^{63}Zn – Comments on evaluation of decay data
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Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) and other analytical techniques were applied to obtain averaged data 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

^{63}Zn ($T_{½}$ = 38.33 min) decays 100 % by electron capture/β^+ decay (Q(EC) = 3366.2 (15) keV) to various excited nuclear levels and the ground state of ^{63}Cu (stable). A reasonably well-defined decay scheme was derived from the gamma-ray measurements of 1967De08, 1969Bo15, 1970Ki06, 1971GiZS, 1974Kl02 and 1982Gr10, consisting of 20 EC/8 β^+ transitions and 64 gamma-ray emissions. Weighted mean relative emission probabilities were calculated for a majority of the main gamma rays, while equivalent data for the other gamma transitions were adopted primarily from the more comprehensive measurements of 1974Kl02; all of these relative emission probabilities were defined in terms of the 669.93-keV gamma ray (100 %).

Nuclear Data

^{63}Zn decay is viewed as a potentially suitable beam monitor for the cyclotron production of β^+ emitters adopted in positron emission tomography (PET).

Half-life

The measurements of 1938St05, 1939De01, 1947Hu20, 1959Ri38, 1961Cu02, 1968Go10, 1969Bo11, 1969Bo15, 1972Cr02, 1974Co16, 1982Gr10 and 2000Le02 were adopted to give a weighted mean half-life of 38.33(10) minutes based on the limitation of relative statistical weight method (LWM).

Reference	Half-life (min)
1938St05	38.3 (5)
1939Bo05	38*
1939De01	38.5 (8)
1947Hu20	38.3 (5)
1948Wa13	38.3*
1959Ri38	38.1 (3)
1960Pr05	36 (2)‡
1961Cu02	38.4 (2)
1961Ra06	39.9 (8)‡
1961Va08	37.6 (3)‡
1965Pa18	39.0 (1)‡
1968Go10	38.4 (1)
1969Bo11	37.9 (2)
1969Bo15	38.5 (1)
1972Cr02	38.6 (2)†
1974Co16	38.0 (1)
1982Gr10	38.47 (5)#
2000Le02	38.1 (8)
Recommended value	38.33 (10)§

* Uncertainty not specified – not included in weighted mean analysis of the data set.
‡ Defined as an outlier, and therefore not adopted in the analytical procedures.
† Weighted mean of seven separate measurements (eighth measurement defined as an outlier), with an uncertainty of 0.2 adopted to align with the smallest uncertainty of the values used to calculate the average value.
# Only the statistical uncertainty was defined by the authors to be 0.05 at the 1σ level – uncertainty has been increased by a factor of two (to 0.10) as a means of introducing an artificial systematic component.
§ Recommended uncertainty has been adjusted from 0.05 to 0.10, in alignment with the smallest uncertainty of the values used to calculate the average value.

Limitation of relative statistical weight method (LWM), normalised residual method (NRM), Rajeval technique, bootstrap method, and Mandel-Paule approach were considered in the analysis of the data set.

Analytical method	Half-life (min)	$\chi^2/(N-1)$	$\chi^2/(N-1)_{critical}$
LWM	38.33 (5)*	2.14	2.25
NRM	38.37 (5)*	1.54	1.79
Rajeval	38.41 (5)*	0.91	−
Bootstrap	38.34 (10)	2.14	−
Mandel-Paule	null result	−	−

* Uncertainty increased from 0.05 to 0.10, in alignment with the smallest measured uncertainty of the values used to calculate the average value.

A half-life value of 38.33 (10) minutes is recommended, as quantified by the LWM analytical procedure.

Q value

Q_{EC}-value for ^{63}Zn EC decay of 3366.2 (15) keV was adopted from Wang *et al.* (2012Wa38).

Gamma-ray energies and emission probabilities

Energies

The well-defined nuclear level energies of 2001Ba27 were used to calculate the gamma transition energies and their uncertainties, and these data were adjusted to account for gamma recoil in the formulation of recommended gamma-ray emission energies and uncertainties. Greater confidence was placed on this approach because of the more wide-ranging origins of the gamma transition data even though the energies of a significant number of gamma-ray emissions have been directly measured by 1967De08, 1969Bo15, 1970Ki06, 1971GiZS and 1974Kl02.

Adopted energies, spins and parities for the nuclear levels of ^{63}Cu (2001Ba27).

Nuclear level number	Nuclear level energy (keV)	Spin and parity
0	0.0	3/2 −
1	669.93 (4)	1/2 −
2	962.02 (3)	5/2 −
3	1326.76 (5)	7/2 −
4	1412.16 (4)	5/2 −
5	1547.00 (5)	3/2 −
6	1860.63 (6)	7/2 −
7	2012.92 (11)	3/2 −
8	2062.45 (8)	(1/2) −
9	2081.32 (22)	5/2 (−)
10	2092.13 (10)	7/2 −
11	2336.54 (12)	5/2 −
12	2497.19 (9)	(3/2 −)
13	2511.06 (6)	1/2, 3/2, 5/2
14	2535.83 (7)	(5/2) −
15	2696.66 (13)	1/2 −, 3/2 −
16	2716.47 (9)	3/2 −, 5/2 −
17	2780.23 (21)	(1/2 −, 3/2 −)
18	2808.10 (8)	3/2 −
19	2857.9 (3)	(1/2 −, 3/2 −)
20	2888.9 (4)	1/2 −, 3/2, 5/2 −
21	3042.59 (8)	(5/2 −)
22	3101.4 (4)	1/2 −, 3/2 −

Gamma transition energies, and measured and recommended gamma-ray energies.

E_{TP} (keV)#	Eγ (keV)									
	1959Ha10	**1959Ri38**	**1961Cu02**	**1961Va08**	**1967De08**	**1969Bo15**	**1970Ki06**	**1971GiZS**	**1974Kl02**	**Recommended**§
244.40 (22)	–	–	–	–	–	–	–	–	244.26 (50)	244.40 (22)
364.74 (6)	–	–	–	–	–	364.5 (20)*	–	–	365.22 (40)	364.74 (6)
443.70 (12)	–	–	–	–	–	–	–	–	443.13 (20)	443.70 (12)
450.14 (5)	–	–	–	–	–	450.0 (5)	449.8 (10)	450.0 (2)	449.93 (5)	450.14 (5)
475.91 (13)	–	–	–	–	–	–	–	–	475.8 (9)	475.91 (13)
–	–	511	511	detected	511	511.0	511	511.0	511.0	annihilation radiation
515.45 (9)	–	–	–	–	–	–	–	–	515.0 (10)*	515.45 (9)
534.32 (23)	–	–	–	–	–	–	–	–	533.8 (6)	534.32 (23)
584.98 (6)	–	–	–	–	–	–	–	585.2 (5)	584.82 (15)	584.98 (6)
624.34 (13)	–	–	–	–	–	–	–	624.1 (6)	624.26 (30)	624.34 (13)
669.93 (4)	670 (20)	670 (5)	669 (2)†	–	688 (1) (	669.6 (2)	669.75 (20)	669.71 (10)	669.62 (5)	669.93 (4)
675.20 (9)	–	–	–	–	(	–	–	–	675.03 (60)	675.20 (9)
683.74 (17)	–	–	–	680 (10)	(	684.7 (17)	–	–	685.6 (6)	683.74 (17)
742.23 (6)	–	–	–	–	–	742.5 (5)	742.0 (10)	742.5 (5)	742.25 (10)	742.23 (6)
754.56 (23)	–	–	–	–	–	–	–	754.4 (7)	754.81 (80)	754.56 (23)
765.37 (11)	–	–	–	–	–	–	–	–	765.7 (5)	765.37 (11)
–	–	810 (10)	–	–	–	–	–	–	–	–
877.07 (6)	–	875 (10)	–	–	–	–	–	–	877.2 (8)	877.06 (6)
898.61 (7)	–	–	–	–	–	–	–	899.2 (6)	899.02 (40)	898.60 (7)
924.38 (13)	–	–	–	–	–	923.5 (10)	–	924.6 (6)	924.30 (50)	924.37 (13)
962.02 (3)	960 (30)	966 (6)	962 (2)†	970 (10)	961 (1)	961.9 (2)	962.1 (2)	962.14 (10)	962.06 (4)	962.01 (3)
988.83 (9)	–	–	–	–	–	–	–	–	989.6 (7)	988.82 (9)
1050.90 (11)	–	–	–	–	–	–	–	–	1048.78 (50)	1050.89 (11)
–	–	–	–	–	–	1087 (2)	–	–	–	–
–	–	1100 (20)	–	–	–	–	–	–	–	–
–	–	–	–	–	1116 (2)	–	–	–	–	^{65}Zn decay
1123.67 (8)	–	–	–	–	–	1123.7 (3)	1123.6 (10)	1123.8 (6)	1123.72 (7)	1123.66 (8)
1130.11 (10)	–	–	–	–	–	–	–	1130.6 (5)	1130.67 (25)	1130.10 (10)
1149.66 (14)	–	–	–	–	–	1150 (2)	–	1149.6 (3)	1149.50 (16)	1149.65 (14)
1169.47 (10)	–	–	–	–	–	1168 (3)	–	–	1169.62 (30)	1169.46 (10)
–	–	–	–	–	–	1189 (3)	–	–	–	–
1209.07 (9)	–	–	–	–	–	1208 (2)	1209.1 (10)	1208.6 (8)	1208.78 (3)	1209.06 (9)
1233.23 (22)	–	–	–	–	–	–	–	–	1233.7 (5)	1233.22 (22)
–	–	1270 (20)	–	–	–	–	–	–	–	–
1326.76 (5)	–	1350 (20)	1330	1350 (20)	1327 (4)	1326.4 (3)	1327.1 (10)	1327.0 (4)	1327.03 (8)	1326.75 (5)

