(C) Searches for Neutrinoless Double β Decay

Limits on an effective Majorana neutrino mass and a lepton-number violating current admixture can be obtained from lifetime limits on $0\nu\beta\beta$ nuclear decay. The derived quantities are highly model-dependent, so the half-life measurements are given first. Where possible we list the references for the matrix elements used in the subsequent analysis. Since rates for the more conventional $2\nu\beta\beta$ decay serve to calibrate the theory, results for this process are also given.

To define the limits on lepton-number violating right-handed current admixtures, we display the relevant part of a phenomenological current-current weak interaction Hamiltonian:

$$H_W = (G_F/\sqrt{2}) \times (J_L \cdot j_L^\dagger + \eta_{RL} J_R \cdot j_L^\dagger + \eta_{LR} J_L \cdot j_R^\dagger + \eta_{RR} J_R \cdot j_R^\dagger) + \text{h.c.}$$

where $j_L^\mu = \bar{e}_L \gamma^\mu \nu_{eL}$, $j_R^\mu = \bar{e}_R \gamma^\mu \nu_{eR}$, and J_L^μ and J_R^μ are left-handed and right-handed hadronic weak currents. Experiments are not sensitive to $\eta_{RL} (\equiv \kappa)$ but quote limits on η_{LR} and η_{RR}. Many authors use an alternative notation in which $\eta_{LR} \equiv \eta$ and $\eta_{RR} \equiv \lambda$. The limits on $\eta_{LR} = \eta$ are of order 10^{-8} while the limits on $\eta_{RR} = \lambda$ are of order 10^{-6}. The reader is warned that a number of earlier experiments did not distinguish between η_{LR} and η_{RR}. Because of evolving reporting conventions and matrix element calculations, we have not tabulated the admixture parameters for experiments published earlier than 1989.

See the section on Marjoran searches for additional limits set by these experiments.

Half-life Measurements and Limits for Double β Decay

In all cases of double beta decay, (Z,A) $\rightarrow$ (Z+2,A) + $2\beta^-$ + (0 or 2)$\overline{\nu}_e$.

