LEPTONS

e

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

Mass $m = 0.51099907 \pm 0.00000015$ MeV [a]
$= (5.485799111 \pm 0.000000012) \times 10^{-4}$ u
$(m_{e^+} - m_{e^-})/m < 4 \times 10^{-8}$, CL = 90%
$\left|q_{e^+} + q_{e^-}\right|/e < 4 \times 10^{-8}$
Magnetic moment $\mu = 1.001159652193 \pm 0.000000000010\ \mu_B$
$(g_{e^+} - g_{e^-})\ /\ g_{\text{average}} = (-0.5 \pm 2.1) \times 10^{-12}$
Electric dipole moment $d = (0.18 \pm 0.16) \times 10^{-26}\ e\,$cm
Mean life $\tau > 4.3 \times 10^{23}$ yr, CL = 68% [b]

μ

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

Mass $m = 105.658389 \pm 0.000034$ MeV [c]
$= 0.113428913 \pm 0.000000017$ u
Mean life $\tau = (2.19703 \pm 0.00004) \times 10^{-6}$ s
$\tau_{\mu^+}/\tau_{\mu^-} = 1.00002 \pm 0.00008$
$c\tau = 658.654$ m
Magnetic moment $\mu = 1.0011659230 \pm 0.0000000084\ e\hbar/2m_\mu$
$(g_{\mu^+} - g_{\mu^-})\ /\ g_{\text{average}} = (-2.6 \pm 1.6) \times 10^{-8}$
Electric dipole moment $d = (3.7 \pm 3.4) \times 10^{-19}\ e\,$cm

Decay parameters [d]

$\rho = 0.7518 \pm 0.0026$
$\eta = -0.007 \pm 0.013$
$\delta = 0.749 \pm 0.004$
$\xi P_\mu = 1.003 \pm 0.008$ [e]
$\xi P_\mu \delta/\rho > 0.99682$, CL = 90% [e]
$\xi' = 1.00 \pm 0.04$
$\xi'' = 0.7 \pm 0.4$
$\alpha/\text{A} = (0 \pm 4) \times 10^{-3}$
$\alpha'/\text{A} = (0 \pm 4) \times 10^{-3}$
$\beta/\text{A} = (4 \pm 6) \times 10^{-3}$
$\beta'/\text{A} = (2 \pm 6) \times 10^{-3}$
$\overline{\eta} = 0.02 \pm 0.08$

μ^+ modes are charge conjugates of the modes below.

μ^- DECAY MODES			Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$e^- \overline{\nu}_e \nu_\mu$			$\approx 100\%$		53
$e^- \overline{\nu}_e \nu_\mu \gamma$		[f]	(1.4 ± 0.4) %		53
$e^- \overline{\nu}_e \nu_\mu e^+ e^-$		[g]	$(3.4\pm0.4) \times 10^{-5}$		53
Lepton Family number (*LF*) violating modes					
$e^- \nu_e \overline{\nu}_\mu$	*LF*	[h]	< 1.2 %	90%	53
$e^- \gamma$	*LF*		$< 4.9 \times 10^{-11}$	90%	53
$e^- e^+ e^-$	*LF*		$< 1.0 \times 10^{-12}$	90%	53
$e^- 2\gamma$	*LF*		$< 7.2 \times 10^{-11}$	90%	53

τ

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

Mass $m = 1777.05^{+0.29}_{-0.26}$ MeV
Mean life $\tau = (290.0 \pm 1.2) \times 10^{-15}$ s
$c\tau = 86.93$ μm
Magnetic moment anomaly > -0.052 and < 0.058, CL = 95%
Electric dipole moment $d > -3.1$ and $< 3.1 \times 10^{-16}$ e cm, CL = 95%

Weak dipole moment

$\text{Re}(d^w_\tau) < 0.56 \times 10^{-17}$ e cm, CL = 95%
$\text{Im}(d^w_\tau) < 1.5 \times 10^{-17}$ e cm, CL = 95%

Weak anomalous magnetic dipole moment

$\text{Re}(\alpha^w_\tau) < 4.5 \times 10^{-3}$, CL = 90%
$\text{Im}(\alpha^w_\tau) < 9.9 \times 10^{-3}$, CL = 90%

Decay parameters

See the τ Particle Listings for a note concerning τ-decay parameters.

