Double-β Decay

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Neutrinoless Double-β Decay

Half-life limits on the neutrino-less double-β decay

In most cases the transitions (Z,A) $\rightarrow$ (Z+2,A) $+ 2e^-$ to the 0^+ ground state of the final nucleus are listed. We also list transitions that decrease the nuclear charge ($2e^+$, e^+ CC and double EC) and transitions to an excited state of the final nucleus (0_i^+, 2^+, and 2_i^+). In the following Listings only the best or comparable limits for the half-lives of each transition are reported and only those with about $T_{1/2} > 10^{23}$ years that are relevant for particle physics.

• • • We do not use the following data for averages, fits, limits, etc. • • •

$t_{1/2}(10^{23}$ yr)	*CL%*	*ISOTOPE*	*TRANSITION*	*METHOD*	*DOCUMENT ID*
> 190	90	^{76}Ge		MAJORANA	[1] AALSETH 18
> 800	90	^{76}Ge		GERDA	[2] AGOSTINI 18
> 180	90	^{136}Xe		EXO-200	[3] ALBERT 18
> 150	90	^{130}Te		CUORE	[4] ALDUINO 18
> 2.5	90	^{82}Se		NEMO-3	[5] ARNOLD 18
> 24	90	^{82}Se		CUPID-0	[6] AZZOLINI 18
> 0.81	90	^{82}Se	g.s $\rightarrow 0_1^+$	CUPID-0	[7] AZZOLINI 18A
> 2.2	90	^{116}Cd		AURORA	[8] BARABASH 18
> 530	90	^{76}Ge		GERDA	[9] AGOSTINI 17
> 1.1	90	^{134}Xe		EXO-200	[10] ALBERT 17C
> 1	90	^{116}Cd		NEMO-3	[11] ARNOLD 17
> 40	90	^{130}Te		CUORE(CINO)	[12] ALDUINO 16
> 260	90	^{136}Xe	g.s.$\rightarrow 2_1^+$	KamLAND-Zen	[13] ASAKURA 16
> 260	90	^{136}Xe	g.s.$\rightarrow 2_2^+$	KamLAND-Zen	[14] ASAKURA 16
> 240	90	^{136}Xe	g.s.$\rightarrow 0_1^+$	KamLAND-Zen	[15] ASAKURA 16
>1070	90	^{136}Xe		KamLAND-Zen	[16] GANDO 16
> 11	90	^{100}Mo		NEMO-3	[17] ARNOLD 15
> 110	90	^{136}Xe		EXO-200	[18] ALBERT 14B
> 9.4	90	^{130}Te	$0^+ \rightarrow 0_1^+$	CUORICINO	[19] ANDREOTTI 12
> 3.6	90	^{82}Se		NEMO-3	[20] BARABASH 11A
> 30	90	^{130}Te		CUORICINO	[21] ARNABOLDI 08
> 0.58	90	^{48}Ca		CaF_2 scint.	[22] UMEHARA 08
> 0.89	90	^{100}Mo	$0^+ \rightarrow 0_1^+$	NEMO-3	[23] ARNOLD 07
> 1.6	90	^{100}Mo	$0^+ \rightarrow 2^+$	NEMO-3	[24] ARNOLD 07
> 1	90	^{82}Se		NEMO-3	[25] ARNOLD 05A
> 1.1	90	^{128}Te		Cryog. det.	[26] ARNABOLDI 03
> 1.7	90	^{116}Cd		$^{116}CdWO_4$ scint.	[27] DANEVICH 03
> 157	90	^{76}Ge		Enriched HPGe	[28] AALSETH 02B
> 190	90	^{76}Ge		Enriched HPGe	[29] KLAPDOR-K... 01

[1] AALSETH 18 uses the MAJORANA Demonstrator to search for the $0\nu\ \beta\beta$ decay. The exposure is 9.95 kg·year. The median sensitivity is 2.1×10^{25} yr.

