

^{60}Ga $\varepsilon+\beta^+$ decay (69.4 ms) 2001Ma96,2021Or01,2025Ow01

Parent: ^{60}Ga : $E=0$; $J^\pi=2^+$; $T_{1/2}=69.4$ ms 2; $Q(\varepsilon+\beta^+)=14160$ 15; $\% \varepsilon+\beta^+$ decay=100.0

$^{60}\text{Ga}-J^\pi$: from the Adopted Levels of ^{60}Ga (2013Br15).

$^{60}\text{Ga}-T_{1/2}$: unweighted average of 70 ms 15 (2001Ma96), 70 ms 13 (2002Lo13), 76 ms 3 (2017Ku12), 70.8 ms 20 (2017GoZT,2020Gi02), 69.4 ms 2 (2021Or01), and 57.7 ms 98 (2025Ow01).

$^{60}\text{Ga}-Q(\varepsilon+\beta^+)$: deduced by evaluators using ^{60}Zn mass excess (2021Wa16) and ^{60}Ga mass excess of -40015 15; weighted average of -40016 15 (2021Or01), -40005 30 (2021Pa44), and -40034 46 (2023Wa10).

$^{60}\text{Ga}-\% \varepsilon+\beta^+$ decay: $\%(\varepsilon+\beta^+)=1.6$ 7, $\%(\varepsilon+\beta^+)\alpha<0.023$ 20 (2001Ma96).

2001Ma96: ^{60}Ga was produced via the $^{28}\text{Si}(^{36}\text{Ar},p3n)$ fusion evaporation reaction using a 4.71 MeV/u ^{36}Ar primary beam at the GSI On-Line Mass Separator. A 55-keV $^{60}\text{Ga}^{1+}$ beam was extracted and implanted into a tape for $\beta\gamma$ measurements and carbon foils for βp and $\beta\alpha$ measurements in a beam-on/beam-off mode. Positrons were detected using a plastic scintillator and γ rays were detected using Ge detectors. Particles were detected using Si $\Delta E-E$ telescopes at another beam line. Measured E_γ , I_γ , $\gamma\gamma$ -coin, $\beta\gamma$ -coin, $E_p(>0.6$ MeV), I_p , E_α , and I_α . Deduced levels, J , π , ^{60}Ga $T_{1/2}$, and ^{60}Ga mass using the known ^{60}Zn mass, the E_γ from the $T=1$ IAS in ^{60}Zn , and the Coulomb displacement energy systematics (1997An07). Identified a total of 802 proton events and deduced $\%(\varepsilon+\beta^+)=1.6$ 7. Identified 9 α candidate events and deduced $\%(\varepsilon+\beta^+)\alpha<0.023$ 20.

2021Or01: ^{60}Ga was produced via the projectile fragmentation of a 345-MeV/u ^{78}Kr primary beam impinging on a 5-mm thick ^9Be target, identified in the RIKEN BigRIPS separator by $B\rho$ - ΔE -ToF, transported to the exit of the ZeroDegree spectrometer, and implanted into the Wide-range Active Silicon Strip Stopper Array for Beta and ion detection (WAS3ABi) consisting of three 1-mm-thick DSSDs. γ rays were detected using the EUroball-RIKEN Cluster Array of 12 cluster-type Ge detectors. Measured $E_p(>1.5$ MeV), E_γ , I_γ , $p\gamma$ -coin, $\beta\gamma$ -coin, $\gamma\gamma$ -coin, and implant-decay time correlations. Deduced levels, ^{60}Ga $T_{1/2}$, and ^{60}Ga mass using the known ^{59}Zn mass, the E_p and E_γ from the $T=2$ IAS in ^{60}Ga populated by ^{60}Ge decay in the same experiment.

The decay scheme is considered incomplete due to a large gap of 9 MeV between the highest observed level at $E=4852$ and $Q(\varepsilon)=14160$ 15. There may be missing transitions from unobserved levels in the gap.

 ^{60}Zn Levels

<u>E(level)</u>	<u>J^π</u>	<u>Comments</u>
0	0^+	
1003.53 10	2^+	
2558.54 23	(2^+)	
4851.97 32	2^+	$T=1$, isobaric analog state of ^{60}Ga g.s.

 ε,β^+ radiations

<u>E(decay)</u>	<u>E(level)</u>	<u>$I\beta^+$ ‡</u>	<u>$I\varepsilon$ ‡</u>	<u>$\text{Log } ft$ †</u>	<u>$I(\varepsilon+\beta^+)$ †‡</u>
(9308 15)	4851.97	44.0 32	0.058 5	3.66 4	44.1 32
(11602 15)	2558.54	9.2 10	0.0061 7	4.85 5	9.2 10
(13157 15)	1003.53	17 5	0.008 2	4.9 +2-1	17 5

† $\varepsilon+\beta^+$ -feeding from $\gamma+ce$ intensity balance at each level. Quoted $I(\varepsilon+\beta^+)$ values are considered upper limits due to the incomplete decay scheme, and the associated $\text{log } ft$ values are considered lower limits.

‡ Absolute intensity per 100 decays.

 $\gamma(^{60}\text{Zn})$

I_γ normalization: absolute γ -ray intensities per 100 decays of ^{60}Ga were measured by 2021Or01 based on the total number of implanted ^{60}Ga (7.6×10^5) and $\beta\gamma$ detection efficiencies, correcting for DAQ dead time.