1342.99 (12)	–	–	–	–	–	–	1340.0 (10)	–	1341.7 (6)	1342.97 (12)
1374.52 (12)	–	–	–	–	–	1374.3 (3)	1374.4 (10)	1374.4 (3)	1374.47 (13)	1374.50 (12)
1389.71 (10)	–	–	–	–	?	–	–	1389.5 (6)	1389.66 (8)	1389.69 (10)
1392.52 (9)	–	–	–	–	1390 (4)	1391.5 (4)	1392.1 (10)	1392.3 (5)	1392.55 (8)	1392.50 (9)
1412.16 (4)	1440 (30)	1440 (30)	1420 (30)	1430 (20)	1412 (1)	1411.9 (2)	1412.1 (10)	1412.07 (20)	1412.08 (5)	1412.14 (4)
1445.7 (3)			–	–	–	–	–	–	1445.8 (4)	1445.7 (3)
1481.34 (9)	–		–	–	–	–	–	–	1479.08 (50)	1481.32 (9)
1547.00 (5)	–	1560 (30)	1550 (50)	1540 (20)	1548 (1)	1546.9 (2)	1546.6 (10)	1546.8 (6)	1547.04 (6)	1546.98 (5)
1573.81 (8)	–		–	–	1573 (4)	1574.0 (20)	1573.3 (10)	1573.4 (5)	1573.71 (20)	1573.79 (8)
1666.61 (13)	–	1670 (30)	–	–	–	–	–	–	1667.2 (6)	1666.59 (13)
1696.6 (10)$^{\Delta}$	–	–	–	–	1700 (4)	–	–	–	1696.6 (10)	1696.6 (10)$^{\Delta}$
1754.45 (9)	–	–	–	–	–	–	–	–	1754.89 (50)	1754.42 (9)
–	–	1800 (30)	–	–	–	1816.9 (10)	–	–	–	–
1827.26 (10)	–	–	1830 (40)?	–	1822 (4)	–	–	1825.4 (6)	1827.0 (5)	1827.23 (10)
1860.63 (6)	–	–	–	–	–	–	?	1860.9 (6)	1861.34 (30)	1860.60 (6)
1865.90 (8)	–	–	–	–	–	1865.3 (3)	1863.4 (10)	1865.7 (6)	1866.08 (30)	1865.87 (8)
1926.9 (4)	–	1900 (40)	–	–	–	1926.4 (20)	–	1926.8 (8)	1927.18 (70)	1926.9 (4)
2012.92 (11)	2000?	–	–	–	–	2012.0 (5)	2010.9 (10)	2012.0 (5)	2011.44 (50)	2012.89 (11)
2026.73 (14)	–	2040 (40)	2040 (40)	–	–	2027.2 (5)	2026.7 (10)	2026.9 (3)	2026.81 (30)	2026.70 (14)
2046.54 (10)	–	–	–	–	–	2048.6 (15)	–	2047.2 (8)	2046.44 (80)	2046.50 (10)
2062.45 (8)	–	–	–	–	2059 (4)	2062.0 (8)	2062.7 (10)	2062.3 (5)	2062.11 (30)	2062.41 (8)
2081.32 (22)	–	–	–	–	2082 (5)	2082.0 (5)	2082.1 (10)	2081.4 (7)	2081.44 (30)	2081.28 (22)
2092.13 (10)	–	–	–	–	–	–	–	2092.5 (8)	2092.64 (50)	2092.09 (10)
–	–	2140 (40)	–	–	–	2103.2 (30)	–	2103.3 (12)	–	–
2110.30 (21)	–	–	–	–	–	–	–	2110.6 (6)	2110.76 (50)	2110.26 (21)
2181.8 (7)$^{\Delta}$	–	–	–	–	–	–	–	–	2181.8 (7)	2181.8 (7)$^{\Delta}$
2188.0 (3)	–	–	–	–	–	–	–	–	2188.0 (7)	2188.0 (3)
2219.0 (4)	–	–	–	–	–	–	–	–	2219.91 (70)	2219.0 (4)
2336.54 (12)	2350 (50)	2330 (40)	2340 (40)	2300 (30)	2337 (2)	2336.5 (2)	2336.7 (10)	2336.8 (3)	2336.54 (30)	2336.49 (12)
–	–	–	–	–	2394 (4)	–	–	–	–	–
2497.19 (9)	–	–	–	–	2497 (4)	2497.7 (4)	2497.1 (10)	2497.5 (6)	2497.43 (40)	2497.14 (9)
2511.06 (6)	–	–	–	–	–	2512.0 (5)	2512.1 (10)	2512.5 (5)	2511.97 (50)	2511.01 (6)
2535.83 (7)	2550 (50)	2550 (50)	2550 (50)	–	2535 (2)	2535.9 (2)	2536.2 (10)	2536.2 (4)	2536.02 (30)	2535.78 (7)
–	–	–	–	–	2617 (6)	–	–	–	–	–
2696.66 (13)	–	2690 (50)	–	–	2694 (2)	2696.7 (2)	2696.7 (10)	2697.0 (4)	2696.57 (30)	2696.60 (13)
2716.47 (9)	–	–	–	–	–	2717.0 (5)	2716.8 (10)	2717.2 (5)	2716.89 (40)	2716.41 (9)
–	–	–	–	–	2767 (4)	–	–	–	–	–
2780.23 (21)	2750 (70)	2780 (60)	2770 (60)	–	2781 (4)	2780.1 (20)	2780.1 (10)	2780.6 (3)	2780.29 (40)	2780.16 (21)

2808.10 (8)	–	–	–	–	2805 (4)	2806.5 (4)	2807 (2)	2807.1 (6)	2806.62 (60)	2808.03 (8)
2857.9 (3)	–	–	–	–	2856 (4)	2857.4 (10)	2856 (2)	2857.8 (7)	2857.56 (80)	2857.8 (3)
–	–	–	–	–	2880 (4)	2882.1 (20)‡	–	–	–	–
2888.9 (4)	–	~ 2900	–	–	–	2891.1 (15)	2890 (2)	2889.5 (5)	2889.44 (80)	2888.8 (4)
3042.59 (8)	–	–	–	–	–	3044.9 (10)	3044 (2)	3044.0 (7)	3044.56 (80)	3042.51 (8)
–	–	–	–	–	–	3090.8 (2)‡	–	–	–	–
3101.4 (4)	–	–	3100 (80)	–	–	3100.9 (7)	3101 (2)	3100.3 (10)	3100.65 (80)	3101.3 (4)

Determined from the nuclear level energies of 2001Ba27.
§ Calculated by subtracting gamma recoil from gamma transition energy (E_{TP} (keV)).
* Data derived from coincidence measurements.
† Energy determined from conversion-electron spectrum.
Δ Unplaced in proposed decay scheme.
‡ Inadequate data arising from insufficient statistics.

