ν_e

$J = \frac{1}{2}$

Not in general a mass eigenstate. See Note on "Neutrino Mass" above.

Revised April 2000 by P. Vogel (Caltech) and A. Piepke (University of Alabama).

These limits apply to ν_1, the primary mass eigenstate in ν_e. They would also apply to any other ν_j which mixes strongly in ν_e and has sufficiently small mass that it can be emitted in the respective decay. (Note that the reactor $\overline{\nu}_e$ disappearance experiments show that the electron neutrino is not strongly coupled ($\sin^2 2\theta \lesssim 0.1$) to any other neutrino for $\Delta m^2 \gtrsim 10^{-3}$ eV^2.) The neutrino mass may be of a Dirac or Majorana type; the former conserves total lepton number while the latter violates it. Either could violate lepton family number, since the neutrino mass eigenstates do not need to coincide with the neutrino interaction eigenstates. For limits on a Majorana ν_e mass, see the section on "Searches for Massive Neutrinos and Lepton Mixing," part (C), entitled "Searches for Neutrinoless Double-β Decay."

The square of the neutrino mass, $m^2_{\nu_e} = \sum |U_{ej}|^2 m^2_{\nu_j}$, where the sum is over the kinematically allowed range of the neutrino masses m_{ν_j}, is measured in beta decay experiments by fitting the shape of the beta spectrum near the endpoint; results are given in one of the tables in this section. Low-energy tritium beta decays, delivering a high number of events near the kinematically interesting endpoint, are studied in a number of careful experiments. The most sensitive of these are reported in LOBASHEV 99 and WEINHEIMER 99. They both find that unknown effects cause an accumulation of events near the endpoint of the electron spectrum. If the fitting hypothesis or data selection does not account for this, unphysical negative values of $m^2_{\nu_e}$ are obtained. In WEINHEIMER 99, two analyses which exclude the spectral anomaly result in an acceptable $m^2_{\nu_e}$ and a mass limit of better than 3 eV. In LOBASHEV 99, the resulting mass limit is also less that 3 eV when the analysis includes an *a priori* form for the anomalous events near the endpoint. We take $m_{\nu_e} < 3$ eV as our evaluation.

The spread of arrival times of the neutrinos from SN1987A, coupled with the measured neutrino energies, provides a simple time-of-flight limit on m_{ν_e}. This statement, clothed in various degrees of sophistication, has been the basis for a very large number of papers. The LOREDO 89 limit (23 eV) is among the most conservative and involves few assumptions; as such, it can be regarded as a safe limit.

ν_e MASS

Most of the data from which these limits are derived are from β^- decay experiments in which a $\overline{\nu}_e$ is produced, so that they really apply to $m_{\overline{\nu}_1}$. Assuming *CPT* invariance, a limit on $m_{\overline{\nu}_1}$ is the same as a limit on m_{ν_1}. Results from studies of electron capture transitions, given below "$m_{\nu_1} - m_{\overline{\nu}_1}$", give limits on m_{ν_1} itself. But see the above Note on the "Electron Neutrino Mass."

VALUE (eV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
< 3 OUR EVALUATION					
< 2.5	95	[1] LOBASHEV	99	SPEC	^{3}H β decay
< 2.8	95	[2] WEINHEIMER	99	SPEC	^{3}H β decay
< 23		LOREDO	89	ASTR	SN 1987A
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 4.35	95	[3] BELESEV	95	SPEC	^{3}H β decay
< 12.4	95	[4] CHING	95	SPEC	^{3}Hβ decay
< 92	95	[5] HIDDEMANN	95	SPEC	^{3}H β decay
$15\ ^{+32}_{-15}$		HIDDEMANN	95	SPEC	^{3}H β decay
< 19.6	95	KERNAN	95	ASTR	SN 1987A
< 7.0	95	[6] STOEFFL	95	SPEC	^{3}H β decay
<460	68	[7] YASUMI	94	CNTR	*e* capture in ^{163}Ho
< 7.2	95	[8] WEINHEIMER	93	SPEC	^{3}H β decay
< 11.7	95	[9] HOLZSCHUH	92B	SPEC	^{3}H β decay
< 13.1	95	[10] KAWAKAMI	91	SPEC	^{3}H β decay
< 9.3	95	[11] ROBERTSON	91	SPEC	^{3}H β decay
< 14	95	AVIGNONE	90	ASTR	SN 1987A
< 16		SPERGEL	88	ASTR	SN 1987A
17 to 40		[12] BORIS	87	SPEC	$\overline{\nu}_e$, ^{3}Hβ decay