<u>E_γ</u>	<u>I_γ †</u>	<u>$E_i(\text{level})$</u>	<u>Comments</u>
$^{x669.3}$ 3	0.58 15		$\%I_\gamma=0.36$ 9
$^{x850.8}$ 1	1.21 16		$\%I_\gamma=0.75$ 10

Continued on next page (footnotes at end of table)

^{60}Ga $\varepsilon+\beta^+$ decay (69.4 ms) [2001Ma96,2021Or01,2025Ow01](#) (continued) $\gamma(^{60}\text{Zn})$ (continued)

E_γ	$I_\gamma^\dagger$	$E_i(\text{level})$	J_i^π	E_f	J_f^π	Comments
$^x913.9$ 3	0.48 16					%I γ =0.30 10
1003.5 1	100 5	1003.53	2 ⁺	0	0 ⁺	%I γ =62.0 31 E γ : from 2021Or01 . Other: 1003.7 2 (2001Ma96). I γ : from 2021Or01 . Other: 100 17 (2001Ma96).
$^x1028.6$ 2	0.61 13					%I γ =0.38 8
$^x1188.4$ 1	2.58 16					%I γ =1.60 10
$^x1201.8$ 2	0.47 11					%I γ =0.29 7
$^x1413.7$ 2	0.57 11					%I γ =0.35 7
$^x1442.1$ 1	0.65 13					%I γ =0.40 8
$^x1481.4$ 1	2.10 16					%I γ =1.30 10
1554.7 3	11.3 8	2558.54	(2 ⁺)	1003.53	2 ⁺	%I γ =7.0 5 E γ : from 2021Or01 . Other: 1554.9 6 (2001Ma96). I γ : from 2021Or01 . Other: 12 5 (2001Ma96).
$^x1780.8$ 6	0.32 16					%I γ =0.20 10
$^x2047.2$ 4	1.13 32					%I γ =0.70 20
2293.2 4	10.2 8	4851.97	2 ⁺	2558.54	(2 ⁺)	%I γ =6.3 5 E γ : from 2021Or01 . Other: 2293.0 10 (2001Ma96). I γ : from 2021Or01 . Other: 10 5 (2001Ma96).
$^x2334.2$ 3	1.29 32					%I γ =0.80 20
$^x2434.2$ 2	2.90 32					%I γ =1.80 20
2558.8 4	13.7 10	2558.54	(2 ⁺)	0	0 ⁺	%I γ =8.5 6 E γ : weighted average of 2559.0 8 (2001Ma96) and 2558.7 4 (2021Or01). I γ : from 2021Or01 . Other: 13 5 (2001Ma96).
$^x2624.3$ 5	0.48 16					%I γ =0.30 10
$^x2826.0$ 2	2.10 32					%I γ =1.30 20
$^x2884.0$ 4	1.29 32					%I γ =0.80 20
$^x2996.8$ 2	3.2 5					%I γ =1.98 31
$^x3337.4$ 1	11.5 10					%I γ =7.1 6
$^x3394.8$ 1	11.3 10					%I γ =7.0 6
3848.5 4	61 5	4851.97	2 ⁺	1003.53	2 ⁺	%I γ =37.8 31 E γ : from 2021Or01 . Other: 3848.3 7 (2001Ma96). I γ : from 2021Or01 . Other: 57 13 (2001Ma96).
$^x3889.1$ 3	4.5 13					%I γ =2.8 8
$^x4000.9$ 2	4.5 7					%I γ =2.8 4
$^x4805.0$ 4	0.65 16					%I γ =0.40 10
$^x4850.2$ 5	0.32 16					%I γ =0.20 10
$^x4891.9$ 3	0.65 16					%I γ =0.40 10

[†] For absolute intensity per 100 decays, multiply by 0.62.^x γ ray not placed in level scheme.

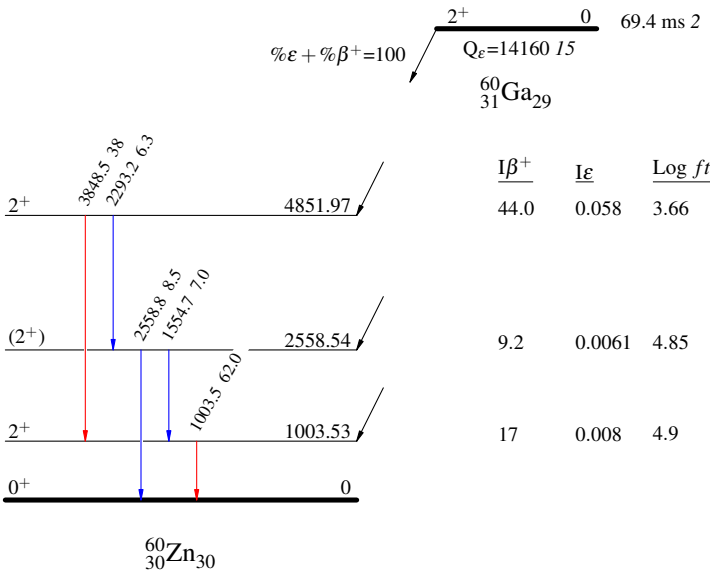
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Decay Scheme

Legend

Intensities: I_γ per 100 parent decays

- $\longrightarrow$ $I_\gamma < 2\% \times I_\gamma^{max}$
- $\longrightarrow$ $I_\gamma < 10\% \times I_\gamma^{max}$
- $\longrightarrow$ $I_\gamma > 10\% \times I_\gamma^{max}$



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