DDEP Evaluation of ^{40}K decay

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Summary

Its long half-life and omnipresence in the environment makes ^{40}K contributing in any radioactive background, from γ-ray spectrometry to geoneutrinos, and helps for dating minerals at geologic times. This contribution presents a new DDEP evaluation of ^{40}K decay considering the literature available by mid of January 2025. Recent new measurements were appealing for a deep revision of its decay data evaluation. New half-life and branching ratios are recommended, as well as specific activities of natural potassium samples. Other relevant nuclear and atomic data are also provided, their complete set being available at the DDEP website.

Evaluation strategy

Previous DDEP evaluations followed a similar method, considering all the experimental values of partial half-lives. The evaluated partial half-lives, completed with a calculated EC/β+ ratio for the transition to ^{40}Ar ground state, served to establish the branching ratios in the decay scheme. Eventually, all the measured partial half-lives were renormalized by the branching ratios to build a dataset of total decay half-lives that was used to establish the recommended ^{40}K total half-life.

In the last few years, a controversy arose in the literature on the inconsistency of the total half-life between radioactive measurements and geochronological constraints. In a recent work, Kossert *et al.* [Ko22] reanalyzed existing results and carried out new accurate measurements, solving the inconsistency. In addition, the EC branch to ^{40}Ar ground state was measured for the first time by Hariasz *et al.* [Ha23], allowing establishing the decay scheme without any theoretical estimate.

Evaluated quantities

Adopted data

Q-values are adopted from AME2020 [Wa21]. Spins, parities and the half-life of the ^{40}Ar excited state are from ENSDF [Ch17].

Branching ratios

The decay scheme is complete and can be built only from experimental information with: $1/P_{EC(0,1)} = 1 + P_{EC(0,0)}/P_{EC(0,1)} + P_{\beta-}/P_{EC(0,1)} \times [\,1 + P_{\beta+}/P_{\beta-}\,]$

- $\mathbf{P_{EC(0,0)}/P_{EC(0,1)} = 0.0095\ (24)}$ is from [Ha23].
- $\mathbf{P_{\beta+}/P_{\beta-} = 1.15\ (14) \times 10^{-5}}$ is a weighted average of three measurements from the 1960s, essentially driven by [En62].
- $P_{\beta-}/P_{EC(0,1)}$ is determined from the specific β and γ activities of the measured natural K samples. The 44 available values are updated with the natural ^{40}K abundance of 0.011668 (8) % [Na13], from which a value of **1.7972 (12) × 10¹⁸ ⁴⁰K atoms per gram of natural K** is deduced. A detailed analysis of the 44 values leads to some rejections and uncertainty increases. Recommended **β and γ specific activities are 28.23 (6) and 3.259 (22) s⁻¹ g⁻¹ of natural K**, respectively. One thus obtain $\mathbf{P_{\beta-}/P_{EC(0,1)} = 8.66\ (6)}$. Recommended branching ratios are given in Table 2.

Capture probabilities, average spectrum energy and log-*ft* values are calculated with BetaShape [Mo19, Mo23].

Half-life

Dataset comprises four experimental values, each established from a complete measurement of ^{40}K decay. Weighted average with minimum experimental uncertainty is recommended: $\mathbf{T_{1/2} = 1.2522\ (27) \times 10^9\ a}$. The value from [Ko22] takes 65% of the average, while the one from [Gr02] weighs about 30%.

Photon emissions

Level energy is determined from the γ-ray energy from [He00], corrected for recoil. Emission intensity is determined from $P_{EC(0,1)}$ and $\mathbf{\alpha_T(E_2) = 10.28\ (15) \times 10^{-5}}$ calculated with BrIcc [Ki08]. Atomic probabilities are calculated with EMISSION [Sc00].

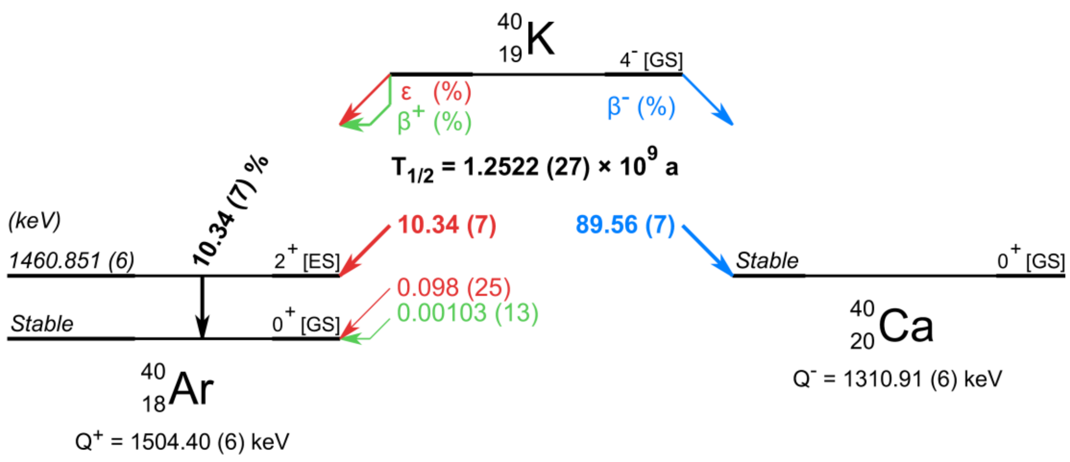
Origin	Energy (keV)	I_{abs} (%)	Origin	Energy (keV)	I_{abs} (%)
XL (Ar)	0.220 – 0.311	0.0034 (7)	$XK_{\beta1}$ (Ar)	3.191	0.092 (4)
$XK_{\alpha2}$ (Ar)	2.956	0.286 (8)	$\gamma\pm$	511	0.00359 (25)
$XK_{\alpha1}$ (Ar)	2.958	0.567 (14)	$\gamma_{1,0}$ (Ar)	1460.822 (6)	10.34 (7)

Table 1 – Energies and absolute intensities of photon emissions.

Consistency

$Q_{EC} \times P_{EC}$ = 157.0 (11) keV and $Q_{\beta} \times P_{\beta-}$ = 1174.1 (9) keV, as calculated with Saisinuc, match perfectly the expected values.

New decay scheme



Reference	$T_{1/2}$ ($\times 10^9$ a)	$P_{\beta-}$ (%)	$P_{EC(0,1)}$ (%)	$P_{EC(0,0)}$ (%)	$P_{\beta+}$ (%)
DDEP 1998	1.265 (13)	89.14 (13)	10.66 (13)	0.20 (10)	0.00100 (13)
DDEP 2009	1.2504 (30)	89.25 (17)	10.55 (11)	0.20 (10)	0.00100 (12)
ENSDF 2017	1.2480 (30)	89.28 (11)	10.67 (11)	0.045 (6)	0.00100 (13)
DDEP 2025	**1.2522 (27)**	**89.56 (7)**	**10.34 (7)**	**0.098 (25)**	**0.00103 (13)**

Table 2 – Comparison of the half-lives and branching ratios from the present and past decay data evaluations.

Call for new measurements

Accuracy of the decay scheme would benefit from new measurements. $P_{EC(0,0)}$ and $P_{\beta+}$ are both determined by a single measurement and other values are required. A high-precision measurement of the specific γ activity, at the precision level of the specific β activity, would reduce by a factor of two the uncertainties on $P_{\beta-}$ and $P_{EC(0,1)}$.

References

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