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LIGHT MASS ELEMENTS TOTAL HALF-LIVES FOR SELECTED LONG-LIVED NUCLIDES

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I. Introduction

In the past, many compilations and evaluations of half-lives have been made which have uncritically accepted authors' values and uncertainties. They have merely recommended weight-averaged reported results. This evaluation attempts to reanalyse each experiment in the literature including an estimate of the standard deviation utilizing, where possible, an estimate of the systematic error. This paper constitutes a preliminary step in the process of recommending values.

The long-lived nuclides of light elements are of interest for their use in dating methods and for calculating cosmic-ray exposure ages of meteorites.

Experimental data on the half-lives of selected nuclides have been evaluated and recommended values and uncertainties are presented for the following nuclides: ^{3}H, ^{10}Be, ^{14}C, ^{26}Al, ^{39}Ar, ^{40}K, ^{50}V, ^{53}Mn, ^{76}Ge, ^{87}Rb, ^{92}Nb, ^{107}Pd, ^{113}Cd, ^{115}In and ^{123}Te.

The impact of the recommended ^{14}C half-life of 5715 years on the carbon dating technique, which uses the Libby value of 5568 years, will be discussed. Also the possible primordial occurrence of ^{92}Nb is now definitely ruled out by the recommended half-life of 3.7×10^{7}.

Finally, based on the recommended ^{26}Al half-life value, the ^{21}Ne production rate for calculating cosmic-ray exposure ages remains too high, compared to rates using the ^{53}Mn and ^{10}Be half-life values.

II. Recommended Data

The recommended data are given in the following tables.

Table 1 - $T_{1/2}(^3H)$

Author	Reference	Value(years)	Comment
Jenks	89	12.46±0.1	
Jones, W. M.	90	$12.41^{+0.15}_{-0.25}$	
Jones, W. M.	3	12.262±.004	precision only
Popov	91	12.57±0.18	
Merritt	92	12.31±0.13	
Jordan	2	12.346±.003	precision only
Jones, P.M.S.	93	12.25±0.03	
Unterweger	4	12.43±0.05	
Recommended Value		12.3±0.1	

The uncertainties quoted by Jones (3) and Jordan (2) are statements of statisticals precision with no estimate of the systematic error. An indication of the systematic error is given by the spread in values measured by various methods, counting, calorimetry, helium growth. The measurement by Unterweger was performed on a tritiated water standard with a 17 years interval between measurements and to fit the measured activity, a half-life much larger than currently accepted was required. The recommended value is based on W. M. Jones[3], Jordan, P. M. S. Jones, and Unterweger and the standard deviation is based on the disagreement between W. M. Jones, Jordan and Unterweger.

Table 2 $T_{1/2}(^{10}Be)$

Author	Reference	Value x (10^{-6}years)	Comment
Hughes	94	2.0 n.u.	Revised from 2.9
McMillian	5	2.5±0.5	see ref. 7
Yiou	6	1.55±0.3	
McMillian	7	1.71±0.34	revision of 5
Emery	8	1.6±0.2	no details
Recommended Value		1.6±0.2	

The recommended value is based on agreement among Yiou, McMillian and Emery.

Table 3 $T_{1/2}$ (^{14}C)

Author	Reference	Value (years)	Comment
Mann	9	5760±50	see 13
Watt	10	5780±65	
Olsson	11	5680±40	
Godwin	12	5730±40	average of 9,10,11
Mann	13	5730±50	revision of 9
Bella	14	5660±30	
Emery	8	5736±84	no details
Recommended Value		5715±45	

Mann (9) discussed the problem of retention of a small amount of high specific activity (~0.02%) carbon dioxide during the gas dilution phase. This systematic effect could cause up to a 30% spread in the resulting half-life and was eliminated by substituting a clean flask during subsequent dilution phases. Earlier measurements, which varied from 4700-7200 years, were performed either with very low enrichment (a few percent) or with the above mentioned dilution process with large systematic error. These results were discarded.

Because of the absence of any details on his measurement, Emery[8] was assigned one half the weight of the others in the unweighted average, and the listed error was adjusted from 59 years as originally quoted in the weighted average.

In Mann's revision of his earlier measurement he mentions a discrepancy between mass spectrometric determination of the amount of ^{14}C atoms. Samples which were run at NBS and Aldermaston showed a lower reading on one of the three machines at NBS. Mann noted that the result obtained on the mass spectrometer at AWRE agreed with the results on the two other NBS instruments but chose not to use this information. In my analysis, I have average the results on the samples from all four instrument which has slightly lowered Mann's half-life.

A weighted average of the data in table 3 (excluding Godwin) gives 5692±20 years, while an unweighted average gives 5715±24 years.