[2] AGOSTINI 18 uses the GERDA detector to search for the $0\nu\ \beta\beta$ decay. The exposure is 46.7 kg·year. The median sensitivity is 5.8×10^{25} yr. Supersedes AGOSTINI 17.

[3] ALBERT 18 uses the EXO-200 detector to search for the $0\nu\ \beta\beta$ decay. The exposure is 177.6 kg·year. The median sensitivity is 3.7×10^{25} years.

[4] ALDUINO 18 uses the CUORE detector to search for the $0\nu\ \beta\beta$ decay of ^{130}Te. The exposure is 86.3 kg·year of natural TeO_2 corresponding to 24.0 kg·year for ^{130}Te. The median sensitivity is 0.7×10^{25} yr. The limit is obtained combining the new data from CUORE with those of CUORE0 (9.8 kg·year of ^{130}Te) and Cuoricino (19.8 kg·year of ^{130}Te).

[5] ARNOLD 18 use the NEMO-3 tracking detector to place a limit on the $0\nu\beta\beta$ decay of ^{82}Se. This is a slightly weaker limit than in BARABASH 11A, using the same detector. Supersedes ARNOLD 05A.

[6] AZZOLINI 18 uses CUPID-0 detector, a novel scintillating cryogenic calorimeter, operated in the LNGS. This results replaces BARABASH 11A (NEMO-3) as the most stringent limit on the $0\nu\ \beta\beta$-decay of ^{82}Se.

[7] AZZOLINI 18A data collected by CUPID-0 based on scintillating bolometers is used to derive a new most stringent limit on the $0\nu\beta\beta$-decay of ^{82}Se to the 0^+_1 state of ^{82}Kr.

[8] BARABASH 18 use 1.162 kg of $^{116}CdWO_4$ scintillating crystals to obtain this limit. Supersedes DANEVICH 03 with analogous source and is more sensitive than ARNOLD 17.

[9] AGOSTINI 17 result corresponds to data collected with GERDA phase 1 and first release of phase 2 for a total of 343 mol-yr exposure. Supersedes AGOSTINI 13A. The median sensitivity is 4.0 10^{25} yr.

[10] ALBERT 17C uses the EXO-200 detector that contains 19.098 ± 0.014% admixture of ^{134}Xe to search for the 0ν and $2\nu\ \beta\beta$ decay modes. The exposure is 29.6 kg·year. The median sensitivity is 1.9×10^{21} years.

[11] ARNOLD 17 use the NEMO-3 tracking calorimeter, containing 410 g of enriched ^{116}Cd exposed for 5.26 yr, to determine the half-life limit. Supersedes BARABASH 11A.

[12] ALDUINO 16 report result obtained with 9.8 kg y of data collected with the CUORE-0 bolometer, combined with data from the CUORICINO. Supersedes ALFONSO 15.

[13] ASAKURA 16 use the KamLAND-Zen liquid scintillator calorimeter (^{136}Xe 89.5 kg yr) to place a limit on the $0\nu\beta\beta$-decay into the first excited state of the daughter nuclide.

[14] ASAKURA 16 use the KamLAND-Zen liquid scintillator calorimeter (^{136}Xe 89.5 kg yr) to place a limit on the $0\nu\beta\beta$-decay into the second excited state of the daughter nuclide.

[15] ASAKURA 16 use the KamLAND-Zen liquid scintillator calorimeter (^{136}Xe 89.5 kg yr) to place a limit on the $0\nu\beta\beta$-decay into the third excited state of the daughter nuclide.

[16] GANDO 16 use the the KamLAND detector to search for the 0ν decay of ^{136}Xe. With a significant background reduction, the combination of results of the first (270.7 days) and the second phase (263.8 days) of the experiment leads to about six fold improvement over the previous limit. Supersedes GANDO 13A. The sensitivity is 5.6 10^{25} yr.

[17] ARNOLD 15 use the NEMO-3 tracking calorimeter with 34.3 kg yr exposure to determine the limit of $0\nu\beta\beta$-half life of ^{100}Mo. Supersedes ARNOLD 2005A and BARABASH 11A.