[1] LOBASHEV 99 report a new measurement which continues the work reported in BELESEV 95. This limit depends on phenomonological fit parameters used to derive their best fit to m_ν^2, making unambiguous interpretation difficult. See the footnote under "m_ν Mass Squared".

[2] WEINHEIMER 99 presents two analyses which exclude the spectral anomaly and result in an acceptable m_ν^2. We report the most conservative limit, but the other (< 2.7 eV) is nearly the same. See the footnote under "m_e Mass Squared."

[3] BELESEV 95 (Moscow) use an integral electrostatic spectrometer with adiabatic magnetic collimation and a gaseous tritium sources. A fit to a normal Kurie plot above 18300–18350 eV (to avoid a low-energy anomaly) plus a monochromatic line 7–15 eV below the endpoint yields $m_\nu^2 = -4.1 \pm 10.9$ eV^2, leading to this Bayesian limit.

[4] CHING 95 quotes results previously given by SUN 93; no experimental details are given. A possible explanation for consistently negative values of m_ν^2 is given.

[5] HIDDEMANN 95 (Munich) experiment uses atomic tritium embedded in a metal-dioxide lattice. Bayesian limit calculated from the weighted mean $m_\nu^2 = 221 \pm 4244$ eV^2 from the two runs listed below.

[6] STOEFFL 95 (LLNL) result is the Bayesian limit obtained from the m_ν^2 errors given below but with m_ν^2 set equal to 0. The anomalous endpoint accumulation leads to a value of m_ν^2 which is negative by more than 5 standard deviations.

[7] The YASUMI 94 (KEK) limit results from their measurement $m_\nu=110^{+350}_{-110}$ eV.

[8] WEINHEIMER 93 (Mainz) is a measurement of the endpoint of the tritium β spectrum using an electrostatic spectrometer with a magnetic guiding field. The source is molecular tritium frozen onto an aluminum substrate.

[9] HOLZSCHUH 92B (Zurich) result is obtained from the measurement $m_\nu^2 = -24 \pm 48 \pm 61$ (1σ errors), in eV^2, using the PDG prescription for conversion to a limit in m_ν.

[10] KAWAKAMI 91 (Tokyo) experiment uses tritium-labeled arachidic acid. This result is the Bayesian limit obtained from the m_ν^2 limit with the errors combined in quadrature. This was also done in ROBERTSON 91, although the authors report a different procedure.

[11] ROBERTSON 91 (LANL) experiment uses gaseous molecular tritium. The result is in strong disagreement with the earlier claims by the ITEP group [LUBIMOV 80, BORIS 87 (+ BORIS 88 erratum)] that m_ν lies between 17 and 40 eV. However, the probability of a positive m^2 is only 3% if statistical and systematic error are combined in quadrature.

[12] See also comment in BORIS 87B and erratum in BORIS 88.

ν_e MASS SQUARED

The tritium experiments actually measure mass squared. A combined limit on mass should therefore be obtained from the weighted average of the results shown here. However, given troubling systematics which result in improbably negative estimators of m_ν^2 in many experiments, we instead use WEINHEIMER 99 and LOBASHEV 99 for that estimate, as discussed above in the Note on the "Electron Neutrino Mass."