Emission Probabilities

Relative gamma-ray emission probabilities have been partially or fully determined in the measurements of 1967De08, 1969Bo15, 1970Ki06, 1971GiZS, 1974Kl02 and 1982Gr10. While greater emphasis was placed on the measurements of 1971GiZS and 1974Kl02, the equivalent studies of 1969Bo15, 1970Ki06 and 1982Gr10 proved to be significant in the weighted-mean analyses of specific gamma-ray emissions. All of the relative emission probabilities were suitably refined and quantified in terms of the emission probability of the 669.93-keV gamma ray (100.0 %).

The determination of both the N_γ(669.93 keV) / $N_{\beta+}$ ratio and associated spectral correction by 1969Bo15 were of great importance in the calculation of the normalisation factor for the relative emission probabilities of the gamma rays and the resulting derivation of a consistent decay scheme:

N_γ(669.93 keV) / $N_{\beta+}$ = 9.14 (36) / 100 = 0.0914 (36)

In-flight annihilation and formation of ortho-positronium mitigates against immediate 100 % positron annihilation, and creates a shortfall in the resulting 511-keV detection of the order of 3.4 % that impacts in a similar manner with respect to the quantification of $N_{\beta+}$:

correction to N_γ(669.93 keV) / $N_{\beta+}$ constitutes a reduction of 0.0914 (36) x 0.034 = 0.00311 (12),

and therefore N_γ(669.93 keV) / $N_{\beta+}$ = 0.0914 (36) – 0.0031 = 0.0883 (35)

Published gamma-ray emission probabilities.

E_γ (keV)	**P_γ**									
	1959Ha10	**1959Ri38**	**1961Cu02**	**1961Va08**	**1967De08#**	**1969Bo15#**	**1970Ki06#**	**1971GiZS***	**1974Kl02***	**1982Gr10***
244.40 (22)	–	–	–	–	–	–	–	–	0.065 (10)	–
364.74 (6)	–	–	–	–	–	0.02 (1)θ	–	–	0.14 (3)	–
443.70 (12)	–	–	–	–	–	–	–	–	0.20 (5)	–
450.14 (5)	–	–	–	–	–	0.27 (5)	0.2 (1)	2.7 (2)	2.88 (20)	–
475.91 (13)	–	–	–	–	–	–	–	–	0.07 (4)	–
511	–	200	200	intense	200	200	200	2188	–	–
515.45 (9)	–	–	–	–	–	–	–	–	0.26 (10)θ	–
534.32 (23)	–	–	–	–	–	–	–	–	0.06 (2)	–
584.98 (6)	–	–	–	–	–	–	–	0.22 (10)	0.40 (5)	–

624.34 (13)	–	–	–	–	–	–	–	0.18 (5)	0.17 (4)	–
669.93 (4)	intense	14.0 (8)	9.0 (6)	–	9.5 (5) (	9.14 (36)	9.7 (2)	100	100	100
675.20 (9)	–	–	–	–	(	–	–	–	0.18 (4)	–
683.74 (17)	–	–	–	detected	(	0.041 (15)	–	–	0.05 (2)	–
742.23 (6)	–	–	–	–	–	0.079 (12)	0.07 (4)	0.76 (13)	0.82 (10)	–
754.56 (23)	–	–	–	–	–	–	–	0.33 (15)	0.08 (3)	–
765.37 (11)	–	–	–	–	–	–	–	–	0.08 (3)	–
810 (10)†	–	1.8 (1)	–	–	–	–	–	–	–	–
877.06 (6)	–	1.2 (1)	–	–	–	–	–	–	0.04 (2)	–
898.60 (7)	–	–	–	–	–	–	–	0.16 (6)	0.15 (3)	–
924.37 (13)	–	–	–	–	–	0.023 (8)	–	0.13 (6)	0.120 (24)	–
962.01 (3)	intense	10.0 (9)	6.7 (7)	detected	7.5 (5)	7.20 (20)	7.8 (2)	79.8 (32)	78.7 (40)	76.6 (19)
988.82 (9)	–	–	–	–	–	–	–	–	0.047 (13)	–
1050.89 (11)	–	–	–	–	–	–	–	–	0.054 (14)	–
1087 (2)†	–	–	–	–	–	0.029 (10)	–	–	–	–
1100 (20)†	–	0.70 (10)	–	–	–	–	–	–	–	–
1116 (2)†	–	–	–	–	detected	–	–	–	–	–
1123.66 (8)	–	–	–	–	–	0.14 (3)	0.16 (4)	1.3 (2)	1.35 (14)	–
1130.10 (10)	–	–	–	–	–	–	–	0.13 (4)	0.16 (3)	–
1149.65 (14)	–	–	–	–	–	0.027 (5)	–	0.21 (5)	0.23 (3)	–
1169.46 (10)	–	–	–	–	–	0.018 (4)	–	–	0.094 (20)	–
1189 (3)†	–	–	–	–	–	0.02 (1)	–	–	–	–
1209.06 (9)	–	–	–	–	–	0.014 (4)	0.03 (1)	0.17 (6)	0.15 (3)	–
1233.22 (22)	–	–	–	–	–	–	–	–	0.03 (1)	–
1270 (20)†	–	0.30 (5)	–	–	–	–	–	–	–	–
1326.75 (5)	–	0.41 (5)	< 0.05	detected	0.07 (4)	0.090 (11)	0.08 (2)	0.84 (6)	0.84 (5)	–
1342.97 (12)	–	–	–	–	–	–	0.06 (2)	–	0.03 (1)	–
1374.50 (12)	–	–	–	–	–	0.044 (8)	0.04 (2)	0.41 (6)	0.42 (3)	–
1389.69 (10)	–	–	–	–	0.17 (5) (	0.16 (1) (	0.17 (3) (	0.44 (9)	0.52 (7)	–
1392.50 (9)	–	–	–	–	(	(	(	1.24 (12)	1.18 (18)	–
1412.14 (4)	modest	0.80 (7)	0.94 (15)	detected	0.95 (8)	0.80 (3)	0.93 (10)	9.3 (4)	9.08 (36)	8.85 (30)
1445.7 (3)	–	–	–	–	–	–	–	–	0.03 (1)	–
1481.32 (9)	–	–	–	–	–	–	–	–	0.02 (1)	–
1546.98 (5)	–	0.20 (5)	0.12 (3)	detected	0.14 (2)	0.13 (2)	0.17 (3)	1.6 (1)	1.49 (6)	–
1573.79 (8)	–	–	–	–	0.02 (1)	0.013 (4)	0.024 (10)	0.19 (7)	0.20 (2)	–
1666.59 (13)	–	0.60 (3)	–	–	–	–	–	–	0.017 (7)	–
1696.6 (1.0)Δ	–	–	–	–	0.03 (1)	–	–	–	0.024 (12)	–
1754.42 (9)	–	–	–	–	–	–	–	–	0.053 (12)	–