[18] ALBERT 14B use 100 kg yr of exposure of the EXO-200 tracking calorimeter to place a lower limit on the $0\nu\beta\beta$-half life of ^{136}Xe. Supersedes AUGER 12.

[19] ANDREOTTI 12 use high resolution TeO_2 bolometric calorimeter to search for the $0\nu\beta\beta$ decay of ^{130}Te leading to the excited 0^1_+ state at 1793.5 keV.

[20] BARABASH 11A use the NEMO-3 detector to measure $2\nu\beta\beta$ rates and place limits on $0\nu\beta\beta$ half lives for various nuclides. Supersedes ARNOLD 05A, ARNOLD 04, ARNOLD 98, and ELLIOTT 92.

[21] Supersedes ARNABOLDI 04. Bolometric TeO_2 detector array CUORICINO is used for high resolution search for $0\nu\beta\beta$ decay. The half-life limit is derived from 3.09 kg yr ^{130}Te exposure.

[22] UMEHARA 08 use CaF_2 scintillation calorimeter to search for double beta decay of ^{48}Ca. Limit is significantly more stringent than quoted sensitivity: 18×10^{21} years.

[23] Limit on 0ν-decay to the first excited 0^+_1-state of daughter nucleus using NEMO-3 tracking calorimeter. Supersedes DASSIE 95.

[24] Limit on 0ν-decay to the first excited 2^+-state of daughter nucleus using NEMO-3 tracking calorimeter.

[25] NEMO-3 tracking calorimeter is used in ARNOLD 05A to place limit on $0\nu\beta\beta$ half-life of ^{82}Se. Detector contains 0.93 kg of enriched ^{82}Se. Supersedes ARNOLD 04.

[26] Supersedes ALESSANDRELLO 00. Array of TeO_2 crystals in high resolution cryogenic calorimeter. Some enriched in ^{128}Te. Ground state to ground state decay.

[27] Limit on $0\nu\beta\beta$ decay of ^{116}Cd using enriched $CdWO_4$ scintillators. Supersedes DANEVICH 00.

[28] AALSETH 02B limit is based on 117 mol·yr of data using enriched Ge detectors. Background reduction by means of pulse shape analysis is applied to part of the data set. Reported limit is slightly less restrictive than that in KLAPDOR-KLEINGROTHAUS 01 However, it excludes part of the allowed half-life range reported in KLAPDOR-KLEINGROTHAUS 01B for the same nuclide. The analysis has been criticized in KLAPDOR-KLEINGROTHAUS 04B. The criticism was addressed and disputed in AALSETH 04.

[29] KLAPDOR-KLEINGROTHAUS 01 is a continuation of the work published in BAUDIS 99. Isotopically enriched Ge detectors are used in calorimetric measurement. The most stringent bound is derived from the data set in which pulse-shape analysis has been used to reduce background. Exposure time is 35.5 kg y. Supersedes BAUDIS 99 as most stringent result.

Half-life measurements of the two-neutrino double-β decay

The measured half-life values for the transitions (Z,A) → (Z+2,A) + $2e^-$ + $2\overline{\nu}_e$ to the 0^+ ground state of the final nucleus are listed. We also list the transitions to an excited state of the final nucleus (0^+_i, etc.). We report only the measuremetnts with the smallest (or comparable) uncertainty for each transition.

