# $^{67}$Ga – Comments on evaluation of decay data

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The initial evaluation was completed in March 2000. This revised evaluation was done in 2011, taking into account the available literature by March 2011.

## 1. Decay Scheme

The spins and parities of the ground state of $^{67}$Ga and of the levels of $^{67}$Zn are from the evaluation of 2005HU18.

The main difficulty in the evaluation of the $^{67}$Ga decay scheme is connected with the lack of measurements of the absolute intensity of the internal conversion electron component P($ce_{1,0}$) from the 93 keV gamma transition (2000SI03). This value determines directly the probability P($\varepsilon_{0,0}$) of the allowed electron capture transition to the ground state of $^{67}$Zn. In many evaluations, including 1991BH06, P($\varepsilon_{0,0}$) was adopted equal to zero. In a more recent evaluation (2005HU18), a value of 0,9 (9) % was adopted.

In this evaluation of the $^{67}$Ga decay scheme, four measurements of P($ce_{1,0}$) were taken into account: 1998AT04, 2000SI03, 2005YA01 and 2007BO. The analysis led to the evaluated value of P($ce_{1,0}$) = 0,3254 (40) and to the probability of the electron capture transition to the $^{67}$Zn ground state P($\varepsilon_{0,0}$) = 3,3 (32) % (see Section 4.2.2). The large uncertainty of P($\varepsilon_{0,0}$) mainly comes from the uncertainty of the evaluated mixing ratio δ(184 keV).

Among the adopted levels in 2005HU18, three levels are placed below the decay energy and are not taken into account in this evaluation: the $9/2^+$ at 604,48 (5) keV, the $7/2^-$ at 814,90 (6) keV and the $5/2^+$ at 979,85 (5) keV. These levels could be fed respectively by 3rd, 2nd and 1st transitions. As all the other electronic capture transitions are allowed, the branch intensities for these three levels must be much lower, and precisely the corresponding gamma-rays were never observed.

## 2. Nuclear Data

Q value is from 2003AU03: $Q^+(^{67}Ga)$ = 1000,8 (12) keV.

## 2.1 $^{67}$Ga half-life

The measured half-life values of $^{67}$Ga are summarized in Table 1. The values from 1948HO04 and 1950HO26 were not used in the evaluation because no experimental uncertainty was reported. The values from 1982HOZJ and 2002UN02 are the same values as respectively 1978ME10 and 1992UN01, and were not used in the evaluation.

1972CR02 gives eight measurements using the same method. As this data set is discrepant, an unweighted mean was chosen, calculated using the LWEIGHT program: $T_{1/2}(^{67}Ga)$ = 3,38 (9) d.

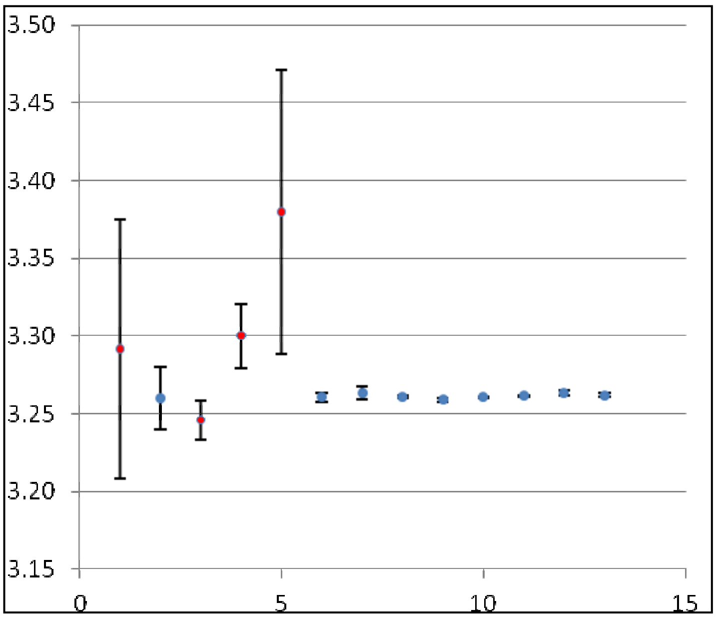
The measured half-life values used in this evaluation are summarized in Figure 1. The statistical processing was done using the LWEIGHT program. Four statistical outliers are excluded according to Chauvenet's criterion: 1938MA01, 1955TO27, 1964RU06 and 1972CR02, in red in Figure 1. A weighted average is 3,26125 (35) d from the resulting consistent data set, with a reduced-$\chi^2$ value of 0,74. The statistical weights are 44 % for 1992UN01 and 20 % for 1980HO17, the two most precise measurements. As there are less than ten values, and as the most precise measurements use the same method, the smallest experimental uncertainty was preferred. Finally, the adopted value is:

**$T_{1/2}(^{67}Ga)$ = 3,2613 (5) d**.

Table 1: $^{67}$Ga half-life measurements. The excluded values are crossed out.

