ν_1 (MEAN LIFE) / MASS

VALUE (s/eV)	CL%	DOCUMENT ID		TECN	COMMENT
>300	90	[24] REINES	74	CNTR	$\overline{\nu}$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$> 2.8 \times 10^{15}$		[25,26] BLUDMAN	92	ASTR	$m_\nu < 50$ eV
> 6.4	90	[27] KRAKAUER	91	CNTR	$\overline{\nu}$ at LAMPF
$> 6.3 \times 10^{15}$		[26,28] CHUPP	89	ASTR	$m_\nu < 20$ eV
		[29] COWSIK	89	ASTR	
$> 1.7 \times 10^{15}$		[26] KOLB	89	ASTR	$m_\nu < 20$ eV
		[30] RAFFELT	89	RVUE	$\overline{\nu}$ (Dirac, Majorana)
		[31] RAFFELT	89B	ASTR	
		[32] BOUCHEZ	88	CNTR	$\overline{\nu}$ (Dirac, Majorana)
		[33] FRIEMAN	88	ASTR	
$> 8.3 \times 10^{14}$		[33] VONFEILIT...	88	ASTR	
> 22	68	[34] OBERAUER	87		$\overline{\nu}_R$ (Dirac)
> 38	68	[34] OBERAUER	87		$\overline{\nu}$ (Majorana)
> 59	68	[34] OBERAUER	87		$\overline{\nu}_L$ (Dirac)
> 30	68	KETOV	86	CNTR	$\overline{\nu}$ (Dirac)
> 20	68	KETOV	86	CNTR	$\overline{\nu}$ (Majorana)
$> 7 \times 10^{9}$		[35] RAFFELT	85	ASTR	
		[36] HENRY	81	ASTR	m_ν= 16–20 eV
		[37] KIMBLE	81	ASTR	m_ν= 10–100 eV
$> 2 \times 10^{21}$		[38] STECKER	80	ASTR	m_ν= 10–100 eV

[24] REINES 74 looked for ν_e of nonzero mass decaying to a neutral of lesser mass + γ. Used liquid scintillator detector near fission reactor. Finds lab lifetime $6. \times 10^7$ s or more. Above value of (mean life)/mass assumes average effective neutrino energy of 0.2 MeV. To obtain the limit $6. \times 10^7$ s REINES 74 assumed that the full $\overline{\nu}_e$ reactor flux could be responsible for yielding decays with photon energies in the interval 0.1 MeV – 0.5 MeV. This represents some overestimate so their lower limit is an over-estimate of the lab lifetime (P. Vogel, private communication, 1984).

[25] BLUDMAN 92 sets additional limits by this method for higher mass ranges. Cosmological limits are also obtained.

[26] Nonobservation of γ's in coincidence with ν's from SN 1987A.

[27] KRAKAUER 91 quotes the limit $\tau/m_{\nu_1} > (0.3a^2 + 9.8a + 15.9)$ s/eV, where a is a parameter describing the asymmetry in the neutrino decay defined as $dN_\gamma/d\cos\theta = (1/2)(1 + a\cos\theta)$ $a = 0$ for a Majorana neutrino, but can vary from -1 to 1 for a Dirac neutrino. The bound given by the authors is the most conservative (which applies for $a = -1$).

[28] CHUPP 89 should be multiplied by a branching ratio (about 1) and a detection efficiency (about 1/4), and pertains to radiative decay of any neutrino to a lighter or sterile neutrino.

[29] COWSIK 89 use observations of supernova SN 1987A to set the limit for the lifetime of a neutrino with $1 < m < 50$ MeV decaying through $\nu_H \rightarrow \nu_1 e e$ to be $\tau > 4 \times 10^{15}$ $\exp(-m/5$ MeV) s.

[30] RAFFELT 89 uses KYULDJIEV 84 to obtain $\tau m^3 > 3 \times 10^{18}$ s eV^3 (based on $\overline{\nu}_e e^-$ cross sections). The bound is not valid if electric and magnetic transition moments are equal for Dirac neutrinos.

