$^{40}_{19}\mathrm{K}_{21}$

Evaluation of the decay data

Xavier Mougeot

Université Paris-Saclay, CEA, List, Laboratoire National Henri Becquerel (LNE-LNHB), 91120 Palaiseau, France

The initial DDEP evaluation was realized by R.G. Helmer in 1998 and updated in 2009 by X. Mougeot. The present revised evaluation was carried out in 2025 with all the literature available up to May 2025.

$^{40}_{19}K_{21}$

1 Decay Scheme

^{40}K is a natural isotope with an isotopic abundance of 0.011668 (8) %. It disintegrates by β^- emission to the ground state of ^{40}Ca at 89.56 (7) %, by electron capture to the 1460-keV level of ^{40}Ar at 10.34 (7) %, and to the ground state of ^{40}Ar by electron capture at 0.098 (25) % and by β^+ at 0.00103 (13) %.

Le ^{40}K est un isotope naturel dont l'abondance est de 0,011668 (8)%. Il se désintègre à 89,56 (7) % par émission β^- vers le niveau fondamental du ^{40}Ca, par capture électronique à 10,34 (7) % vers le niveau à 1460 keV du ^{40}Ar, et vers le niveau fondamental du ^{40}Ar à 0,098 (25) % par capture électronique et à 0,00103 (13) % par émission β^+.

2 Nuclear Data

$T_{1/2}$(^{40}K)	:	1,2522	(27)	10^9 a
Q^+(^{40}K)	:	1504,40	(6)	keV
Q^-(^{40}K)	:	1310,91	(6)	keV

2.1 Electron Capture Transitions

	Energy (keV)	Probability (%)	Nature	log ft	P_K	P_L	P_M
$\epsilon_{0,1}$	43,55 (6)	10,34 (7)	Unique 1st Forbidden	11,54	0,7537 (7)	0,22248 (33)	0,02379 (32)
$\epsilon_{0,0}$	1504,40 (6)	0,098 (25)	Unique 3rd Forbidden	21,64	0,8908 (7)	0,0965 (5)	0,01271 (15)

2.2 β^- Transitions

	Energy (keV)	Probability (%)	Nature	log ft
$\beta^-_{0,0}$	1310,91 (6)	89,56 (7)	Unique 3rd Forbidden	20,59

2.3 β^+ Transitions

	Energy (keV)	Probability (%)	Nature	log ft
$\beta^+_{0,0}$	482,40 (6)	0,00103 (13)	Unique 3rd Forbidden	21,64

2.4 Gamma Transitions and Internal Conversion Coefficients

	Energy (keV)	$P_{\gamma+ce}$ (%)	Multipolarity	α_K (10^{-5})	α_L (10^{-5})	α_M (10^{-5})	α_T (10^{-5})	α_π (10^{-5})
$\gamma_{1,0}$(Ar)	1460,851 (6)	10,34 (7)	E2	2,63 (4)	0,215 (3)	0,0210 (3)	10,28 (15)	7,41 (11)

3 Atomic Data

3.1 Ar

ω_K	:	0,1199	(28)
$\bar{\omega}_L$	:	0,00147	(30)
n_{KL}	:	1,697	(6)

3.1.1 X Radiations

		Energy (keV)	Relative probability
X_K			
	$K\alpha_2$	2,95566	50,49
	$K\alpha_1$	2,95774	100
	$K\beta_1$	3,1905	16,24
X_L			
	$L\ell$	0,2195	
	$L\eta$	0,2215	
	$L\beta$	0,3112 - 0,3114	

3.1.2 Auger Electrons

	Energy (keV)	Relative probability
Auger K		
KLL	2,511 - 2,669	100
KLX	2,831 - 2,942	21,6
KXY	3,149 - 3,174	1,16
Auger L	0,17 - 0,31	

4 Electron Emissions

		Energy (keV)		Electrons (per 100 disint.)
e_{AL}	(Ar)	0,17 - 0,31		2,307 (16)
e_{AK}	(Ar)			
	KLL	2,511 - 2,669		6,94 (6)
	KLX	2,831 - 2,942		
	KXY	3,149 - 3,174		
$ec_{1,0\ T}$	(Ar)	1457,645 - 1460,835		0,001063 (17)
$\beta^+_{0,0}$	max:	482,40	(6)	0,00103 (13)
	avg:	251,757	(28)	
$\beta^-_{0,0}$	max:	1310,91	(6)	89,56 (7)
	avg:	582,898	(26)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy (keV)	Photons (per 100 disint.)	
XL	(Ar)	0,2195 - 0,3114	0,0034 (7)	
$XK\alpha_2$	(Ar)	2,95566	0,286 (8)	$K\alpha$
$XK\alpha_1$	(Ar)	2,95774	0,567 (14)	
$XK\beta_1$	(Ar)	3,1905	0,092 (4)	$K'\beta_1$

5.2 Gamma Emissions

	Energy (keV)	Photons (per 100 disint.)
$\gamma^{\pm}$	511	0,00359 (25)
$\gamma_{1,0}$(Ar)	1460,822 (6)	10,34 (7)