| Reference | $T_{1/2}(^{67}Ga)$ measurements | $T_{1/2}(^{67}Ga)$ in d | Comments |
|---|---|---|---|
| ~~1938MA01~~ | ~~79 (2) h~~ | ~~3,29 (8)~~ | Excluded by Chauvenet's criterion |
| ~~1948HO04~~ | ~~83 h~~ | ~~3,46~~ | Not used: no uncertainty |
| 1948MC32 | 3,26 (2) d | 3,26 (2) | |
| ~~1950HO26~~ | ~~80 h~~ | ~~3,33~~ | Not used: no uncertainty |
| ~~1955TO27~~ | ~~77,9 (3) h~~ | ~~3,246 (13)~~ | Excluded by Chauvenet's criterion |
| ~~1964RU06~~ | ~~79,2 (5) h~~ | ~~3,300 (21)~~ | Excluded by Chauvenet's criterion |
| 1972CR02 | 78,5 (15) h | 3,27 (6) | |
| | 78,2 (12) h | 3,26 (5) | |
| | 84,7 (23) h | 3,53 (10) | |
| | 79,1 (14) h | 3,30 (6) | |
| | 69,7 (36) h | 2,90 (15) | |
| | 84,2 (11) h | 3,508 (46) | |
| | 90,7 (42) h | 3,78 (18) | |
| | 83,8 (44) h | 3,49 (18) | |
| **~~1972CR02~~** | **~~LWEIGHT~~** | **~~3,38 (9)~~** | Unweighted mean, excluded by Chauvenet's criterion |
| 1972LE37 | 78,26 (7) h | 3,2608 (29) | |
| 1978LA21 | 78,33 (10) h | 3,2638 (42) | |
| 1978ME10 | 3,261 (1) d | 3,261 (1) | |
| 1979DE42 | 3,2594 (12) d | 3,2594 (12) | |
| 1980HO17 | 3,2607 (8) d | 3,2607 (8) | |
| ~~1982HOZJ~~ | ~~3,261 (1) d~~ | ~~3,261 (1)~~ | Not used: same as 1978ME10 |
| 1992UN01 | 3,2615 (5) d | 3,2615 (5) | |
| ~~2002UN02~~ | ~~3,2615 (5) d~~ | ~~3,2615 (5)~~ | Not used: same as 1992UN01 |
| 2004DA05 | 3,2634 (16) d | 3,2634 (16) | |
| 2004SC04 | 3,2623 (15) d | 3,2623 (15) | |
| **Adopted** | | **3,2613 (5) d** | |

Figure 1: $T_{1/2}$ measurements used for the present evaluation. The red ones are excluded by LWEIGHT according to Chauvenet's criterion.



### 2.2 Half-lives of $^{67}Zn$ 93 keV and 184 keV metastable states

The measured half-life values of the first excited state of $^{67}Zn$, at 93 keV, are given in Table 2. The value from 1953KE was not used because of the lack of uncertainty. The value from 1972LE37 comes from the same author as 1973LE18. 1973LE18 reports two consistent measurements, obtained with two independent methods. A weighted mean was chosen: $T_{1/2}(^{67}Zn, 93\ keV) = 9,15\ (14)\ \mu s$.

No outlier was found by the LWEIGHT program in the consistent data set. A weighted average was 9,002 (41) µs with a reduced-$\chi^2$ value of 2,2. The statistical weight is 85 % for the most precise value from 1996HW03. For the same reasons as $T_{1/2}(^{67}Ga)$, the smallest experimental uncertainty was preferred. Finally, the adopted value, with its external uncertainty, is:

**$T_{1/2}(^{67}Zn, 93\ keV) = 9,00\ (4)\ \mu s$.**

Table 2: $T_{1/2}$ half-life measurements of the 93 keV level of $^{67}Zn$.
The excluded values are crossed out.

| Reference | $T_{1/2}$ in µs | Comments |
|---|---|---|
| ~~1953KE~~ | ~~8,5~~ | Not used: no uncertainty |
| 1953ME52 | 9,5 (10) | |
| 1957BU39 | 9,4 (3) | |
| 1969IV02 | 8,8 (18) | |
| 1971SU18 | 8,7 (1) | |
| ~~1972LE37~~ | ~~9,10 (15)~~ | Not used: same as 1973LE18 |
| 1973LE18 | 9,20 (20) | |
| | 9,10 (20) | |
| **1973LE18** | **9,15 (14)** | Consistent set, same author, independent methods: weighted mean chosen |
| 1975RO25 | 9,1 (4) | |
| 1996HW03 | 9,01 (3) | |
| 1998AT04 | 9,34 (20) | |

The measured half-life values of the second excited state of $^{67}Zn$, at 184 keV, are given in Table 3. The value from 1964AL28 is given with asymmetric uncertainties, and was symmetrised according to the method described in 2003AU02.

