^{40}K - Comments on evaluation of decay data by X. Mougeot, R.G. Helmer

The initial evaluation was completed in 1998. This revised evaluation was done in 2009, taking into account the available literature by April 2009.

1 Decay Scheme

The decay scheme is complete since all of the levels in ^{40}Ar and ^{40}Ca below the decay energies are populated.

The J^{π} and half-life of the excited level are from 1990EN08 evaluation.

2 Nuclear Data

Q values are from Audi and Wapstra 2003 (2003AU03).

A full list of the half-life measurements available by April 2009, and the reasons why certain have been excluded by the evaluator, is given in Table 3.

Three types of measurements were carried out: $T_{1/2}(\beta^-)$ and $T_{1/2}$(EC, 1460 keV) which are partial half-lives, and $T_{1/2}$ which is the total half-life. Branching ratios are needed to evaluate the ^{40}K half-life from these measurements: $P_{\beta-}$ for the $^{40}K \rightarrow ^{40}Ca$ transition, $P_{ec,1460}$ for the $^{40}K \rightarrow ^{40}Ar^{2+}$(1460 keV) transition, $P_{\beta+}$ and $P_{ec,gs}$ for the $^{40}K \rightarrow ^{40}Ar^{0+}$(ground state) transition. So, $T_{1/2}(\beta^-)$ and $T_{1/2}$(EC, 1460 keV) have been evaluated first and then, the branching ratios and the ^{40}K total half-life.

2.1 Partial half-lives

2.1.1 $T_{1/2}$(b$^-$)

Table 1: Partial measured β^- half-lives.

Reference	Partial $T_{1/2}(\beta^-)$ ($\times 10^9$ a)	Comments
1948Graf	1.48 (7)	
1948Hirzel	1.18 (19)	Excluded by LWEIGHT (Chauvenet's criterion)
1949Stout	1.29 (8)	
1950Smaller	1.76 (5)	Excluded by LWEIGHT (3σ criterion)
1951Delaney	1.24 (1)	Excluded by LWEIGHT (Chauvenet's criterion)
1951Good	1.46 (3)	
1955SU38	1.34 (3)	
1955KO21	1.36 (5)	
1956MC20	1.44 (1)	
1959KE26	1.46 (3)	
1960SA31	1.37 (4)	
1961GL07	1.400 (15)	
1962FL05	1.45 (40)	
1965BR25	1.36 (2)	
1965LE15	1.400 (2)	Uncertainty increased to 6.4 $\times 10^6$ a by LWEIGHT
1966FE09	1.41 (2)	
1966Egelkraut	1.40 (7)	
1971Venkataramaiah	1.31 (6)	

The statistical processing was done using the LWEIGHT program. For $T_{1/2}(\beta^-)$, the program turned up three statistical outliers: 1948Hirzel (Chauvenet's criterion), 1950Smaller (3σ criterion), and 1951Delaney (Chauvenet's criterion). From the resulting discrepant data set, with a reduced-χ^2 value of 2.62, a weighted average was deduced. LWEIGHT increased the uncertainty of the most precise measurement (1965LE15) from 2 to 6.4×10^6 a in order to have a maximum contribution of 50 %. The second main contribution is 1956MC20 amounting for 20 %. Finally, this evaluation leads to:

$$\mathbf{T_{1/2}(\beta^-) = 1.407\ (7) \times 10^9\ a}.$$

2.1.2 $T_{1/2}$(EC, 1460 keV)

Table 2: Partial measured EC half-lives.