6 Main Production Modes

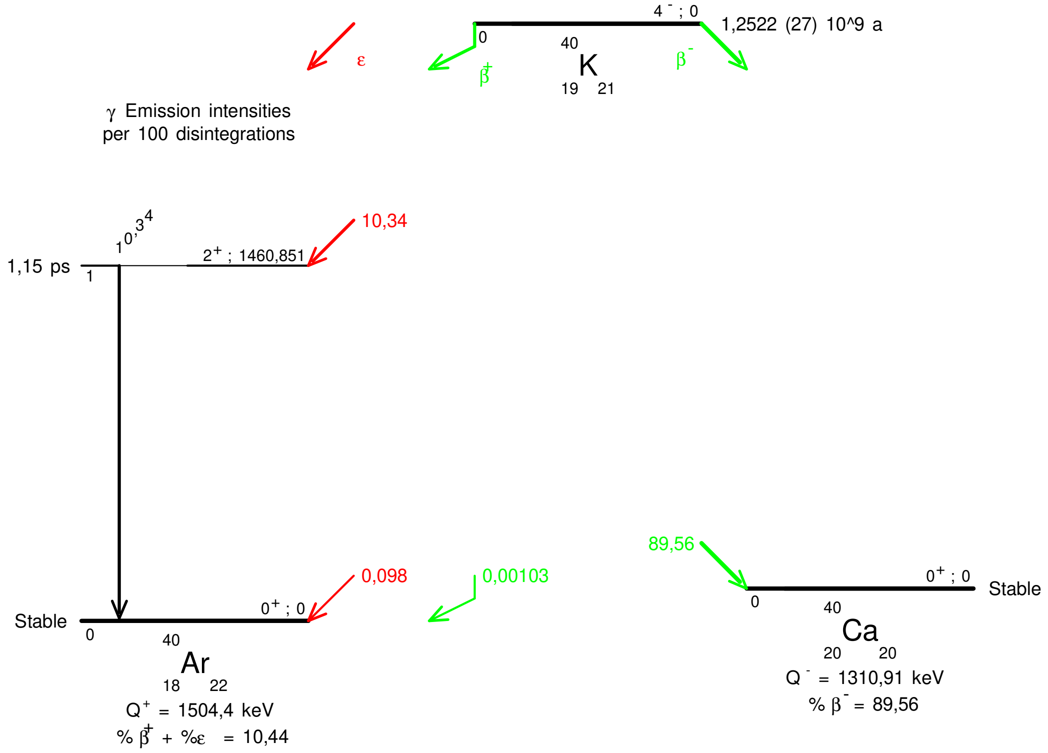
Naturally occurring

7 References

- G.Orbán. Sitzb. Akad. Wiss. Wien Abt. IIa 140 (1931) 121
  (λ_γ)
- E.Gleditsch, T.Gráf. Phys. Rev. 72 (1947) 640
  (λ_γ)
- L.H.Ahrens, R.D.Evans. Phys. Rev. 74 (1948) 279
  (λ_γ)
- T.Gráf. Phys. Rev. 74 (1948) 831
  (λ_β)
- O.Hirzel, H.Wäffel. Phys. Rev. 74 (1948) 1553
  (λ_β)
- R.W.Stout. Phys. Rev. 75 (1949) 1107
  (λ_β)
- J.J.Floyd, L.B.Borst. Phys. Rev. 75 (1949) 1106
  ($T_{1/2}$, λ_β, λ_γ)
- G.A.Sawyer, M.L.Wiedenbeck. Phys. Rev. 76 (1949) 1535
  (λ_γ)
- G.A.Sawyer, M.L.Wiedenbeck. Phys. Rev. 79 (1950) 490
  ($T_{1/2}$, λ_β)
- F.W.Spiers. Nature 165 (1950) 356
  ($T_{1/2}$)
- B.Smaller, J.May, M.Freedman. Phys. Rev. 79 (1950) 940
  (λ_β)
- F.G.Houtermans, O.Haxel, J.Heintze. Z. Physik 128 (1950) 657
  ($T_{1/2}$, λ_β, λ_γ)
- W.R.Faust. Phys. Rev. 78 (1950) 624
  ($T_{1/2}$, λ_β, λ_γ)
- T.Gráf. Rev. Sci. Inst. 21 (1950) 285
  (λ_γ)
- C.F.G.Delaney. Phys. Rev. 81 (1951) 158
  (λ_β)
- M.L.Good. Phys. Rev. 83 (1951) 1054
  (λ_β)
- P.R.J.Burch. Nature 172 (1953) 361
  (λ_γ)
- A.D.Suttle Jr., W.F.Libby. Anal. Chem. 27 (1955) 921
  ($T_{1/2}$, λ_β, λ_γ)
- S.Kono. J. Phys. Soc. Japan 10 (1955) 495
  (λ_β)
- G.Backenstoss, K.Goebel. Z. Naturforschg. 10a (1955) 920
  (λ_γ)