The LWEIGHT program found two statistical outliers, excluded according to Chauvenet's criterion: 1961HO05 and 1962RI09. A weighted average was 1,028 (13) ns in the resulting consistent data set, with a reduced-$\chi^2$ value of 0,3. The statistical weight is 83 % for the most precise value from 1972EN08. For the same reasons as $T_{1/2}(^{67}Ga)$, the smallest experimental uncertainty was preferred. Finally, the adopted value, with its internal uncertainty, is:

**$T_{1/2}(^{67}Zn, 184\ keV) = 1,028\ (14)\ ns$.**

Table 3: $T_{1/2}$ half-life measurements of the 184 keV level of $^{67}Zn$.
The excluded values are crossed out.

| Reference | $T_{1/2}$ in ns | Comments |
|---|---|---|
| ~~1961HO05~~ | ~~1,45 (15)~~ | Excluded by Chauvenet's criterion |
| ~~1962RI09~~ | ~~2,2 (7)~~ | Excluded by Chauvenet's criterion |
| 1964AL28 | 1,1 (5) | Symmetrised according to method of 2003AU02 |
| 1968LI02 | 1,01 (5) | |
| 1972EN08 | 1,026 (14) | |
| 1975RO25 | 1,06 (4) | |

### 2.3 Electron Capture Transitions

The energies of the electron capture (ε) transitions were calculated from the Q value and the level energies deduced from gamma transition energies. The log *ft* values were computed using the LOGFT program.

The electron capture probabilities were calculated from the balance of the evaluated $P_{\gamma+ce}$ values taking into account the evaluated absolute intensity $P(ce_{1,0})$ = 0,3254 (26) (see Section 4.2.2) that allows normalizing the total ground state gamma transition probability to 96,7 (31) per 100 disintegrations.

The experimental values of $P_K$ are available for $\varepsilon_{0,2}$ and $\varepsilon_{0,3}$ from 1988BE55: $P_K(\varepsilon_{0,2})$ = 0,89 (4) and $P_K(\varepsilon_{0,3})$ = 0,88 (3). They were obtained using an old value of $\omega_K$ = 0,430 (7).

The $P_K$, $P_L$, $P_M$ and $P_N$ values were computed using the EC-capture program. The $P_{L2}/P_{L1}$ ratios were computed by the LOGFT program and were used to determine the $P_{L1}$ and $P_{L2}$ values.

## 2.4 Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of gamma transitions are the energies of gamma-rays with adding the recoil energy (see Section 4.2.1).

### 2.4.1 Mixing ratios and multipolarities

The multipolarities of the 93 keV ($\gamma_{1,0}$) and 794 keV ($\gamma_{4,1}$) transitions are pure E2. For the 794 keV transition, the admixture of M3 is possible and was evaluated. The other gamma transitions have an M1 + E2 multipolarity. Only the absolute values of the mixing ratios were evaluated to deal with the inconsistency of the signs. The mixing ratios measurements are given in Table 4.

Table 4: Mixing ratios measurements of the gamma transitions in $^{67}$Zn. The excluded values, by the evaluator or by Chauvenet's criterion during the statistical process, are crossed out. The mixtures are M1 + E2 for all the transitions, except for the 794 keV transition which has an E2 + M3 mixture.

| Reference | 91 keV | 184 keV | 209 keV | 300 keV | 393 keV | 494 keV | 703 keV | 794 keV | 887 keV |
|---|---|---|---|---|---|---|---|---|---|
| 1961HO05 | | ~~$\delta^2$ = 0,15~~ | | | | | | | |
| 1962RI09 | $\lvert\delta\rvert \leq 0{,}07$ | 0,51 (7) | | | | | | | |
| 1964AL28 | | 0,43 (8) | | | | | | | |
| 1968LI02 | | 0,41 (6) | | | | | | | |
| 1969BO41 | | | ~~0,40 (15)~~ | | | | | | |
| 1971SU18 | -0,11 (5) | 0,38 (3) | | ~~pure M1~~ | ~~0,5 (1)~~ | 0,18 (6) | | | |
| 1973BA54 | | | 0,034 (21) | -0,181 (8) | 0,043 (10) | | 0,090 (28) | | |
| 1974NI01 | | $\delta \begin{cases} > -0{,}8 \\ < -0{,}1 \end{cases}$ | 0,02 (4) | -0,21 (5) | 0,11 (6) | ~~2,2 (6)~~ | | 0,04 (17) | |
| 1975TH01 | 0,06 (5) | 0,48 (11) | 0,01 (20) | 0,05 (7) | -0,02 (17) | -0,22 (20) | | 0,47 (11) | 0,8 (6) |
| 1975WE08 | -0,15 (3)<br>~~2,6 (3)~~ | -0,17 (7) | 0,08 (5)<br>~~-5,7 (20)~~ | -0,11 (4)<br>~~2,3 (3)~~ | 0,09 (2)<br>~~3,2 (3)~~ | 0,06 (4)<br>~~2,8 (4)~~ | | | |
| 1978DU04 | | 0,08 (4)<br>~~-5,0 (8)~~ | -0,10 (6)<br>~~3,6 (8)~~ | 0,20 (8)<br>~~-3,1 (4)~~ | -0,17 (8)<br>~~-2,4 (3)~~ | -0,17 (8)<br>~~-1,7 (6)~~ | | -0,1 (1) | 0,9 (3) |
| 1978LO06 | | | | | | 0,14 (3) | | 0,04 (4) | -0,96 (9) |

Some values are given with asymmetric uncertainties: δ(184 keV) from 1964AL28 ; δ(300 keV) from 1973BA54 ; δ(794 keV) and δ(494 keV) from 1974NI01; δ(393 keV), δ(494 keV), δ(794 keV) and δ(887 keV) from 1975TH01. They were symmetrised according to the method described in 2003AU02.