Reference	Partial $T_{1/2}$(EC, 1460) ($\times 10^9$ a)	Comments
1947GL07	11 (2)	Excluded by LWEIGHT (Chauvenet's criterion)
1948Ahrens	11.6 (2)	
1950Sawyer	12 (1)	
1950Graf	12 (2)	
1953BU58	11.7 (5)	
1955SU38	13.4 (2)	Excluded by LWEIGHT (Chauvenet's criterion)
1955BA25	11.3 (5)	
1957WE43	11.7 (4)	
1960SA31	12.3 (6)	
1965LE15	12.2 (3)	
1966DeRuytter	12.2 (2)	
1966Egelkraut	11.8 (5)	

For the electronic capture (EC) part, all the partial half-lives, given in Table 2, were measured by detecting the 1460 keV gamma-ray in ^{40}Ar. In Table 3, a partial half-life for EC is listed, evaluated by 1956Wetherill: this evaluation used four measurements of the ^{40}Ar/^{40}K concentration ratio in young mica. Obviously, in this case, the total branching ratio of the $^{40}K \rightarrow {}^{40}Ar$ was determined. So, this result cannot be used to evaluate the partial $T_{1/2}$(EC, 1460 keV).

The statistical processing was done using the LWEIGHT program. It turned up two statistical outliers: 1947GL07 and 1955SU38 (Chauvenet's criterion). A weighted average was adopted from the resulting consistent data set, with a reduced-χ^2 value of 0.87. The main contributions are 30 % for 1966DeRuytter and 1948Ahrens, and 13 % for 1965LE15. Finally, this evaluation gives:

$$\mathbf{T_{1/2}(EC,\ 1460\ keV) = 11.90\ (11) \times 10^9\ a}.$$

2.2 Branching ratios

The branching ratios were calculated following Helmer's method (1999BeZS). From the decay scheme:

$$\mathbf{P_{ec,1460} + P_{\beta+} + P_{\beta-} + P_{ec,gs} = 1}.$$

In order to calculate each branching ratio, the following quantities: $P_{ec,1460}/P_{\beta-}$, $P_{\beta+}/P_{\beta-}$ and $P_{ec,gs}/P_{\beta+}$ must be known.

The $P_{ec,1460}/P_{\beta-}$ ratio comes from the $T_{1/2}(\beta^-)/T_{1/2}$(EC, 1460 keV) ratio. The partial half-lives evaluated above leads to: $\mathbf{P_{ec,1460}/P_{\beta-} = 0.1182\ (12)}$.

The β^+ transition of the ^{40}K is a difficult measurement, due to a very low intensity and the pair production which comes from the 1460 keV gamma-ray of ^{40}Ar. Few experiments were able to give more than an upper limit: 1959TI20 ($1.3\ (7) \times 10^{-5}$), 1962EN01 ($1.12\ (14) \times 10^{-5}$) and 1965LE15 ($1.5\ (5) \times 10^{-5}$). The experimental set-up of 1962EN01 minimized the pair production. Following Helmer's choice, the most precise result is used in the present evaluation: $\mathbf{P_{\beta+}/P_{\beta-} = 1.12\ (14) \times 10^{-5}}$.

The $P_{ec,gs}/P_{\beta+}$ ratio was calculated theoretically by Helmer, as described hereafter. The LOGFT program cannot calculate this ratio for this unique 3rd forbidden (3U) transition. But it can calculate the theoretical value for 1U and 2U transitions. For the former (1U), this ratio is 8.51 (9) and for the latter (2U), it is 45.20 (47). Making the assumption that the 3U ratio rises by the same factor (45.20/8.51), then $P_{ec,gs}/P_{\beta+}$ = 240. Following Helmer's choice, a value of **200 (100)** for $\mathbf{P_{ec,gs}/P_{b+}}$ was adopted in the present calculation.

The following branching ratios are then deduced:

$\mathbf{P_{b-}}$ **= 89.25 (17) %,** $\mathbf{P_{ec,1460}}$ **= 10.55 (11) %,** $\mathbf{P_{ec,gs}}$ **= 0.20 (10) %,** $\mathbf{P_{b+}}$ **= 0.00100 (12) %**.

2.3 Total ^{40}K half-life

Table 3: Total half-lives used for the evaluation, determined from measurements and branching ratios.

