$^{87}_{37}\mathrm{Rb}_{50}$

Evaluation of the decay data

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This evaluation was completed including the literature available by end of November 2018, and updated in October 2021 for modification of the Q-value.

$$^{87}_{37}\mathrm{Rb}_{50}$$

1 Decay Scheme

Rb-87 decays 100% by beta minus emission directly to the ground state of Sr-87.
Le rubidium 87 se désintègre à 100 % par émission bêta moins vers le niveau fondamental du strontium 87.

2 Nuclear Data

$T_{1/2}(^{87}\mathrm{Rb})$	:	49,650	(40)	10^9 a
$Q^-(^{87}\mathrm{Rb})$	:	282,275	(6)	keV

2.1 β^- Transitions

	Energy (keV)	Probability (%)	Nature	lg ft
$\beta^-_{0,0}$	282,275 (6)	100	3rd Forbidden non-unique	17,1

3 Electron Emissions

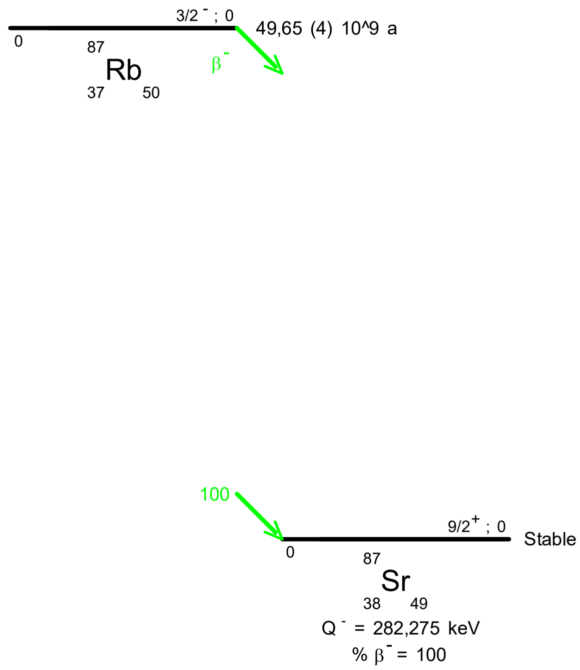
		Energy (keV)	Electrons (per 100 disint.)
$\beta^-_{0,0}$	max:	282,275 (6)	100
	avg:	56,4715 (10)	

4 Main Production Modes

Naturally occurring

5 References

- J.Flinta, S.Eklund. Arkiv Fysik 7 (1954) 401
  (Half-life)
- L.T.Aldrich, G.W.Wetherill, G.R.Tilton, G.L.Davis. Phys.Rev. 103 (1956) 1045
  (Half-life)
- K.Fritze, F.Strassmann. Z.Naturforsch. 11a (1956) 277
  (Half-life)
- E.Huster. Nucl.process in geo.sett 19 (1956)
  (Half-life)
- W.F.Libby. Anal.Chem. 29 (1957) 1566
  (Half-life)
- G.V.Ovichinnikova. Geokhimia 5 (1960) 556
  (Half-life)
- A.Kovach. Acta. Phys .Acad. Sci. Hung. 17 (1964) 341
  (Half-life)
- G.A.Brinkman, A.H.W.Aten, Jr., J.T.Veenboer. Physica 31 (1965) 1305
  (Half-life)
- C.C.McMullen, K.Fritze, R.H.Tomlinson. Can.J.Phys. 44 (1966) 3033
  (Half-life)
- W.Neumann, E.Huster. Z.Phys. 270 (1974) 121
  (Half-life)
- D.W.Davis, J.Gray, G.L.Cumming, H.Baadsgaard. Geochim.Cosmochim.Acta 41 (1977) 1745
  (Half-life)
- J.-F.Minster, J.-L.Birck, C.J.Allegre. Nature(London) 300 (1982) 414
  (Half-life)
- C.-Y.Shih, L.E.Nyguist, D.D.Bogard, J.L.Wooden, B.M.Bansal, H.Wiesmann. Geochim.Cosmochim.Acta 49 (1985) 411
  (Half-life)
- Y.Amelin, A. N.Zaitsev. Geochim.Cosmochim.Acta66 13 (2002) 2399
  (Half-life)
- K.Kossert. Appl.Radiat.Isot. 59 (2003) 377
  (Half-life)
- C. Dulieu, M.M.Be, V.Chiste. Proceeding of the International Conference on Nuclear Data for Science and Technology (2008) 97
  (Saisinuc)
- O.Nebel, E.Scherer, K.Mezger. Earth and Planetary Science Letters 301 (2011) 1
  (Half-life)
- E.Rotenberg, D.W.Davis, Y.Amelin, S.Ghosh, B.A.Bergquist. Geochimica et Cosmochimica Acta 85 (2012) 41
  (Half-life)
- X. Mougeot. Appl. Rad. Isotopes 154 (2019) 108884
  (BetaShape)
- M.Wang, W.J.Huang, F.G.Kondev, G.Audi, S.Naimi. Chin.Phys.C 45 (2021) 030003
  (Q)