The unweighted average is recommended because the wide variation in authors estimates of systematic error sources tends to penalize those who do the best job of error analysis. The standard deviation is expanded to account for the variation in the weighted and unweighted averages and to allow for undisclosed systematic errors.

It should be noted that although the fifth (Godwin[12]) and sixth (Johnson[189]) International Carbon-14 Conferences recognized that the best available half-life at that time for the decay of radiocarbon was 5730±40 years, the measurers of radiocarbon dates would continue to use 5568 years realizing that to obtain the correct dates, a factor of 1.03 must be used. The factor now becomes 1.026 with this recommended half-life.

Table 4 $T_{1/2}$ (^{26}Al)

Author	Reference	Value (10^{-5}years)	Comment
Rightmire	15	7.14±0.32	Revised using 16
Norris	153	7.05±0.24	
Thomas	154	7.8±0.5	
Recommended Value		7.17±0.18	

The specific activity measurement by Rightmire has been revised using the Ge(Li) measurement of gamma ray intensities by Samworth[16] to obtain the positron branching ratio more accurately.

Table 5 $T_{1/2}$ (^{39}Ar)

Author	Reference	Value (years)	Comment
Zeldes	19	265±30	
Stoenner	7	268±8	Revised ^{37}Ar half-life by Kishore (ref. 18)

The weighted average is 268±8 years, where the 3% systematic error quoted by Stoenner has been used rather than the 1% statistical error usually associated with the half-life.

Table 6 $T_{1/2}$ (^{40}K)

Author	Reference	Value x (10^{-9}years)	Comment
Gleditsch	125	11±2	electron capture
Ahrens	126	11.8±0.2	electron capture
Graf	127	1.47±0.07	β decay
Stout	128	1.29±0.08	β decay
Floyd	129	1.54±0.39	total decay
Sawyer	130	12±	
Graf	131	12±2	electron capture
Spiers	132	1.18	total decay
Faust	133	1.13±0.10	total decay
Sawyer	134	1.3-1.4	β decay
Houtermans	135	1.31±0.07	total
Smaller	136	1.75±0.05	β decay
Delaney	137	1.23±0.01	β decay
Good	20	1.46±0.03	β decay
Burch	138	11.7±0.5	electron capture
Suttle	21	1.33±0.03	β decay
		13.3±0.2	electron capture
McNair	22	1.44±0.01	β decay
		11.6±0.2	electron decay
Backenstoss	32	11.3±0.5	electron capture
Wetherill	33	12.2±0.6	electron capture
Kelly	23	1.45±0.03	β
Glendenin	24	1.40±0.015	β
Fleishman	25	1.45±004	β precision only
Brinkman	26	1.35±0.02	β
Leutz	27	12.1±0.3	εc
		1.40±0.002	β
Wetherill	34	11.6±0.4	εc
Kono	28	1.36±0.05	β
Feuerhake	31	1.42±0.02	β
DeRuytter	35	12.2±0.2	γ
Egelkraut	29	11.8±0.5	εc
		1.40±0.07	β

Saha	30	12.3±0.6	ε c
		1.37±0.04	β
Venkataramaish	139	1.31±0.06	β
Gopal	140	1.13±0.06	β
Cesana	36	12.3±0.04	ε c

The half-life is determined by averaging the beta branch using Good, Suttle, McNair, Kelly, Glendenin, Fleishman, Brinkman, Leutrz, Kono, Egelkraut, Saha, and Feuerhake, and by averaging the electron capture branch using Backenstoss, McNair, Wetherill, Saha, Egelkraut, Leutz, DeRuytter, and Cesana.

Table 7 $T_{1/2}$ (^{50}V)

Author	Reference	Value (10^{-17} years)	Comment
Bauminger	155	.005	
McNair	156	>.08	electron capture
		>.12	β−
Watt	157	.06	
Sonntag	158	>0.9	electron capture
		>0.69	β−
Pape	159	>7.	β−
		>8.8	electron capture
Alburger	160	$1.5^{+0.3}_{-0.7}$	
Simpson	161	$1.2^{+0.8}_{-0.4}$	
Recommended Value		$1.4^{+0.5}_{-0.6}$	

The recommended value is based on the Alburger and Simpson measurements.