The excluded values are crossed out in the table. For the 91 keV transition, the result from 1962RI09 rules out the second possibility from 1975WE08. For the 184 keV transition, the result from 1974NI01 rules out the second possibility from 1978DU04, and there is no uncertainty with the result of 1961HO05. For the 209 keV, 300 keV, 393 keV and 494 keV transitions, the second possibilities from 1975WE08 and 1978DU04 are ruled out by comparison with the other results. For the 300 keV transition, the result from 1971SU18 is ruled out by comparison with the other results. For the 494 keV transition, the second possibility from 1974NI01 is ruled out by comparison with the most precise measurement from 1978LO06.

The other values that are crossed out were excluded according to Chauvenet's criterion during the statistical processing with the LWEIGHT program: 1969BO41 for 209 keV and 1971SU18 for 393 keV. All the data set are consistent except for the 184 keV and 794 keV transitions which are discrepant. The existence of only one measurement from 1973BA54 for the 703 keV transition should be underlined. A weighted average was used for each gamma transition. The adopted values are given in Table 5. Internal uncertainty was chosen by the LWEIGHT program for the red adopted values, external uncertainty for the green ones and expanded uncertainty for the blue one.

Table 5: Adopted mixing ratios and the corresponding multipolarity.
Internal uncertainty was chosen by LWEIGHT for the red adopted values,
external uncertainty for the green ones and expanded uncertainty for the blue one.

| | Adopted \|δ\| | Multipolarity | Comments |
|---|---|---|---|
| **91 keV** | 0,123 (25) | M1 + 1,5 (6) % E2 | Consistent, weighted average |
| **184 keV** | 0,31 (7) | M1 + 8,8 (36) % E2 | Discrepant, weighted average |
| **209 keV** | 0,042 (17) | M1 + 0,18 (14) % E2 | Consistent, weighted average |
| **300 keV** | 0,178 (10) | M1 + 3,07 (33) % E2 | Consistent, weighted average |
| **393 keV** | 0,051 (16) | M1 + 0,26 (16) % E2 | Consistent, weighted average |
| **494 keV** | 0,110 (34) | M1 + 1,2 (7) % E2 | Consistent, weighted average |
| **703 keV** | 0,090 (28) | M1 + 0,8 (5) % E2 | Only one measurement |
| **794 keV** | 0,09 (11) | E2 + 0,8 (19) % M3 | Discrepant, weighted average |
| **887 keV** | 0,95 (9) | M1 + 47,4 (47) % E2 | Consistent, weighted average |

### 2.4.2 Internal conversion coefficients

The internal conversion coefficients measurements of the gamma transitions of $^{67}$Zn are summarized in Table 6.

The adopted values are calculated with the BrIcc program (2008KI07) and can be seen in Table 7. They were calculated using the mixing ratios evaluated previously. These values agree satisfactorily with the measured ones. For the 794 keV transition, the two possible multipolarities were tested and the calculated internal conversion coefficients agree well inside the uncertainties. The possible admixture of M3 is kept.

## 3. Atomic Data

### 3.1 Fluorescence yields

The fluorescence yields are taken from 1996SC06.

Table 6: Internal conversion coefficients measurements of the gamma transitions of $^{67}$Zn.

| Reference | 91 keV | 93 keV | 184 keV | 209 keV | 300 keV | 393 keV | 494 keV | 887 keV |
|---|---|---|---|---|---|---|---|---|
| 1938AL02 | $\alpha_K$ ~ 0,07 | | | | | | | |
| 1953KE | $\alpha_K$ = 0,074 | $\alpha_K$ = 0,63 | $\alpha_K$ = 0,011 | $\alpha_K$ = 0,029 | $\alpha_K$ = 0,0029 | $\alpha_K$ = 0,0019 | | |
| 1953ME52 | | $\alpha_T$ = 0,54 (5) | | | | | | |
| 1966FR12 | | $\alpha_K$ = 0,77 (8) | $\alpha_K$ = 0,0156 (10) | $\alpha_K$ = 0,0075 (7) | $\alpha_K$ = 0,00337 (30) | $\alpha_K$ = 0,00192 (15) | $\alpha_K$ = 0,00119 (15) | $\alpha_K$ = 0,00034 (7) |
| 1969LI04 | $\alpha_K$ = 0,066 (10)<br>$\alpha_{L1}$ = 0,0069 (11)<br>$\alpha_{L2,3}$ = 0,00069 (30) | | | | | | | |
| 1988BE55 | | | $\alpha_K$ = 0,89 (4) | | | $\alpha_K$ = 0,883 (28) | | |

Table 7: BrIcc calculations for the internal conversion coefficients of the gamma transitions of $^{67}$Zn.