Reference	Type of measurement	$T_{1/2}$ ($\times 10^9$ a)	Coefficient (%)	Total $T_{1/2}$ ($\times 10^9$ a)	Comments
1931Orban	Partial, EC 1460	0.5	-	-	Not used : no uncertainty
1947GL07	Partial, EC 1460	11 (2)	10.55 (11)	1.16 (21)	
1948Ahrens	Partial, EC 1460	11.6 (2)	10.55 (11)	1.224 (25)	
1948Graf	Partial, β^-	1.48 (7)	89.25 (17)	1.32 (6)	
1948Hirzel	Partial, β^-	1.18 (19)	89.25 (17)	1.05 (17)	Excluded by LWEIGHT (Chauvenet's criterion)
1949Stout	Partial, β^-	1.29 (8)	89.25 (17)	1.15 (7)	
1949Floyd	Total	1.54 (39)	100	1.54 (39)	Excluded by LWEIGHT (Chauvenet's criterion)
1950Sawyer	Partial, EC 1460	12 (1)	10.55 (11)	1.27 (11)	
1950Graf	Partial, EC 1460	12 (2)	10.55 (11)	1.27 (21)	
1950Faust	Total	1.14 (10)	100	1.14 (10)	
1950SA52	Total	1.27 (5)	100	1.27 (5)	
1950Spiers	Total	1.18	-	-	Not used : no uncertainty
1950Houtermans	Total	1.31 (7)	100	1.31 (7)	
1950Smaller	Partial, β^-	1.76 (5)	89.25 (17)	1.571 (45)	Excluded by LWEIGHT (3σ criterion)
1951Delaney	Partial, β^-	1.24 (1)	89.25 (17)	1.107 (9)	Excluded by LWEIGHT (Chauvenet's criterion)
1951Good	Partial, β^-	1.46 (3)	89.25 (17)	1.303 (27)	
1953BU58	Partial, EC 1460	11.7 (5)	10.55 (11)	1.23 (5)	
1955SU38	Partial, β^-	1.34 (3)	89.25 (17)	1.196 (27)	
1955SU38	Partial, EC 1460	13.4 (2)	10.55 (11)	1.414 (26)	Excluded by LWEIGHT (Chauvenet's criterion)
1955KO21	Partial, β^-	1.36 (5)	89.25 (17)	1.214 (45)	
1955BA25	Partial, EC 1460	11.3 (5)	10.55 (11)	1.19 (5)	
1956MC20	Partial, β^-	1.44 (1)	89.25 (17)	1.285 (9)	
1956Wetherill	Partial, EC and β^+	12.2 (6)	10.75 (15)	1.31 (7)	^{40}Ar/^{40}K in young mica
1957WE43	Partial, EC 1460	11.7 (4)	10.55 (11)	1.234 (44)	Direct measurement
1959KE26	Partial, β^-	1.46 (3)	89.25 (17)	1.303 (27)	
1960SA31	Partial, EC 1460	12.3 (6)	10.55 (11)	1.30 (6)	
1960SA31	Partial, β^-	1.37 (4)	89.25 (17)	1.223 (36)	
1961GL07	Partial, β^-	1.400 (15)	89.25 (17)	1.249 (14)	
1962FL05	Partial, β^-	1.45 (40)	89.25 (17)	1.29 (36)	
1965BR25	Partial, β^-	1.36 (2)	89.25 (17)	1.214 (18)	
1965LE15	Partial, EC 1460	12.2 (3)	10.55 (11)	1.287 (34)	
1965LE15	Partial, β^-	1.400 (2)	89.25 (17)	1.2495 (30)	

