed to be too large. In any case, the value is negligible in determining the normalization of the γ-ray emission probabilities. These three $I_{\beta-}$ are all set to zero in this scheme.

The average β^- energies and the log *ft*'s are from the LOGFT program.

2.2 Gamma Transitions and Internal Conversion Coefficients

The multipolarities and mixing ratios are from the Adopted γ data in the Nuclear Data Sheets (1994Pe19). For the 131-keV : M1 + 1.7% (+14-5) E2 ; 241-keV : M1 + 0.2% (+8-2)E2 ; 266-keV : M1 + 99.8% (+2-5) E2 ; 328-keV : M1 + 0.24% (6) E2 ; 751-keV : M1 + 11.5% (17) E2 ; 815-keV : M1 + 0.005% (+20-5) E2; 867-keV : E1 + 0.16% (+20-12) M2 ; 925-keV : M1 + 1.0% (+9-6) E2.
See sect. 4.2 for comments on normalization of relative photon emission probabilities to absolute values.

3 Atomic data

3.1 Fluorescence yields

The data are from Schönfeld and Janßen (1996Sc06).

3.2 X-ray radiations

Relative emission probabilities are from Schönfeld and Janßen (1996ScZX).

4 Radiations

4.1 Electron Emission

The conversion electron data were computed from the internal-conversion coefficients interpolated from the tables of Rösel (1978Ro21) and of Band (1976Ba63) and the multipolarities are from the evaluation of 1994Pe19. The adopted internal pair coefficient for the 1596-keV γ ray is 0.000106 (1) deduced from the measured value of $\alpha(pair)/\alpha_K$ = 0.156 (15) from 1968Be57; the theoretical value is 0.000115 (1979Sc31).

4.2 Photon Emissions

The γ-ray energies were determined from the reported values in Table 1. All of these 197 energies were entered into a simultaneous least-squares fit to determine the energies of the 18 excited levels. The possible γ rays at 936 and 2533 keV, which were reported only once, are not included in the adopted decay scheme or the list of γ rays. The adopted γ-ray energies were then computed from the differences between these level energies, with the corrections for recoil. As a result, the consistency of the several values for a single γ ray is not determined, but the consistency of the whole set is determined. For this fit, the reduced-χ^2 value is 1.07 indicating that the input uncertainties are quite reasonable. This method occasionally produces γ-ray energy uncertainties that are much smaller than would be determined from the measurements for that γ ray alone.

The relative γ-ray intensities were determined from the data in Table 2. Several of these sets of data were published as emission probabilities and have been scaled by the evaluator to obtain values relative to the 1596-keV γ ray. The Limitation of Relative Statistical Weight method, as implemented in the LWEIGHT program, was used to compute the average values. In this calculation, if a particular value contributes more than 50% of the relative weight and the initial fit has a reduced-χ^2 of more than the critical reduced-χ^2 for the number of input values, the uncertainty of the most precise value is increase to reduce its relative weight to 50%. The critical reduced-χ^2 values are: 6.6 for 2 input values; 4.6 for 3; 3.8 for 4; 3.3 for 5; 3.0 for 6; 2.5 for 9; 2.4 for 10; 2.3 for 11; and 2.2 for 12 or 13. Some values have been deleted from the averaging, as indicated in the table and the evaluator has arbitrarily increased a few input uncertainties.

At the time many of these measurements were made, there was a lack of good Ge detector efficiency calibration standards in the region of 1596 keV. Therefore, the evaluator has introduced an energy-dependent scaling factor based on the emission probabilities from 1977De34 for thirteen lines from 266 to 2521 keV. This factor, which is shown in Table 2 and varies by 3%, corrects for this assumed systematic deviation of the Ge detector efficiencies. The total γ-ray feeding of the ground state is set to 100%, with no direct β^- decay, to obtain a normalization factor of 0.9540 (8) to convert these relative γ emission probabilities to absolute probabilities as given in the last column of Table 2.