3/2 ⁻ ; 0
49,65 (4) 10^9 a
0
87
Rb
37
50
β⁻
100
9/2⁺ ; 0
Stable
0
87
Sr
38
49
Q ⁻ = 282,275 keV
% β⁻ = 100

^{87}Rb - Comments on evaluation of decay data

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This evaluation was completed by A. Singh in November 2018 with the same literature cutoff date. The evaluation was later updated by S. Leblond in October 2021 for modification of the Q-value. The review of this work was performed by X. Huang in April 2022.

The Limitation of Relative Statistical Weights Experimental Method (LWM) was applied to average the decay data when appropriate by use of the LWEIGHT Excel add-in developed at LNHB. All uncertainties are given as the combined uncertainty to one standard deviation.

1 Decay Scheme

^{87}Rb decays by β^- (100%) to the ground state of ^{87}Sr. The energies, spins and parities of the ground state of the mother and daughter nuclei are taken from [2015Jo11]. The available energy for the decay ($Q_{\beta-}$ = 282.275 (6) keV) has been adopted from [2021WA16].

2 Nuclear data

2.1 Half-life

The ^{87}Rb half-life has been intensively studied with more than 50 different publications since 1919. These studies have been performed both by the Nuclear Physics community and by the Geological community. The references considered for this evaluation are listed in Table 1.

In the table, the references are sorted according to their NSR keynumbers. When no key was available for a reference, a NSR-type keynumber has been generated using UX for the last two characters (X being an integer from 0 to 9). The status of each reference (used or discarded) is specified on the third column and the quality of the measurement is commented. All the measurement uncertainties are adapted, if necessary, to match DDEP regulations. It is worth mentioning that for several measurements, the authors reported the result in form of a decay constant rather than a half-life: the values reported in such works, as well as the associated uncertainties, were converted in half-life for the sake of comparison.