$\rho^\tau(e \text{ or } \mu) = 0.748 \pm 0.010$
$\rho^\tau(e) = 0.745 \pm 0.012$
$\rho^\tau(\mu) = 0.741 \pm 0.030$
$\xi^\tau(e \text{ or } \mu) = 1.01 \pm 0.04$
$\xi^\tau(e) = 0.98 \pm 0.05$
$\xi^\tau(\mu) = 1.07 \pm 0.08$
$\eta^\tau(e \text{ or } \mu) = 0.01 \pm 0.07$
$\eta^\tau(\mu) = -0.10 \pm 0.18$
$(\delta\xi)^\tau(e \text{ or } \mu) = 0.749 \pm 0.026$
$(\delta\xi)^\tau(e) = 0.733 \pm 0.033$
$(\delta\xi)^\tau(\mu) = 0.78 \pm 0.05$
$\xi^\tau(\pi) = 0.99 \pm 0.05$
$\xi^\tau(\rho) = 0.996 \pm 0.010$
$\xi^\tau(a_1) = 1.02 \pm 0.04$
$\xi^\tau(\text{all hadronic modes}) = 0.997 \pm 0.009$

τ^+ modes are charge conjugates of the modes below. "$h^\pm$" stands for $\pi^\pm$ or $K^\pm$. "ℓ" stands for e or μ. "Neutral" means neutral hadron whose decay products include γ's and/or π^0's.

τ^- DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Modes with one charged particle				
particle$^- \geq 0$ neutrals $\geq 0K^0_L\nu_\tau$ ("1-prong")		(84.71 ± 0.13) %	S=1.2	–
particle$^- \geq 0$ neutrals $\geq 0K^0\nu_\tau$		(85.30 ± 0.13) %	S=1.2	–
$\mu^-\overline{\nu}_\mu\nu_\tau$	[i]	(17.37 ± 0.09) %		885
$\mu^-\overline{\nu}_\mu\nu_\tau\gamma$	[g]	$(3.0 \pm 0.6) \times 10^{-3}$		–
$e^-\overline{\nu}_e\nu_\tau$	[i]	(17.81 ± 0.07) %		889
$h^- \geq 0$ neutrals $\geq 0K^0_L\ \nu_\tau$		(49.52 ± 0.16) %	S=1.2	–
$h^- \geq 0K^0_L\ \nu_\tau$		(12.32 ± 0.12) %	S=1.5	–
$h^-\nu_\tau$		(11.79 ± 0.12) %	S=1.5	–
$\pi^-\nu_\tau$	[i]	(11.08 ± 0.13) %	S=1.4	883
$K^-\nu_\tau$	[i]	$(7.1 \pm 0.5) \times 10^{-3}$		820
$h^- \geq 1$ neutralsν_τ		(36.91 ± 0.17) %	S=1.2	–
$h^-\pi^0\nu_\tau$		(25.84 ± 0.14) %	S=1.1	–
$\pi^-\pi^0\nu_\tau$	[i]	(25.32 ± 0.15) %	S=1.1	878
$\pi^-\pi^0$ non-$\rho(770)\nu_\tau$		$(3.0 \pm 3.2) \times 10^{-3}$		878
$K^-\pi^0\nu_\tau$	[i]	$(5.2 \pm 0.5) \times 10^{-3}$		814
$h^- \geq 2\pi^0\nu_\tau$		(10.79 ± 0.16) %	S=1.2	–
$h^-2\pi^0\nu_\tau$		(9.39 ± 0.14) %	S=1.2	–
$h^-2\pi^0\nu_\tau$(ex.K^0)		(9.23 ± 0.14) %	S=1.2	–
$\pi^-2\pi^0\nu_\tau$(ex.K^0)	[i]	(9.15 ± 0.15) %	S=1.2	862
$K^-2\pi^0\nu_\tau$(ex.K^0)	[i]	$(8.0 \pm 2.7) \times 10^{-4}$		796
$h^- \geq 3\pi^0\nu_\tau$		(1.40 ± 0.11) %	S=1.1	–
$h^-3\pi^0\nu_\tau$		(1.23 ± 0.10) %	S=1.1	–
$\pi^-3\pi^0\nu_\tau$(ex.K^0)	[i]	(1.11 ± 0.14) %		836
$K^-3\pi^0\nu_\tau$(ex.K^0)	[i]	$(4.3\ ^{+10.0}_{-\ 2.9}) \times 10^{-4}$		766
$h^-4\pi^0\nu_\tau$(ex.K^0)		$(1.7 \pm 0.6) \times 10^{-3}$		–
$h^-4\pi^0\nu_\tau$(ex.K^0,η)	[i]	$(1.1 \pm 0.6) \times 10^{-3}$		–
$K^- \geq 0\pi^0\ \geq 0K^0\ \nu_\tau$		(1.66 ± 0.10) %		–
$K^- \geq 1\ (\pi^0$ or $K^0)\ \nu_\tau$		$(9.5 \pm 1.0) \times 10^{-3}$		–