$t_{1/2}(10^{21}$ yr)	CL%	ISOTOPE	TRANSITION	METHOD	DOCUMENT ID
• • • We do not use the following data for averages, fits, limits, etc. • • •					
> 44	68	^{100}Mo 0ν	$0^+ \rightarrow 0^+$	Si(Li)	ALSTON-... 93
>340	90	^{136}Xe 0ν	$0^+ \rightarrow 0^+$	TPC	[127,128] VUILLEUMIER 93
>260	90	^{136}Xe 0ν	$0^+ \rightarrow 0^+$	TPC	[128,129] VUILLEUMIER 93
> 0.21	90	^{136}Xe 2ν	$0^+ \rightarrow 0^+$	TPC	[128] VUILLEUMIER 93
> 2.5	90	^{130}Te 0ν	$0^+ \rightarrow 0^+$	Bolometer	ALESSAND... 92
> 0.093	90	^{136}Xe 2ν	$0^+ \rightarrow 0^+$	Drift chamber	ARTEMJEV 92
>1400	90	^{76}Ge 0ν	$0^+ \rightarrow 0^+$	Enriched HPGe	[130] BALYSH 92
> 430	90	^{76}Ge 0ν	$0^+ \rightarrow 2^+$	Enriched HPGe	[130] BALYSH 92
2.7 $\pm$ 0.1		^{130}Te		Geochem	BERNATOW... 92
7200 $\pm$400		^{128}Te		Geochem	[131] BERNATOW... 92
> 0.5	90	^{100}Mo 2ν	$0^+ \rightarrow 2_1^+$	HPGe	[132] BLUM 92
> 0.9	90	^{100}Mo 2ν	$0^+ \rightarrow 0_1^+$	HPGe	[132] BLUM 92
> 0.6	90	^{100}Mo 2ν	$0^+ \rightarrow 2_2^+$	HPGe	[132] BLUM 92
> 27	68	^{82}Se 0ν	$0^+ \rightarrow 0^+$	TPC	ELLIOTT 92
$0.108^{+0.026}_{-0.006}$		^{82}Se 2ν	$0^+ \rightarrow 0^+$	TPC	ELLIOTT 92
> 0.15	68	^{100}Mo 2ν	$0^+ \rightarrow 2_1^+$	Spect	[133] KUDOMI 92
> 1.1	68	^{100}Mo 0ν	$0^+ \rightarrow 2_1^+$	Spect	[133] KUDOMI 92
> 0.08	68	^{100}Mo 2ν	$0^+ \rightarrow 0_1^+$	Spect	[133] KUDOMI 92
> 0.56	68	^{100}Mo 0ν	$0^+ \rightarrow 0_1^+$	Spect	[133] KUDOMI 92
> 0.051	68	^{100}Mo 2ν	$0^+ \rightarrow 4_1^+$	Spect	[133] KUDOMI 92
> 0.63	68	^{100}Mo 0ν	$0^+ \rightarrow 4_1^+$	Spect	[133] KUDOMI 92
> 0.065	68	^{100}Mo 2ν	$0^+ \rightarrow 2_2^+$	Spect	[133] KUDOMI 92
> 0.12	68	^{100}Mo 0ν	$0^+ \rightarrow 2_2^+$	Spect	[133] KUDOMI 92
> 330	90	^{76}Ge 0ν	$0^+ \rightarrow 0^+$	HPGe	[134] REUSSER 92
> 65	90	^{76}Ge 0ν	$0^+ \rightarrow 2^+$	HPGe	[134] REUSSER 92
$0.92^{+0.07}_{-0.04}$		^{76}Ge 2ν	$0^+ \rightarrow 0^+$	Enriched HPGe	[135] AVIGNONE 91
> 12	95	^{136}Xe 0ν	$0^+ \rightarrow 0^+$	Prop cntr	[127,136] BELLOTTI 91
> 10	95	^{136}Xe 0ν	$0^+ \rightarrow 0^+$	Prop cntr	[129,136] BELLOTTI 91
> 3.3	95	^{136}Xe 0ν	$0^+ \rightarrow 2^+$	Prop cntr	[136] BELLOTTI 91
> 0.16	95	^{136}Xe 2ν		Prop cntr	BELLOTTI 91
> 4.7	68	^{100}Mo 0ν		Spect	EJIRI 91
$0.0115^{+0.0030}_{-0.0020}$		^{100}Mo 2ν		Spect	EJIRI 91
				Mass spect	[137] HYKAWY 91
2.0 $\pm$ 0.6		^{238}U		Geochem	[138] TURKEVICH 91
> 250	90	^{136}Xe 0ν	$0^+ \rightarrow 0^+$	TPC	[127,139] WONG 91
> 170	90	^{136}Xe 0ν	$0^+ \rightarrow 0^+$	TPC	[129,139] WONG 91
> 9.5	76	^{48}Ca 0ν		CaF_2 scint.	YOU 91
> 0.14	68	^{100}Mo $0\nu+2\nu$	$0^+ \rightarrow 2^+$	γ in HPGe	BARABASH 90
> 0.042	68	^{100}Mo $0\nu+2\nu$	$0^+ \rightarrow 0_1^+$	γ in HPGe	BARABASH 90
> 0.17	68	^{116}Cd $0\nu+2\nu$	$0^+ \rightarrow 2^+$	γ in HPGe	BARABASH 90
$1.12^{+0.48}_{-0.26}$		^{76}Ge 2ν	$0^+ \rightarrow 0^+$	HPGe	[140] MILEY 90
>1300	68	^{76}Ge 0ν	$0^+ \rightarrow 0^+$	Enriched Ge(Li)	[141] VASENKO 90
0.9 $\pm$ 0.1		^{76}Ge 2ν		Enriched Ge(Li)	VASENKO 90
> 4.0	68	^{100}Mo 0ν	$0^+ \rightarrow 0^+$	Si(Li)	ALSTON-... 89
> 0.40	68	^{100}Mo 0ν	$0^+ \rightarrow 2^+$	Si(Li)	ALSTON-... 89
> 3.3	68	^{136}Xe 0ν	$0^+ \rightarrow 0^+$	Ion chamber	[127] BARABASH 89
> 2.9	68	^{136}Xe 0ν	$0^+ \rightarrow 0^+$	Ion chamber	[129] BARABASH 89
> 1.5	68	^{136}Xe 0ν	$0^+ \rightarrow 2^+$	Ion chamber	BARABASH 89
> 0.084	68	^{136}Xe 2ν	$0^+ \rightarrow 0^+$	Ion chamber	BARABASH 89
> 9	90	^{136}Xe 0ν	$0^+ \rightarrow 0^+$	Prop chamber	[127] BELLOTTI 89
> 8	90	^{136}Xe 0ν	$0^+ \rightarrow 0^+$	Prop chamber	[129] BELLOTTI 89
> 1.3	68	^{116}Cd 0ν		$^{116}CdWO_4$ scint	DANEVICH 89
> 160	90	^{76}Ge 0ν	$0^+ \rightarrow 0^+$	HPGe	FISHER 89
> 60	90	^{76}Ge 0ν	$0^+ \rightarrow 2^+$	HPGe	FISHER 89
> 60	68	^{76}Ge 0ν	$0^+ \rightarrow 2^+$	HPGe	[142] MORALES 88
> 4.7	68	^{128}Te	$0^+ \rightarrow 2^+$	Ge(Li)	[143] BELLOTTI 87
> 4.5	68	^{130}Te	$0^+ \rightarrow 2^+$	Ge(Li)	[143] BELLOTTI 87
> 500	68	^{76}Ge 0ν	$0^+ \rightarrow 0^+$	HPGe	CALDWELL 87
$0.11^{+0.08}_{-0.03}$		^{82}Se 2ν	$0^+ \rightarrow 0^+$	TPC	ELLIOTT 87B
> 120	68	^{76}Ge 0ν	$0^+ \rightarrow 0^+$	HPGe	BELLOTTI 86
> 12	68	^{76}Ge 0ν	$0^+ \rightarrow 2^+$	HPGe	BELLOTTI 86
> 250	68	^{76}Ge 0ν	$0^+ \rightarrow 0^+$	HPGe	CALDWELL 86
> 50	68	^{76}Ge 0ν	$0^+ \rightarrow 2^+$	HPGe	CALDWELL 86
> 7.0	68	^{82}Se 0ν	$0^+ \rightarrow 0^+$	TPC	ELLIOTT 86
> 0.10	68	^{82}Se 2ν	$0^+ \rightarrow 0^+$	TPC	[144] ELLIOTT 86
> 50	68	^{76}Ge 0ν		HPGe	CALDWELL 85
> 2.3	68	^{76}Ge 0ν		Ge(Li)	[145] HUBERT 85
> 120	68	^{76}Ge 0ν	$0^+ \rightarrow 0^+$	Ge(Li)	BELLOTTI 84
> 17	68	^{76}Ge 0ν		Ge	FORSTER 84
> 17	90	^{76}Ge 0ν		Intrinsic Ge	AVIGNONE 83
> 20	68	^{76}Ge 0ν	$0^+ \rightarrow 0^+$	Ge(Li)	BELLOTTI 83
> 800	95	^{128}Te		Geochem	[146] KIRSTEN 83
2.60 $\pm$ 0.28		^{130}Te		Geochem	[146] KIRSTEN 83