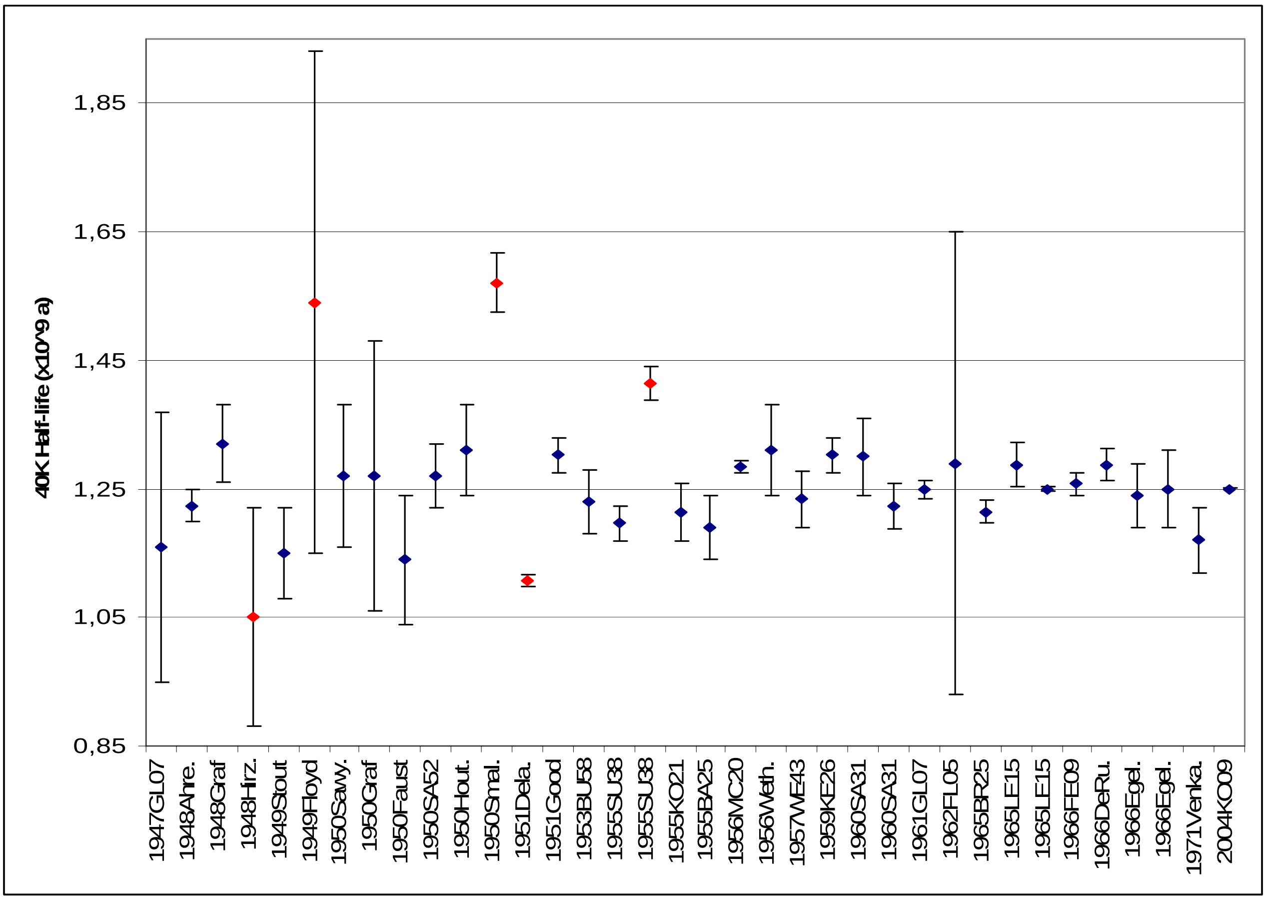
Reference	Type of measurement	$T_{1/2}$ ($\times 10^9$ a)	Coefficient (%)	Total $T_{1/2}$ ($\times 10^9$ a)	Comments
1966FE09	Partial, β^-	1.41 (2)	89.25 (17)	1.258 (18)	
1966DeRuytter	Partial, EC 1460	12.2 (2)	10.55 (11)	1.287 (25)	
1966Egelkraut	Partial, EC 1460	11.8 (5)	10.55 (11)	1.24 (5)	
1966Egelkraut	Partial, β^-	1.40 (7)	89.25 (17)	1.25 (6)	
1971Venkataramaiah	Partial, β^-	1.31 (6)	89.25 (17)	1.17 (5)	
1972Gopal	Partial, β^-	1.13 (6)	-	-	Not used : erroneous uncertainty, see also 2001BE81
1977CE04	Partial, EC 1460	12.30 (4)	-	-	Not used : erroneous uncertainty, see also 2001BE81
2004KO09	Total	1.248 (3)	100	1.2480 (30)	

In order to evaluate the ^{40}K half-life, each partial half-life was recalculated using the appropriate branching ratio. The corresponding uncertainty was also calculated.