• • • We do not use the following data for averages, fits, limits, etc. • • •

$t_{1/2}(10^{21}$ yr)			*ISOTOPE*	*TRANSITION*	*METHOD*	*DOCUMENT ID*	
0.0939	±0.0017	±0.0058	^{82}Se		NEMO-3	[1] ARNOLD	18
0.0263	$^{+0.0011}_{-0.0012}$		^{116}Cd		AURORA	[2] BARABASH	18
> 0.87			^{134}Xe		EXO-200	[3] ALBERT	17C
0.82	±0.02	±0.06	^{130}Te		CUORE-0	[4] ALDUINO	17
0.00690	±0.00015	±0.00037	^{100}Mo		CUPID	[5] ARMENGAUD	17
0.0274	±0.0004	±0.0018	^{116}Cd		NEMO-3	[6] ARNOLD	17
0.064	$^{+0.007}_{-0.006}$	$^{+0.012}_{-0.009}$	^{48}Ca		NEMO-3	[7] ARNOLD	16
0.00934	±0.00022	$^{+0.00062}_{-0.00060}$	^{150}Nd		NEMO-3	[8] ARNOLD	16A
1.926	±0.094		^{76}Ge		GERDA	[9] AGOSTINI	15A
0.00693	±0.00004		^{100}Mo		NEMO-3	[10] ARNOLD	15
2.165	±0.016	±0.059	^{136}Xe		EXO-200	[11] ALBERT	14
9.2	$^{+5.5}_{-2.6}$	±1.3	^{78}Kr		BAKSAN	[12] GAVRILYAK	13

2.38	± 0.02	± 0.14	^{136}Xe		KamLAND-Zen	[13] GANDO	12A
0.7	± 0.09	± 0.11	^{130}Te		NEMO-3	[14] ARNOLD	11
0.0235	± 0.0014	± 0.0016	^{96}Zr		NEMO-3	[15] ARGYRIADES	10
0.69	$^{+0.10}_{-0.08}$	± 0.07	^{100}Mo	$0^+ \to 0^+_1$	Ge coinc.	[16] BELLI	10
0.57	$^{+0.13}_{-0.09}$	± 0.08	^{100}Mo	$0^+ \to 0^+_1$	NEMO-3	[17] ARNOLD	07
0.096	± 0.003	± 0.010	^{82}Se		NEMO-3	[18] ARNOLD	05A
0.029	$^{+0.004}_{-0.003}$		^{116}Cd		^{116}CdWO$_4$ scint.	[19] DANEVICH	03

[1] ARNOLD 18 use the NEMO-3 tracking detector to determine the $2\nu\beta\beta$ half-life of ^{82}Se. 0.93 kg of ^{82}Se was observed for 5.25 y. The half-life value was obtained based on the single-state-dominance (SSD) hypothesis, preferred in this case by about 2 σ. Supersedes ARNOLD 05A.

[2] BARABASH 18 use 1.162 kg of ^{116}CdWO$_4$ scintillating crystals to obtain this value. Supersedes DANEVICH 03 with analogous source and agrees with ARNOLD 17 with the NEMO-3 detector.

[3] ALBERT 17C uses the EXO-200 detector that contains 19.098 ± 0.014% admixture of ^{134}Xe to search for the $2\nu\ \beta\beta$ decay mode. The exposure is 29.6 kg·year. The median sensitivity is 1.2×10^{21} years.

[4] ALDUINO 17 use the CUORE-0 detector containing 10.8 kg of ^{130}Te in 52 crystals of TeO$_2$. The exposure was 9.3 kg yr of ^{130}Te. This is a more accurate rate determination than in ARNOLD 11 and BARABASH 11A.

[5] ARMENGAUD 17 use 185.9 ± 0.1 g crystal of Li$_2$^{100}MoO$_4$ to determine the ^{100}Mo $2\nu\ \beta\beta$ half-life. The exposure was of 1303 ± 26 hours only, using novel technique.

[6] ARNOLD 17 use the NEMO-3 tracking calorimeter, containing 410 grams of enriched ^{116}Cd exposed for 5.26 years, to determine the half-life value.

[7] ARNOLD 16 use the NEMO-3 detector and a source of 6.99 g of ^{48}Ca. The half-life is based on 36.7 g year exposure. It is consistent, although somewhat longer, than the previous determinations of the half-life. Supersedes BARABASH 11A.

[8] ARNOLD 16A use the NEMO-3 tracking calorimeter, containing 36.6 g of ^{150}Nd exposed for 1918.5 days, to determine the half-life. Supersedes ARGYRIADES 09.

[9] AGOSTINI 15A use 17.9 kg yr exposure of the GERDA calorimeter to derive an improved measurement of the $2\nu\beta\beta$ decay half life of ^{76}Ge.