- G.W.Wetherill, G.J.Wasserberg, L.T.Aldrich, G.R.Tilton, R.J.Hayden. Phys. Rev. 103 (1956) 987
  (λ_γ)
- A.McNair, R.N.Glover, H.W.Wilson. Phil. Mag. 1 (1956) 199
  (λ_β, λ_γ)
- G.W.Wetherill. Science 126 (1957) 545
  (λ_β, λ_γ)
- D.R.Tilley, L.Madansky. Phys. Rev. 116 (1959) 413
  (β^+/β^-)
- W.H.Kelly, G.B.Beard, R.A.Peters. Nucl. Phys. 11 (1959) 492
  (λ_β)
- N.K.Saha, J.B.Gupta. Proc. Natl. Inst. Sci. India 26A (1960) 486
  (λ_β, λ_γ)
- K.Egelkraut, H.Leutz. Physik Verhandl. 11 (1960) 67
  (λ_β, λ_γ)
- L.E.Glendenin. Ann. N.Y. Acad. Sci. 91 (1961) 166
  (λ_β)
- D.G.Fleishman, V.V.Glazunov. Sov. J. At. Energy 12 (1962) 338
  (λ_β)
- D.W.Engelkemeir, K.F.Flynn, L.E.Glendenin. Phys. Rev. 126 (1962) 1818
  (β^+/β^-)
- G.A.Brinkman, A.H.W.Aten Jr., J.Th.Veenboer. Physica 31 (1965) 1305
  (λ_β)
- H.Leutz, G.Schulz, H.Wenninger. Z. Phys. 187 (1965) 151
  ($T_{1/2}$, λ_β, λ_γ, β^+/β^-)
- A.W.De Ruytter, A.H.W.Aten Jr., A.Van Dulmen, C.Krol-Konig, E.Zuidema. Physica 32 (1966) 991
  (λ_γ)
- I.Feuerhake, A.Hinzpeter. Naturwiss. 53 (1966) 272
  (λ_β)
- P.Venkataramaiah, H.Sanjeevaiah, B.Sanjeevaiah. Ind. J. Pure Appl. Phys. 9 (1971) 133
  (λ_β)
- N.B.Gove, M.J.Martin. Nucl. Data Tables A10 (1971) 205
  (LogFT code)
- K.Gopal, H.Sanjeevaiah, B.Sanjeevaiah. Am. J. Phys. 40 (1972) 721
  (λ_β)
- A.Cesana, M.Terrani. Anal. Chem. 49 (1977) 1156
  (λ_γ)
- R.G.Helmer, R.J.Gehrke, R.C.Greenwood. Nucl. Instrum. Methods 166 (1979) 547
  (E_γ)
- N.E.Holden. Pure Appl. Chem. 62 (1990) 941
  ($T_{1/2}$ evaluation)
- E.Schönfeld, H.Janssen. Nucl. Instrum. Methods Phys. Res. A369 (1996) 527
  (Atomic Data)
- M.-M.Bé, B.Duchemin, E.Browne, S.-C.Wu, V.Chechev, R.G.Helmer, E.Schönfeld. CEA report ISBN 2-7272-211-3 (1999)
  (DDEP valuation)
- R.G.Helmer, C.van der Leuven. Nucl. Instrum. Methods Phys. Res. A450 (2000) 35
  (E_γ)
- E.Schönfeld, H.Janssen. Appl. Radiat. Isotopes 52 (2000) 595
  (P_X, P_{A_e})
- F.Begemann, K.R.Ludwig, G.W.Lugmair, K.Min, L.E.Nyquist, P.J.Patchett, P.R.Renne, C.-Y.Shih, I.M.Villa, R.J.Walker. Geochim. Cosmochim. Acta 65 (2001) 111
  (Uncertainties)
- A.Grau Malonda, A.Grau Carles. Appl. Radiat. Isotopes 56 (2002) 153
  ($T_{1/2}$)
- K.Kossert, E.Günther. Appl. Rad. Isotop. 60 (2004) 459
  ($T_{1/2}$)
- C.Dulieu, M.-M.Bé, V.Chisté. Proc. Intern. Conf. Nuclear Data for Science and Technology 97 (2008)
  (Saisinuc software)

- T.Kibédi, T.W.Burrows, M.B.Trzhaskovskaya, P.M.Davidson, C.W.Nestor Jr. Nucl. Instrum. Methods Phys. Res. A589 (2008) 202
(BrICC code)
- M.-M.Bé, V.Chisté, C.Dulieu, X.Mougeot, E.Browne, V.Chechev, N.Kuzmenko, F.G.Kondev, A.Luca, M.Galán, A.L.Nichols, A.Arinc, X.Huang. Monographie BIPM-5 ISBN 92-822-2234-8 vol. 5 (2010)
(DDEP evaluation)
- P.R.Renne, R.Mundil, G.Balco, K.Min, K.R.Ludwig. Geochim. Cosmochim. Acta 74 (2010) 5349
($T_{1/2}$)
- P.R.Renne, G.Balco, K.R.Ludwig, R.Mundil, K.Min. Geochim. Cosmochim. Acta 75 (2011) 5097
($T_{1/2}$)
- M.O.Naumenko, K.Mezger, T.F.Nägler, I.M.Villa. Geochim. Cosmochim. Acta 122 (2013) 353
(Isotopic abundance)
- J.Chen. Nucl. Data Sheets 140 (2017) 1
(ENSDF evaluation)
- X.Mougeot. Appl. Radiat. Isotopes 154 (2019) 108884
(BetaShape code, EC)
- M.Wang, W.J.Huang, F.G.Kondev, G.Audi. Chin. Phys. C 45 (2021) 030003
(Q-values, atomic masses)
- K.Kossert, Y.Amelin, D.Arnold, R.Merle, X.Mougeot, M.Schmiedel, D.Zapata-Garcia. Appl. Radiat. Isotopes 188 (2022) 110362
($T_{1/2}$, λ_β, λ_γ)
- L.Hariasz, et al. Phys. Rev. C 108 (2023) 014327
($P_{EC(0,0)}/P_{EC(0,1)}$)
- X.Mougeot. Appl. Radiat. Isotopes 201 (2023) 111018
(BetaShape code, β)
- M.Stukel, et al. Phys. Rev. Lett. 131 (2023) 052503
($P_{EC(0,0)}/P_{EC(0,1)}$)
- P.J.Mohr, D.B.Newell, B.N.Taylor, E.Tiesinga. arXiv [hep-ph] 2409.03787v1 (2024)
(m_e)


4⁻ ; 0
1,2522 (27) 10^9 a
ε
β+
β-
40 K 19 21
γ Emission intensities
per 100 disintegrations
10,34
1,15 ps
2+ ; 1460,851
0,098
0,00103
89,56
0+ ; 0
Stable
Stable
40 Ar 18 22
Q+ = 1504,4 keV
% β+ + %ε = 10,44
40 Ca 20 20
Q- = 1310,91 keV
% β- = 89,56

^{40}K - Comments on evaluation of the decay data

X. Mougeot

Université Paris-Saclay, CEA, List, Laboratoire National Henri Becquerel (LNE-LNHB), 91120 Palaiseau, France

The initial evaluation was completed in 1998 [1999BEZS] and revised in 2009 [2010BEZQ]. The present revision was performed considering the literature available by end of May 2025. Datasets have been averaged with the LWEIGHT (*Limitation of Relative Statistical Weight*) program.

1. Decay scheme

Potassium-40 is a naturally-occurring radioisotope with an abundance of 0.011668 (8) % [2013Naum]. This radionuclide disintegrates by β^- emission to the ground state (level 0) of ^{40}Ca, by electron capture to the first excited state (level 1) of ^{40}Ar, and by a competing transition (electron capture versus β^+) to the ground state (level 0) of ^{40}Ar.