Table 1: List of references of interest for evaluation of the ^{87}Rb half-life

Reference	$T_{1/2}$($\times 10^{10}$ year)	Comments
1919HaU0	7	Discarded from analysis: absence of uncertainty
1926HoU0	14	Discarded from analysis: absence of uncertainty
1930MuU0	12	Discarded from analysis: absence of uncertainty
1931OrU0	4.5	Discarded from analysis: absence of uncertainty
1937Ha06	20 to 40	Discarded from analysis: absence of uncertainty
1938SaU0	6.3	Discarded from analysis: absence of uncertainty
1938HaU0	6.4	Discarded from analysis: absence of uncertainty
1942SeU0	7.459	Discarded from analysis: absence of uncertainty
1947EkS0	5.8 (1)	Superseded by 1954Fl18
1948HaU0	6.5 (6)	Discarded from analysis: solid angle not well defined, self-absorption not taken into account
1948HaU1	6.9 (7)	Superseded by 1948Ha001
1949KeU0	6 (6)	Discarded from analysis: solid angle not well defined, self-absorption not taken into account
1951Cu30	6.15 (30)	Discarded from analysis: solid angle not well defined, self-absorption not taken into account
1952Le24	5.9 (3)	Discarded from analysis : no background subtraction is performed
1952Ma20	6.29 (3)	Superseded by 1954Ma31
1952GeU0	6	Discarded from analysis: absence of uncertainty
1953MaU0	6.4 (3)	Superseded by 1954Ma31
1954Ma31	6.2 (3)	Discarded from analysis: self-absorption in the source is not properly taken into account
1954Fl18	**6.1 (2)**	Omitted due to the Chauvenet's criterion
1954Ge60	4.5 (6)*	Published value: $4.3^{+0.7}_{-0.4}\ 10^{10}$ years Superseded by 1955Ge0
1955Ge0	4.36 (25)*	Published value: $4.3^{+0.3}_{-0.2}\ 10^{10}$ years Discarded from analysis: poor knowledge of the measurement background
1956Al31	**5.0 (2)**	**Used in the final dataset**
1956Fr12	**4.6 (5)**	Omitted due to the Chauvenet's criterion
1956We0	5.0 (2)	Superseded by 1956Al31
1956HuU0	**4.3 (2)**	Omitted due to the Chauvenet's criterion
1957Li42	**5.07 (20)**	Omitted due to the Chauvenet's criterion
1959Fl40	4.7 (1)	Discarded from analysis: extrapolation to zero thickness questionable
1960OvU0	**5.02 (20)**	**Used in the final dataset**
1960Ra11	4.72 (8)	Discarded from analysis: effect of after-pulses in the counting rate not taken into account

1961Be41	5.53 (10)	Discarded from analysis: doubts regarding the homogeneity in the grown crystal
1961Eg01	5.82 (10)	Superseded by 1962Le08
1961GlU0	4.70 (5)	Discarded from analysis: extrapolation to zero thickness questionable
1961Mc07	5.25 (10)	Discarded from analysis: extrapolation to zero thickness questionable
1962Le08	5.80 (12)	Discarded from analysis: doubts regarding the homogeneity in the grown crystal
1963KlU0	4.7	Discarded from analysis: absence of uncertainty
1964ZaU0	4.85	Discarded from analysis: absence of uncertainty
1964Ko11	**4.77 (10)**	Omitted due to the Chauvenet's criterion
1965Br25	**5.22 (15)**	Omitted due to the Chauvenet's criterion
1965ThZy	4.60 (6)	Superseded by 1966Mc12
1966Mc12	**4.72 (4)**	Omitted due to the Chauvenet's criterion
1970AfU0	4.99	Discarded from analysis: absence of uncertainty
1972Ne19	4.88 (10)	Superseded by 1974Ne14
1974AfU0	4.88	Discarded from analysis: absence of uncertainty
1974Ne14	**4.85 (8)***	Published value: $4.88^{+0.06}_{-0.1}$ 10^{10} years Omitted due to the Chauvenet's criterion
1977De22	**4.93 (2)$**	Published value: 4.89 ± 0.04 years Omitted due to the Chauvenet's criterion
1982Mi14	**4.944 (28)**	**Used in the final dataset**
1985ShU0	**4.944 (19)#**	Published value: 4.944 ± 0.039 years **Used in the final dataset**
<u>2002AmU0</u>	**<u>4.965 (11)#</u>**	Published value: 4.965 ± 0.021 years **<u>Used in the final dataset</u>**
<u>2003Ko66</u>	**<u>4.967 (32)</u>**	**<u>Used in the final dataset</u>**
<u>2011NeU0</u>	**<u>4.976 (7)#</u>**	Published value: 4.976 ± 0.014 years **<u>Used in the final dataset</u>**
<u>2012RoU0</u>	**<u>4.9614 (40)*#</u>**	Published value: $4.9624^{+0.65}_{-0.95}$ 10^{10} years **<u>Used in the final dataset</u>**
1977StU0	4.49 (4)	Evaluation
2001Be81	4.94 (3)	Evaluation
2011Ch65	4.84 (12)	Evaluation
2015Jo11	4.97 (3)	NDS Evaluation, from 2003Ko66
2015Vi02	4.961 (16)	Evaluation

[*] Published uncertainty was asymmetric. The value and uncertainty were updated using the Experimental Method described in 2021Ko07.