| | $\alpha_T$ | $\alpha_K$ | $\alpha_{Ltot}$ | Comments |
|---|---|---|---|---|
| **91 keV** | 0,091 (6) | 0,081 (5) | 0,008 7 (7) | |
| **93 keV** | 0,854 (12) | 0,748 (11) | 0,092 2 (13) | |
| **184 keV** | 0,016 9 (21) | 0,015 1 (19) | 0,001 58 (20) | |
| **209 keV** | 0,009 01 (14) | 0,008 06 (13) | 0,000 827 (13) | |
| **300 keV** | 0,003 88 (6) | 0,003 48 (6) | 0,000 354 (6) | |
| **393 keV** | 0,001 93 (3) | 0,001 728 (25) | 0,000 174 8 (25) | |
| **494 keV** | 0,001 149 (18) | 0,001 030 (16) | 0,000 103 8 (17) | |
| **703 keV** | 0,000 524 (8) | 0,000 470 (7) | 0,000 047 0 (7) | |
| **794 keV** E2+M3 | 0,000 54 (6) | 0,000 48 (5) | 0,000 049 (6) | Adopted |
| **794 keV** pure E2 | 0,000 523 (8) | 0,000 469 (7) | 0,000 047 3 (7) | |
| **887 keV** | 0,000 354 (7) | 0,000 318 (6) | 0,000 031 8 (6) | |

### 3.2 X Radiations and Auger electrons

The X-ray energies are based on the wave lengths in the compilation of 1967BE65 (Bearden). The energies of Auger electrons are from the SAISINUC software (see also 1977LA19 (Larkins) and 1987Table (Table de Radionucléides)).

The X-ray and Auger electron probabilities were computed using the EMISSION program with the atomic data from 1996SC06.

## 4. Photon Emissions

### 4.1 X-Ray Emissions

The total absolute emission probabilities of the K and L X-rays were computed using the EMISSION program with the atomic data from 1996SC06, the evaluated electron capture probabilities and the evaluated conversion electron probabilities.

The authors of 1979DE42 measured the following ratios: $P(XK_\alpha)/P(184keV)$ = 2,37 (5) and $P(XK_\beta)/P(184keV)$ = 0,331 (7). The absolute intensity measurements from 2005YA01 are:

P($XK_{\alpha 2}$) = 17,1 (8) %, P($XK_{\alpha 1}$) = 32,3 (14) %, P($XK_{\beta 1,3}$) = 6,44 (28) % and P(184 keV) = 21,4 (9) %. The relative uncertainties were increased to 4,4 % (see Section 4.2.2). This leads to the consistent ratio P($XK_{\alpha}$)/P(184 keV) = 2,31 (12) and the discrepant ratio P($XK_{\beta}$)/P(184 keV) = 0,301 (18).

With the previous calculations and the evaluated value of P(184 keV) (see Section 4.2.2), these ratios become: P($XK_{\alpha}$)/P(184 keV) = 2,39 (8) and P($XK_{\beta}$)/P(184 keV) = 0,338 (14). They are summarized in Table 8.

Table 8: Comparison of the P($XK_{\alpha}$)/P(184 keV) and P($XK_{\beta}$)/P(184 keV) ratios.

| | 1979DE42 | 2005YA01 | Evaluated |
|---|---|---|---|
| P($XK_{\alpha}$)/P(184 keV) | 2,37 (5) | 2,31 (12) | 2,39 (8) |
| P($XK_{\beta}$)/P(184 keV) | 0,331 (7) | 0,301 (18) | 0,338 (14) |

## 4.2 Gamma Emissions

### 4.2.1 Gamma-ray energies

The gamma-ray energy measurements are given in Table 9. The excluded values are crossed out. The values from 1978ME10 come from the same author as 1990ME15. The most recent data set was preferred, even if it corresponds to the less precise measurements of the two publications. The other values that are crossed out were excluded according to Chauvenet's criterion during the statistical process by the LWEIGHT program. All the data set are consistent and a weighted average was used each time. The adopted values are in red or in green when respectively the internal or the external uncertainties were chosen. The reduced-$\chi^2$ are also mentioned.

Table 9: $E_{\gamma}$ measurements of the levels of $^{67}$Zn.
The excluded values are crossed out. The values from 1978ME10 come from the same author as 1990ME15. The other values were excluded according to Chauvenet's criterion. Internal uncertainty was chosen by LWEIGHT for the red adopted values, external uncertainty for the green ones.