Modes with K^0's

K^0(particles)$^- \nu_\tau$		(1.66 ± 0.09) %	S=1.4	–
$h^- \overline{K}^0 \geq 0$ neutrals $\geq 0 K^0_L \nu_\tau$		(1.62 ± 0.09) %	S=1.4	–
$h^- \overline{K}^0 \nu_\tau$		$(9.9 \pm 0.8) \times 10^{-3}$	S=1.5	–
$\pi^- \overline{K}^0 \nu_\tau$	[i]	$(8.3 \pm 0.8) \times 10^{-3}$	S=1.4	812
$\pi^- \overline{K}^0$ (non-$K^*(892)^-$) ν_τ		$< 1.7 \times 10^{-3}$	CL=95%	812
$K^- K^0 \nu_\tau$	[i]	$(1.59 \pm 0.24) \times 10^{-3}$		737
$h^- \overline{K}^0 \pi^0 \nu_\tau$		$(5.5 \pm 0.5) \times 10^{-3}$		–
$\pi^- \overline{K}^0 \pi^0 \nu_\tau$	[i]	$(3.9 \pm 0.5) \times 10^{-3}$		794
$\overline{K}^0 \rho^- \nu_\tau$		$(1.9 \pm 0.7) \times 10^{-3}$		–
$K^- K^0 \pi^0 \nu_\tau$	[i]	$(1.51 \pm 0.29) \times 10^{-3}$		685
$\pi^- \overline{K}^0 \pi^0 \pi^0 \nu_\tau$		$(6 \pm 4) \times 10^{-4}$		–
$K^- K^0 \pi^0 \pi^0 \nu_\tau$		$< 3.9 \times 10^{-4}$	CL=95%	–
$\pi^- K^0 \overline{K}^0 \nu_\tau$	[i]	$(1.21 \pm 0.21) \times 10^{-3}$	S=1.2	682
$\pi^- K^0_S K^0_S \nu_\tau$		$(3.0 \pm 0.5) \times 10^{-4}$	S=1.2	–
$\pi^- K^0_S K^0_L \nu_\tau$		$(6.0 \pm 1.0) \times 10^{-4}$	S=1.2	–
$\pi^- K^0_S K^0_S \pi^0 \nu_\tau$		$< 2.0 \times 10^{-4}$	CL=95%	–
$\pi^- K^0_S K^0_L \pi^0 \nu_\tau$		$(3.1 \pm 1.2) \times 10^{-4}$		–
$K^- K^0 \geq 0$ neutrals ν_τ		$(3.1 \pm 0.4) \times 10^{-3}$		–
$K^0 h^+ h^- h^- \geq 0$ neutrals ν_τ		$< 1.7 \times 10^{-3}$	CL=95%	–
$K^0 h^+ h^- h^- \nu_\tau$		$(2.3 \pm 2.0) \times 10^{-4}$		–