[#] The uncertainty in the reference is given at the 95% confidence level and thus was corrected to match DDEP regulations.

[$] The value and uncertainty of 1977De22 were corrected based on the analysis and correction proposed by 2012RoU0.

The complete data set is highly inconsistent (χ^2=10.1 / χ^2_{crit}=1.7) and has been refined by the evaluator based on a careful analysis of the reported works.

- Most of the early measurements were performed using direct counting Experimental Methods with gas counters. The knowledge of the detection system was generally poor and generally, no uncertainty estimate is detailed in the reference. Most of these measurements were thus discarded for this evaluation.
- From the 1950's, the direct experimental methods have improved greatly with new methods such as in-growth crystal scintillation or liquid scintillation. Yet several sources of uncertainty were not well controlled, most notably the source self-absorption or the energy cut-off of the acquisition system. Various measurements from this period were thus discarded for this evaluation.
- Regarding the in-growth crystal method, only three measurements ([1952Le24], [1961Be41] and [1962Le08]) have been performed. The three measurements are consistent; however, several questions have been raised regarding the crystal purity and homogeneity in these measurements (see for example [1974Ne14] and [1976Ne10]). As they are systematically higher than and inconsistent with more recent measurements, these three references were discarded for this evaluation.

In total, after carefully evaluating all the bibliography, 17 references were kept in the evaluation dataset. The Chauvenet's criterion used by the Lweight code excludes nine of these measurements to keep a consistent data set (χ^2=0.8 / χ^2_{crit}=2.6) of eight references: [1956Al31], [1960OvU0], [1977De22], [1982Mi14], [1985ShU0], [2002AmU0], [2003Ko66], [2011NeU0] and [2012RoU0]. The weighted mean of the eight measurements is $T_{1/2}$ = 4.9633 (32) 10^{10} years with about 63% of the weight being taken by 2012RoU0. The four most recent measurements (performed after 2000) represent 93% of the total weight and are consistent with a value between 4.96 and 4.97 10^{10} years, while the five oldest measurements represents only 7% of the total weight and are consistent with a value around 4.94 10^{10} years.

Given the superior robustness of the most recent publications, both in terms of experimental work and uncertainty budget estimation, only the last four references were kept for the half-life recommendation: [2002AmU0], [2003Ko66], [2011NeU0] and [2012RoU0]. The dataset obtained is consistent (χ^2=1.1 / χ^2_{crit}=3.8) and the weighted average is $T_{1/2}$ = 4.9650 (33) 10^{10} years. The uncertainty is extended to match the most precise measurement, to give the final recommendation: **$T_{1/2}$ = 4.9650 (40) 10^{10} years.** This value is almost identical to the one deduced with the previously selected eight references (0.03% relative deviation), and consistent given the estimated uncertainty.

Prior to this work, two recent evaluations of the decay data from ^{87}Rb were performed. The first one, published in 2015 by Johnson and Wu ([2015JO11] in the scope of the Evaluated Nuclear Structure Data File (ENSDF), recommends a half-life of $T_{1/2}$ = 4.97 (3) 10^{10} years. The second one, published in 2015 by I.M. Villa *et al.* in the scope a joint evaluation between IUPAC (Union of Pure and Applied Chemistry) and IUGS (International Union of Geological Sciences), recommends $T_{1/2}$ = 4.961 (16) 10^{10} years [2015ViU0]. Both are consistent with the current evaluation of the DDEP recommended half-life.

2.2 Beta minus transition

The single beta decay branch is a third forbidden non-unique transition going from the ground state of ^{87}Rb to the ground state of ^{87}Sr.

The maximum electron energy was calculated using the adopted Q-value. It is worth mentioning that the various experimental measurements of the maximum energy of the beta decay ([1973Ru02], [1961Be41], [1961Eg01], [1959Fl40]) are systematically lower (around 275 keV) than the results obtained from the Q-value (around 282 keV). Given that the recommended Q-value is based on trap measurements (such as [1999BR47]) which are three order of magnitude more precise than the energy end-point measurements, it was decided to keep the value deduced from the Atomic Mass Evaluation [2021WA16].