Table 1. Measured g-ray energy values

1964Re09	1967Ka12	1968Ba18	1968Gu05	1970Ka18	1970Ke06	1972GeZG	1978Ar28	1979Bo26	1980Ka32	1982Ad02	Adopted
	24.595(4)										24.595(4)
	64.130(7)	64.135(10)									64.129(4)
	68.916(6)	69.0(3)									68.923(5)
	109.417(6)	109.418(7)				109.47(20)				109.422(11)	109.417(4)
	131.122(8)	131.121(8)				131.15 (20)			130.97(20)	131.117(8)	131.121(4)
	173.550(11)	173.536(12)				173.50(20)			173.49(17)	173.543(9)	173.546(5)
241.97(3)	241.961(22)	241.966(12)				241.90(8)	241.88(10)		242.06(9)	241.933(30)	241.959(6)
266.52(6)	266.547(22)	266.551(14)				266.61(6)	266.58(10)		266.67(7)	266.543(12)	266.554(5)
		306.9(2)				306.5(4)			307.1(2)	306.9(2)	307.08(4)
328.789(15)		328.768(12)	328.752(30)		328.745(15)	328.76(5)	328.80(10)	328.746(25)	328.78(5)	328.762(8)	328.761(4)
	397.8(3)	397.79(11)				397.66(10)			397.8(1)	397.52(5)	397.674(6)
432.55(8)	432.62(6)	432.530(29)			432.490(20)	432.52(4)	432.51(10)		432.66(4)	432.493(12)	432.513(8)
				438.5 (4)					438(1)	438.5(5)	438.178(6)
									445(1)	445.5(5)	444.57(4)
487.027(24)	487.042(29)	487.029(19)	487.032(30)		486.995(30)	487.009(30)	487.09(10)	487.15(25)	486.99(3)	487.021(12)	487.022(6)
		618.2(7)				617.7(3)			618.2(1)	618.12(5)	618.12(4)
752.42(33)	751.75(8)	751.83(8)				751.655(35)	751.66(10)		751.65(4)	751.637(18)	751.653(7)
815.82(10)	815.85(7)	815.80(9)			815.735(40)	815.775(30)	815.80(10)		815.78(4)	815.772(19)	815.781(6)
867.9(5)	867.87(15)	867.82(14)				867.842(35)	867.85(10)		867.80(4)	867.856(20)	867.839(16)
	919.63(15)	919.5(2)				919.54(4)	919.63(10)		919.48(6)	919.550(23)	919.533(10)
924.1(6)	925.24(9)	925.20(17)				925.188(35)	925.21(10)		925.14(6)	925.189(21)	925.198(7)

				936.9(4)							none
	950.9(3)	951.1(4)		951.4(4)		951.00(6)			950.95(6)	950.987(26)	950.988(20)
										992.9(5)	992.64(18)
						1045.2(3)			1045.0(1)	1045.05(24)	1045.02(9)
						1097.2(3)			1097.2(2)	1097.20(23)	1097.58(9)
									1303.3(1)	1303.5(4)	1303.34(7)
						1404.5(2)			1404.9(2)	1405.20(17)	1404.66(9)
1596.34(25)	1596.49(24)	1596/6(2)	1596.20(4)		1596.170(25)	1596.17(6)	1596.22(10)		1596.17(6)	1596.210(35)	1596.203(13)
										1877.29(19)	1877.33 (18)
	1903.15(30)								1903 (1)		1903.28(4)
						1924.2(3)			1924.4(1)	1924.62(13)	1924.5 (2)
									2082.9(2)	2083.2(5)	2083.219(14)
	2348.1(7)	2348.8 (6)				2347.80(6)			2347.82(6)	2347.88(5)	2347.847(14)
				2465.3(8)					2464.0(1)	2464.1(5)	2464.031(20)
2519.7(34)	2521.7(5)	2522.2(4)				2521.32(6)	2522.03(10)		2521.36(6)	2521.40(5)	2521.390(14)
				2533.4(7)							none
	2547.1(8)	2548.6(8)		2547.5(6)		2547.14(6)			2547.19(7)	2547.34(11)	2547.180(23)
	2900(2)	2899.7(5)		2899.7(8)		2899.5(2)			2899.5(2)	2899.61(16)	2899.53(7)
	3119(2)	3118.3(7)		3119.0(8)		3118.52(15)			3118.4(2)	3118.51(16)	3118.49(10)
	3322(4)	3319.7(25)		3319.6(9)		3319.4(6)			3319.3(3)	3320.4(6)	3319.52(24)