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
− 2.5± 3.3 OUR AVERAGE					
− 1.9± 3.4± 2.2		[13] LOBASHEV	99	SPEC	^{3}H β decay
− 3.7± 5.3± 2.1		[14] WEINHEIMER	99	SPEC	^{3}H β decay

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

− 22	± 4.8			[15] BELESEV	95	SPEC	^{3}H β decay
129	±6010			[16] HIDDEMANN	95	SPEC	^{3}H β decay
313	±5994			[16] HIDDEMANN	95	SPEC	^{3}H β decay
−130	± 20	±15	95	[17] STOEFFL	95	SPEC	^{3}H β decay
− 31	± 75	±48		[18] SUN	93	SPEC	^{3}Hβ decay
− 39	± 34	±15		[19] WEINHEIMER	93	SPEC	^{3}H β decay
− 24	± 48	±61		[20] HOLZSCHUH	92B	SPEC	^{3}H β decay
− 65	± 85	±65		[21] KAWAKAMI	91	SPEC	^{3}H β decay
−147	± 68	±41		[22] ROBERTSON	91	SPEC	^{3}H β decay

[13] LOBASHEV 99 report a new measurement which continues the work reported in BELESEV 95. The data were corrected for electron trapping effects in the source, eliminating the dependence of the fitted neutrino mass on the fit interval. The analysis assuming a pure beta spectrum yields significantly negative fitted $m_\nu^2 \approx -(20\text{–}10)$ eV^2. This problem is attributed to a discrete spectral anomaly of about 6×10^{-11} intensity with a time-dependent energy of 5–15 eV below the endpoint. The data analysis accounts for this anomaly by introducing two extra phenomenological fit parameters resulting in a best fit of $m_\nu^2 = -1.9 \pm 3.4 \pm 2.2\,\text{eV}^2$ which is used to derive a neutrino mass limit. However, the introduction of phenomenological fit parameters which are correlated with the derived m_ν^2 limit makes unambiguous interpretation of this result difficult.

[14] WEINHEIMER 99 is a continuation of the work reported in WEINHEIMER 93 . Using a lower temperature of the frozen tritium source eliminated the dewetting of the T_2 film, which introduced a dependence of the fitted neutrino mass on the fit interval in the earlier work. An indication for a spectral anomaly reported in LOBASHEV 99 has been seen, but its time dependence does not agree with LOBASHEV 99. Two analyses, which exclude the spectral anomaly either by choice of the analysis interval or by using a particular data set which does not exhibit the anomaly, result in acceptable m_ν^2 fits and are used to derive the neutrino mass limit published by the authors. We list the most conservative of the two.

[15] BELESEV 95 (Moscow) use an integral electrostatic spectrometer with adiabatic magnetic collimation and a gaseous tritium sources. This value comes from a fit to a normal Kurie plot above 18300–18350 eV (to avoid a low-energy anomaly), including the effects of an apparent peak 7–15 eV below the endpoint.

[16] HIDDEMANN 95 (Munich) experiment uses atomic tritium embedded in a metal-dioxide lattice. They quote measurements from two data sets.

[17] STOEFFL 95 (LLNL) uses a gaseous source of molecular tritium. An anomalous pileup of events at the endpoint leads to the negative value for m_ν^2. The authors acknowledge that "the negative value for the best fit of m_ν^2 has no physical meaning" and discuss possible explanations for this effect.

[18] SUN 93 uses a tritiated hydrocarbon source. See also CHING 95.

[19] WEINHEIMER 93 (Mainz) is a measurement of the endpoint of the tritium β spectrum using an electrostatic spectrometer with a magnetic guiding field. The source is molecular tritium frozen onto an aluminum substrate.

[20] HOLZSCHUH 92B (Zurich) source is a monolayer of tritiated hydrocarbon.

[21] KAWAKAMI 91 (Tokyo) experiment uses tritium-labeled arachidic acid.