The average energy of the electron and the log *ft* were calculated using BetaShape program based on the work of X. Mougeot [2019MO35]. The experimental shape factor used by the calculation is taken from [2007GR05].

3 References

1919HaU0 O. Hahn et al., Physikalische Zeitschrift 20 (1919), 194-202 [Half-life]

1926HoU0 A. Holmes et al, Nature 117 (1926), 620-621 [Half-life]

1930MuU0 W. Mühlholff et al., Annalen der Physik 7 (1930), 205-224 [Half-life]

1931OrU0 G. Orbàn et al., Sitzungesberichte – Akademie der Wissenschaften in Wien, Mathematisch – Naturwissenschaftliche Klasse. Abteilung IIa : Mathematik, Astronomie, Physik, Meteorologie und Mecanik 140 (1931) 121 – 141 [Half-life]

1937Ha06 O. Hahn et al, The Science of Nature 25 (1937), 189 [Half-life]

1938SaU0 F. Strassmann et al., Berichte der Deutschen Chemischen Gesellschaft 71 (1938), 1 [Half-life]

1942SeU0 P.K. Sen-Chowdhury et al., Proceeding of the National Institute of Sciences of India 8 (1942), 45 [Half-life]

1947EkU0 S. Eklund et al. Arkiv för Matematik, Atronomi och Fysik 33a (1947), 60 [Half-life]

1948HaU0 O. Haxel et al, Physical Review 74 (1948), 1886-1887 [Half-life]

1948HaU1 O. Haxel et al, Zeitschrift für Physik 124 (1948), 705–713 [Half-life]

1949KeU0 M. Kemmerich, Zeitschrift für Physik 126 (1949), 399-409 [Half-life]

1951Cu30 S.C. Curran et al., Physical Review 84 (1951), 151-152 [Half-life]

1952Le24 G.M. Lewis et al., Philosophical Magazin 43 (1952), 1070-1074 [Half-life]

1952Ma20 M.H. MacGregor et al., Physical Review 86 (1952), 420-421 [Half-life]

1952GeU0 I. Geese-Bähnisch et al., Naturwissenschatfen 39 (1952), 379-380 [Half-life]

1953MaU0 M.H. MacGregor et al., Proceeding of the Conference on Nuclear Processes in Geologic Settings 1 (1953) [Half-life]

1954Ma31 M.H. MacGregor et al., Physical Review 94 (1954), 138-140 [Half-life]

1954Fl18 J. Flinta et al., ARkiv Fysik 7 (1954) 401 [Half-life]

1954Ge60 I. Geese-Bähnisch et al., Naturwissenschaften 41 (1954), 459 [Half-life]

1955GeU0 I. Geese-Bähnisch, Zeitschrift für Physik 142 (1955), 565-584 [Half-life]

1956Al31 L.T. Aldrich et al,. Physical Review 103 (1956), 1045-1047 [Half-life]

1956Fr12 K. Fritze et al., Z. Naturforschung 11a (1956), 277-280 [Half-life]

1956WeU0 G.W. Wetherill et al., Bulletin of the American Physical Society 1 (1956), 1 [Half-life]

1956HuU0 E. Huster, Nuclear Processes in Geologic Settings, Proceedings of the Second Conference. Nuclear Science Series Report Number 19 (1956) [Half-life]

1957Li42 W.F. Libby, Analytical Chemistry 29 (1957), 29 [Half-life]

1959Fl40 K.F. Flynn et al., Physical Review 116 (1959), 744-748 [Half-life, Maximum electron energy]

1960OvU0 G.V. Ovchinnikova et al., Gokhi,iya 5 (1960) 392 [Half-life]

1960Ra11 W. Rausch et al., Physik. Verhandl. 11 (1960) 66 [Half-life]

1961Be41 G.B. Beard et al., Nuclear Physics 28 (1961) 570-577 [Half-life, Maximum electron energy]

1961Eg01 K. Egelkraut et al., Zeitschrift für Physik 161 (1961) 13-19 [Half-life, Maximum electron energy]

1961GlU0 L.E. Glendenin, Annals of the New York Academy of Sciences 91 (1961), 166-179 [Half-life]