Table 8 $T_{1/2}$ (^{53}Mn)

Author	Reference	Value x (10^{-6} years)	Comment
Kaye	94	1.9±0.5	
Hohlfelder	95	10.8±4.5	
Matsuda	96	2.9±1.2	
Hondo	37	3.71±0.14	revised
Wolfle	39	3.84±0.62	revised
Heimann	38	3.73±0.41	revised

The early measurements assumed a constant cosmic ray flux over a period of 10 million years, which is a questionable assumption. Hondo's measurement was revised for the ^{54}Mn half-life of 312 days rather than 303 days used by the author. Wolfle's measurement was revised for the ^{54}Mn half-life of 312 days rather than 308 days used by the author. Heimann's measurement was revised for the ^{26}Al half-life of 0.714×10^6 years rather than 0.75×10^6 years used by the author. The recommended value is $3.7 \pm 0.2 \times 10^6$ years.

Table 9 $T_{1/2}$ (^{76}Ge)

Author	Reference	Value x(10^{-22}years)	Comment
Leccia	163	>0.2	
Bellotti	164	>0.8	first excited state
		>2.	ground state
Avignone	165	>1.3	
Forster	106	>1.9	
Simpson	167	>1.6	first excited state
		>3.2	ground state
Goulding	168	>4.	

The recommended value is based on Goulding's preliminary data.

Table 10 $T_{1/2}$ (^{87}Rb)

Author	Reference	Value x(10^{-10}years)	Comment
Geese-Bahnisch	142	$4.3\pm^{+0.3}_{-0.2}$	
Fritze	143	4.6±0.5	
Aldrich	144	5.0±0.2	
Libby	151	5.07±0.2	
Flynn	145/24	4.7±0.1	
Ovchinnikova	146	5.0±0.2	
McNair	147	5.25±0.10	
Egelkraut	148	5.82±0.1	
Leutz	149	5.80±0.12	
Brinkman	26	5.22±0.15	
McMullen	150	4.72±0.04	
Neumann	40	$4.88^{+0.06}_{-0.10}$	
Davis	41	4.89±0.04	
Akatsu	162	5.56±0.025	
Recommended Value		4.88±0.05	

The most accurate measurements of those of Neumann and Davis, who remeasured McMullen's sample. The recommended value is based on these two measurements. The recent measurement by Akatsu was ignored.

Table 11 $T_{1/2}$ (^{92}Nb)

Author	Reference	Value (10^{-7} years)	Comment
Apt	97	~17	
Makino	42	3.5±0.4	revised
Nethaway	43	3.9±0.5	revised
Recommended Value		3.7±0.5	

Makino's result for the specific activity measurement as reported is in error. It should give $T_{1/2} = 3.98\pm0.76\times10^{7}$ years.

In Nethaway's measurement, he ignores all other measured (n,2n) cross section values for producing the m-state except his own (ref. 98) The author notes a 10% effect is involved in treating the cross section for producing the long lived state, the author averages all total (n,2n) cross sections from 13 to 15 MeV, but selects the peak cross section for m-state production at 14.8 MeV. In this evaluation, I have renormalized the ^{238}U (n,f) flux monitor to the latest value of the Evaluated Nuclear Data File ENDF/B-V and I have recalculated the half life on the basis of 13-15 MeV average (n,2n) cross section difference for total and m-state production as well as 14,8 MeV differences. The former gives 3.79×10^{7} years and the latter 4.02×10^{7} years. An average is selected to represent this experiment.

The recommended value is $3.7\pm0.5\times10^{7}$ years.

Table 12 $T_{1/2}$ (^{107}Pd)

Author	Reference	Value (10^{-6}years)	Comment
Flynn	54	6.5±0.3	enriched sample

Table 13 $T_{1/2}$ (^{113}Cd)

Author	Reference	Value(10^{-5}years)	Comment
Martell	99	>0.6	natural Cd
Kalkstein	100	>0.5	natural Cd
Selig	101	>3.	natural Cd
Watt	46	>1.3	natural Cd
Greth	44	9.3±1.9	96.38% ^{113}Cd

The recommended value is based on the 96.3% enriched ^{113}Cd measurement by Greth.

Table 14 $T_{1/2}$ (^{115}In)

Author	Reference	Value(10^{-14}years)	Comment
Martell	99	6±2	
Cohen	102	~1	
Beard	103	7.05±1.51	revised
Watt	46	5.1±0.4	
Pfeiffer	45	4.41±0.25	

The recommended value is based on Pfeiffer's measurement. This was a Indium loaded liquid scintillator measurement.

Table 15 $T_{1/2}$ (^{123}Te)

Author	Reference	Value (10^{-13}years)	Comment
Heintze	152	>100 >1	K-capture L-capture
Watt	46	1.2±0.1	K-capture
Selig	101	>5	L-capture

The recommended half-life is based on Watt's measurement in the low background laboratories at Glasgow and Aldermaston, which has been revised for the isotopic abundance value for ^{123}Te of 0.908% rather than the 0.87% assumed. This measurement is preferred to the others where the number of counts were lost in the background and assumed to be zero.