[127] Limit in the case of a transition induced by a Majorana mass.

[128] VUILLEUMIER 93 data is from the search for neutrinoless double beta decay of ^{136}Xe in the TPC experiment in the St. Gotthard tunnel deep underground laboratory.

[129] Limit for lepton-number violating right-handed current-induced (RHC) decay.

[130] BALYSH 92 presents results from the Heidelberg-Moscow experiment searching for neutrinoless double beta decay of ^{76}Ge.

[131] BERNATOWICZ 92 finds ^{128}Te/^{130}Te activity ratio from slope of ^{128}Xe/^{132}Xe vs ^{130}Xe/^{132}Xe ratios during extraction, and normalizes to lead-dated ages for the ^{130}Te lifetime. The authors state that their results imply that "(a) the double beta decay of ^{128}Te has been firmly established and its half-life has been determined ... without any ambiguity due to trapped Xe interferences... (b) Theoretical calculations ... underestimate the [long half-lives of ^{128}Te ^{130}Te] by 1 or 2 orders of magnitude, pointing to a real supression in the 2ν decay rate of these isotopes. (c) Despite [this], most $\beta\beta$-models predict a *ratio* of 2ν decay widths ... in fair agreement with observation." Further details of the experiment are given in BERNATOWICZ 93. Our listed half-life has been revised downward from the published value by the authors, on the basis of reevaluated cosmic-ray ^{128}Xe production corrections.

[132] BLUM 92 reports lifetime limits for the decay of ^{100}Mo to several excited states of ^{100}Ru. Limits for decay to the 0_1^+ state are about 30% higher if decay to the 2^+ states are assumed negligable. Uses 99.5% enriched ^{100}Mo.

[133] KUDOMI 92 reports lifetime limits for 0ν and 2ν decays to four excited states of the daughter ^{100}Ru. The limits were obtained from searches for the two individual electrons in coincidence with photons from the decays of the excited states. The experiment was performed in the Kamioka underground laboratory. See EJIRI 91 for the group's ground-state transition measurement.

[134] REUSSER 92 contains the final results for the search for neutrinoless double beta decay of ^{76}Ge in the Gotthard tunnel underground laboratory.

[135] AVIGNONE 91 reports confirmation of the MILEY 90 and VASENKO 90 observations of $2\nu\beta\beta$ decay of ^{76}Ge. Error is 2σ.

[136] BELLOTTI 91 uses difference between natural and enriched ^{136}Xe runs to obtain $\beta\beta0\nu$ limits, leading to "less stringent, but safer limits."