[22] ROBERTSON 91 (LANL) experiment uses gaseous molecular tritium. The result is in strong disagreement with the earlier claims by the ITEP group [LUBIMOV 80, BORIS 87 (+ BORIS 88 erratum)] that m_ν lies between 17 and 40 eV. However, the probability of a positive m_ν^2 is only 3% if statistical and systematic error are combined in quadrature.

$m_{\nu_1} - m_{\overline{\nu}_1}$

These are measurement of m_{ν_1} (in contrast to $m_{\overline{\nu}_1}$, given above). The masses can be different for a Dirac neutrino in the absense of *CPT* invariance. The test is not very strong.

VALUE (eV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<$ 225	95	SPRINGER	87	CNTR	ν, ^{163}Ho
$<$ 550	68	YASUMI	86	CNTR	ν, ^{163}Ho
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<$ 4.5×10^5	90	CLARK	74	ASPK	K_{e3} decay
$<$4100	67	BECK	68	CNTR	ν, ^{22}Na

ν_1 CHARGE

VALUE (units: electron charge)	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$<2 \times 10^{-14}$	[23] RAFFELT	99	ASTR	Red giant luminosity
$<6 \times 10^{-14}$	[24] RAFFELT	99	ASTR	Solar cooling
$<2 \times 10^{-15}$	[25] BARBIELLINI	87	ASTR	SN 1987A
$<1 \times 10^{-13}$	BERNSTEIN	63	ASTR	Solar energy losses

[23] This RAFFELT 99 limit applies to all neutrino flavors which are light enough ($<$5 kEe) to be emitted from globular-cluster red giants.

[24] This RAFFELT 99 limit is derived from the helioseismological limit on a new energy-loss channel of the Sun, and applies to all neutrino flavors which are light enough ($<$1 keV) to be emitted from the sun.

[25] Precise BARBIELLINI 87 limit depends on assumptions about the intergalactic or galactic magnetic fields and about the direct distance and time through the field.

ν_1 MEAN LIFE

VALUE (s)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[26] BILLER	98	ASTR	m_ν= 0.05–1 eV
		[27] COWSIK	89	ASTR	m_ν = 1–50 MeV
		[28] RAFFELT	89	RVUE	$\overline{\nu}$ (Dirac, Majorana)
		[29] RAFFELT	89B	ASTR	
$>$278	90	[30] LOSECCO	87B	IMB	
$>$ 1.1×10^{25}		[31] HENRY	81	ASTR	m_ν= 16–20 eV
$>$ 10^{22}–10^{23}		[32] KIMBLE	81	ASTR	m_ν= 10–100 eV

[26] BILLER 98 use the observed TeV γ-ray spectra to set limits on the mean life of a radiatively decaying neutrino between 0.05 and 1 eV. Curve shows $\tau_\nu/\mathrm{B}_\gamma > 0.15 \times 10^{21}$ s at 0.05 eV, $> 1.2 \times 10^{21}$ s at 0.17 eV, $> 3 \times 10^{21}$ s at 1 eV, where B_γ is the branching ratio to photons.

[27] 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.

[28] 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.

[29] RAFFELT 89B analyze stellar evolution and exclude the region $3 \times 10^{12} < \tau m^3 < 3 \times 10^{21}$ s eV^3.
[30] LOSECCO 87B assumes observed rate of 2.1 SNU (solar neutrino units) comes from sun while 7.0 ± 3.0 is theory.
[31] HENRY 81 uses UV flux from clusters of galaxies to find limit for radiative decay.
[32] KIMBLE 81 uses extreme UV flux limits.