Modes with three charged particles

$h^- h^- h^+ \geq 0$neut. ν_τ ("3-prong")		(15.18 ± 0.13) %	S=1.2	–
$h^- h^- h^+ \geq 0$ neutrals ν_τ (ex. $K^0_S \to \pi^+ \pi^-$)		(14.60 ± 0.13) %	S=1.2	–
$\pi^- \pi^+ \pi^- \geq 0$ neutrals ν_τ		(14.60 ± 0.14) %		–
$h^- h^- h^+ \nu_\tau$		(9.96 ± 0.10) %	S=1.1	–
$h^- h^- h^+ \nu_\tau$ (ex.K^0)		(9.62 ± 0.10) %	S=1.1	–
$h^- h^- h^+ \nu_\tau$ (ex.K^0,ω)		(9.57 ± 0.10) %	S=1.1	–
$\pi^- \pi^+ \pi^- \nu_\tau$		(9.56 ± 0.11) %	S=1.1	–
$\pi^- \pi^+ \pi^- \nu_\tau$ (ex.K^0)		(9.52 ± 0.11) %	S=1.1	–
$\pi^- \pi^+ \pi^- \nu_\tau$ (ex.K^0,ω)	[i]	(9.23 ± 0.11) %	S=1.1	–
$h^- h^- h^+ \geq 1$ neutrals ν_τ		(5.18 ± 0.11) %	S=1.2	–

$h^- h^- h^+ \geq 1$ neutrals ν_τ (ex. $K^0_S \rightarrow \pi^+ \pi^-$)		(4.98 ± 0.11) %	S=1.2	–
$h^- h^- h^+ \pi^0 \nu_\tau$		(4.50 ± 0.09) %	S=1.1	–
$h^- h^- h^+ \pi^0 \nu_\tau$ (ex.K^0)		(4.31 ± 0.09) %	S=1.1	–
$h^- h^- h^+ \pi^0 \nu_\tau$ (ex. K^0, ω)		(2.59 ± 0.09) %		–
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$		(4.35 ± 0.10) %		–
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex.K^0)		(4.22 ± 0.10) %		–
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex.K^0,ω)	[*i*]	(2.49 ± 0.10) %		–
$h^- (\rho\pi)^0 \nu_\tau$		(2.88 ± 0.35) %		–
$(a_1(1260)\, h)^- \nu_\tau$		< 2.0 %	CL=95%	–
$h^- \rho \pi^0 \nu_\tau$		(1.35 ± 0.20) %		–
$h^- \rho^+ h^- \nu_\tau$		$(4.5 \pm 2.2) \times 10^{-3}$		–
$h^- \rho^- h^+ \nu_\tau$		(1.17 ± 0.23) %		–
$h^- h^- h^+ 2\pi^0 \nu_\tau$		$(5.4 \pm 0.4) \times 10^{-3}$		–
$h^- h^- h^+ 2\pi^0 \nu_\tau$ (ex.K^0)		$(5.3 \pm 0.4) \times 10^{-3}$		–
$h^- h^- h^+ 2\pi^0 \nu_\tau$ (ex.K^0,ω,η)	[*i*]	$(1.1 \pm 0.4) \times 10^{-3}$		–
$h^- h^- h^+ \geq 3\pi^0 \nu_\tau$	[*i*]	$(1.4 {+0.9 \atop -0.7}) \times 10^{-3}$	S=1.5	–
$h^- h^- h^+ 3\pi^0 \nu_\tau$		$(2.9 \pm 0.8) \times 10^{-4}$		–
$K^- h^+ h^- \geq 0$ neutrals ν_τ		$(5.4 \pm 0.7) \times 10^{-3}$	S=1.1	–
$K^- \pi^+ \pi^- \geq 0$ neutrals ν_τ		$(3.1 \pm 0.6) \times 10^{-3}$	S=1.1	–
$K^- \pi^+ \pi^- \nu_\tau$		$(2.3 \pm 0.4) \times 10^{-3}$		–
$K^- \pi^+ \pi^- \nu_\tau$ (ex.K^0)	[*i*]	$(1.8 \pm 0.5) \times 10^{-3}$		–
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$		$(8 \pm 4) \times 10^{-4}$		–
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex.K^0)	[*i*]	$(2.4 {+4.3 \atop -1.6}) \times 10^{-4}$		–
$K^- \pi^+ K^- \geq 0$ neut. ν_τ		$< 9 \times 10^{-4}$	CL=95%	–
$K^- K^+ \pi^- \geq 0$ neut. ν_τ		$(2.3 \pm 0.4) \times 10^{-3}$		–
$K^- K^+ \pi^- \nu_\tau$	[*i*]	$(1.61 \pm 0.26) \times 10^{-3}$		685
$K^- K^+ \pi^- \pi^0 \nu_\tau$	[*i*]	$(6.9 \pm 3.0) \times 10^{-4}$		–
$K^- K^+ K^- \geq 0$ neut. ν_τ		$< 2.1 \times 10^{-3}$	CL=95%	–
$K^- K^+ K^- \nu_\tau$		$< 1.9 \times 10^{-4}$	CL=90%	–
$\pi^- K^+ \pi^- \geq 0$ neut. ν_τ		$< 2.5 \times 10^{-3}$	CL=95%	–
$e^- e^- e^+ \overline{\nu}_e \nu_\tau$		$(2.8 \pm 1.5) \times 10^{-5}$		889
$\mu^- e^- e^+ \overline{\nu}_\mu \nu_\tau$		$< 3.6 \times 10^{-5}$	CL=90%	885