[10] ARNOLD 15 use the NEMO-3 tracking calorimeter with 34.3 kg yr exposure to determine the $2\nu\beta\beta$-half life of ^{100}Mo. Supersedes ARNOLD 05A and ARNOLD 04.

[11] ALBERT 14 use the EXO-200 tracking detector for a re-measurement of the $2\nu\beta\beta$-half life of ^{136}Xe. A nuclear matrix element of 0.0218 ± 0.0003 MeV^{-1} is derived from this data. Supersedes ACKERMAN 11.

[12] GAVRILYAK 13 use a proportional counter filled with Kr gas to search for the $2\nu 2$K decay of ^{78}Kr. Data with the enriched and depleted Kr were used to determine signal and background. A 2.5σ excess of events obtained with the enriched sample is interpreted as an indication for the presence of this decay.

[13] GANDO 12A use a modification of the existing KamLAND detector. The $\beta\beta$ decay source/detector is 13 tons of enriched ^{136}Xe-loaded scintillator contained in an inner balloon. The $2\nu\beta\beta$ decay rate is derived from the fit to the spectrum between 0.5 and 4.8 MeV. This result is in agreement with ACKERMAN 11.

[14] ARNOLD 11 use enriched ^{130}Te in the NEMO-3 detector to measure the $2\nu\ \beta\beta$ decay rate. This result is in agreement with, but more accurate than ARNABOLDI 03.

[15] ARGYRIADES 10 use 9.4 ± 0.2 g of ^{96}Zr in NEMO-3 detector and identify its $2\nu\beta\beta$ decay. The result is in agreement and supersedes ARNOLD 99.

[16] BELLI 10 use enriched ^{100}Mo with 4 HP Ge detectors to record the 590.8 and 539.5 keV γ rays from the decay of the 0^+_1 state in ^{100}Ru both in singles and coincidences. This result confirms the measurement of KIDD 09 and ARNOLD 07 and supersedes them.

[17] First exclusive measurement of 2ν-decay to the first excited 0^+_1-state of daughter nucleus. ARNOLD 07 use the NEMO-3 tracking calorimeter to detect all particles emitted in decay. Result agrees with the inclusive ($0\nu + 2\nu$) measurement of DEBRAECKELEER 01.

[18] ARNOLD 05A use the NEMO-3 tracking detector to determine the $2\nu\beta\beta$ half-life of ^{82}Se with high statistics and low background (389 days of data taking). Supersedes ARNOLD 04.

[19] Calorimetric measurement of $2\nu\beta\beta$ ground state decay of ^{116}Cd using enriched CdWO$_4$ scintillators. Agrees with EJIRI 95 and ARNOLD 96. Supersedes DANEVICH 00.

$\langle m_\nu \rangle$, The Effective Weighted Sum of Majorana Neutrino Masses Contributing to Neutrinoless Double-β Decay

$\langle m_\nu \rangle = |\Sigma U^2_{ei} m_{\nu_i}|$, i = 1,2,3. It is assumed that ν_i are Majorana particles and that the transition is dominated by the known (light) neutrinos. Note that U^2_{ei} and not $|U_{ei}|^2$ occur in the sum, and that consequently cancellations are possible. The experiments obtain the limits on $\langle m_\nu \rangle$ from the measured ones on $T_{1/2}$ using a range of nuclear matrix elements (NME), which is reflected in the spread of $\langle m_\nu \rangle$. Different experiments may choose different NME. All assume $g_A = 1.27$. In the following Listings, only the best or comparable limits for each isotope are reported. When not mentioned explicitly the transition is between ground states, but transitions between excited states are also reported.