ν_1 (MEAN LIFE) / MASS

VALUE (s/eV)	CL%	DOCUMENT ID		TECN	COMMENT
> 7 × 10^{9}		[33] RAFFELT	85	ASTR	
>300	90	[34] REINES	74	CNTR	$\overline{\nu}$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$> 2.8 \times 10^{15}$		[35,36] BLUDMAN	92	ASTR	$m_\nu < 50$ eV
> 6.4	90	[37] KRAKAUER	91	CNTR	$\overline{\nu}$ at LAMPF
$> 6.3 \times 10^{15}$		[36,38] CHUPP	89	ASTR	$m_\nu < 20$ eV
$> 1.7 \times 10^{15}$		[36] KOLB	89	ASTR	$m_\nu < 20$ eV
$> 8.3 \times 10^{14}$		[39] VONFEILIT...	88	ASTR	
> 22	68	[40] OBERAUER	87		$\overline{\nu}_R$ (Dirac)
> 38	68	[40] OBERAUER	87		$\overline{\nu}$ (Majorana)
> 59	68	[40] OBERAUER	87		$\overline{\nu}_L$ (Dirac)
> 30	68	KETOV	86	CNTR	$\overline{\nu}$ (Dirac)
> 20	68	KETOV	86	CNTR	$\overline{\nu}$ (Majorana)
$> 2 \times 10^{21}$		[41] STECKER	80	ASTR	m_ν= 10–100 eV

[33] RAFFELT 85 limit is from solar x- and γ-ray fluxes. Limit depends on ν flux from pp, now established from GALLEX and SAGE to be > 0.5 of expectation.
[34] 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 (VOGEL 84). If so, OBERAUER 87 may be comparable or better.
[35] BLUDMAN 92 sets additional limits by this method for higher mass ranges. Cosmological limits are also obtained.
[36] Nonobservation of γ's in coincidence with ν's from SN 1987A.
[37] 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 $a = -1$).
[38] 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.
[39] Model-dependent theoretical analysis of SN 1987A neutrinos.
[40] OBERAUER 87 bounds are from comparison of observed and expected rate of reactor neutrinos.
[41] STECKER 80 limit based on UV background; result given is $\tau > 4 \times 10^{22}$ s at $m_\nu = 20$ eV.

$\left|(v - c)/c\right|$ ($v \equiv \nu_1$ 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	[42] STODOLSKY	88	ASTR	SN 1987A
<0.2		[43] LONGO	87	ASTR	SN 1987A

[42] 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 Mont Blanc (four hours later) does not change the result.

[43] LONGO 87 argues that uncertainty between light and neutrino transit times is ± 3 hr, ignoring Mont Blanc events.

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 × 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 (10^{-10} μ_B)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
< 1.5	90	[44] BEACOM	99	SKAM	ν spectrum shape
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 0.01–0.04		[45] AYALA	99	ASTR	$\nu_L \rightarrow \nu_R$ in SN 1987A
< 0.03		[46] RAFFELT	99	ASTR	Red giant luminosity
< 4		[47] RAFFELT	99	ASTR	Solar cooling
< 0.62		[48] ELMFORS	97	COSM	Depolarization in early universe plasma
< 0.003–0.0005		[49] GOYAL	95		SN 1987A
< 1.9	95	[50] DERBIN	93	CNTR	Reactor $\overline{\nu}_e e \rightarrow \overline{\nu}_e e$
< 2.4	90	[51] VIDYAKIN	92	CNTR	Reactor $\overline{\nu}_e e \rightarrow \overline{\nu}_e e$
<10.8	90	[52] KRAKAUER	90	CNTR	LAMPF $\nu_e e \rightarrow \nu_e e$
< 0.02		[53] RAFFELT	90	ASTR	Red giant luminosity
< 0.1		[54] RAFFELT	89B	ASTR	Cooling helium stars
		[55] FUKUGITA	88	COSM	Primordial magn. fields