1961Mc07 A. McNair Philosophy Magazin 6 (1961), 563-572 [Half-life]

1962Le08 H. Leutz, Zeitschrift für Physik 169 (1962), 409-416 [Half-life]

1963KlU0 J.L. Klup et al., Proceeding of the symposium on radioactive dating held by IAEA (1963), 341-351 [Half-life]

1963ZaU0 R.E. Zartman, Ph.D dissertation California Institute of Technology (1963) [Half-life]

1964Ko11 A. Kovach, Acta Physica Academiae Scientiarum Hungaricae 17 (1964), 341-351 [Half-life]

1965Br25 G.A. Brinkman et al., Physical 31 (1965), 1305-1319 [Half-life]

1965ThZy H.G. Thode et al., MacMaster Nuclear Reactor- Reactor Research Report NP-15037 (1965), B27-B28 [Half-life]

1966Mc12 C.C. McMullen et al., Canadian Journal of Physics 44 (1966) [Half-life]

1970AfU0 G.D Afanass'yev et al., Eclogae Geologicae Helvetiae 63 (1970), 9-14 [Half-life]

1972Ne19 W. Neumann et al., Zeitschrift für Naturforschung 27a (1972), 862 [Half-life]

1973Ru02 B. Rüttenauer et al., Zeitschrift für Physik A 258, (1973) 351–366 [Maximum electron energy]

1974AfU0 Afanass'yev et al., Abstract for the International Meeting for Geochronology, Cosmochronology and Isotope Geology (1974) [Half-life]

1974Ne14 W. Neumann et al., Zeitschrift für Physik 270 (1974), 121-127 [Half-life]

1976Ne10 W. Neumann et al., Earth and Planetary Science Letters 33 (1976) 277-288 [Half-life discussion]

1977De22 D. W. Davis et al., Geochimica et Cosmochimica Acta 41 (1977), 1745-1749 [Half-life]

1977StU0 R.H. Steiger et al., Earth and Planetary Science Letters 36 (1977), 359-362 [Half-life evaluation]

1982Mi14 J-F. Minster et al., Nature 300 (1982), 414-419 [Half-life]

1985ShU0 C.Y. Shih et al., Geochimica et Cosmochimica Acta 49 (1985), 411-426 [Half-life]

1999Br47 M.P.Bradley et al, Physical Review Letter 83 (1999), 4510-4513 [Mass measurement]

2001Be81 F. Begemann et al., Geochimica et Cosmochimica Acta 65 (2001), 111-121 [Half-life evaluation]

2002AmU0 Y. Amelin et al., Geochimica et Cosmochimica Acta 66 (2002), 2399-2419 [Half-life]

2003Ko66 K. Kossert, Applied Radiation and Isotopes 59 (2003), 377-382 [Half-life]

2007Gr05 A. Grau Carles et al., Nuclear Instruments and Experimental Methods in Physics Research A 572 (2007) 760-767 [Beta shape factor]

2008DuZX C. Dulieu, Proceeding of the International Conference on Nuclear Data for Science and Technology (2008), 97 [SAISINUC]

2011Ch65 V.P. Chechev, Physics of Atomic Nuclei volume 74 (2011), 1713-1717 [Half-life evaluation]

2011NeU0 O. Nebel et al., Earth and Planetary Science Letters 301 (2011), 1-8 [Half-life]

2012RoU0 E. Rotenberg et al., Geochimica et Cosmochimica Acta 85 (2012), 41-57 [Half-life]

2015Jo11 T.D. Johnson et al., Nuclear Data Sheet 129 (2015), 1-190 [Half-life evaluation]

2015Vi02 I.M. Villa et al., Geochimica et Cosmochimica Acta 162 (2015), 382-385 [Half-life evaluation]

2019Mo35 X. Mougeot. Applied Radiation and Isotopes 154 (2019), 108884 [Emission calculations for beta-, logft]

2021Ko07 F.G.Kondev et al., Chinese Physics C 45 (2021), 030001 [Uncertainty Symmetrization]

2021Wa16 M. Wang, Chinese Physics C 45 (2021), 030003 [Q-value]