Modes with five charged particles

$3h^- 2h^+ \geq 0$ neutrals ν_τ (ex. $K^0_S \rightarrow \pi^- \pi^+$) ("5-prong")		$(9.7 \pm 0.7) \times 10^{-4}$		–
$3h^- 2h^+ \nu_\tau$ (ex.K^0)	[*i*]	$(7.5 \pm 0.7) \times 10^{-4}$		–
$3h^- 2h^+ \pi^0 \nu_\tau$ (ex.K^0)	[*i*]	$(2.2 \pm 0.5) \times 10^{-4}$		–
$3h^- 2h^+ 2\pi^0 \nu_\tau$		$< 1.1 \times 10^{-4}$	CL=90%	–

Miscellaneous other allowed modes

$(5\pi)^- \nu_\tau$		$(7.4 \pm 0.7) \times 10^{-3}$		–
$4h^- 3h^+ \geq 0$ neutrals ν_τ (“7-prong”)		$< 2.4 \times 10^{-6}$	CL=90%	–
$K^*(892)^- \geq 0(h^0 \neq K^0_S)\nu_\tau$		(1.94 ± 0.31) %		–
$K^*(892)^- \geq 0$ neutrals ν_τ		(1.33 ± 0.13) %		–
$K^*(892)^- \nu_\tau$		(1.28 ± 0.08) %		665
$K^*(892)^0 K^- \geq 0$ neutrals ν_τ		$(3.2 \pm 1.4) \times 10^{-3}$		–
$K^*(892)^0 K^- \nu_\tau$		$(2.1 \pm 0.4) \times 10^{-3}$		539
$\overline{K}^*(892)^0 \pi^- \geq 0$ neutrals ν_τ		$(3.8 \pm 1.7) \times 10^{-3}$		–
$\overline{K}^*(892)^0 \pi^- \nu_\tau$		$(2.2 \pm 0.5) \times 10^{-3}$		653
$(\overline{K}^*(892)\pi)^- \nu_\tau \rightarrow \pi^- \overline{K}^0 \pi^0 \nu_\tau$		$(1.1 \pm 0.5) \times 10^{-3}$		–
$K_1(1270)^- \nu_\tau$		$(4 \pm 4) \times 10^{-3}$		433
$K_1(1400)^- \nu_\tau$		$(8 \pm 4) \times 10^{-3}$		335
$K^*_2(1430)^- \nu_\tau$		$< 3 \times 10^{-3}$	CL=95%	317
$\eta \pi^- \nu_\tau$		$< 1.4 \times 10^{-4}$	CL=95%	798
$\eta \pi^- \pi^0 \nu_\tau$	[i]	$(1.74 \pm 0.24) \times 10^{-3}$		778
$\eta \pi^- \pi^0 \pi^0 \nu_\tau$		$(1.4 \pm 0.7) \times 10^{-4}$		746
$\eta K^- \nu_\tau$		$(2.7 \pm 0.6) \times 10^{-4}$		720
$\eta \pi^+ \pi^- \pi^- \geq 0$ neutrals ν_τ		$< 3 \times 10^{-3}$	CL=90%	–
$\eta \pi^- \pi^+ \pi^- \nu_\tau$		$(3.4 \pm 0.8) \times 10^{-4}$		–
$\eta a_1(1260)^- \nu_\tau \rightarrow \eta \pi^- \rho^0 \nu_\tau$		$< 3.9 \times 10^{-4}$	CL=90%	–
$\eta \eta \pi^- \nu_\tau$		$< 1.1 \times 10^{-4}$	CL=95%	637
$\eta \eta \pi^- \pi^0 \nu_\tau$		$< 2.0 \times 10^{-4}$	CL=95%	559
$\eta'(958) \pi^- \nu_\tau$		$< 7.4 \times 10^{-5}$	CL=90%	–
$\eta'(958) \pi^- \pi^0 \nu_\tau$		$< 8.0 \times 10^{-5}$	CL=90%	–
$\phi \pi^- \nu_\tau$		$< 2.0 \times 10^{-4}$	CL=90%	585
$\phi K^- \nu_\tau$		$< 6.7 \times 10^{-5}$	CL=90%	–
$f_1(1285) \pi^- \nu_\tau$		$(5.8 \pm 2.3) \times 10^{-4}$		–
$f_1(1285) \pi^- \nu_\tau \rightarrow \eta \pi^- \pi^+ \pi^- \nu_\tau$		$(1.9 \pm 0.7) \times 10^{-4}$		–
$h^- \omega \geq 0$ neutrals ν_τ		(2.36 ± 0.08) %		–
$h^- \omega \nu_\tau$	[i]	(1.93 ± 0.06) %		–
$h^- \omega \pi^0 \nu_\tau$	[i]	$(4.3 \pm 0.5) \times 10^{-3}$		–
$h^- \omega 2\pi^0 \nu_\tau$		$(1.9 \pm 0.8) \times 10^{-4}$		–

