# $^{36}$Cl - Comments on evaluation of decay data by M.-M. Bé and V.P. Chechev

This evaluation was completed in 1998, it was updated in January 2012. The literature available by this date was included. A new mean energy of the β decay is proposed.

## 1. Decay Scheme and total Decay Energy

$^{36}$Cl decay scheme is based on the measurements of Drever (1955Dr35) and Pierson (1967Pi04).
The Q-values taken from Audi *et al.* (2011AuZZ) are based on many measurements.

## 2. Half-Life

The following values of the $^{36}$Cl half-life in relation to $\beta^-$-decay to $^{36}$Ar($T_{1/2\beta-}$) presented in Table 1 have been considered .

Table 1. Results of $^{36}$Cl $\rightarrow$ $^{36}$Ar decay half-life measurements

| Reference NSRkeynumber | $T_{1/2}$ ($\beta^-$) ($10^5$ *a*) | Method and remarks |
|---|---|---|
| 1949Re** | 3,6 | Microwave spectrometer, β G-M |
| 1949Re** | 2 | Abundance by calculation from bombardment data |
| 1949Wu15 | 4,4 (5) | Microwave spectrometer, β G-M |
| 1955Ba93 | 3,08 (3) | Mass spectrometry, 4πβpc |
| 1957Wr37 | 2,6 (4) | Cl(n,γ)Yield, β G-M. |
| 1957Wr37 | 2,5 (4) | Mass spectrometry, β G-M. Same activity as above |
| 1966Go07 | 3,10 (4) | Mass spectrometry, 4πβpc |
| 1966Go07 | 3,06 (2) | Mass spectrometry, liq.scint. Same mass concentration as above |

Wright *et al.* (1957Wr37) gave two results for $^{36}$Cl half-life. The mass concentration of the samples was determined by two different methods, but the specific activity was determined only once and used to derive both half-life values, so, these values are not independent. Then, in this evaluation, the simple mean of the two results has been introduced for the statistical process.
Goldstein (1966Go07) published two results as well. However, in this work, they carried out one determination of the mass concentration and two separate measurements of the sample activity. Two half-life values were derived. Similarly, the simple mean is adopted, in this evaluation, with the highest experimental uncertainty because the author said that “he did not include any systematic error”.

The values used for the statistical analysis are:

| Reference | $T_{1/2}$ ($\beta^-$), ($10^5$ *a*) | |
|---|---|---|
| 1949Wu15 | 4,4 (5) | |
| 1955Ba93 | 3,08 (3) | |
| 1957Wr37 | 2,55 (40) | |
| 1966Go07 | 3,08 (4) | |
| | | |
| $\chi^2$ crit. = 3,8 | | |

| | | |
|---|---|---|
| $\chi^2$ /n-1 = 2,9 | | |
| UWM | 3,28 | |
| LWM | 3,08 | Int. $u_c$ = 0,024 ; Ext. $u_c$ = 0,04 |

The adopted value is: 3,08 (4) $10^5$ *a*.

From the basic relations:
$T_{1/2} = \ln 2 / (\lambda_{ec} + \lambda_{\beta-})$ and $\lambda_{ec}/\lambda_{\beta-} = P_{ec}/P_{\beta-}$

the total half-life of $^{36}$Cl is obtained $T_{1/2}(\beta^-) \times 0{,}981$ (1) = 3,02 (4)$\cdot 10^5$ *a*.

### 3. Electron Capture

An experimental value of the ratio $(P_L/P_K)_{exp}$ = 0,112 (8) was measured in 1962Do07, and a theoretical value $(P_L/P_K)_T$ was calculated, assuming an allowed transition or 1$^{st}$ forbidden, from the tables of Schönfeld to be 0,095 (5) and, 0,0944 by using the LOGFT program. Theoretical and measured values are not consistent.
On one hand, there is only one measured value; on the other hand, this transition was shown to be of a non-unique second forbidden order.
However, the energy involved is high (1142 keV) so the difference between a 1$^{st}$ and a 2$^{nd}$ forbidden transition should be expected to be low. Then, the theoretical results are preferred and a conservative uncertainty of 5 % was applied.

The probability of the electron capture $P_{EC}$ = 1,9 (1) % was deduced from the measured ratio $P\varepsilon_K/P_{\beta^-}$ = 0,017 (1) (1955Dr35) and $P\varepsilon_K$ = 0,904 (5) × $P_{EC}$ .

