^{6}He - Comments on evaluation of decay data

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The simplicity of the ^{6}He beta decay makes its spectrum shape a sensitive probe of the electroweak standard model, and of some of the possible new types of interaction beyond the standard model. Such analyses require a high-precision half-life, what motivates the most recent experiments.

The Limitation of Relative Statistical Weights Experimental Method (LWM) was applied to average the decay data when appropriate. All uncertainties are given as the combined uncertainty to one standard deviation.

1 Decay Scheme

Nuclear structure pointwise, ^{6}He nucleus is best described as a halo nucleus, with an alpha core and two neutrons. The 0^+ ground state of ^{6}He decays to the 1^+ ground state of ^{6}Li through an allowed, pure Gamow-Teller beta minus transition (100%). The spins and parities have been adopted from [2002TI10].

The available energy for the decay is $Q_{\beta-}$ = 3505.21 (5) keV, which is the latest recommended value from the Atomic Mass Evaluation (AME) 2020 [2021WA16].

Only the first excited state of ^{6}Li at 2186 (2) keV [2002TI10] could be populated by this decay. However, this state is 3^+, which would correspond to a second forbidden unique transition of a lower transition energy. The probability of such a transition compared to the allowed transition would be extremely low and has never been observed.

A very weak branch due to beta-delayed deuteron decay, i.e. the direct decay of ^{6}He nucleus to unbound final state consisting in a deuteron and an alpha particle, was first observed in [1990RI01] and was also reported in [2002AN06]. It has been studied both experimentally and theoretically since then (see e.g. [2018TU02] for a recent compilation of literature). The probability of this process is of about ($2 \cdot 10^{-6}$). It has been ignored in the present evaluation.

The decay scheme is thus considered as complete.

2 Nuclear data

2.1 Half-life

The ^{6}He half-life has been intensively studied for more than 70 years. The list of published measurements is given in Table 1. The whole dataset is discrepant and this longstanding inconsistency has been discussed in the literature. Two high-precision measurements have been performed in the last 10 years that definitely solve this discrepancy.

The systematic uncertainty given in [2012KN01, 2012KN02] is asymmetric. It has been symmetrized according to the NUBASE rules [2021KO07], what slightly changes the central value. The systematic and statistical uncertainties have then been combined in quadrature, what has also been done for [2022KA42] value.

In the present evaluation, measurements with an uncertainty higher than 10 ms have been discarded because of their negligible contribution in any statistical analysis compared with the measurements from [2012KN01, 2012KN02] and [2022KA42] that have an uncertainty 50 times lower. In addition, [1974WI14] has not been considered as it is superseded by [1982AL17].

Table 1 – Measurements of ^{6}He half-life and recommended value.

Reference	$T_{1/2}$ (ms)	Comments
1946SO05	850 (50)	Too large uncertainty.
1947CA15	870 (60)	Too large uncertainty.
1948KN13	820 (60)	Too large uncertainty.
1949HO24	823 (13)	Too large uncertainty.
1952SH44	860 (30)	Too large uncertainty.
1952VE1A	840 (30)	Too large uncertainty.
1953BA04	830 (30)	Too large uncertainty.
1954KL36	799 (3)	Insufficient details.
1955RU06	850 (30)	Too large uncertainty.
1956VE10	852 (16)	Too large uncertainty.
1958HE46	830 (20)	Too large uncertainty.
1962BI14	797 (3)	Important influence of contaminants.
1962MA38	862 (17)	Too large uncertainty.
1963VI06	830 (20)	Too large uncertainty.
1974WI14	808.1 (20)	Superseded by 1982AL17.
1981BA58	798.1 (10)	Contaminants; diffusion not accounted for.
1982AL17	**805.4 (20)**	With 1974WI14, detailed study.
2002AN06	810 (8)	No detail about uncertainty assignment.
2009RA33	801 (10)	Too large uncertainty.
2012KN01, 2012KN02	**806.92 (24)**	Original: 806.89 (± 0.11) stat. (+ 0.23 / - 0.19) sys.
2022KA42	**807.25 (19)**	Original: 807.25 (± 0.16) stat. (± 0.11) sys.
This evaluation	**807.11 (15)**	Weighted average of values in bold.

In the resulting discrepant dataset of seven values, two groups of measurements clearly appear, the two most recent and precise values being fully consistent. This led the evaluator to a further selection. [1954KL36] does not provide sufficient details about the measurement and the uncertainty assignment. [2002AN06] does also not provide any detail about uncertainty assignment. These two values have thus been discarded. In the study of [1962BI14], an important influence of the contaminants, not clearly identified, was found during their analysis. The reported uncertainty seems to be underestimated. In [1981BA58], an important influence of a ~7 s half-life contaminant was also noticed and removed by increasing the counting time up to 20 s. However, this increased the time available for ^6He ion to diffuse out of the target and the detector, what was not taken into account correctly in the analysis. This value has thus been discarded too. Together with information given in [1974WI14], [1982AL17] provides many details about the measurement and the uncertainty assignment. The two most recent studies from [2012KN01, 2012KN02] and [2022KA42] are very well detailed.

Eventually, only the three measurements from [1982AL17], [2012KN01, 2012KN02] and [2022KA42] have been retained. This dataset is consistent (χ^2 = 0.95 and critical-χ^2 = 4.6) and a weighted average with internal uncertainty has been determined. For such a small dataset, one usually prefers to take a conservative uncertainty as the minimum experimental uncertainty reported. However, the two high-precision measurements available are independent and consistent at one standard deviation. The evaluator has thus chosen to keep the internal uncertainty. The recommended half-life of ^6He decay is then: **$T_{1/2}$ = 807.11 (15) ms**. It is noteworthy that [1982AL17] contributes only to 0.5% in the average. Not considering this value does not significantly change the half-life, which becomes 807.12 (15) ms.

2.2 Beta minus transition

The single beta decay branch is an allowed transition going from the ground state of ^6He to the ground state of ^6Li. The maximum electron energy corresponds to the adopted Q-value. The mean energy of the continuous energy spectrum of the emitted electron and the log *ft* value are from theory and have been determined with the BetaShape code, version 2.2 [2019MO35].

The f-value from BetaShape, *f* = 1005.3169 (28), is slightly higher than the one estimated in [2012KN01, 2012KN02], *f* = 995.224 (68). The uncertainty from BetaShape is underestimated as it only includes the propagation of the Q-value uncertainty. With the half-life from this evaluation, the log *ft* values remain very close to each other but are not consistent within the uncertainties: *f*-value from [2012KN01, 2012KN02] gives log *ft* = 2.90485 (9), while BetaShape gives log *ft* = 2.90924 (8).

3 Atomic data

No physical process that could lead to the creation of atomic vacancies has been considered in this evaluation.

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5 References

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