Lepton Family number (*LF*), Lepton number (*L*), or Baryon number (*B*) violating modes (In the modes below, ℓ means a sum over e and μ modes)

L means lepton number violation (*e.g.* $\tau^- \to e^+\pi^-\pi^-$). Following common usage, *LF* means lepton family violation *and not* lepton number violation (*e.g.* $\tau^- \to e^-\pi^+\pi^-$). *B* means baryon number violation.

$e^-\gamma$	*LF*	$<$ 2.7	$\times 10^{-6}$	CL=90%	888
$\mu^-\gamma$	*LF*	$<$ 3.0	$\times 10^{-6}$	CL=90%	885
$e^-\pi^0$	*LF*	$<$ 3.7	$\times 10^{-6}$	CL=90%	883
$\mu^-\pi^0$	*LF*	$<$ 4.0	$\times 10^{-6}$	CL=90%	880
e^-K^0	*LF*	$<$ 1.3	$\times 10^{-3}$	CL=90%	819
μ^-K^0	*LF*	$<$ 1.0	$\times 10^{-3}$	CL=90%	815
$e^-\eta$	*LF*	$<$ 8.2	$\times 10^{-6}$	CL=90%	804
$\mu^-\eta$	*LF*	$<$ 9.6	$\times 10^{-6}$	CL=90%	800
$e^-\rho^0$	*LF*	$<$ 2.0	$\times 10^{-6}$	CL=90%	722
$\mu^-\rho^0$	*LF*	$<$ 6.3	$\times 10^{-6}$	CL=90%	718
$e^-K^*(892)^0$	*LF*	$<$ 5.1	$\times 10^{-6}$	CL=90%	663
$\mu^-K^*(892)^0$	*LF*	$<$ 7.5	$\times 10^{-6}$	CL=90%	657
$e^-\overline{K}^*(892)^0$	*LF*	$<$ 7.4	$\times 10^{-6}$	CL=90%	663
$\mu^-\overline{K}^*(892)^0$	*LF*	$<$ 7.5	$\times 10^{-6}$	CL=90%	657
$e^-\phi$	*LF*	$<$ 6.9	$\times 10^{-6}$	CL=90%	596
$\mu^-\phi$	*LF*	$<$ 7.0	$\times 10^{-6}$	CL=90%	590
$\pi^-\gamma$	*L*	$<$ 2.8	$\times 10^{-4}$	CL=90%	883
$\pi^-\pi^0$	*L*	$<$ 3.7	$\times 10^{-4}$	CL=90%	878
$e^-e^+e^-$	*LF*	$<$ 2.9	$\times 10^{-6}$	CL=90%	888
$e^-\mu^+\mu^-$	*LF*	$<$ 1.8	$\times 10^{-6}$	CL=90%	882
$e^+\mu^-\mu^-$	*LF*	$<$ 1.5	$\times 10^{-6}$	CL=90%	882
$\mu^-e^+e^-$	*LF*	$<$ 1.7	$\times 10^{-6}$	CL=90%	885
$\mu^+e^-e^-$	*LF*	$<$ 1.5	$\times 10^{-6}$	CL=90%	885
$\mu^-\mu^+\mu^-$	*LF*	$<$ 1.9	$\times 10^{-6}$	CL=90%	873