Table 2. Measured relative g-ray emission probabilities – Part 1 : references from 1962 to 1975

E_{γ}	1962Ha14	1967Ka12	1968Ba18	1969KuZV	1970Ka18	1974HeYW	1975Ha50
K_{α}					2.4 (7)		
K_{β}					0.36 (8)		
64					~ 0.01		
68			0.065 (13)		0.064 (16)		
109		0.50 (20)	0.27 (4)	0.23 (2)	0.210 (15)	0.17 (4)	0.20 (4)
131		1.05 (15)	0.61 (9)	0.47 (3)	0.50 (3)	0.42 (5)	0.58 (4)
173			0.13 (5)		0.130 (20)	0.60 (20)	
241		0.83 (10)	0.45 (6)	0.58 (6)	0.410 (30)	0.51 (8)	0.66 (3)
266		0.83 (10)	0.56 (6)	0.53 (4)	0.490 (30) @	0.50 (5)	0.34 (3)
307			0.022 (11)		0.035 (17)		
328		25.4 (20)	21.4 (11)	22.4 (4)	19.4 (1) @	19.6 (13)	18.8 (5)
397			0.054 (25)		0.110 (35)	0.12 (3)	
432		3.5 (3)	3.11 (16)	3.06 (9)	2.85 (15)	2.94 (20)	3.0 (2)
438					0.021 (10)		
444					~ 0.25		
487		49.6 (32)	49.4 (25)	48.2 (5)	45.0 (2) @	44.7 (30)	39.7 (5)
618		0.4 (3)	0.044 (22)		~ 0.045		
751		4.5 (4)	4.40 (22)	4.66 (23)	4.40 (20)	4.5 (3)	4.9 (2)
815		23.5 (20)	24.1 (12)	24.9 (2)	23.5 (7)	24.2 (15)	26.8 (11)

867		5.6 (5)	5.64 (28)	5.91 (24)	5.60 (30)	5.7 (3)	6.5 (1)
919		2.5 (6)	2.73 (16)	2.59 (10)	2.64 (16)	2.89 (20)	3.4 (2)
925		6.8 (6)	7.24 (43)	6.94 (21)	7.10 (30)	7.2 (4)	7.9 (3)
950		0.8 (3)	0.56 (5)	0.62 (9)	0.550 (30)	0.56 (4)	
992							
1045							
1097							
1303							
1405							
1596	100.	100.	100.	100.	100.	100.	100.
1877						0.05 (2)	
1924						0.023 (5)	
2083							
2347	0.86 (17)	1.0 (2)	0.901 (45)	0.85 (6)	0.90 (6)	0.89 (6)	
2464					0.0018 (6) #		
2521	3.0 (6)	3.5 (2)	3.52 (18)	3.37 (10)	3.60 (18)	3.59 (18)	4.9 (4)
2547		0.11 (2)	0.122 (9)		0.110 (7)	0.110 (6)	
2899	0.082 (17)	0.060 (10)	0.070 (5)		0.065 (6)	0.073 (8)	
3118	0.035 (10)	0.030 (10)	0.027 (3)		0.027 (4)	0.028 (3)	
3320			0.008 (4)		0.0047 (15)	0.050 (3)	