| Reference | $E_{\gamma 2,1}$ (keV) | $E_{\gamma 1,0}$ (keV) | $E_{\gamma 2,0}$ (keV) | $E_{\gamma 3,2}$ (keV) | $E_{\gamma 3,1}$ (keV) |
|---|---|---|---|---|---|
| 1958CH08 | 91,22 (4) | 93,26 (4) | 184,46 (27) | | |
| 1966FR12 | 91,275 (20) | 93,317 (20) | 184,595 (40) | 208,96 (6) | 300,24 (7) |
| 1969RA15 | 91,26 (10) | 93,25 (10) | 184,53 (10) | 208,95 (10) | 300,22 (10) |
| 1971SU18 | ~~91 (2)~~ | ~~93 (2)~~ | 184 (2) | ~~208 (2)~~ | ~~299 (2)~~ |
| 1974AR22 | | ~~93,2 (2)~~ | 184,0 (2) | | |
| 1974HEYW | 91,31 (5) | 93,32 (2) | 184,56 (2) | 208,93 (2) | ~~300,18 (2)~~ |
| 1977AB02 | | | 184 (1) | | |
| 1978DU04 | | 93,3 (5) | 184,63 (3) | 208,91 (4) | 300,24 (5) |
| ~~1978ME10~~ | ~~91,266 (5)~~ | ~~93,311 (5)~~ | ~~184,577 (10)~~ | ~~208,951 (10)~~ | ~~300,219 (10)~~ |
| 1990ME15 | 91,237 (35) | 93,291 (30) | 184,569 (30) | 208,970 (30) | 300,230 (25) |
| **Adopted** | 91,263 (15) | 93,307 (12) | 184,577 (17) | 208,939 (15) | 300,232 (21) |
| $\chi^2$ | 0,74 | 0,54 | 1,7 | 0,48 | 0,02 |

| Reference | $E_{\gamma 3,0}$ (keV) | $E_{\gamma 4,3}$ (keV) | $E_{\gamma 4,2}$ (keV) | $E_{\gamma 4,1}$ (keV) | $E_{\gamma 4,0}$ (keV) |
|---|---|---|---|---|---|
| 1966FR12 | 393,65 (6) | 494,31 (10) | 703,6 (2) | 794,7 (2) | 888,0 (2) |
| 1969RA15 | 393,60 (10) | | | | |
| 1971SU18 | 393 (2) | ~~493 (2)~~ | 701 (2) | 794 (2) | ~~886 (2)~~ |
| 1974HEYW | 393,47 (3) | 494,19 (8) | | 794,49 (20) | 887,68 (15) |
| 1977AB02 | 393 (3) | | | | ~~884 (12)~~ |
| 1978DU04 | 393,54 (5) | 494,1 (6) | 703,2 (3) | 794,39 (8) | 887,67 (7) |
| ~~1978ME10~~ | ~~393,529 (10)~~ | ~~494,169 (15)~~ | ~~703,110 (15)~~ | ~~794,386 (15)~~ | ~~887,693 (15)~~ |
| 1990ME15 | 393,539 (25) | 494,132 (30) | 703,08 (5) | 794,38 (5) | 887,664 (40) |
| **Adopted** | 393,528 (20) | 494,143 (28) | 703,11 (8) | 794,400 (41) | 887,676 (33) |
| $\chi^2$ | 1,5 | 1,3 | 2,5 | 0,67 | 0,91 |

The energies of the gamma transitions were then deduced by adding the recoil energy of the nucleus. The proton and neutron masses come from 2008MO18. The mass excess of $^{67}$Zn comes from 2003AU02. The largest recoil energy is for the 887 keV transition, with a value less than 6,3 eV.

### 4.2.2 Gamma-ray emission probabilities

The measurements of gamma-ray emission probabilities are summarized in Table 10. The excluded values are crossed out. 1953KE was not used because of the lack of uncertainty. The intensity of the doublet from 1967VR03 is not useful. In 1975TH01, the intensities are normalized by level. With the 184 keV emission as reference, only the measurement of the 91 keV intensity can be used. In 1978LO06, the reference is the complete decay of the 888 keV level. As there is no value for the 184 keV emission, these values were not used. The values from 1978ME10 come from the same author as 1990ME15. The most recent data set was preferred.

Table 10: Measurements of gamma-ray emission probabilities from the decay of $^{67}$Ga.
The values that are crossed out were excluded by the evaluator.
Values from 1969LI04, 2005YA01 and 2007BO are absolute emission probabilities measurements.
The relative uncertainties of the values from 2005YA01 were increased up to 4,4 %.