VALUE (eV)	*ISOTOPE*	*TRANSITION*	*METHOD*	*DOCUMENT ID*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
< 0.24–0.52	^{76}Ge		MAJORANA Dem	[1] AALSETH 18
< 0.12–0.26	^{76}Ge		GERDA	[2] AGOSTINI 18
< 0.15–0.40	^{136}Xe		EXO-200	[3] ALBERT 18
< 0.11–0.52	^{130}Te		CUORE	[4] ALDUINO 18
< 1.2–3.0	^{82}Se		NEMO-3	[5] ARNOLD 18
< 0.376–0.770	^{82}Se		CUPID-0	[6] AZZOLINI 18
< 1.0–1.7	^{116}Cd		AURORA	[7] BARABASH 18
< 0.15–0.33	^{76}Ge		GERDA	[8] AGOSTINI 17
< 1.4–2.5	^{116}Cd		NEMO-3	[9] ARNOLD 17
< 0.27–0.76	^{130}Te		CUORE(CINO)	[10] ALDUINO 16
< 1.6–5.3	^{150}Nd		NEMO-3	[11] ARNOLD 16A
< 0.061–0.165	^{136}Xe		KamLAND-Zen	[12] GANDO 16
< 0.33–0.62	^{100}Mo		NEMO-3	[13] ARNOLD 15
< 0.19–0.45	^{136}Xe		EXO-200	[14] ALBERT 14B
< 0.89–2.43	^{82}Se		NEMO-3	[15] BARABASH 11A
< 7.2–19.5	^{96}Zr		NEMO-3	[16] ARGYRIADES 10
< 3.5–22	^{48}Ca		CaF$_2$ scint.	[17] UMEHARA 08
< 0.2–1.1	^{130}Te		Cryog. det.	[18] ARNABOLDI 05
< 0.37–1.9	^{130}Te		Cryog. det.	[19] ARNABOLDI 04
< 1.5–1.7	^{116}Cd		^{116}CdWO$_4$ scint.	[20] DANEVICH 03
< 0.350	^{76}Ge		Enriched HPGe	[21] KLAPDOR-K... 01
<8.3	^{48}Ca		CaF$_2$ scint.	YOU 91

[1] AALSETH 18 uses the MAJORANA Demonstrator detector to establish this limit.

[2] AGOSTINI 18 uses the GERDA detector to establish this limit.

[3] ALBERT 18 uses the EXO-200 experiment to obtain this limit.

[4] ALDUINO 18 use the combined data of CUORE, CUORE0, and Cuoricino to obtain this limit.

[5] ARNOLD 18 use the NEMO-3 tracking detector to constrain the $0\nu\beta\beta$ decay of ^{82}Se. The limit on $\langle m_{\beta\beta}\rangle$ is obtained assuming light neutrino exchange; the range reflects different calculations of the nuclear matrix elements. This is a somewhat weaker limit than in BARABASH 11A using the same detector.

[6] AZZOLINI 18 uses data collected by the CUPID-0 scintillating cryogenic calorimeter, operated in the LNGS, to derive a range of limits on $\langle m_\nu\rangle$. The reported range reflects the spread of the nuclear matrix element calculations considered in this work. Use g_A= 1.269.

[7] BARABASH 18 use 1.162 kg of ^{116}CdWO$_4$ scintillating crystals to obtain these limits. The spread reflects the estimated uncertainty in the nuclear matrix element. Supersedes DANEVICH 03.

[8] AGOSTINI 17 is based on 343 mol yr of data from GERDA phase 1 and phase 2 first part and the corresponding limit on T$_{1/2}$ using the different nuclear matrix elements mentioned by the authors. Supersedes AGOSTINI 13A.

[9] ARNOLD 17 utilize NEMO-3 data, taken with enriched ^{116}Cd to limit the effective Majorana neutrino mass. The reported range results from the use of different nuclear matrix elements. Supersedes BARABASH 11A.

[10] ALDUINO 16 place a limit on the effective Majorana neutrino mass using the combined data of the CUORE-0 and CUORICINO experiments. The range reflects the authors' evaluation of the variability of the nuclear matrix elements. Supersededs ALFONSO 15.

[11] ARNOLD 16A limit is derived from data taken with the NEMO-3 detector and ^{150}Nd. A range of nuclear matrix elements that include the effect of nuclear deformation have been used. Supersedes ARGYRIADES 09.