Table 2. Measured relative g-ray emission probabilities – Part 2 : references from 1976 to 1991

E_γ (keV)	1976Li06	1977De34	1977Ge12	1978Ar28	1980Ka32	1982Ad02	1991Ch05	Wtd. Avg.	reduced χ^2	scaling factor	Adopted	Emission probability (%)
K_α						1.77 (6)	1.72 (4)	1.74 (3)		1.027	1.79 (3)	1.71 (3)
K_β						0.45 (2)	0.395 (14)	0.406 (16)	2.8	1.027	0.417 (16)	0.398 (15)
64						0.011 (4)	0.015 (2)	0.0142 (18)		1.027	0.146 (18)	0.139 (17)
68					0.070 (16)	0.080 (6)	0.079 (2)	0.0785 (19)		1.027	0.0806 (19)	0.0769 (18)
109	0.20 (9)				0.170 (10) @	0.220 (10)	0.230 (4)	0.221 (6)	1.9	1.027	0.227 (6)	0.217 (6)
131	0.46 (9)				0.44 (1) @	0.48 (3)	0.49 (1) *	0.479 (15)	2.9	1.027	0.492 (15)	0.469 (14)
173					0.120 (10)	0.110 (10)	0.133 (4)	0.129 (5)	2.2	1.027	0.132 (5)	0.126 (5)
241	0.52 (18)	0.6 (1)		0.51 (9)	0.450 (10)	0.460 (30)	0.434 (8) *	0.445 (10)	2.7	1.027	0.457 (10)	0.436 (10)
266	0.53 (6)	0.7 (1)		0.50 (3)	0.520 (10)	0.500 (30)	0.488 (8)	0.502 (9)	2.3	1.027	0.516 (19)	0.492 (9)
307					0.022 (6)	0.020 (5)	0.026 (7)	0.022 (3)		1.027	0.023 (3)	0.022 (3)
328	21.2 (6)	22 (2)	21.46 (22)	21.5 (6)	21.5 (4)	21.7 (4)	21.1 (3)	21.2 (3)	5.0	1.027	21.8 (3)	20.8 (3)
397					0.078 (3)	0.070 (5)	0.077 (5)	0.0763(24)	1.15	1.027	0.0784 (25)	0.0748 (24)
432	3.0 (4)	3.5 (2)	3.08 (3)	2.96 (16)	3.05 (3)	2.97 (15)	3.04 (3)	3.056 (17)	1.01	1.027	3.139 (17)	2.995 (16)
438					0.006 (3) *	<0.0014	0.041 (10)	0.0 18 (10)	4.1	1.027	0.018 (10)	0.017 (10)
444					0.005 (3)	0.0036 (12)	0.003 (1)	0.0034 7)		1.027	0.0035 (7)	0.0033 (7)
487	46.2 (11)	47 (2)	47.7 (5)	47.3 (9)	46.6 (9)	46.4 (8)	47.7 (6)	47.0 (4)	2.6	1.027	48.3 (4)	46.1 (4)
618					0.049 (6)	0.014 (3) #	0.039 (4)	0.042 (3)	1.12	1.015	0.043 (3)	0.041 (3)
751	4.40 (17)	4.6 (1)	4.65 (5)	4.37 (22)	4.45 (5)	4.36 (16)	4.54 (4)	4.536 (25)	1.10	1.015	4.604 (25)	4.392 (24)