Recommended decay energies have been adopted from the latest Atomic Mass Evaluation [2021WA16]: Q_β = 1310.91 (6) keV and Q_{EC} = 1504.40 (6) keV. The level energy of the first excited state of ^{40}Ar has been deduced from the γ-ray energy. Total angular momenta and parities, and the half-life of the excited level of ^{40}Ar are from [2017CH09]. The decay scheme is complete, with all the levels in ^{40}Ar and ^{40}Ca below the decay energies being populated.

2. Nuclear data

The initial evaluation [1999BEZS] followed for the half-life the strategy proposed in [1990HO28], with some improvements. A lack of comprehensive measurements of ^{40}K decay at that time led the evaluator to consider all the experimental values of partial half-lives.

$T_{1/2}(\beta^-)$ and $T_{1/2}$(EC, 1460 keV) were evaluated individually, whereby their recommended values served to establish the branching ratios in the decay scheme. Finally, all the measured partial half-lives were renormalized by the recommended branching ratios to build a dataset of total decay half-lives that was used to establish the recommended ^{40}K half-life. The same reasoning was followed in the later evaluation [2010BEZQ], including the total decay measurement from [2004KO09]. New studies have been carried out since then that call for a revision of this strategy in the present evaluation.

All the measurements compiled in [2010BEZQ] have been updated with the natural ^{40}K abundance from [2013Naum] and the number of ^{40}K atoms per gram of natural K. The latter quantity has been established to be 1.7972 (12) $\times$ 10^{18} from the average atomic mass of natural K, as determined to be 39.0983 (25) u from the atomic masses from [2021WA16] and the conversion factor of 1 u = 931 494.102 42 (28) keV defined in [2021WA16].

2.1. Half-life

The total half-life has been evaluated by considering only the experimental values that were determined from complete measurements of ^{40}K decay, i.e., both the beta and electron-capture branches. Both the original and updated values are given in Table 1. Measurements from [1949Floy], [1950Faus], [1950Hout] and [1955SU38] are excluded by the Chauvenet criterion, while the value of [2004KO09] is superseded by the more recent studies from [2022KO22]. Measurements from [2002GR01] were not considered in the later evaluation [2010BEZQ], while the value of [1965LE15] has been revised with updated partial half-lives (see Section 2.2). The resulting dataset is consistent with a χ^2 of 0.30 compared to a critical χ^2 of 3.78, and the weighted average with the minimum experimental uncertainty has been adopted: **$T_{1/2}$ = 1.2522 (27) × 10^9 a**. The value from [2022KO22] has a weighting of 67%, while that of [2002GR01] contributes a weight of 30%. This recommended half-life is consistent with the value of 1.2533 (31) × 10^9 a from [2010RE06], which was obtained by a detailed analysis of the Fish Canyon sanidine standard.

Table 1 – Total half-life measurements

Reference	**$T_{1/2}$ (× 10^9 a)**	**Update (× 10^9 a)**	**Comment**
1949Floy	1.54 (39)		Excluded by the Chauvenet criterion
1950Faus	1.14 (10)	1.13 (10)	Excluded by the Chauvenet criterion
1950Hout	1.31 (7)	1.30 (8)	Excluded by the Chauvenet criterion
1950SA52	1.27 (5)	1.25 (6)	
1950Spie	1.18		No uncertainty – not used
1955SU38	1.25 (4)	1.23 (4)	Excluded by the Chauvenet criterion
1965LE15	1.266 (7)	1.253 (14)	
2002GR01	1.248 (4)	1.249 (4)	Re-analysed in 2022KO22
2004KO09	1.248 (3)	1.253 (3)	Re-analysed and superseded by 2022KO22
2022KO22	1.2536 (27)		
Recommended	**1.2522 (27)**	Weighted mean with minimum experimental uncertainty	

2.2. Branching ratios

The decay scheme is complete and, the transition probabilities are connected by:

$$P_{\beta-} + P_{EC(0,0)} + P_{\beta+} + P_{EC(0,1)} = 1 \qquad (1)$$

A theoretical ratio of $P_{EC(0,0)}/P_{\beta+}$ = 200 (100) was necessary to establish the branching ratios in earlier evaluations, as estimated from the results of the LogFT code [1971GO40] which is unable to consider transitions that were defined as third forbidden unique. However, the BetaShape code [2019MO35, 2023MO21] has been developed in recent years, and made available to calculate this degree of forbiddenness correctly. Thus, $P_{EC(0,0)}/P_{\beta+}$ = 211.8 (24) is predicted for the ^{40}K third forbidden unique transition based on the AME2020 Q_{EC}-value.

The recent measurement of the ratio $P_{EC(0,0)}/P_{EC(0,1)}$ provides the means of building a full decay scheme directly from experimental information only, which is judged to be a more robust approach. Rearranging Eq. (1):

$$1/P_{EC(0,1)} = 1 + P_{EC(0,0)}/P_{EC(0,1)} + P_{\beta-}/P_{EC(0,1)} \times [\ 1 + P_{\beta+}/P_{\beta-}\ ] \qquad (2)$$

The $P_{EC(0,0)}/P_{EC(0,1)}$ ratio was measured recently for the first time: $P_{EC(0,0)}/P_{EC(0,1)}$ = 0.0095 (24), and has been adopted from this study [2023HA25, 2023ST09].

Three measurements are available to evaluate the $P_{\beta+}/P_{\beta-}$ ratio: 1.3 (7) × 10^{-5} given as an upper limit by [1959TI20]; 1.12 (14) × 10^{-5} from [1962EN01]; and 1.5 (5) × 10^{-5} from [1965LE15]. The experimental setup of [1962EN01] was designed to minimize pair production, and explains the lower uncertainty of this work, while the upper limit from [1959TI20] has been considered in the present evaluation on the basis of the observed consistency with respect to the other two values. The recommended value $P_{\beta+}/P_{\beta-}$ = 1.15 (14) × 10^{-5} corresponds to a weighted average, and the uncertainty is taken to be the minimum experimental uncertainty.