[12] GANDO 16 result is based on the 2016 KamLAND-Zen half-life limit. The stated range reflects different nuclear matrix elements, an unquenched $g_A = 1.27$ is used. Supersedes GANDO 13A.

[13] ARNOLD 15 use the NEMO-3 tracking calorimeter with 34.3 kg yr exposure to determine the neutrino mass limit based on the $0\nu\beta\beta$-half life of ^{100}Mo. The spread range reflects different nuclear matrix elements. Supersedes ARNOLD 14 and BARABASH 11A.

[14] ALBERT 14B is based on 100 kg yr of exposure of the EXO-200 tracking calorimeter. The mass range reflects the nuclear matrix element calculations. Supersedes AUGER 12.

[15] BARABASH 11A limit is based on NEMO-3 data for ^{82}Se. The reported range reflects different nuclear matrix elements. Supersedes ARNOLD 05A and ARNOLD 04.

[16] ARGYRIADES 10 use ^{96}Zr and the NEMO-3 tracking detector to obtain the reported mass limit. The range reflects the fluctuation of the nuclear matrix elements considered.

[17] Limit was obtained using CaF$_2$ scintillation calorimeter to search for double beta decay of ^{48}Ca. Reported range of limits reflects spread of QRPA and SM matrix element calculations used. Supersedes OGAWA 04.

[18] Supersedes ARNABOLDI 04. Reported range of limits due to use of different nuclear matrix element calculations.

[19] Supersedes ARNABOLDI 03. Reported range of limits due to use of different nuclear matrix element calculations.

[20] Limit for $\langle m_\nu\rangle$ is based on the nuclear matrix elements of STAUDT 90 and ARNOLD 96. Supersedes DANEVICH 00.

[21] KLAPDOR-KLEINGROTHAUS 01 uses the calculation by STAUDT 90. Using several other models in the literature could worsen the limit up to 1.2 eV. This is the most stringent experimental bound on m_ν. It supersedes BAUDIS 99B.

Limits on Lepton-Number Violating (V+A) Current Admixture

For reasons given in the discussion at the beginning of this section, we list only results from 1989 and later. $\langle\lambda\rangle = \lambda\sum U_{ej} V_{ej}$ and $\langle\eta\rangle = \eta\sum U_{ej} V_{ej}$, where the sum is over the number of neutrino generations. This sum vanishes for massless or unmixed neutrinos. In the following Listings, only best or comparable limits or lifetimes for each isotope are reported.

$\langle\lambda\rangle$ (10^{-6})	*CL%*	$\langle\eta\rangle$ (10^{-8})	*CL%*	*ISOTOPE*	*METHOD*	*DOCUMENT ID*	
• • • We do not use the following data for averages, fits, limits, etc. • • •							
< 2.2–2.6	90	< 1.7–2.1	90	^{82}Se	NEMO-3	[1] ARNOLD	18
< 1.8–22	90	< 1.6–21	90	^{116}Cd	AURORA	[2] BARABASH	18
< 0.9–1.3	90	< 0.5–0.8	90	^{100}Mo	NEMO-3	[3] ARNOLD	14
<120	90			^{100}Mo	$0^+ \rightarrow 2^+$	[4] ARNOLD	07
$0.692^{+0.058}_{-0.056}$	68	$0.305^{+0.026}_{-0.025}$	68	^{76}Ge	Enriched HPGe	[5] KLAPDOR-K...	06A
< 2.5	90			^{100}Mo	0ν, NEMO-3	[6] ARNOLD	05A
< 3.8	90			^{82}Se	0ν, NEMO-3	[7] ARNOLD	05A
< 1.5–2.0	90			^{100}Mo	0ν, NEMO-3	[8] ARNOLD	04
< 3.2–3.8	90			^{82}Se	0ν, NEMO-3	[9] ARNOLD	04
< 1.6–2.4	90	< 0.9–5.3	90	^{130}Te	Cryog. det.	[10] ARNABOLDI	03
< 2.2	90	<2.5	90	^{116}Cd	^{116}CdWO$_4$ scint.	[11] DANEVICH	03
< 3.2–4.7	90	< 2.4–2.7	90	^{100}Mo	ELEGANT V	[12] EJIRI	01
< 1.1	90	<0.64	90	^{76}Ge	Enriched HPGe	[13] GUENTHER	97
< 4.4	90	<2.3	90	^{136}Xe	TPC	[14] VUILLEUMIER	93
		<5.3		^{128}Te	Geochem	[15] BERNATOW...	92