815	23.8 (6)	24.2 (4)	24.85 (25)	24.1 (5)	24.0 (4)	23.5 (7)	24.4 (2)	24.49 (13)	1.43	1.015	24.86 (13)	23.72 (12)
867	6.0 (5)	5.8 (3)	5.90 (6)	5.69 (10	5.69 (6)	5.56 (19)	5.77 (7)	5.77 (3)		1.015	5.85 (3)	5.58 (3)
919	3.1 (4)	2.6 (2)	2.91 (4)	2.57 (14)	2.83 (4)	2.80 (9)	2.79 (3)	2.812 (24)	1.65	1.015	2.862 (24)	2.730 (23)
925	7.3 (8)	7.2 (3)	7.42 (8)	7.25 (16)	7.26 (8)	7.10 (21)	7.23 (7)	7.27 (4)		1.015	7.38 (4)	7.04 (4)
950	0.63 (12)	0.67 (6)			0.553 (7)	0.56 (3)	0.544 (7)	0.549 (5)		1.015	0.557 (5)	0.531 (5)
992						0.009 (3)	0.014 (5)	0.0103 (26)		1.015	0.0105 (26)	0.0100 (25)
1045					0.024 (4)	0.016 (4)	0.026 (15)	0.0202 (29)	1.08	1.015	0.021 (3)	0.020 (3)
1097					0.024 (5)	0.022 (5)	0.024 (5)	0.0233 (29)		1.015	0.024 (3)	0.023 (3)
1303					0.046 (6)	0.050 (7)	0.044 (7)	0.047 (4)		1.000	0.047 (4)	0.045 (4)
1405					0.066 (9)	0.068 (8)	0.062 (7)	0.065 (5)		1.000	0.065 (5)	0.062 (5)
1596	100.0	100.0 (3)	100 (1)	100.0 (3)	100.0	100.	100.0 (15)	100.0		1.000	100.0	95.40 (8)
1877						0.042 (6)	0.043 (4)	0.043 (3)		1.000	0.043 (3)	0.041 (3)
1924					0.014 (3)	0.006 (2)	0.014 (2)	0.0115 (28)	5.0	1.000	0.012 (3)	0.011 (3)
2083					0.045 (3)	0.007 (2) #	0.031 (2)	0.038 (7)	11	1.000	0.038 (7)	0.036 (7)
2347		0.90 (4)	0.891 (16)		0.89 (1)	0.89 (3)	0.89 (3)	0.890 (7)		0.996	0.886 (7)	0.845 (7)
2464					0.012 (1)	0.008 (1)	0.012 (2)	0.0102 (14)	4.4	0.996	0.0102 (14)	0.0097 (13)
2521		3.5 (2)	3.62 (7)	3.65 (18)	3.58 (5)	3.61 (9)	3.63 (4)	3.591 (25)		0.996	3.577 (25)	3.412 (24)
2547			0.109 (3)		0.105 (2)	0.109 (5)	0.106 (3)	0.1070 (13)		0.996	0.1066 (13)	0.1017 (12)
2899			0.069 (1)		0.070 (1)	0.069 (3)	0.070 (2)	0.0695 (6)		0.996	0.0692 (6)	0.0660 (6)
3118			0.027 (1)		0.027 (1)	0.028 (2)	0.026 (1)	0.0269 (5)		0.996	0.0268 (5)	0.0256 (5)
3320					0.0040 (3)	0.0045 (4)	0.0040 (3)	0.00413 (19)		0.996	0.00411 (19)	0.00392 (18)

Comments on Table 2 :

* Uncertainties were increased in LRSW analysis to reduce relative weight to 50%; this change is only made if the reduced-χ^2 is greater than the associated critical value. These changes were: 131 keV, 1991Ch05 0.010 to 0.012; 241, 1991Ch05 0.008 to 0.0087; and 438 keV, 1980Ka32 0.003 to 0.007.

@ Uncertainties were increased by evaluator due to large deviation from average. These changes were: 109 keV, 1980Ka32 0.01 to 0.02; 131, 1980Ka32 0.01 to 0.02; 266, 1970Ka18 0.03 to 0.06; 328, 1970Ka18 0.1 to 0.3; and 487, 1970Ka18 0.2 to 0.5.

Deleted from calculation.

The K x-ray intensities are from the measured data.

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