### 4. β+ Transition

The probability $P_{\beta}$+=1,57 (30) $10^{-3}$ % has been obtained by averaging the experimental data shown in Table 3.

Table 3. Measurement results for the probability of $^{36}$Cl $\beta^+$ -decay ($P_{\beta+}$), per 100 $^{36}$Cl disintegrations.

| Reference | $P_{\beta}$+ ($10^{-3}$) % | Remarks |
|---|---|---|
| 1962Do07 | 1,2 (5) | $P_{\beta}$+ = 1,7 (1) × 7(+3-1) $10^{-4}$ = 1,2 (+0,5-0,2) $10^{-3}$ %. The greatest uncertainty is adopted. |
| 1962Be29, 1963Be38 | 2,3 (9) | |
| 1965To05 | 1 | No uncertainty, omitted |
| 1967Pi04 | 1,66 (11) | Uncertainty increased to 0,40 to limit its weight |
| Recommended value | 1,57 (30) | Reduced $\chi^2$ =0,6 ; crit $\chi^2$ = 4,6 |

The recommended value $P_{\beta}$+ has been obtained by using the LWM procedure with the three input values from (1962Do07, 1963Be38 and 1967Pi04). The set of data is consistent then, the adopted value is the weighted mean with the internal uncertainty.

### 5. $\beta^-$ Transition

The probability $P_{\beta}$- = 98,1 (1) % was calculated from the balance relation:
$P_{\beta}- = 1 - P_{EC} - P_{\beta}+$

### 6. Atomic Data

The atomic constants $\omega_K$, $n_{KL}$ and relative emission probabilities of K X-ray components and K-Auger have been taken from Schönfeld (1996Sc06).
The energy values for Auger electrons have been taken from Larkins (1977La19).

## 7. Photon Emissions

The emission probabilities of K X-ray components and K-Auger electrons in sulfur were derived from the probability of the electron capture $P_{EC}$ and the adopted values $P_K$ and $\omega_K$.

The emission probabilities of K X-ray components and Auger electrons of argon due to K-shell auto-ionization have been calculated using $P_{XK}(Ar)/P_{XK}(S)$ = 0,149 (22) from 1976Lj03 and atomic constants.

The number of photons per 100 disintegrations for the annihilation radiation was deduced from the $P_{\beta}+$ value as determined above.

## 8. Beta Emissions

The end-point of the $^{36}$Cl $\beta^-$ spectrum has been obtained from $E_{\beta}- = Q_{\beta}- - E_r$ where $E_r$ = 18 eV is the maximum recoil energy of the $^{36}$Ar atom.
The end-point energy of the $^{36}$Cl $\beta^+$ spectrum has been calculated as $E_{\beta}+ = Q\varepsilon - E_{r'}$ – 1022,0 keV, where $E_{r'}$ = 2 eV is the maximum recoil energy of $^{36}$S atom.

Several papers report measurements or calculations of the $^{36}$Cl $\beta^-$ spectrum (see as examples: 1949Wu18, 1972Ma72, 1974Re11, 1993Sa24, 2004Kr10, 2005Gr41, 2008Ro31, etc.).
When using the program BetaShape (2011MoZU), which is based on theoretical considerations, for the mean $\beta^-$ energy, we obtain:
- with the hypothesis of an allowed transition: 251 keV,
- with the hypothesis of a 2$^{nd}$ non-unique forbidden order, accepted as 1$^{st}$ unique forbidden: 278 keV,
- with the hypothesis of a 2$^{nd}$ non-unique forbidden order, accepted as 2$^{st}$ unique forbidden: 303 keV.

Recently, Rotzinger *et al.* (2008Ro31) measured the $^{36}$Cl $\beta^-$ spectrum by mean of a magnetic calorimeter, they kindly provided us their original recorded data, from which a mean $\beta^-$ energy value of 316 keV has been derived.
This latter value is adopted, an uncertainty of 5 % is supposed, however it is difficult to estimate it correctly.

The $\beta^+$ transition is also of a 2$^{nd}$ non-unique forbidden order. Similarly the mean $\beta^+$ energy was calculated as 50 keV for an allowed transition and 58 keV for a 1$^{st}$ unique forbidden transition by the BetaShape program. The adopted value is 54 keV with an uncertainty which covers both hypothesis.

**References**

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