$e^-\pi^+\pi^-$	*LF*	$<$ 2.2	$\times 10^{-6}$	CL=90%	877
$e^+\pi^-\pi^-$	*L*	$<$ 1.9	$\times 10^{-6}$	CL=90%	877
$\mu^-\pi^+\pi^-$	*LF*	$<$ 8.2	$\times 10^{-6}$	CL=90%	866
$\mu^+\pi^-\pi^-$	*L*	$<$ 3.4	$\times 10^{-6}$	CL=90%	866
$e^-\pi^+K^-$	*LF*	$<$ 6.4	$\times 10^{-6}$	CL=90%	814
$e^-\pi^-K^+$	*LF*	$<$ 3.8	$\times 10^{-6}$	CL=90%	814
$e^+\pi^-K^-$	*L*	$<$ 2.1	$\times 10^{-6}$	CL=90%	814
$e^-K^+K^-$	*LF*	$<$ 6.0	$\times 10^{-6}$	CL=90%	739
$e^+K^-K^-$	*L*	$<$ 3.8	$\times 10^{-6}$	CL=90%	739
$\mu^-\pi^+K^-$	*LF*	$<$ 7.5	$\times 10^{-6}$	CL=90%	800
$\mu^-\pi^-K^+$	*LF*	$<$ 7.4	$\times 10^{-6}$	CL=90%	800
$\mu^+\pi^-K^-$	*L*	$<$ 7.0	$\times 10^{-6}$	CL=90%	800

$\mu^- K^+ K^-$	*LF*	<	1.5	$\times 10^{-5}$	CL=90%	699
$\mu^+ K^- K^-$	*L*	<	6.0	$\times 10^{-6}$	CL=90%	699
$e^- \pi^0 \pi^0$	*LF*	<	6.5	$\times 10^{-6}$	CL=90%	878
$\mu^- \pi^0 \pi^0$	*LF*	<	1.4	$\times 10^{-5}$	CL=90%	867
$e^- \eta \eta$	*LF*	<	3.5	$\times 10^{-5}$	CL=90%	700
$\mu^- \eta \eta$	*LF*	<	6.0	$\times 10^{-5}$	CL=90%	654
$e^- \pi^0 \eta$	*LF*	<	2.4	$\times 10^{-5}$	CL=90%	798
$\mu^- \pi^0 \eta$	*LF*	<	2.2	$\times 10^{-5}$	CL=90%	784
$\overline{p} \gamma$	*L,B*	<	2.9	$\times 10^{-4}$	CL=90%	641
$\overline{p} \pi^0$	*L,B*	<	6.6	$\times 10^{-4}$	CL=90%	632
$\overline{p} \eta$	*L,B*	<	1.30	$\times 10^{-3}$	CL=90%	476
e^- light boson	*LF*	<	2.7	$\times 10^{-3}$	CL=95%	–
μ^- light boson	*LF*	<	5	$\times 10^{-3}$	CL=95%	–

Heavy Charged Lepton Searches

$L^\pm$ – charged lepton

Mass $m >$ 80.2 GeV, CL = 95% $\quad m_\nu \approx 0$

$L^\pm$ – stable charged heavy lepton

Mass $m >$ 84.2 GeV, CL = 95%

Neutrinos

See the Particle Listings for a Note "Neutrino Mass" giving details of neutrinos, masses, mixing, and the status of experimental searches.