1816.9 (10)[†]	–	0.02 (1)	–	–	–	0.0028 (3)	–	–	–	–
1827.23 (10)	–	–	0.02 (1)?	–	0.02 (1)	–	–	0.11 (4)	0.051 (13)	–
1860.60 (6)	–	–	–	–	–	0.035 (3) (	0.035 (20) (	0.24 (5)	0.170 (24)	–
1865.87 (8)	–	–	–	–	–	(	(	0.26 (5)	0.240 (26)	–
1926.9 (4)	–	0.08 (1)	–	–	–	0.006 (1)	–	0.082 (25)	0.070 (14)	–
2012.89 (11)	very weak	–	–	–	–	0.011 (2)	0.015 (5)	0.14 (3)	0.13 (2)	–
2026.70 (14)	–	0.12 (1)	0.14 (3)	–	–	0.060 (10)	0.08 (2)	0.78 (5)	0.68 (7)	–
2046.50 (10)	–	–	–	–	–	0.007 (1)	–	0.041 (14)	0.045 (13)	–
2062.41 (8)	–	–	–	–	0.04 (1)	0.032 (7)	0.04 (4)	0.41 (6)	0.42 (4)	–
2081.28 (22)	–	–	–	–	0.03 (2)	0.015 (4)	0.02 (1)	0.21 (5)	0.18 (2)	–
2092.09 (10)	–	–	–	–	–	–	–	0.057 (25)	0.03 (1)	–
2103.3 (12)[†]	–	0.06 (1)	–	–	–	0.003 (2)	–	0.069 (30)	–	–
2110.26 (21)	–	–	–	–	–	–	–	0.087 (22)	0.075 (15)	–
2181.8 (7)[Δ]	–	–	–	–	–	–	–	–	0.016 (10)	–
2188.0 (3)	–	–	–	–	–	–	–	–	0.02 (1)	–
2219.0 (4)	–	–	–	–	–	–	–	–	0.036 (10)	–
2336.49 (12)	weak	0.05 (1)	0.07 (2)	detected	0.080 (8)	0.095 (6)	0.09 (2)	0.99 (8)	0.91 (6)	–
2394 (4)[†]	–	–	–	–	0.010 (5)	–	–	–	–	–
2497.14 (9)	–	–	–	–	0.015 (5)	0.023 (2)	0.03 (2)	0.25 (3)	0.26 (3)	–
2511.01 (6)	–	–	–	–	–	0.013 (2)	0.009 (5)	0.12 (3)	0.12 (2)	–
2535.78 (7)	weak	0.08 (1)	0.06 (2)	–	0.07 (2)	0.077 (4)	0.09 (2)	0.80 (5)	0.81 (8)	–
2617 (6)[†]	–	–	–	–	0.005 (3)	–	–	–	–	–
2696.60 (13)	–	0.04 (1)	–	–	0.03 (1)	0.043 (8)	0.05 (2)	0.48 (4)	0.49 (5)	–
2716.41 (9)	–	–	–	–	–	0.012 (2)	0.016 (5)	0.140 (12)	0.16 (2)	–
2767 (4)[†]	–	–	–	–	0.009 (5)	–	–	–	–	–
2780.16 (21)	weak	0.03 (1)	0.04 (2)	–	0.010 (5)	0.018 (2)	0.018 (5)	0.180 (15)	0.19 (2)	–
2808.03 (8)	–	–	–	–	0.005 (2)	0.0027 (6)	0.005 (2)	0.039 (7)	0.05 (1)	–
2857.8 (3)	–	–	–	–	0.003 (1)	0.0033 (7)	0.004 (2)	0.032 (6)	0.04 (1)	–
2882.1 (20)[†]	–	–	–	–	0.0025 (10) (	0.0010 (3)[‡]	–	–	–	–
2888.8 (4)	–	< 0.02	–	–	(	0.0024 (5)	0.003 (1)	0.026 (3)	0.03 (1)	–
3042.51 (8)	–	–	–	–	< 0.004	0.0050 (10)	0.006 (1)	0.058 (10)	0.06 (1)	–
3090.8 (2)[†]	–	–	–	–	–	0.0004 (2)[‡]	–	–	–	–
3101.3 (4)	–	–	0.02 (1)	–	–	0.0008 (2)	0.002 (1)	0.009 (4)	0.007 (2)	–

[#] Emission probabilities expressed relative to P_γ for 511-keV annihilation radiation of 200 %.
[*] Emission probabilities expressed relative to P_γ(669.93 keV) of 100 %.
[θ] Data derived from coincidence measurements.
[†] Gamma emission not observed with confidence and regularity – not considered as identifiable with ^{63}Zn decay, and therefore not included in the proposed decay scheme.
[Δ] Unplaced in proposed decay scheme.
[‡] Inadequate data arising from insufficient statistics.

Measured and recommended gamma-ray emission probabilities relative to P_{γ}(669.93 keV) of 100 %.