$<$ 0.01	[56,57,58] GOLDMAN	88	ASTR	SN 1987A
$<$ 0.005	[54,58] LATTIMER	88	ASTR	SN 1987A
$\leq$ 0.015	[54,58] NOETZOLD	88	ASTR	SN 1987A
$\leq$ .3	[54] RAFFELT	88B	ASTR	He burning stars
$<$ 0.11	[54] FUKUGITA	87	ASTR	Cooling helium stars
$<$ 0.4	LYNN	81	ASTR	
$<$ 0.1–0.2	MORGAN	81	COSM	^{4}He abundance
$<$ 0.85	BEG	78	ASTR	Stellar plasmons
$<$ 0.6	[59] SUTHERLAND	76	ASTR	Red giants + degen. dwarfs
$<$ 1	BERNSTEIN	63	ASTR	Solar cooling
$<$14	COWAN	57	CNTR	Reactor $\overline{\nu}_e$

[44] BEACOM 99 obtain the limit using the shape, but not the absolute magnitude which is affected by oscillations, of the solar neutrino spectrum obtained by Superkamiokande (825 days). This μ_ν can be different from the reactor μ_ν in certain oscillation scenarios.

[45] AYALA 99 improves the limit of BARBIERI 88.

[46] RAFFELT 99 is an update of RAFFELT 90. This limit applies to all neutrino flavors which are light enough ($<$ 5 keV) to be emitted from globular-cluster red giants. This limit pertains equally to electric dipole moments and magnetic transition moments, and it applies to both Dirac and Majorana neutrinos.

[47] RAFFELT 99 is essenitally an update of BERNSTEIN 63, but is derived from the helioseismological limit on a new energy-loss channel of the Sun. This limit applies to all neutrino flavors which are light enough ($<$1 keV) to be emitted from the Sun. This limit pertains equally to electric dipole and magnetic transition moments, and it applies to both Dirac and Majorana neutrinos.

[48] ELMFORS 97 calculate the rate of depolarization in a plasma for neutrinos with a magnetic moment and use the constraints from a big-bang nucleosynthesis on additional degrees of freedom.

[49] GOYAL 95 assume that helicity flip via μ_ν would result in faster cooling and hence shorter burst from SN1987A. Limit is based on the assumed presence of a pion condensate or quark core in the remanant.

[50] DERBIN 93 updated in review DERBIN 94.

[51] 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.

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

[53] 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.

[54] Significant dependence on details of stellar models.

[55] 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.

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

[57] Some dependence on details of stellar models.

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

[59] 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	95	MOURAO	92	ASTR	HOME/KAM2 ν rates
<7.3	90	[60] VIDYAKIN	92	CNTR	Reactor $\overline{\nu}_e e \rightarrow \overline{\nu}_e e$
1.1±2.3		ALLEN	91	CNTR	Repl. by ALLEN 93
		[61] GRIFOLS	89B	ASTR	SN 1987A

[60] 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.

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

ν_e REFERENCES

AYALA	99	PR D59 111901	A. Ayala, J.C. D'Olivo, M. Torres	
BEACOM	99	PRL 83 5222	J.F. Beacom, P. Vogel	
LOBASHEV	99	PL B460 227	V.M. Lobashev et al.	
RAFFELT	99	PRPL 320 319	G.G. Raffelt	
WEINHEIMER	99	PL B460 219	Ch. Weinheimer et al.	
Also	99B	PL B464 352 (erratum)	Ch. Weinheimer et al.	
BILLER	98	PRL 80 2992	S.D. Biller et al.	(WHIPPLE Collab.)
ELMFORS	97	NP B503 3	P. Elmfors et al.	
BELESEV	95	PL B350 263	A.I. Belesev et al.	(INRM, KIAE)
CHING	95	IJMP A10 2841	C.R. Ching et al.	(CST, BEIJT, CIAE)
GOYAL	95	PL B346 312	A. Goyal, S. Dutta, S.R. Choudhury	(DELH)
HIDDEMANN	95	JP G21 639	K.H. Hiddemann, H. Daniel, O. Schwentker	(MUNT)
KERNAN	95	NP B437 243	P.J. Kernan, L.M. Krauss	(CASE)
STOEFFL	95	PRL 75 3237	W. Stoeffl, D.J. Decman	(LLNL)
DERBIN	94	PAN 57 222	A.V. Derbin	(PNPI)
		Translated from YAF 57 236.		
YASUMI	94	PL B334 229	S. Yasumi et al.	(KEK, TSUK, KYOT+)
ALLEN	93	PR D47 11	R.C. Allen et al.	(UCI, LANL, ANL+)
DERBIN	93	JETPL 57 768	A.V. Derbin et al.	(PNPI)
		Translated from ZETFP 57 755.		
SUN	93	CJNP 15 261	H.C. Sun et al.	(CIAE, CST, BEIJT)
WEINHEIMER	93	PL B300 210	C. Weinheimer et al.	(MANZ)
BLUDMAN	92	PR D45 4720	S.A. Bludman	(CFPA)
HOLZSCHUH	92B	PL B287 381	E. Holzschuh, M. Fritschi, W. Kundig	(ZURI)
MOURAO	92	PL B285 364	A.M. Mourao, J. Pulido, J.P. Ralston	(LISB, LISBT+)
VIDYAKIN	92	JETPL 55 206	G.S. Vidyakin et al.	(KIAE)
		Translated from ZETFP 55 212.		