The $P_{\beta-}/P_{EC(0,1)}$ ratio is identical to the ratio of the partial decay constants λ_β and $\lambda_{EC(0,1)}$. Measurements of natural or enriched sources have been mostly reported as specific activities in the literature, i.e., the number of counts per second and per gram of natural K. However, partial decay constants or partial half-lives were only given in some cases. When possible, all available results have been re-calculated as specific activities, and updated as explained previously.

Table 2 lists all the measured specific β^- activities of natural K. The value of [1960EG01] was not used after being superseded by [1965LE15]. While the value of [1972Gopa] would be expected to supersede [1971Venk], the slightly later study in 1972 seems to be of lesser merit than the latter, an opinion also shared by [2001BE81] – thus, the measurement of [1971Venk] is preferred. Measurements from [1948Hirz], [1950Smal] and [1951Dela] have been excluded on the basis of the Chauvenet criterion. The resulting dataset of 19 values is discrepant, with a χ^2 of 2.34 versus a critical χ^2 of 1.93 that arise from the values of [1965BR25] and [1965LE15]. [1965BR25] does not contain sufficient detail of the uncertainties, and the original study is contained within an inaccessible PhD thesis. The uncertainty documented in [1965LE15] is unrealistically low and most probably accounts for the statistical fitting procedure only. Therefore, these uncertainties have been increased to the minimum required to make the dataset consistent (χ^2 of 1.92): 29.2 (5) becomes 29.2 (10) for [1965BR25]; and 28.26 (5) becomes 28.26 (30) for [1965LE15]. The LWEIGHT program limits the contribution of [2022KO22] to 50% and recommends a weighted average with external uncertainty. The specific β^- activity calculated from this dataset is 28.04 (12) s^{-1} g^{-1} of natural K, which corresponds to λ_β = 4.924 (21) × 10^{-10} a^{-1}.

Table 3 lists all the measured specific γ activities of natural K. [1931Orba] did not quantify the uncertainty, and therefore has not been considered in the determination of the weighted average. Values of [1950Graf] and [1965LE15] supersede [1947GL07] and [1960EG01], respectively. [1956Weth] did not undertake direct counting measurements and therefore has been rejected, while the studies of [1949Floy] have been excluded on the basis of the Chauvenet criterion. The resulting dataset of 15 values is consistent, with a χ^2 of 0.90 versus a critical χ^2 of 2.08, whereby a weighting of 84% was assigned to the value of [1977CE04], as also noted by [2001BE81]. Therefore, the decision was made to increase the uncertainty of [1977CE04] close to the level of the second most precise value of the dataset from [2022KO22]: 3.210 (10) increased to 3.210 (30). The dataset is still consistent (χ^2 of 0.78) with equivalent weightings for [1977CE04] and [2022KO22] of 36% and 39%, respectively, along with the adoption of the internal uncertainty. The specific γ activity is then 3.237 (18) s^{-1} g^{-1} of natural K, which corresponds to $\lambda_{EC(0,1)}$ = 5.684 (32) × 10^{-11} a^{-1}.

The ratio of the partial decay constants gives $P_{\beta-}/P_{EC(0,1)}$ = 8.66 (6). The branching ratios have then been deduced: **$P_{\beta-}$ = 89.56 (7) %**; **$P_{EC(0,1)}$ = 10.34 (7) %**; **$P_{EC(0,0)}$ = 0.098 (25) %**; **$P_{\beta+}$ = 0.00103 (13) %**. Notably, the capture probability to the ground state of ^{40}Ar is half the value determined in the earlier evaluation [2010BEZQ]. The corresponding capture-to-positron ration is $P_{EC(0,0)}/P_{\beta+}$ = 95 (27), which is half of the value predicted by the BetaShape code. This inaccuracy of the theoretical prediction may be due to the atomic modelling, as recently studied by [2024Ando].

The total decay half-life corresponds to the decay constant **λ_{tot} = 5.535 (12)** × **10^{-10} a^{-1}**. The recommended partial decay constants have been deduced using the branching ratios established above: **λ_β = 4.958 (11) × 10^{-10} a^{-1}**; **λ_{EC} = 5.778 (13) × 10^{-11} a^{-1}**; and **$\lambda_{EC(0,1)}$ = 5.723 (38) × 10^{-11} a^{-1}**. While the decay constants λ_β and $\lambda_{EC(0,1)}$ are not identical to those determined above because their datasets have been assembled from different experiments, their ratios are identical. Finally, the following specific activities have been determined: **specific β^- activity** of **28.23 (6) s^{-1} g^{-1} of natural K**, and **specific γ activity** of **3.259 (22) s^{-1} g^{-1} of natural K**.

Table 4 summarizes the evaluated half-life and branching ratios and compares them with previous evaluations.

2.3. Beta transition

There is only a single β^- transition in the ^{40}K decay scheme that directly populates the ground state of ^{40}Ca. The transition energy corresponds to Q_β = 1310.91 (6) keV. As evaluated in Section 2.2, the branching ratio is 89.56 (7) %. The average spectrum energy $E_{\beta-}$ = 582.898 (26) keV and the log *ft* = 20.5935 (11) value have been calculated by means of the BetaShape code version 2.4 [2023MO21]. This program also provides an average spectrum energy of 583.913 (26) keV as determined from the spectrum of [1965LE15] measured from 100 to 1100 keV. Both mean energies are in good agreement to within less than 0.2%.

2.4. Electron capture transitions

The electron-capture transition from the ^{40}K ground state to the first excited state of ^{40}Ar is first forbidden unique, with a transition energy of 43.55 (6) keV deduced from Q_{EC} = 1504.40 (6) keV and a level energy of $E_1(^{40}Ar)$ = 1460.851 (6) keV, as determined in Section 2.5. Relative capture probabilities P_K, P_L, etc. and the log *ft* = 11.536 (8) value have been calculated by means of the BetaShape code version 2.4 [2019MO35].