[31] RAFFELT 89B analyze stellar evolution and exclude the region $3 \times 10^{12} < \tau m^3 < 3 \times 10^{21}$ s eV^3.

[32] BOUCHEZ 88 reports limits in the nearly degenerate mass case.

[33] Model-dependent theoretical analysis of SN 1987A neutrinos.

[34] OBERAUER 87 bounds are from comparison of observed and expected rate of reactor neutrinos.

[35] RAFFELT 85 limit is from solar x- and γ-ray fluxes.

[36] HENRY 81 uses UV flux from clusters of galaxies to find $\tau > 1.1 \times 10^{25}$ s for radiative decay.

[37] KIMBLE 81 uses extreme UV flux limits to find $\tau > 10^{22}$–10^{23} s.

[38] STECKER 80 limit based on UV background; result given is $\tau > 4 \times 10^{22}$ s at $m_\nu = 20$ eV.

$|(v - c) / c|$ ($v \equiv \nu_1$ VELOCITY)

Expected to be zero for massless neutrino, but tests also whether photons and neutrinos have the same limiting velocity in vacuum.

VALUE (units 10^{-8})	EVTS	DOCUMENT ID		TECN	COMMENT
<1	17	[39] STODOLSKY	88	ASTR	SN 1987A

[39] STODOLSKY 88 result based on <10 hr between $\overline{\nu}_e$ detection in IMB and KAMI detectors and beginning of light signal. Inclusion of the problematic 5 neutrino events from FREJ (four hours later) does not change the result.

ν_1 MAGNETIC MOMENT

Must vanish for Majorana neutrino or purely chiral massless Dirac neutrino. The value of the magnetic moment for the standard SU(2)×U(1) electroweak theory extended to include massive neutrinos (see FUJIKAWA 80) is $\mu_\nu = 3eG_F m_\nu/(8\pi^2\sqrt{2}) = (3.20 \times 10^{-19}) m_\nu \mu_B$ where m_ν is in eV and $\mu_B = e\hbar/2m_e$ is the Bohr magneton. Given the upper bound $m_{\nu_1} < 7.3$ eV, it follows that for the extended standard electroweak theory, $\mu(\nu_1) < 2.3 \times 10^{-18}$ μ_B. Current experiments are not yet challenging this limit. There is considerable controversy over the validity of many of the claimed upper limits on the magnetic moment from the astrophysical data. For example, VOLOSHIN 90 states that "in connection with the astrophysical limits on μ_ν, ... there is by now a general consensus that contrary to the initial claims (BARBIERI 88, LATTIMER 88, GOLDMAN 88, NOTZOLD 88), essentially no better than quoted limits (from previous constraints) can be derived from detection of the neutrino flux from the supernova SN1987A." See VOLOSHIN 88 and VOLOSHIN 88C.

VALUE (μ_B)	CL%	DOCUMENT ID		TECN	COMMENT
<1.08 × 10^{-9}	90	[40] KRAKAUER	90	CNTR	LAMPF $\nu_e e \rightarrow \nu_e e$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<1.9 \times 10^{-10}$	95	DERBIN	93	CNTR	Reactor $\overline{\nu}_e e \rightarrow \overline{\nu}_e e$
$<7.7 \times 10^{-10}$	95	MOURAO	92	ASTR	HOME/KAM2 ν rates
$<2.4 \times 10^{-10}$	90	[41] VIDYAKIN	92	CNTR	Reactor $\overline{\nu}_e e \rightarrow \overline{\nu}_e e$
		[42] FIORENTINI	91	ASTR	
$<2 \times 10^{-12}$	95	[43] RAFFELT	90	ASTR	Red giant luminosity
$<1 \times 10^{-11}$		[44] RAFFELT	89B	ASTR	Cooling helium stars
$<(2\text{–}8) \times 10^{-12}$		[44,45,46] BARBIERI	88	ASTR	Supernova SN 1987A
		[47] FUKUGITA	88	COSM	Primordial magn. fields
$<1 \times 10^{-12}$		[45,46,48] GOLDMAN	88	ASTR	Supernova SN 1987A
$<5 \times 10^{-13}$		[44,46] LATTIMER	88	ASTR	Supernova SN 1987A
$\leq 1.5 \times 10^{-12}$		[44,46] NOETZOLD	88	ASTR	Supernova SN 1987A
$\leq 3 \times 10^{-11}$		[44] RAFFELT	88B	ASTR	He burning stars
$<1.1 \times 10^{-11}$		[44] FUKUGITA	87	ASTR	Cooling helium stars
$<4 \times 10^{-11}$		LYNN	81	ASTR	
$< 1\text{–}2 \times 10^{-11}$		MORGAN	81	COSM	^{4}He abundance
$<8.5 \times 10^{-11}$		BEG	78	ASTR	Stellar plasmons
$<6 \times 10^{-11}$		[49] SUTHERLAND	76	ASTR	Red giants + degen. dwarfs
$<1 \times 10^{-10}$		BERNSTEIN	63	ASTR	Cooling white dwarfs
$<1.4 \times 10^{-9}$		COWAN	57	CNTR	Reactor $\overline{\nu}_e$