ALLEN	91	PR D43 R1	R.C. Allen *et al.*	(UCI, LANL, UMD)
KAWAKAMI	91	PL B256 105	H. Kawakami *et al.*	(INUS, TOHOK, TINT+)
KRAKAUER	91	PR D44 R6	D.A. Krakauer *et al.*	(LAMPF E225 Collab.)
ROBERTSON	91	PRL 67 957	R.G.H. Robertson *et al.*	(LASL, LLL)
AVIGNONE	90	PR D41 682	F.T. Avignone, J.J. Collar	(SCUC)
KRAKAUER	90	PL B252 177	D.A. Krakauer *et al.*	(LAMPF E225 Collab.)
RAFFELT	90	PRL 64 2856	G.G. Raffelt	(MPIM)
VOLOSHIN	90	NP B (Proc. Suppl) 19 433	M. Voloshin	(ITEP)
		Neutrino 90 Conference		
CHUPP	89	PRL 62 505	E.L. Chupp, W.T. Vestrand, C. Reppin	(UNH, MPIM)
COWSIK	89	PL B218 91	R. Cowsik, D.N. Schramm, P. Hoflich	(WUSL, TATA+)
GRIFOLS	89B	PR D40 3819	J.A. Grifols, E. Masso	(BARC)
KOLB	89	PRL 62 509	E.W. Kolb, M.S. Turner	(CHIC, FNAL)
LOREDO	89	ANYAS 571 601	T.J. Loredo, D.Q. Lamb	(CHIC)
RAFFELT	89	PR D39 2066	G.G. Raffelt	(PRIN, UCB)
RAFFELT	89B	APJ 336 61	G. Raffelt, D. Dearborn, J. Silk	(UCB, LLL)
BARBIERI	88	PRL 61 27	R. Barbieri, R.N. Mohapatra	(PISA, UMD)
BARBIERI	88B	PL B213 69	R. Barbieri, R.N. Mohapatra, T. Yanagida	(PISA+)
BORIS	88	PRL 61 245 erratum	S.D. Boris *et al.*	(ITEP, ASCI)
FUKUGITA	88	PRL 60 879	M. Fukugita *et al.*	(KYOTU, MPIM, UCB)
GOLDMAN	88	PRL 60 1789	I. Goldman *et al.*	(TELA)
LATTIMER	88	PRL 61 23	J.M. Lattimer, J. Cooperstein	(STON, BNL)
Also	88B	PRL 61 2633 erratum	J.M. Lattimer, J. Cooperstein	(STON, BNL)
NOETZOLD	88	PR D38 1658	D. Notzold	(MPIM)
NOTZOLD	88	PR D38 1658	D. Notzold	(MPIM)
RAFFELT	88B	PR D37 549	G.G. Raffelt, D.S.P. Dearborn	(UCB, LLL)
SPERGEL	88	PL B200 366	D.N. Spergel, J.N. Bahcall	(IAS)
STODOLSKY	88	PL B201 353	L. Stodolsky	(MPIM)
VOLOSHIN	88	PL B209 360	M.B. Voloshin	(ITEP)
Also	88B	JETPL 47 501	M.B. Voloshin	(ITEP)
		Translated from ZETFP 47 421.		
VOLOSHIN	88C	JETPL 68 690	M.B. Voloshin	(ITEP)
VONFEILIT...	88	PL B200 580	F. von Feilitzsch, L. Oberauer	(MUNT)