The electron-capture transition to the ground state of ^{40}Ar is third forbidden unique. The transition energy corresponds to Q_{EC}, and a β^+ transition competes with a transition energy of (Q_{EC} - 2 m_ec^2) = 482.40 (6) keV in which the electron mass has been taken from [2024Mohr]. Calculations of the relative capture probabilities and log *ft* values has been performed with BetaShape enforcing maintenance of the evaluated branching ratios to prevent update of the balance between $P_{EC(0,0)}$ and $P_{\beta+}$. The average spectrum energy is $E_{\beta+}$ = 251.757 (28) keV. Total log *ft* = 21.64 (11) is dominated by the electron-capture component that exhibits log f_{EC} = 2.0325 (49), while the β^+ component is similarly defined by log $f_{\beta+}$ = - 0.28302 (45).

Table 2 – Specific β⁻ activities of one gram of natural K

Reference	Counts (s^{-1})	Comment
1948Graf	26.8 (12)	
1948Hirz	34 (6)	Excluded by the Chauvenet criterion.
1949Stou	30.6 (20)	
1949Floy	27.8 (26)	
1950SA52	28.3 (10)	
1950Faus	31.2 (30)	
1950Hout	27.1 (15)	
1950Smal	22.5 (7)	In [1957WE43]; Excluded by the Chauvenet criterion.
1951Dela	32.0 (30)	In [1957WE43]; Excluded by the Chauvenet criterion.
1951GO29	27.1 (6)	In [1957WE43].
1955SU38	29.6 (7)	
1955KO21	29.2 (10)	
1956MC20	27.50 (30)	
1959KE26	27.2 (5)	
1960EG01	28.5 (14)	Superseded by [1965LE15] – not used.
1960SA31	28.8 (9)	In [1972Gopa] and [1990HO28].
1961GL07	28.20 (30)	In [1965BR25].
1962FL05	27.20 (30)	Uncertainty extended with 1.5% dispersion given in the publication, and rectangular uncertainty.
1965BR25	29.2 (5)	Uncertainty increased to 29.2 (10).
1965LE15	28.26 (5)	Uncertainty increased to 28.26 (30).
1966FE09	27.90 (30)	
1971Venk	30.2 (13)	
1972Gopa	35.0 (20)	Same authors as [1971Venk] but measurement of inferior quality (see also [2001Be81]) – not used.
2022KO22	28.20 (7)	Weighting limited to 50% by LWEIGHT.
Evaluated from dataset	**28.04 (12)**	Weighted mean with external uncertainty.
Recommended	**28.23 (6)**	From half-life and branching ratios.

Table 3 – Specific γ activities of one gram of natural K

Reference	Counts (s^{-1})	Comment
1931Orba	79	In [1990HO28], no uncertainty and discrepant at more than 5σ – not used.
1947GL07	3.6 (8)	Superseded by [1950Graf] – not used.
1948Ahre	3.4 (5)	Recalculated with current γ-ray energy – original uncertainty unrealistic. Adopted uncertainty is from [1950Graf]: same method, but much more details provided.
1949Floy	1.20 (28)	Incorrect gamma efficiency: I_γ/I_β = 0.05 (1) was determined. Excluded by the Chauvenet criterion.
1949Sawy	2.88 (30)	In [1957WE43].
1950Graf	3.4 (5)	
1950Hout	3.10 (30)	
1950Faus	3.60 (40)	
1953BU58	3.37 (20)	Value depends on average energy of ion-pair production in air. Use of 32.5 eV while current value close to 34 eV – uncertainty doubled.
1955SU38	2.96 (30)	
1955BA25	3.50 (14)	In [1957WE43].
1956MC20	3.33 (11)	Keeping their specific β activity and taking their second, more robust value I_γ/I_β = 0.121(4).
1956Weth	3.24 (15)	Not direct counting measurement – not used.
1957WE43	3.39 (12)	
1960SA31	3.21 (16)	In [1990HO28].
1960EG01	3.38 (14)	Superseded by [1965LE15] – not used.
1965LE15	3.20 (8)	Measurement of an enriched KCl source is more robust.
1966DeRu	3.25 (6)	
1977CE04	3.210 (10)	Incomplete uncertainty (see also [2001Be81]). Uncertainty increased to 3.210 (30).
2022KO22	3.240 (29)	
Evaluated from dataset	**3.237 (18)**	Weighted mean with internal uncertainty.
Recommended	**3.259 (22)**	From half-life and branching ratios.

Table 4 – Comparison of the half-lives and branching ratios from the different evaluations

Reference	$T_{1/2}$ (× 10^9 a)	$P_{\beta-}$ (%)	$P_{EC(0,1)}$ (%)	$P_{EC(0,0)}$ (%)	$P_{\beta+}$ (%)
1999BEZS	1.265 (13)	89.14 (13)	10.66 (13)	0.20 (10)	0.00100 (13)
2010BEZQ	1.2504 (30)	89.25 (17)	10.55 (11)	0.20 (10)	0.00100 (12)
2017CH09	1.2480 (30)	89.28 (11)	10.67 (11)	0.045 (6)	0.00100 (13)
This evaluation	**1.2522 (27)**	**89.56 (7)**	**10.34 (7)**	**0.098 (25)**	**0.00103 (13)**

2.5. Gamma transition

The γ-ray energy has been adopted from the initial evaluation [1999BEZS] in which R.G. Helmer re-scaled his 1979 recommended value of 1460.830 (5) keV [1979HE13], down by 5.8 ppm following the methodology described further in [2000HE14]. This manipulation of the γ-ray energy results in E_γ = 1460.822 (6) keV. The recoil energy was determined using the atomic mass of ^{40}Ar corrected for the binding electrons [2021WA16], and the electron mass [2024Mohr]: E_r = 28.67083 (24) eV. The level energy was then deduced to be $E_1(^{40}Ar)$ = 1460.851 (6) keV.