The LWEIGHT program turned up five statistical outliers: four by Chauvenet's criterion (1948Hirzel, 1949Floyd, 1951Delaney, 1955SU38 (EC, 1460)) and one by 3σ criterion (1950Smaller). A weighted average was adopted from the resulting consistent data set, with a reduced-χ^2 value of 1.62. The data used for the evaluation of the ^{40}K half-life can be seen in Figure 1. The two main contributions come from 1965LE15 (β^-) and 2004KO09, each of them amounting by 43 %. The adopted value is: $T_{1/2} = 1.2504\ (25) \times 10^9$ a. Since these measurements are not all independent, the adopted uncertainty is the most precise uncertainty on measurement: 3.0×10^6 a, identical for 1965LE15 (β^-) and 2004KO09.

The recommended value for the ^{40}K half-life is then: **$T_{1/2}$ = 1.2504 (30) ´ 10^9 a**, in good agreement with the evaluations by Helmer ($1.265\ (13) \times 10^9$ a) (1999BeZS) and Chechev ($1.258\ (10) \times 10^9$ a) (2001Chechev).

Figure 1: $T_{1/2}$ measurements used for the present evaluation, recalculated with the branching ratios. The red ones are excluded by LWEIGHT.



2.4 Electron Capture Transitions

The evaluation of the branching ratios is described in Section 2.2. That is: $P_{ec,1460}$ = 10.55 (11) % and $P_{ec,gs}$ = 0.20 (10) %.

The log *ft* value for the 1U transition ($^{40}K \rightarrow ^{40}Ar^{2+}$) was computed using the LOGFT program: log *ft* = 11.55 (1).

LOGFT cannot calculate the log *ft* value for the 3U transition ($^{40}K \rightarrow ^{40}Ar^{gs}$). The evaluator chose the same method used in Section 2.2 to calculate the $P_{ec,gs}/\beta^+$ ratio.
So, log *ft* (1U) = 19.51 (5) and log *ft* (2U) = 20.41 (5) and then, log *ft* (3U) = 21.35 (10).

The P_K, etc. values were computed by the LOGFT program.

2.5 b- Transitions

The β^- branching ratio is 89.25 (17) %, as deduced in Section 2.2. The average energy is from the LOGFT program.

The log *ft* value for this 3U transition ($^{40}K \rightarrow ^{40}Ca$) is calculated with the same method as previously, then log *ft* (3U) = 20.58 (1).

2.6 Gamma Transitions

The internal conversion coefficients were calculated using the BrIcc program (2008KI07) for the K, L and M shells. The total internal conversion coefficient is: $\alpha = 10.28\ (15) \times 10^{-5}$.

From the theoretical tables of 1979SC31, the internal pair formation coefficient is: $\alpha_\pi(1460, E2) = 7.3\ (5) \times 10^{-5}$.

So: $\alpha_T = \alpha + \alpha_\pi(1460, E2) = 17.6\ (5) \times 10^{-5}$

3 Atomic Data (Ar, Z=10)

3.1 X Radiations and Auger electrons

The X-ray and Auger electron data were computed using the EMISSION program with the atomic data of Schönfeld and Janßen (1996SC06).

4 Radiation Emissions

4.1 Electron Emission

The β^+ and β^- intensities were evaluated as described above in Section 2.

4.2 Photon Emissions

No new measurement was carried out for the 1460 keV gamma-ray energy in ^{40}Ar since 1998. The adopted value was evaluated by Helmer (1999BeZS): E_γ = 1460.822 (6) keV.

The gamma emission intensity is deduced from the electronic capture probability (see Section 2.2) and internal conversion coefficient (see Section 2.6):

$$I_\gamma(1460) = P_{EC}(1460) / [1 + \alpha_T] = 10.55\ (11) / 1.000176\ (5)\ \%.$$

So we have:

$$I_\gamma(1460) = 10.55\ (11)\ \%.$$

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