Eγ (keV)	P_{γ}^{rel}						
	1967De08[#]	1969Bo15[#]	1970Ki06[#]	1971GiZS	1974Kl02	1982Gr10	Recommended[†]
244.40 (22)	–	–	–	–	**0.065 (10)**	–	0.065 (10)
364.74 (6)	–	0.2 (1)[θ]	–	–	**0.14 (3)**	–	0.14 (3)
443.70 (12)	–	–	–	–	0.20 (5)	–	**0.16 (5)**
450.14 (5)	–	**3.0 (6)**	**2 (1)**	**2.7 (2)**	**2.88 (20)**	–	2.79 (20)
475.91 (13)	–	–	–	–	**0.07 (4)**	–	0.07 (4)
511	2105	2188	2062	2188	–	–	annihilation radiation
515.45 (9)	–	–	–	–	**0.26 (10)**[θ]	–	0.26 (10)
534.32 (23)	–	–	–	–	**0.06 (2)**	–	0.06 (2)
584.98 (6)	–	–	–	0.22 (10)	**0.40 (5)**	–	0.40 (5)
624.34 (13)	–	–	–	0.18 (5)	0.17 (4)	–	**0.14 (5)**
669.93 (4)	100 (5) (	100 (4)	100 (2)	100	100	100	100
675.20 (9)	(	–	–	–	**0.18 (4)**	–	0.18 (4)
683.74 (17)	(	0.45 (16)	–	–	**0.05 (2)**	–	0.05 (2)
742.23 (6)	–	**0.86 (13)**	0.7 (4)	**0.76 (13)**	**0.82 (10)**	–	0.82 (10)
754.56 (23)	–	–	–	0.33 (15)	0.08 (3)	–	**0.19 (7)**
765.37 (11)	–	–	–	–	**0.08 (3)**	–	0.08 (3)
877.06 (6)	–	–	–	–	**0.04 (2)**	–	0.04 (2)
898.60 (7)	–	–	–	0.16 (6)	0.15 (3)	–	**0.11 (4)**
924.37 (13)	–	0.25 (9)	–	**0.13 (6)**	**0.120 (24)**	–	0.121 (24)
962.01 (3)	**79 (5)**	**78.8 (22)**	**80 (2)**	**79.8 (32)**	**78.7 (40)**	**76.6 (19)**[§]	79.4 (20)
988.82 (9)	–	–	–	–	**0.047 (13)**	–	0.047 (13)
1050.89 (11)	–	–	–	–	**0.054 (14)**	–	0.054 (14)
1123.66 (8)	–	**1.5 (3)**	**1.6 (4)**	**1.3 (2)**	**1.35 (14)**	–	1.37 (14)
1130.10 (10)	–	–	–	0.13 (4)	**0.16 (3)**	–	0.16 (3)
1149.65 (14)	–	0.30 (6)	–	**0.21 (5)**	**0.23 (3)**	–	0.23 (3)
1169.46 (10)	–	0.20 (4)	–	–	**0.094 (20)**	–	0.094 (20)
1209.06 (9)	–	0.15 (4)	0.3 (1)	**0.17 (6)**	0.15 (3)	–	0.17 (4)
1233.22 (22)	–	–	–	–	**0.03 (1)**	–	0.03 (1)
1326.75 (5)	0.7 (4)	0.98 (12)	**0.8 (2)**	**0.84 (6)**	**0.84 (5)**	–	0.84 (5)
1342.97 (12)	–	–	0.6 (2)	–	**0.03 (1)**	–	0.03 (1)
1374.50 (12)	–	**0.48 (9)**	**0.4 (2)**	**0.41 (6)**	**0.42 (3)**	–	0.42 (3)
1389.69 (10)	1.8 (5) (	1.8 (1) (	1.8 (3) (	0.44 (9)	**0.52 (7)**	–	0.52 (7)
1392.50 (9)	(	(	(	**1.24 (12)**	**1.18 (18)**	–	1.22 (12)
1412.14 (4)	10.0 (8)	**8.8 (3)**	**9.6 (10)**	**9.3 (4)**	**9.08 (36)**	**8.85 (30)**	9.0 (3)
1445.7 (3)	–	–	–	–	**0.03 (1)**	–	0.03 (1)
1481.32 (9)	–	–	–	–	**0.02 (1)**	–	0.02 (1)
1546.98 (5)	**1.5 (2)**	**1.4 (2)**	**1.8 (3)**	**1.6 (1)**	**1.49 (6)**	–	1.52 (6)
1573.79 (8)	**0.2 (1)**	**0.14 (4)**	**0.25 (10)**	**0.19 (7)**	**0.20 (2)**	–	0.19 (2)
1666.59 (13)	–	–	–	–	**0.017 (7)**	–	0.017 (7)
1696.6 (1.0)[Δ]	0.3 (1)	–	–	–	**0.024 (12)**	–	0.024 (12)
1754.42 (9)	–	–	–	–	**0.053 (12)**	–	0.053 (12)
1827.23 (10)	0.2 (1)	–	–	0.11 (4)	**0.051 (13)**	–	0.051 (13)
1860.60 (6)	–	0.38 (3) (	0.36 (21) (	0.24 (5)	0.170 (24)	–	**0.14 (4)**
1865.87 (8)	–	(	(	**0.26 (5)**	**0.240 (26)**	–	0.244 (26)
1926.9 (4)	–	**0.06 (1)**	–	**0.082 (25)**	**0.070 (14)**	–	0.065 (14)
2012.89 (11)	–	**0.12 (2)**	**0.15 (5)**	**0.14 (3)**	**0.13 (2)**	–	0.13 (2)
2026.70 (14)	–	**0.66 (11)**	**0.8 (2)**	**0.78 (5)**	**0.68 (7)**	–	0.73 (5)
2046.50 (10)	–	0.08 (1)	–	**0.041 (14)**	**0.045 (13)**	–	0.043 (13)
2062.41 (8)	**0.4 (1)**	**0.35 (8)**[§]	**0.4 (4)**	**0.41 (6)**	**0.42 (4)**	–	0.42 (4)
2081.28 (22)	**0.3 (2)**[§]	**0.16 (4)**	**0.2 (1)**	**0.21 (5)**	**0.18 (2)**	–	0.18 (2)
2092.09 (10)	–	–	–	**0.057 (25)**	0.03 (1)	–	**0.06 (3)**
2110.26 (21)	–	–	–	**0.087 (22)**	**0.075 (15)**	–	0.079 (15)
2181.8 (7)[Δ]	–	–	–	–	**0.016 (10)**	–	0.016 (10)
2188.0 (3)	–	–	–	–	**0.02 (1)**	–	0.02 (1)
2219.0 (4)	–	–	–	–	**0.036 (10)**	–	0.036 (10)
2336.49 (12)	**0.84 (8)**	**1.04 (7)**	**0.9 (2)**	**0.99 (8)**	**0.91 (6)**	–	0.94 (6)
2497.14 (9)	0.16 (5)	**0.25 (2)**	**0.3 (2)**	**0.25 (3)**	**0.26 (3)**	–	0.25 (2)

2511.01 (6)	−	**0.14 (2)**	**0.09 (5)**	**0.12 (3)**	**0.12 (2)**	−	0.13 (2)
2535.78 (7)	0.7 (2)	**0.84 (4)**	**0.9 (2)**	**0.80 (5)**	**0.81 (8)**	−	0.82 (4)
2696.60 (13)	0.3 (1)	**0.47 (9)**	**0.5 (2)**	**0.48 (4)**	**0.49 (5)**	−	0.48 (4)
2716.41 (9)	−	0.13 (2)	**0.16 (5)**	**0.140 (12)**	**0.16 (2)**	−	0.146 (12)
2780.16 (21)	0.11 (6)	**0.20 (2)**	**0.19 (5)**	**0.180 (15)**	**0.19 (2)**	−	0.188 (15)
2808.03 (8)	**0.05 (2)**	0.030 (7)	**0.05 (2)**	**0.039 (7)**	**0.05 (1)**	−	0.044 (7)
2857.8 (3)	**0.03 (1)**	**0.036 (8)**	**0.04 (2)**	**0.032 (6)**	**0.04 (1)**	−	0.034 (6)
2888.8 (4)	**0.026 (10)**	**0.026 (5)**	**0.03 (1)**	**0.026 (3)**	**0.03 (1)**	−	0.026 (3)
3042.51 (8)	< 0.04	**0.055 (11)**	**0.06 (1)**	**0.058 (10)**	**0.06 (1)**	−	0.058 (10)
3101.3 (4)	−	**0.009 (2)**	0.02 (1)	**0.009 (4)**	**0.007 (2)**	−	0.008 (2)

[#] Emission probabilities adjusted in order to be expressed relative to $P_γ$(669.93 keV) of 100 %.
[†] Weighted mean values adopted when judged appropriate.
[θ] Data derived from coincidence measurements.
[§] Defined as outlier, and therefore not adopted for consideration in the analytical procedures.
[Δ] Unplaced in proposed decay scheme.

Weighted-mean analyses of the measured relative emission probabilities were carried out when judged appropriate. However, considerably more detail can be found within the gamma-ray measurements of Giesler (1971GiZS) and, in particular, Klaasse and Goudsmit (1974Kl02). Under these circumstances, the data of 1974Kl02 and sometimes 1971GiZS were directly adopted in preference to any semi-artificial weighting procedure. The relative emission probabilities of the 443.70-, 624.34-, 754.56-, 898.60-, 1860.60- and 2092.09-keV gamma rays were subsequently adjusted from 0.20 (5), 0.17 (4), 0.08 (3), 0.15 (3), 0.183 (24) and 0.03 (1) to 0.16 (5), 0.14 (5), 0.19 (7), 0.11 (4), 0.14 (4) and 0.06 (3), respectively, to achieve population-depopulation balances for the 1326.76-, 1860.63- and 2092.13-keV nuclear levels (shown as red in the table). Both the 1696.6- and 2181.8-keV gamma rays observed only by Klaasse and Goudsmit (1974Kl02) remain within the recommended data set, although they could not be placed in the proposed decay scheme.

The normalisation factor for the relative emission probabilities of the gamma rays can be directly determined from the spectral measurements of $P_{\gamma}^{abs}(669.93\ keV)$ by 1961Cu02, 1967De08, 1969Bo15 and 1970Ki06.

	$P_{\gamma}^{abs}(669.93\ keV)$	Comments
1961Cu02	9.0 (6)	3" x 3" NaI(Tl) detector, 8 % resolution
1967De08	9.5 (5)	5 x 20 mm^2 Ge(Li) detector; defined as 688 (1) keV (presumably a misprint (668 keV)?)
1969Bo15	9.14 (36)	0.7 x 4.4 and 0.7 x 8.5 cm^2 Ge(Li) detectors; Ge(Li)-NaI(Tl) coincidence system
1970Ki06	9.7 (2)	38 cm^3 Ge(Li) detector (FWHM of 3.5 keV for 1332 keV ^{60}Co)

Inadequate spectral resolution is a significant issue in the measurements involving the NaI(Tl) detector system (1961Cu02), while the gamma-ray spectrum shown in detail by 1967De08 would appear to pose problems with respect to accurate peak-area analyses in the vicinity of 650 to 750 keV. Both 1969Bo15 and 1970Ki06 exhibit improved resolution over the gamma-ray energy range of 650 to 750 keV; however, these particular studies are not necessarily equivalent, and their reported $P_{\gamma}^{abs}(669.93\ keV)$ values do not overlap and are effectively close to being discrepant. Therefore, as described in more detail below, the normalisation factor for the relative emission probabilities of the gamma rays has been preferably determined from the $N_γ$(669.93 keV)/$N_{β+}$ ratio (1969Bo15).