This γ transition is pure E2, and undergoes low internal conversion as a consequence of the small atomic number (Z = 19) and high γ-ray energy. The internal conversion coefficients have been calculated by means of the BrIcc program [2008KI07] within the frozen orbital approximation for the K, L, etc. shells: total internal conversion coefficient is $\alpha_T = 10.28\ (15) \times 10^{-5}$, with the shell component $\alpha_{CE} = 2.87\ (4) \times 10^{-5}$ and an internal pair-creation component α_π (1460 keV, E2) = $7.41\ (11) \times 10^{-5}$.

A γ emission intensity of I_γ(1460 keV) = 10.34 (7) % has been deduced from the electronic capture probability (see Section 2.2) and the total internal conversion coefficient, although the latter contribution is negligible. The 511-keV γ-ray intensity is twice the sum of the β^+ emission probability and the pair creation from internal conversion: $I_{\gamma\pm}$ = 0.00359 (25) %.

3. Atomic data

Only the capture and conversion processes have been considered to create atomic vacancies in the present evaluation of ^{40}K decay. Thus, the atomic data are related to Ar element only.

Fluorescence yield data, relative K X-ray emission probabilities and ratios P(KLX)/P(KLL) and P(KXY)/P(KLL) are from Schönfeld *et al.* [1996SC06]. Auger electron and X-ray absolute probabilities have been determined from the related decay data by means of the EMISSION program [2000SC47]. Table 5 summarizes the absolute photon emission intensities obtained for the ^{40}K decay, including X-rays.

4. Consistency

The consistency of the recommended data has been checked by Saisinuc calculations [2008DUZX] of the total average energy emitted per decay mode for all emissions involved in the ^{40}K decay process, including atomic processes:

- resulting total emission energy of electron-capture branch: $Q_{EC} \times P_{EC}$ = 157.0 (11) keV;
- resulting total emission energy of β^- branch: $Q_\beta \times P_{\beta-}$ = 1174.1 (9) keV.

Both are in perfect agreement with the expected values of 157.0 (11) keV and 1174.1 (9) keV, respectively.

Table 5 – Energies and absolute intensities of photon emissions.

Origin	Energy (keV)	Absolute intensity (%)
XL (Ar)	0.220 – 0.311	0.0034 (7)
$XK_{\alpha2}$ (Ar)	2.956	0.286 (8)
$XK_{\alpha1}$ (Ar)	2.958	0.567 (14)
$XK_{\beta1}$ (Ar)	3.191	0.092 (4)
$\gamma^{\pm}$	511	0.00359 (25)
$\gamma_{1,0}$ (Ar)	1460.822 (6)	10.34 (7)

5. Recommendation of measurements

Any further improvement of the uncertainties on $P_{\beta-}$ and $P_{EC(0,1)}$ would require a high-precision measurement of the specific β^- and γ activities, which currently have relative uncertainties of 0.21% and 0.68%, respectively. Focusing on the specific γ activity would be more beneficial, whereby reduction in the uncertainty by a factor of three, down to the level of the specific β^- activity, would reduce the uncertainties of $P_{\beta-}$ and $P_{EC(0,1)}$ by a factor of two.

Knowledge of the branching ratio to the ground state of ^{40}Ar is essentially based on a single measurement of the electron-capture component by [2023HA25, 2023ST09] and of the β^+ emission by [1962EN01]. These two measurements are difficult to perform, especially with ^{40}K sources made of natural K. Nevertheless, new measurements are strongly recommended to help improve both the accuracy and uncertainties in the ^{40}K decay scheme.

6. References

1931Orba G. Orban, Sitzb. Akad. Wiss. Wien Abt. IIa, 140, 121 (1931) [λ_γ]

1947GL07 E. Gleditsch, T. Graf, Phys. Rev. 72, 640 (1947) [λ_γ]

1948Ahre L.H. Ahrens, R.D. Evans, Phys. Rev. 74, 279 (1948) [λ_γ]

1948Graf T. Graf, Phys. Rev. 74, 831 (1948) [λ_β]

1948Hirz O. Hirzel, H. Wäffel, Phys. Rev. 74, 1553 (1948) [λ_β]

1949Floy J.J. Floyd, L.B. Borst, Phys. Rev. 75, 1106 (1949) [Half-life, λ_β, λ_γ]

1949Sawy G.A. Sawyer, M.L. Wiedenbeck, Phys. Rev. 76, 1535 (1949) [λ_γ]

1949Stou R.W. Stout, Phys. Rev. 75, 1107 (1949) [λ_β]

1950Faus W.R. Faust, Phys. Rev. 78, 624 (1950) [Half-life, λ_β, λ_γ]

1950Graf T. Graf, Rev. Sci. Inst. 21, 285 (1950) [λ_γ]

1950Hout F.G. Houtermans, O. Haxel, J. Heintze, Z. Physik 128, 657 (1950) [Half-life, λ_β, λ_γ]

1950SA52 G.A. Sawyer, M.L. Wiedenbeck, Phys. Rev. 79, 490 (1950) [Half-life, λ_β]

1950Smal B. Smaller, J. May, M. Freedman, Phys. Rev. 79, 940 (1950) [λ_β]

1950Spie F.W. Spiers, Nature 165, 356 (1950) [Half-life]

1951Dela C.F.G. Delaney, Phys. Rev. 81, 158 (1951) [λ_β]

1951GO29 M.L. Good, Phys. Rev. 83, 1054 (1951) [λ_β]

1953BU58 P.R.J. Burch, Nature 172, 361 (1953) [λ_γ]

1955BA25 G. Backenstoss, K. Goebel, Z. Naturforschg. 10a, 920 (1955) [λ_γ]

1955KO21 S. Kono, J. Phys. Soc. Japan 10, 495 (1955) [λ_β]

1955SU38 A.D. Suttle, W.F. Libby, Anal. Chem. 22, 921 (1955) [Half-life, λ_β, λ_γ]

1956MC20 A. McNair, R.N. Grover, H.W. Wilson, Phil. Mag. 1, 199 (1956) [λ_β, λ_γ]