| Reference | 91 keV | 93 keV | 184 keV | 209 keV | 300 keV | 393 keV | 494 keV | 703 keV | 794 keV | 887 keV |
|---|---|---|---|---|---|---|---|---|---|---|
| ~~1953KE~~ | ~~2,7~~ | ~~63,9~~ | ~~29,6~~ | ~~1~~ | ~~20,2~~ | ~~4,9~~ | ~~0,4~~ | | ~~0,2~~ | ~~0,4~~ |
| 1953ME52 | 7,0 (5) | 93,0 (5) | 44,1 (30) | 3,0 (8) | 27,5 (10) | 9,7 (10) | | | | |
| 1966FR12 | 1,5 (4) | 73 (7) | 23,1 (16) | 2,50 (25) | 16,2 (16) | | 0,100 (15) | 0,015 (2) | 0,06 (1) | 0,160 (16) |
| 1967VR03 | ~~$\gamma_{2,1}+\gamma_{1,0}$ 229 (20)~~ | | 100 | 10,9 (5) | 75,6 (50) | 20,4 (12) | 0,24 (3) | 0,05 (1) | 0,23 (2) | 0,58 (6) |
| 1969LI04 | 3,27 (45) | 38,4 (38) | 23,7 (27) | | | | | | | |
| 1969RA15 | ~~155 (11)~~ | ~~360 (25)~~ | ~~1000 (70)~~ | ~~2,4 (3)~~ | ~~15,7 (12)~~ | ~~4,3 (4)~~ | | | | |
| 1974HEYW | 13 (1) | 100 (5) | 62 (3) | 7,1 (4) | 50 (3) | 14 (1) | 3,7 (3) | | 0,15 (2) | 0,43 (4) |
| 1975TH01 | 13,1 (4) | | 86,9 (25) | ~~9,6 (3)~~ | ~~70,3 (21)~~ | ~~20,1 (6)~~ | ~~23,8 (11)~~ | ~~4,8 (4)~~ | ~~18,4 (7)~~ | ~~53,2 (16)~~ |
| ~~1978LO06~~ | | | | | | | ~~25 (2)~~ | ~~5 (2)~~ | ~~21 (2)~~ | ~~49 (2)~~ |
| 1978ME10 | ~~80,0 (3)~~ | ~~1000 (3)~~ | ~~552 (2)~~ | ~~62,8 (3)~~ | ~~448 (1)~~ | ~~125,4 (5)~~ | ~~1,83 (2)~~ | ~~0,292 (9)~~ | ~~1,37 (5)~~ | ~~3,88 (2)~~ |
| 1979DE42 | 15,0 (5) | 185 (6) | 100,0 (11) | 11,35 (13) | 79,9 (9) | 22,0 (3) | 0,322 (7) | 0,060 (5) | 0,251 (7) | 0,712 (11) |
| 1990ME15 | 30 (2) | 366 (14) | 217 (9) | 24 (1) | 166 (4) | 45 (1) | 0,7 (1) | 0,10 (1) | 0,53 (3) | 1,49 (5) |
| 2005YA01 | 3,11 (14) | 38,8 (17) | 21,4 (9) | 2,46 (11) | 16,6 (7) | 4,6 (2) | | | | |
| 2007BO | 3,11 (3) | 38,61 (35) | 21,13 (10) | 2,396 (13) | 16,74 (8) | 4,642 (25) | 0,0657 (33) | | 0,0565 (24) | 0,1522 (35) |

The value from 1966FR12 for the 91 keV emission is given with asymmetric uncertainties, and was symmetrised according to the method described in 2003AU02. 2005YA01 and 2007BO measured absolute emission probabilities. The uncertainties from 2005YA01 are too low. They should be at least about 4,4 % according to the authors, and they were expanded.

In this evaluation, the data were normalized to the 184 keV emission, used as reference. They are given in Table 11. The crossed out values were excluded according to Chauvenet's criterion during the statistical process by LWEIGHT. All the data sets are consistent and a weighted average was used each time. Red adopted values stand for internal uncertainty, green ones stand for external uncertainty. The reduced-$\chi^2$ are also mentioned.

Table 11: Measurements of gamma-ray emission probabilities used in this evaluation, normalized to the 184 keV emission used as reference.
The values that are crossed out were excluded according to Chauvenet's criterion during the statistical process by LWEIGHT.
Red values stand for internal uncertainty, green ones stand for external uncertainty.

| Reference | 91 keV | 93 keV | 184 keV | 209 keV | 300 keV | 393 keV | 494 keV | 703 keV | 794 keV | 887 keV |
|---|---|---|---|---|---|---|---|---|---|---|
| 1953ME52 | 15,9 (16) | ~~211 (14)~~ | 100 | ~~6,8 (19)~~ | ~~62,4 (48)~~ | 22,0 (27) | | | | |
| 1966FR12 | ~~6,5 (18)~~ | ~~316 (37)~~ | 100 | 10,8 (13) | ~~70 (8)~~ | | 0,43 (7) | 0,065 (10) | 0,260 (47) | 0,69 (8) |
| 1967VR03 | | | 100 | 10,9 (5) | 76 (5) | 20,4 (12) | 0,24 (3) | 0,05 (1) | 0,23 (2) | ~~0,58 (6)~~ |
| 1969LI04 | 13,8 (25) | 162 (24) | 100 | | | | | | | |
| 1974HEYW | ~~21,0 (19)~~ | 161 (11) | 100 | 11,5 (9) | 81 (6) | 22,6 (19) | ~~6,0 (6)~~ | | 0,242 (34) | 0,69 (7) |
| 1975TH01 | 15,1 (6) | | 100 | | | | | | | |
| 1979DE42 | 15,0 (5) | 185 (6) | 100 | 11,35 (18) | 79,9 (13) | 22,00 (39) | 0,322 (8) | 0,060 (5) | 0,251 (8) | 0,712 (14) |
| 1990ME15 | 13,8 (11) | 169 (10) | 100 | 11,1 (7) | 76,5 (37) | 20,7 (10) | 0,32 (5) | 0,046 (5) | 0,244 (17) | 0,687 (37) |
| 2005YA01 | 14,53 (6) | 181 (8) | 100 | 11,5 (5) | 77,7 (34) | 21,3 (11) | | | | |
| 2007BO | 14,72 (16) | 182,7 (19) | 100 | 11,34 (8) | 79,2 (5) | 21,97 (16) | 0,31 (16) | | 0,267 (11) | 0,720 (17) |
| **Adopted** | 14,74 (14) | 181,8 (19) | 100 | 11,33 (7) | 79,22 (48) | 21,92 (14) | 0,318 (12) | 0,0539 (42) | 0,252 (6) | 0,712 (10) |
| $\chi^2$ | 0,34 | 1,3 | - | 0,20 | 0,32 | 0,61 | 2,4 | 1,8 | 0,67 | 0,21 |