Multipolarities, and Internal Conversion and Internal-Pair Coefficients

The nuclear level scheme specified by Bai and Huo Junde has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities (2001Ba27). Limited studies of the angular correlation coefficients, B(E2) values and mixing ratios support the proposed transition types: (M1 + E2) for the 364.74-, 450.14-, 669.93-, 962.01-, 1412.14- and 1546.98-keV gamma rays (1972Ro21, 1980Ku08 and 1998Si25). Other (M1 + E2) gamma transitions judged to be of reasonable importance in the derivation of the decay scheme were arbitrarily assigned multipolarities of (50 % M1 + 50 % E2) – i.e. gamma rays with energies of 443.70, 1123.66 and 1392.50 keV.

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). A significant number of gamma transitions undergo decay via internal-pair formation, and the coefficient for this process has also been quantified in a few cases from the tabulations of 2008Ki07.

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

E_γ (keV)	Multipolarity	α_K	α_L	α_{M+}	$\alpha_{totalICC}$	α_{IPF}	α_{total}
244.40 (22)	(E2)	0.019 0 (3)	0.001 98 (3)	0.000 32	0.021 3 (3)	−	0.021 3 (3)
364.74 (6)	99.64% M1 + 0.36% E2 δ = − 0.060(5) (1980Ku08)	0.001 84 (3)	0.000 184 (3)	0.000 026	0.002 05 (3)	−	0.002 05 (3)
443.70 (12)	(50% M1 + 50% E2) δ = 1.0 (2)	0.001 77 (14)	0.000 179 (14)	0.000 031	0.001 98 (16)	−	0.001 98 (16)
450.14 (5)	98.7% M1 + 1.3% E2 δ = 0.115 (10) (1980Ku08)	0.001 14 (4)	0.000 113 (5)	0.000 017	0.001 27 (5)	−	0.001 27 (5)
475.91 (13)	M1 + E2	−	−	−	−	−	−
515.45 (9)	(M1 + E2)	−	−	−	−	−	−
534.32 (23)	(M1 + E2)	−	−	−	−	−	−
584.98 (6)	M1 + E2	−	−	−	−	−	−
624.34 (13)	(E2)	−	−	−	−	−	−
669.93 (4)	98.8% M1 + 1.2% E2 δ = 0.11 (2) (1980Ku08)	0.000 466 (7)	0.000 046 2 (7)	0.000 006 8	0.000 519 (8)	−	0.000 519 (8)
675.20 (9)	(M1 + E2)	−	−	−	−	−	−
683.74 (17)	M1 + E2	−	−	−	−	−	−
742.23 (6)	E2	0.000 512 (8)	0.000 051 1 (8)	0.000 007 4	0.000 571 (8)	−	0.000 571 (8)
754.56 (23)	(M1 + E2)	−	−	−	−	−	−
765.37 (11)	M1 + E2	−	−	−	−	−	−
877.06 (6)	M1 + E2	−	−	−	−	−	−
898.60 (7)	M1 + E2	−	−	−	−	−	−
924.37 (13)	M1 + E2	−	−	−	−	−	−
962.01 (3)	81.3% M1 + 18.7% E2 δ = − 0.48 (2) (1980Ku08)	0.000 226 (4)	0.000 022 3 (4)	0.000 003 1	0.000 251 (4)	−	0.000 251 (4)
988.82 (9)	(M1 + E2)	−	−	−	−	−	−
1050.89 (11)	M1 + E2	−	−	−	−	−	−
1123.66 (8)	(50% M1 + 50% E2) δ = 1.0 (2)	0.000 171 (4)	0.000 016 9 (4)	0.000 002 5	0.000 190 (4)	0.000 001 41 (6)	0.000 192 (4)
1130.10 (10)	M1 + E2	−	−	−	−	−	−
1149.65 (14)	M1 + E2	−	−	−	−	−	−
1169.46 (10)	M1 + E2	−	−	−	−	−	−
1209.06 (9)	(M1 + E2)	−	−	−	−	−	−
1233.22 (22)	M1 + E2	−	−	−	−	−	−
1326.75 (5)	E2	0.000 126 8 (18)	0.000 012 51 (18)	0.000 001 81	0.000 141 1 (18)	0.000 034 6 (5)	0.000 175 7 (25)
1342.97 (12)	M1 + E2	−	−	−	−	−	−
1374.50 (12)	M1 + E2	−	−	−	−	−	−
1389.69 (10)	(E2)	−	−	−	−	−	−

1392.50 (9)	(50% M1 + 50% E2) δ = 1.0 (2)	0.000 109 8 (19)	0.000 010 80 (19)	0.000 001 57	0.000 122 2 (19)	0.000 045 1 (16)	0.000 167 (4)
1412.14 (4)	63.4% M1 + 36.6% E2 δ = 0.76 (7) (1980Ku08)	0.000 105 5 (16)	0.000 010 38 (15)	0.000 001 50	0.000 117 4 (16)	0.000 048 2 (10)	0.000 166 (3)
1445.7 (3)	(E2)	–	–	–	–	–	–
1481.32 (9)	E2	–	–	–	–	–	–
1546.98 (5)	86.8% M1 + 13.2% E2 δ = 0.39 (7) (1980Ku08)	0.000 087 0 (13)	0.000 008 54 (13)	0.000 001 24	0.000 096 8 (13)	0.000 084 4 (16)	0.000 181 (3)
1573.79 (8)	(M1 + E2)	–	–	–	–	–	–
1666.59 (13)	E2	–	–	–	–	–	–
1754.42 (9)	M1 + E2	–	–	–	–	–	–
1827.23 (10)	(M1 + E2)	–	–	–	–	–	–
1860.60 (6)	E2	0.000 064 6 (9)	0.000 006 35 (9)	0.000 000 98	0.000 071 9 (9)	0.000 244 (4)	0.000 316 (5)
1865.87 (8)	(E2)	0.000 064 3 (9)	0.000 006 31 (9)	0.000 000 92	0.000 071 5 (9)	0.000 247 (4)	0.000 319 (5)
1926.9 (4)	(E2)	–	–	–	–	–	–
2012.89 (11)	M1 + E2	–	–	–	–	–	–
2026.70 (14)	M1 + E2	–	–	–	–	–	–
2046.50 (10)	M1 + E2	–	–	–	–	–	–
2062.41 (8)	(M1 + E2)	–	–	–	–	–	–
2081.28 (22)	(M1 + E2)	–	–	–	–	–	–
2092.09 (10)	E2	–	–	–	–	–	–
2110.26 (21)	M1 + E2	–	–	–	–	–	–
2188.0 (3)	M1 + E2	–	–	–	–	–	–
2219.0 (4)	M1 + E2	–	–	–	–	–	–
2336.49 (12)	M1 + E2	–	–	–	–	–	–
2497.14 (9)	(M1 + E2)	–	–	–	–	–	–
2511.01 (6)	[M1 + E2]	–	–	–	–	–	–
2535.78 (7)	(M1 + E2)	–	–	–	–	–	–
2696.60 (13)	M1 + E2	–	–	–	–	–	–
2716.41 (9)	M1 + E2	–	–	–	–	–	–
2780.16 (21)	M1 + E2	–	–	–	–	–	–
2808.03 (8)	M1 + E2	–	–	–	–	–	–
2857.8 (3)	M1 + E2	–	–	–	–	–	–
2888.8 (4)	M1 + E2	–	–	–	–	–	–
3042.51 (8)	M1 + E2	–	–	–	–	–	–
3101.3 (4)	M1 + E2	–	–	–	–	–	–

The normalisation factor for the relative emission probabilities of the gamma rays has been preferentially determined from the N_γ(669.93 keV)/$N_{\beta+}$ ratio:

(a) N_γ(669.93 keV) / $N_{\beta+}$ ratio and associated spectral correction (1969Bo15)

N_γ(669.93 keV) / $N_{\beta+}$ = 0.0914 (36) – 0.0031 = 0.0883 (35),

(b) P_{EC}(total) determined from balances of the relative transition probabilities calculated from the relative emission probabilities and total conversion coefficients of the γ rays populating-depopulating the nuclear levels of ^{63}Cu, and

(c) theoretical capture-to-positron ratios (ϵ/β^+) for the EC/β+ branches to the relevant nuclear levels of ^{63}Cu (1971Go40).