1956Weth G.W. Wetherill *et al.*, Phys. Rev. 103, 987 (1956) [λ_γ]

1957WE43 G.W. Wetherill, Science 126, 545 (1957) [λ_β, λ_γ]

1959KE26 W.H. Kelly, G.B. Beard, R.A. Peters, Nucl. Phys. 11, 492 (1959) [λ_β]

1959TI20 D.R. Tilley, L. Madansky, Phys. Rev. 116, 413 (1959) [β^+/β^-]

1960EG01 K. Egelkraut, H. Leutz, Physik Verhandl. 11, 67, paper 7 (1960) [λ_β, λ_γ]

1960SA31 N.K. Saha, J.B. Gupta, Proc. Natl. Inst. Sci. India 26A, 486 (1960) [λ_β, λ_γ]

1961GL07 L.E. Glendenin, Ann. N.Y. Acad. Sci. 91, 166 (1961) [λ_β]

1962EN01 D.W. Engelkemeir, K.F. Flynn, L.E. Glendenin, Phys. Rev. 126, 1818 (1962) [β^+/β^-]

1962FL05 D.G. Fleishman, V.V. Glazunov, Sov. At. En. 12, 338 (1962) [λ_β]

1965BR25 G.A. Brinkman, A.H.W. Aten, Jr., J.Th. Veenboer, Physica 31, 1305 (1965) [λ_β]

1965LE15 H. Leutz, G. Schulz, H. Wenninger, Z. Phys. 187, 151 (1965) [Half-life, λ_β, λ_γ, β^+/β^-]

1966DeRu A.W. DeRuytter *et al.*, Physica 32, 991 (1966) [λ_γ]

1966FE09 I. Feuerhake, A. Hinzpeter, Naturwiss. 53, 272 (1966) [λ_β]

1971GO40 N.B. Gove, M.J. Martin, Nucl. Data Tables A10, 205 (1971) [LogFT code]

1971Venk P. Venkataramaiah, H. Sanjeevaiah, B. Sanjeevaiah, Ind. J. Pure Appl. Phys. 9, 133 (1971) [λ_β]

1972Gopa K. Gopal, H. Sanjeevaiah, B. Sanjeevaiah, Am. J. Phys. 40, 721 (1972) [λ_β]

1977CE04 A. Cesana, M. Terrani, Anal. Chem. 49, 1156 (1977) [λ_γ]

1979HE13 R.G. Helmer, R.J. Gehrke, R.C. Greenwood, Nucl. Instr. Methods 166, 547 (1979) [E_γ]

1985ZIZY W.L. Zijp, ECN report FYS/RASA-85/19, ECN-197, Energieonderzoek Centrum Nederland, Petten, the Netherlands (1985) [LWEIGHT program]

1990HO28 N.E. Holden, Pure Appl. Chem. 62, 941 (1990) [Half-life evaluation]

1996SC06 E. Schönfeld, H. Janssen, Nucl. Instrum. Methods Phys. Res. A369, 527 (1996) [Atomic data]

1999BEZS M.-M. Bé *et al.*, CEA report, ISBN 2-7272-211-3 (1999) [DDEP evaluation]

2000HE14 R.G. Helmer, C. van der Leun, Nucl. Instrum. Methods Phys. Res. A450, 35 (2000) [E_γ]

2000SC47 E. Schönfeld, H. Janssen, Appl. Radiat. Isot. 52, 595 (2000) [P(X), P(Ae)]

2001BE81 F. Begemann *et al.*, Geochim. Cosmochim. Acta 65, 111 (2001) [Uncertainties]

2002GR01 A. Grau Malonda, A. Grau Carles, Appl. Radiat. Isot. 56, 153 (2002) [Half-life]

2004KO09 K. Kossert, E. Günther, Appl. Rad. Isot. 60, 459-464 (2004) [Half-life]

2008DUZX C. Dulieu, M.-M. Bé, V. Chisté, Proc. Intern. Conf. Nuclear Data for Science and Technology p.97 (2008) [Saisinuc]

2008KI07 T. Kibédi *et al.*, Nucl. Instrum. Methods Phys. Res. A589, 202 (2008) [BrIcc code]

2010BEZQ M.-M. Bé *et al.*, Monographie BIPM-5, Vol.5., ISBN 92-822-2234-8 (2010) [Evaluation]

2010RE06 P.R. Renne *et al.*, Geochim. Cosmochim. Acta 74, 5349 (2010); Response Geochim. Cosmochim. Acta 75, 5097 (2011) [Half-life]

2013Naum M.O. Naumenko *et al.*, Geochim. Cosmochim. Acta 122, 353-362 (2013) [Abundance]

2017CH09 J. Chen, Nucl. Data Sheets 140, 1 (2017) [Evaluation]

2019MO35 X. Mougeot, Appl. Radiat. Isot. 154, 108884 (2019) [BetaShape code, EC]

2021WA16 M. Wang *et al.*, Chin. Phys. C 45, 030003 (2021) [Q-values, atomic masses]

2022KO22 K. Kossert *et al.*, Appl. Radiat. Isot. 188, 110362 (2022) [Half-life, λ_β, λ_γ]

2023HA25 L. Hariasz *et al.*, Phys. Rev. C 108, 014327 (2023) [$P_{EC(0,0)}/P_{EC(0,1)}$]

2023MO21 X. Mougeot, Appl. Radiat. Isot. 201, 111018 (2023) [BetaShape code, β]

2023ST09 M. Stukel *et al.*, Phys. Rev. Lett. 131, 052503 (2023) [$P_{EC(0,0)}/P_{EC(0,1)}$]

2024Ando A. Andoche *et al.*, Phys. Rev. A 109, 032826 (2024) [Atomic modelling]

2024Mohr P.J. Mohr, D.B. Newell, B.N. Taylor, E. Tiesinga, arXiv:2409.03787v1 [hep-ph] [m_e]