BARBIELLINI	87	Nature 329 21	G. Barbiellini, G. Cocconi	(CERN)
BORIS	87	PRL 58 2019	S.D. Boris *et al.*	(ITEP, ASCI)
Also	88	PRL 61 245 erratum	S.D. Boris *et al.*	(ITEP, ASCI)
BORIS	87B	JETPL 45 333	S.D. Boris *et al.*	(ITEP)
		Translated from ZETFP 45 267.		
FUKUGITA	87	PR D36 3817	M. Fukugita, S. Yazaki	(KYOTU, TOKY)
LONGO	87	PR D36 3276	M.J. Longo	(MICH)
LOSECCO	87B	PR D35 2073	J.M. LoSecco *et al.*	(IMB Collab.)
OBERAUER	87	PL B198 113	L.F. Oberauer, F. von Feilitzsch, R.L. Mossbauer	
SPRINGER	87	PR A35 679	P.T. Springer *et al.*	(LLNL)
KETOV	86	JETPL 44 146	S.N. Ketov *et al.*	(KIAE)
		Translated from ZETFP 44 114.		
YASUMI	86	PL B181 169	S. Yasumi *et al.*	(KEK, OSAK, TOHOK, TSUK+)
RAFFELT	85	PR D31 3002	G.G. Raffelt	(MPIM)
KYULDJIEV	84	NP B243 387	A.V. Kyuldjiev	(SOFI)
VOGEL	84	PR D30 1505	P. Vogel	
HENRY	81	PRL 47 618	R.C. Henry, P.D. Feldman	(JHU)
KIMBLE	81	PRL 46 80	R. Kimble, S. Bowyer, P. Jakobsen	(UCB)
LYNN	81	PR D23 2151	B.W. Lynn	(COLU)
MORGAN	81	PL 102B 247	J.A. Morgan	(SUSS)
FUJIKAWA	80	PRL 45 963	K. Fujikawa, R. Shrock	(STON)
LUBIMOV	80	PL 94B 266	V.A. Lyubimov *et al.*	(ITEP)
Also	80	SJNP 32 154	V.S. Kozik *et al.*	(ITEP)
		Translated from YAF 32 301.		
Also	81	JETP 54 616	V.A. Lyubimov *et al.*	(ITEP)
		Translated from ZETF 81 1158.		
STECKER	80	PRL 45 1460	F.W. Stecker	(NASA)
BEG	78	PR D17 1395	M.A.B. Beg, W.J. Marciano, M. Ruderman	(ROCK+)
LEE	77C	PR D16 1444	B.W. Lee, R.E. Shrock	(STON)
SUTHERLAND	76	PR D13 2700	P. Sutherland *et al.*	(PENN, COLU, NYU)
CLARK	74	PR D9 533	A.R. Clark *et al.*	(LBL)
REINES	74	PRL 32 180	F. Reines, H.W. Sobel, H.S. Gurr	(UCI)
Also	78	Private Comm.	V.E. Barnes	(PURD)
BECK	68	ZPHY 216 229	E. Beck, H. Daniel	(MPIH)
BERNSTEIN	63	PR 132 1227	J. Bernstein, M. Ruderman, G. Feinberg	(NYU+)
COWAN	57	PR 107 528	C.L. Cowan, F. Reines	(LANL)