Knowing the relative P_{EC}(total) that populates each nuclear level by a combination of EC and β^+ decay, and their theoretical capture-to-positron ratios, relative $P_{\beta+}$ values can be determined:

Relative positron emission probabilities calculated from P_{EC}(total) and ϵ/β^+ ratios.

	Nuclear level energy (keV)	Calculated relative P_{EC}(total)	ϵ/β^+ (1971Go40)	Relative $P_{\beta+}$
9	2081.32 (22)	0.43 (8)	79.91	0.005
8	2062.45 (8)	1.90 (16)	61.55	0.030
7	2012.92 (11)	0.164 (3)	33.38	0.005
5	1547.00 (5)	1.239 (136)	1.459	0.504 (55)
4	1412.16 (4)	11.089 (400)	0.8551	5.978 (216)
2	962.02 (3)	75.018 (2012)	0.2397	60.513 (1623)
1	669.93 (4)	96.567 (184)	0.1320	85.307 (163)
0	0.0	$X \rightarrow$ to be calculated	0.0465	X / 1.0465

Total relative positron emission probability ($P^{rel}_{\beta^+}$)

$$= \sum relative\ P_{\beta^+} = [\ (X / 1.0465) + 152.342\ (1646)\ ]$$

where X is the relative total EC transition probability (P_{EC}(total)) directly to the ground state of ^{63}Cu.

Adopting the N_γ(669.93 keV) / $N_{\beta+}$ ratio and associated spectral correction (1969Bo15)

N_γ(669.93 keV) / $N_{\beta+}$ = 0.0914 (36) – 0.0031 = 0.0883 (35),

this equation can be suitably re-arranged to accommodate the known relative transition probabilities and determine the value of X:

$$N_\gamma(669.93\ \text{keV}) = 100 \text{ x } F$$

$$N_{\beta+} = [\ (X / 1.0465) + 152.342\ (1646)\ ] \text{ x } F$$

where F is the normalisation factor for the relative emission probabilities of the gamma rays. Thus, making these substitutions in the equation that quantifies the N_γ(669.93 keV) / $N_{\beta+}$ ratio:

$$\frac{100\ x\ F}{[\ (X / 1.0465)\ +\ 152.342\ (1646)\ ]\ x\ F} = 0.0883\ (35)$$

$$\frac{100}{0.0883\ (35)} = \frac{X}{1.0465} + 152.342\ (1646)$$

which can be re-arranged to give X = [1132.503 (44890) − 152.342 (1646)] x 1.0465

= 980.161 (44920) x 1.0465 = 1025.738 (47009)

Direct γ population of the ground state of ^{63}Cu was calculated to sum to a relative transition probability of 194.864 (2027), and since the total population of this level can be expressed by the following equation:

$$\sum(\gamma\ transition\ probabilities\ direct\ to\ ground\ state) + \quad total\ EC/\beta^+\ direct\ to\ ground\ state$$

$$= 100$$

$$194.864\ (2027)\ \times\ F\ +\ 1025.738\ (47009)\ \times\ F\ =\ 100$$

$$F\ =\ 100\ /\ 1220.602\ (47053)\ =\ 0.0819\ (32)$$

When the relative EC/β^+ transition probabilities are also summed to 100 %, a normalisation factor is obtained in full agreement with the above value:

$$\sum(total\ EC/\beta^+\ transition\ probabilities\ populating\ all\ nuclear\ levels\ of\ {}^{63}Cu\ )\ =\ 100$$

$$194.93\ (208)\ \times\ F\ +\ 1025.738\ (47009)\ \times\ F\ =\ 100$$

$$F\ =\ 100\ /\ 1220.668\ (47055)\ =\ 0.0819\ (32)$$

Therefore, a value of 0.082 (3) was adopted as the normalisation factor in order to determine the absolute transition and emission probabilities of the EC, β^+ particles and γ rays from their relative transition and emission probabilities.

EC/β+ Transitions

Energies

All EC/β^+ energies were derived from the structural details of the proposed decay scheme. The nuclear level energies of 2001Ba27 and evaluated Q_{EC}-value of 3366.2 (15) keV (2012Wa38) were used to determine the recommended energies and uncertainties of the EC transitions and β^+ emissions.

Transition and Emission Probabilities

Total EC transition probabilities were derived for the population-depopulation imbalances of the relative emission probabilities of the gamma rays, their theoretical internal conversion and internal-pair formation coefficients, and a normalisation factor of 0.082 (3) for the gamma-ray emissions as calculated above. Component EC and β^+ transition and emission probabilities were determined from EC/β^+ ratios (1971Go40), and log*ft* values and average $E_{\beta+}$ energies were derived by means of the LOGFT code. Fractional EC probabilities P_K, P_L, P_M and P_N were calculated by means of the EC-CAPTURE code (1998Sc28) as developed from the data tabulations of 1995ScZY.

EC decay to the ground state of Cu-63 can be determined by two routes: (a) from the normalisation factor and relative emission probabilities of all the gamma rays that populate the ground state directly, and (b) from the normalisation factor and calculated relative transition probabilities of all EC decays to the excited nuclear levels of Cu-63.

(a) Normalisation factor and relative emission probabilities of gamma rays populating the ground state of Cu-63 directly

P_{EC} decay direct to ground state = 100 % − Σ (P_γ populating ground state of Cu-63)
= 100 − [194.864 (2027) x F]
= 100 − [194.864 (2027) x 0.0819 (32)]
= 100 − 16.0 (6) = 84.0 (6) %

(b) Normalisation factor and relative transition probabilities of EC decay to excited nuclear levels of Cu-63

P_{EC} direct decay to ground state = 100 % − Σ (P_{EC} populating excited states of Cu-63)
= 100 − [194.93 (208) x F]
= 100 − [194.93 (208) x 0.0819 (32)]
= 100 − 16.0 (6) = 84.0 (6) %

Therefore, a value and uncertainty of 84.0 (0.6) % was adopted for the total P_{EC} transition directly to the ground state of Cu-63.

The emission probability for the 511-keV annihilation radiation was derived from the total positron emission probability of 92.8 (6) % as determined during the evaluation of the EC/β+ decay mode:

$$P_\gamma^{\pm}\ =\ 2\ \times\ 92.8\ (6)\ =\ 185.6\ (0.9)\ \%$$

A consistent decay scheme was derived that consists of 20EC/8β^+ transitions and 64 gamma-ray emissions, of which 84.0 (6) % of the EC/β^+ decay occurs directly to the ground state of ^{63}Cu. Two observed gamma-ray emissions could not be placed in the proposed decay scheme, and there is also substantial 511-keV positron-annihilation radiation.

Recommended energies and transition probabilities of the EC/β^+ decay of ^{63}Zn.