[40] KRAKAUER 90 experiment fully reported in ALLEN 93.

[41] VIDYAKIN 92 limit is from a $(e\nu u)_e$ elastic scattering experiment. No experimental details are given except for the cross section from which this limit is derived. Signal/noise was 1/10. The limit uses $\sin^2\theta_W = 0.23$ as input.

[42] FIORENTINI 91 is a study of the statistical significance of possible correlation of solar neutrino flux with sunspot cycle. Data do not imply any evidence for a nonzero neutrino magnetic moment, although they are consistent with a moment of order $1 \times 10^{-10}/\mu_B$.

[43] RAFFELT 90 limit applies for a diagonal magnetic moment of a Dirac neutrino, or for a transition magnetic moment of a Majorana neutrino. In the latter case, the same analysis gives $< 1.4 \times 10^{-12}$. Limit at 95%CL obtained from δM_c.

[44] Significant dependence on details of stellar models.

[45] A limit of 10^{-13} is obtained with even more model-dependence.

[46] These papers have assumed that the right-handed neutrino is inert; see BARBIERI 88B.

[47] FUKUGITA 88 find magnetic dipole moments of any two neutrino species are bounded by $\mu < 10^{-16}$ $[10^{-9}\ G/B_0]$ where B_0 is the present-day intergalactic field strength.

[48] Some dependence on details of stellar models.

[49] We obtain above limit from SUTHERLAND 76 using their limit $f < 1/3$.

NONSTANDARD CONTRIBUTIONS TO NEUTRINO SCATTERING

We report limits on the so-called neutrino charge radius squared in this section. This quantity is not an observable, physical quantity and this is reflected in the fact that it is gauge dependent (see LEE 77C). It is not necessarily positive. A more general interpretation of the experimental results is that they are limits on certain nonstandard contributions to neutrino scattering.

VALUE (10^{-32} cm^2)	CL%	DOCUMENT ID		TECN	COMMENT
0.9±2.7		ALLEN	93	CNTR	LAMPF $\nu_e e \rightarrow \nu_e e$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<2.3 \times 10^{-32}$	95	MOURAO	92	ASTR	HOME/KAM2 ν rates
<7.3	90	[50] VIDYAKIN	92	CNTR	Reactor $\overline{\nu}_e e \rightarrow \overline{\nu}_e e$
1.1 ± 2.3		ALLEN	91	CNTR	Repl. by ALLEN 93
		[51] GRIFOLS	89B	ASTR	SN 1987A

[50] VIDYAKIN 92 limit is from a $e\overline{\nu}_e$ elastic scattering experiment. No experimental details are given except for the cross section from which this limit is derived. Signal/noise was 1/10. The limit uses $\sin^2\theta_W = 0.23$ as input.

[51] GRIFOLS 89B sets a limit of $\langle r^2 \rangle < 0.2 \times 10^{-32}$ cm^2 for right-handed neutrinos.