[1] ARNOLD 18 use the NEMO03 tracking detector, with 0.93 kg of ^{82}Se mass and 5.25 y exposure to obtain the limits for the hypothetical right-handed currents. Supersedes ARNOLD 05A.

[2] BARABASH 18 use 1.162 kg of ^{116}CdWO$_4$ scintillating crystals to obtain this limits for the hypothetical right-handed currents in the $0\nu\beta\beta$ decay of ^{116}Cd.

[3] ARNOLD 14 is based on 34.7 kg yr of exposure of the NEMO-3 tracking calorimeter. The reported range limit on $\langle\lambda\rangle$ and $\langle\eta\rangle$ reflects the nuclear matrix element uncertainty in ^{100}Mo.

[4] ARNOLD 07 use NEMO-3 half life limit for 0ν-decay of ^{100}Mo to the first excited 2^+-state of daughter nucleus to limit the right-right handed admixture of weak currents $\langle\lambda\rangle$. This limit is not competitive when compared to the decay to the ground state.

[5] Re-analysis of data originally published in KLAPDOR-KLEINGROTHAUS 04A. Modified pulse shape analysis leads the authors to claim 6σ statistical evidence for observation of 0ν-decay. Authors use matrix element of MUTO 89 to determine $\langle\lambda\rangle$ and $\langle\eta\rangle$. Uncertainty of nuclear matrix element is not reflected in stated errors.

[6] ARNOLD 05A derive limit for $\langle\lambda\rangle$ based on ^{100}Mo data collected with NEMO-3 detector. No limit for $\langle\eta\rangle$ is given. Supersedes ARNOLD 04.

[7] ARNOLD 05A derive limit for $\langle\lambda\rangle$ based on ^{82}Se data collected with NEMO-3 detector. No limit for $\langle\eta\rangle$ is given. Supersedes ARNOLD 04.

[8] ARNOLD 04 use the matrix elements of SUHONEN 94 to obtain a limit for $\langle\lambda\rangle$, no limit for $\langle\eta\rangle$ is given. This limit is more stringent than the limit in EJIRI 01 for the same nucleus.

[9] ARNOLD 04 use the matrix elements of TOMODA 91 and SUHONEN 91 to obtain a limit for $\langle\lambda\rangle$, no limit for $\langle\eta\rangle$ is given.

[10] Supersedes ALESSANDRELLO 00. Cryogenic calorimeter search. Reported a range reflecting uncertainty in nuclear matrix element calculations.

[11] Limits for $\langle\lambda\rangle$ and $\langle\eta\rangle$ are based on nuclear matrix elements of STAUDT 90. Supersedes DANEVICH 00.

[12] The range of the reported $\langle\lambda\rangle$ and $\langle\eta\rangle$ values reflects the spread of the nuclear matrix elements. On axis value assuming $\langle m_\nu\rangle$=0 and $\langle\lambda\rangle$=$\langle\eta\rangle$=0, respectively.

[13] GUENTHER 97 limits use the matrix elements of STAUDT 90. Supersedes BALYSH 95 and BALYSH 92.

[14] VUILLEUMIER 93 uses the matrix elements of MUTO 89. Based on a half-life limit 2.6 × 10^{23} y at 90%CL.

[15] BERNATOWICZ 92 takes the measured geochemical decay width as a limit on the 0ν width, and uses the SUHONEN 91 coefficients to obtain the least restrictive limit on η. Further details of the experiment are given in BERNATOWICZ 93.

Double-β Decay REFERENCES

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