These evaluated relative emission probabilities were used with the absolute emission probability of the 93 keV level P(93 keV) to calculate the absolute gamma-ray emission probabilities. P(93 keV) was determined using the total internal conversion coefficient $\alpha_T$(93 keV) calculated with the BrIcc program in Section 2.4.2, and the evaluated value of P($ce_{1,0}$).

Four values of P($ce_{1,0}$) were used in this evaluation: 0,3285 (40) from 1998AT04; 0,3198 (40) from 2000SI03; 0,331 (15) from 2005YA01; 0,330 (6) from 2007BO. The first value was recalculated by 2000SI03. The second value is an unweighted mean of the two results 0,3213 (14) and 0,3182 (27). The authors of 2000SI03 precise that the uncertainties are only 1σ statistical uncertainties. The final uncertainty of P($ce_{1,0}$) was increased to be at least the second lowest uncertainty, the one from 1998AT04. The values from 2005YA01 and 2007BO were calculated with the measured absolute intensities and with $\alpha_T$(93 keV). The relative uncertainty of 2005YA01 was increased to 4,4 %, as explained above.

No outlier was found by the LWEIGHT program in the consistent data set. A weighted average was 0,3254 (26) with a reduced-$\chi^2$ value of 1,1. The statistical weight is 40 % for the two most precise values from 1998AT04 and 2000SI03. As there are only four useful values, the smallest experimental uncertainty was preferred. Finally, the adopted value, with its external uncertainty, is:

**P($ce_{1,0}$) = 0,3254 (40)**.

With $\alpha_T$(93 keV) = 0,854 (12) (see Table 7 in Section 2.4.2), the absolute intensity of the 93 keV gamma-ray transition was found to be:

**P(93keV) = 0,381 (7)**.

With the absolute gamma-ray emission probabilities and the adopted total internal conversion coefficient of each transition, the transition probabilities $P_{\gamma+ce}$ were determined. They are given in Table 12. The resulting probabilities of the electron capture transitions were found to be: **P($\varepsilon_{0,4}$) = 0,280 (8) %**; **P($\varepsilon_{0,3}$) = 23,60 (47) %**; **P($\varepsilon_{0,2}$) = 22,3 (27) %**; **P($\varepsilon_{0,1}$) = 50,5 (17) %**. It leads to the probability of the electron capture to the ground state of $^{67}$Zn: **P($\varepsilon_{0,0}$) = 3,3 (32) %**. The large uncertainty of P($\varepsilon_{0,0}$) mainly comes from the uncertainty of the evaluated mixing ratio δ(184 keV).

Table 12: The absolute gamma-ray emission probabilities,
calculated with the evaluated value of P($ce_{1,0}$) and the adopted $\alpha_T$(93 keV).
The transition probabilities were calculated from the $P_\gamma$ and the $\alpha_T$ of each transition.

| Transition | Relative intensity | $P_\gamma$ x100 | $P_{\gamma+ce}$ x100 |
|---|---|---|---|
| $\gamma_{2,1}$ (91 keV) | 14,74 (14) | 3,09 (7) | 3,37 (24) |
| $\gamma_{1,0}$ (93 keV) | 181,8 (19) | 38,1 (7) | 70,6 (16) |
| $\gamma_{2,0}$ (184 keV) | 100 | 20,96 (44) | 21,3 (27) |
| $\gamma_{3,2}$ (209 keV) | 11,33 (7) | 2,37 (5) | 2,40 (6) |
| $\gamma_{3,1}$ (300 keV) | 79,22 (48) | 16,60 (37) | 16,67 (45) |
| $\gamma_{3,0}$ (393 keV) | 21,92 (14) | 4,59 (10) | 4,60 (12) |
| $\gamma_{4,3}$ (494 keV) | 0,318 (12) | 0,0666 (29) | 0,0667 (31) |
| $\gamma_{4,2}$ (703 keV) | 0,0539 (42) | 0,0113 (9) | 0,0113 (9) |
| $\gamma_{4,1}$ (794 keV) | 0,252 (6) | 0,0528 (17) | 0,053 (6) |
| $\gamma_{4,0}$ (887 keV) | 0,712 (10) | 0,1492 (38) | 0,1493 (48) |

## 5. Electron Emissions

The energies of the conversion electrons were calculated from the gamma-transition energies given in Section 4.2.1 and the electron binding energies.

The emission probabilities of the conversion electrons were calculated using the internal conversion coefficients given in Section 2.4.2. The emission probabilities of K-Auger electrons were calculated using the transition probabilities given in Sections 2.3 and 2.4, the atomic data given in Section 3, and the internal conversion coefficients given in Section 2.4.2.

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