	E_{EC} (keV)*	$E_{\beta+}$ (keV)	Av. $E_{\beta+}$ (keV)	P_{EC}(total)	ϵ/β^+ (theory)	P_{EC}	$P_{\beta+}$	^{63}Zn	^{63}Cu	transition type	log *ft*	P_K	P_L	P_M	P_N
$EC_{0,22}$	264.8 (16)	–	–	0.0007 (2)	–	0.0007 (2)	–	3/2 −	1/2 −, 3/2 −	allowed	6.89	0.8802 (16)	0.1020 (13)	0.0168 (5)	0.0011 (1)
$EC_{0,21}$	323.6 (15)	–	–	0.0048 (8)	–	0.0048 (8)	–	3/2 −	(5/2 −)	(allowed)	6.24	0.8814 (16)	0.1010 (13)	0.0166 (5)	0.0010 (1)
$EC_{0,20}$	477.3 (16)	–	–	0.0104 (14)	–	0.0104 (14)	–	3/2 −	1/2 −, 3/2, 5/2 −	allowed	6.24	0.8831 (16)	0.0996 (13)	0.0163 (5)	0.0010 (1)
$EC_{0,19}$	508.3 (15)	–	–	0.0069 (12)	–	0.0069 (12)	–	3/2 −	(1/2 −, 3/2 −)	(allowed)	6.48	0.8833 (16)	0.0994 (13)	0.0163 (5)	0.0010 (1)
$EC_{0,18}$	558.1 (15)	–	–	0.0052 (10)	–	0.0052 (10)	–	3/2 −	3/2 −	allowed	6.68	0.8836 (16)	0.0992 (13)	0.0162 (5)	0.0010 (1)
$EC_{0,17}$	586.0 (15)	–	–	0.0298 (21)	–	0.0298 (21)	–	3/2 −	(1/2 −, 3/2 −)	(allowed)	5.97	0.8837 (16)	0.0991 (13)	0.0162 (5)	0.0010 (1)
$EC_{0,16}$	649.7 (15)	–	–	0.082 (7)	–	0.082 (7)	–	3/2 −	3/2 −, 5/2 −	allowed	5.62	0.8840 (16)	0.0988 (13)	0.0162 (5)	0.0010 (1)
$EC_{0,15}$	669.5 (15)	–	–	0.122 (6)	–	0.122 (6)	–	3/2 −	1/2 −, 3/2 −	allowed	5.47	0.8841 (16)	0.0988 (13)	0.0161 (5)	0.0010 (1)
$EC_{0,14}$	830.4 (15)	–	–	0.261 (14)	–	0.261 (14)	–	3/2 −	(5/2) −	(allowed)	5.33	0.8846 (16)	0.0984 (13)	0.0161 (5)	0.0010 (1)
$EC_{0,13}$	855.1 (15)	–	–	0.011 (2)	–	0.011 (2)	–	3/2 −	1/2, 3/2, 5/2	[allowed]	6.73	0.8846 (16)	0.0983 (13)	0.0161 (5)	0.0010 (1)
$EC_{0,12}$	869.0 (15)	–	–	0.0247 (20)	–	0.0247 (20)	–	3/2 −	(3/2 −)	(allowed)	6.40	0.8846 (16)	0.0983 (13)	0.0161 (5)	0.0010 (1)
$EC_{0,11}$	1029.7 (15)	–	–	0.141 (9)	–	0.141 (9)	–	3/2 −	5/2 −	allowed	5.79	0.8849 (16)	0.0980 (13)	0.0160 (5)	0.0010 (1)
$EC_{0,9}$	1284.9 (15)	262.9 (15)	115.1 (6)	0.035 (7)	79.91	0.035 (7)	0.00043 (9)	3/2 −	5/2 (−)	(allowed)	6.59	0.8853 (16)	0.0978 (13)	0.0160 (5)	0.0010 (1)
$EC_{0,8}$	1303.8 (15)	281.8 (15)	123.0 (6)	0.155 (13)	61.55	0.153 (13)	0.0025 (2)	3/2 −	(1/2) −	(allowed)	5.96	0.8853 (16)	0.0978 (13)	0.0160 (5)	0.0010 (1)
$EC_{0,7}$	1353.3 (15)	331.3 (15)	143.6 (6)	0.0134 (3)	33.38	0.0130 (3)	0.00039 (2)	3/2 −	3/2 −	allowed	7.06	0.8853 (16)	0.0977 (13)	0.0160 (5)	0.0010 (1)
$EC_{0,5}$	1819.2 (15)	797.2 (15)	341.0 (7)	0.102 (11)	1.459	0.060 (7)	0.042 (4)	3/2 −	3/2 −	allowed	6.65	0.8856 (16)	0.0975 (13)	0.0159 (5)	0.0010 (1)
$EC_{0,4}$	1954.0 (15)	932.0 (15)	399.7 (7)	0.91 (3)	0.8551	0.42 (2)	0.49 (2)	3/2 −	5/2 −	allowed	5.87	0.8857 (16)	0.0974 (13)	0.0159 (5)	0.0010 (1)
$EC_{0,2}$	2404.2 (15)	1382.2 (15)	599.5 (7)	6.15 (16)	0.2397	1.19 (3)	4.96 (13)	3/2 −	5/2 −	allowed	5.601	0.8858 (16)	0.0973 (13)	0.0159 (5)	0.0010 (1)
$EC_{0,1}$	2696.3 (15)	1674.3 (15)	732.0 (7)	7.92 (2)	0.1320	0.92 (1)	7.00 (2)	3/2 −	1/2 −	allowed	5.813	0.8859 (16)	0.0972 (13)	0.0159 (5)	0.0010 (1)
$EC_{0,0}$	3366.2 (15)	2344.2 (15)	1041.9 (7)	84.0 (6)	0.0465	3.75 (5)	80.3 (6)	3/2 −	3/2 −	allowed	5.397	0.8860 (16)	0.0971 (13)	0.0158 (5)	0.0010 (1)
				Σ 99.985			Σ 92.8 (6)								

* Determined from the nuclear level energies of 2001Ba27 and Q-value of 3366.2(15) keV (2012Wa38).

Atomic Data

The x-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and 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 4.02, 28 February 2012), as described in 2000Sc47. This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray energies and emission probabilities of ^{63}Zn.

			Energy (keV)	Photons per 100 disint.	Relative probability
XL		(Cu)	0.811 – 1.022	0.095 8 (16)	5.68
	XL_l	(Cu)	0.811	0.003 11 (8)	
	XL_α	(Cu)	0.929 – 0.930	0.054 7 (13)	
	XL_η	(Cu)	0.831	0.001 86 (5)	
	XL_β	(Cu)	0.949 – 1.022	0.036 1 (10)	
	XL_γ	(Cu)	0.952	0.000 052 (8)	
XK_α	$XK_{\alpha2}$	(Cu)	8.027 92 (1)	0.865 (12)	51.3
	$XK_{\alpha1}$	(Cu)	8.047 87 (1)	1.686 (22)	100
$XK'_{\beta1}$	$XK_{\beta3}$	(Cu)	8.905 41 (4)	)	
	$XK_{\beta1}$	(Cu)	8.905 39 (6)	) 0.355 (6)	21.1
	$XK''_{\beta5}$	(Cu)	8.977 1 (2)	)	

Auger-electron energies and emission probabilities of ^{63}Zn.

	Energy (keV)	Electrons per 100 disint.	Relative probability
e_{AK} (Cu)		3.50 (5)	
KLL	6.731 – 7.059	2.69 (4)	100
KLX	7.746 – 8.064	0.749 (13)	27.8
KXY	8.739 – 8.982	0.052 0 (13)	1.93
e_{AL} (Cu)	0.68 – 0.80	9.30 (9)	346

Cu: ω_K = 0.454 (4); ϖ_L = 0.0097 (4); n_{KL} = 1.357 (4) were taken from 1996Sc06.

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_{EC}-value of 3366.2 (15) keV has been adopted from the atomic mass evaluation of Wang *et al.* (2012Wa38) while in the course of formulating the decay scheme of ^{63}Zn. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{63}Zn EC-decay process (i.e. EC/β^+, electron, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 3367\ (14)\ \text{keV}$$

Percentage deviation from the Q-value of Wang *et al.* is − 0.024 (42) %, which supports the derivation of a consistent decay scheme with a significant variant.

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