ν_e

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

Mass *m*: Unexplained effects have resulted in significantly negative m^2 in the new, precise tritium beta decay experiments. It is felt that a real neutrino mass as large as 10–15 eV would cause observable spectral distortions even in the presence of the end-point count excesses.

Mean life/mass, $\tau/m_{\nu_e} > 7 \times 10^9$ s/eV (solar)

Mean life/mass, $\tau/m_{\nu_e} > 300$ s/eV, CL = 90% (reactor)

Magnetic moment $\mu < 1.8 \times 10^{-10}\ \mu_B$, CL = 90%

ν_μ

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

Mass $m <$ 0.17 MeV, CL = 90%
Mean life/mass, $\tau/m_{\nu_\mu} >$ 15.4 s/eV, CL = 90%
Magnetic moment $\mu < 7.4 \times 10^{-10}\ \mu_B$, CL = 90%

ν_τ

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

Mass $m <$ 18.2 MeV, CL = 95%
Magnetic moment $\mu < 5.4 \times 10^{-7}\ \mu_B$, CL = 90%
Electric dipole moment $d < 5.2 \times 10^{-17}$ e cm, CL = 95%

Number of Light Neutrino Types

(including ν_e, ν_μ, and ν_τ)

Number $N = 2.994 \pm 0.012$ (Standard Model fits to LEP data)
Number $N = 3.07 \pm 0.12$ (Direct measurement of invisible Z width)

Massive Neutrinos and Lepton Mixing, Searches for

For excited leptons, see Compositeness Limits below.

See the Particle Listings for a Note "Neutrino Mass" giving details of neutrinos, masses, mixing, and the status of experimental searches.

While no direct, uncontested evidence for massive neutrinos or lepton mixing has been obtained, suggestive evidence has come from solar neutrino observations, from anomalies in the relative fractions of ν_e and ν_μ observed in energetic cosmic-ray air showers, and possibly from a $\overline{\nu}_e$ appearance experiment at Los Alamos. Sample limits are:

Stable Neutral Heavy Lepton Mass Limits

Mass $m >$ 45.0 GeV, CL = 95% (Dirac)
Mass $m >$ 39.5 GeV, CL = 95% (Majorana)

Neutral Heavy Lepton Mass Limits

Mass $m >$ 69.0 GeV, CL = 95% (Dirac ν_L coupling to e, μ, τ with $|U_{\ell j}|^2 > 10^{-12}$)
Mass $m >$ 58.2 GeV, CL = 95% (Majorana ν_L coupling to e, μ, τ with $|U_{\ell j}|^2 > 10^{-12}$)

Solar Neutrinos

Detectors using gallium ($E_\nu \gtrsim 0.2$ MeV), chlorine ($E_\nu \gtrsim 0.8$ MeV), and Ĉerenkov effect in water ($E_\nu \gtrsim 7$ MeV) measure significantly lower neutrino rates than are predicted from solar models. The deficit in the solar neutrino flux compared with solar model calculations could be explained by oscillations with $\Delta m^2 \leq 10^{-5}$ eV^2 causing the disappearance of ν_e.

Atmospheric Neutrinos

Underground detectors observing neutrinos produced by cosmic rays in the atmosphere have measured a ν_μ/ν_e ratio much less than expected and also a deficiency of upward going ν_μ compared to downward. This could be explained by oscillations leading to the disappearance of ν_μ with $\Delta m^2 \approx 10^{-3}$ to 10^{-2} eV^2.

ν oscillation: $\overline{\nu}_e \not\to \overline{\nu}_e$ (θ = mixing angle)

$\Delta m^2 < 9 \times 10^{-4}$ eV^2, CL = 90% (if $\sin^2 2\theta = 1$)
$\sin^2 2\theta < 0.02$, CL = 90% (if $\Delta(m^2)$ is large)

ν oscillation: ν_μ ($\overline{\nu}_\mu$) $\to$ ν_e ($\overline{\nu}_e$) (any combination)

$\Delta m^2 < 0.075$ eV^2, CL = 90% (if $\sin^2 2\theta = 1$)
$\sin^2 2\theta < 1.8 \times 10^{-3}$, CL = 90% (if $\Delta(m^2)$ is large)

NOTES

[*a*] The uncertainty in the electron mass in unified atomic mass units (u) is ten times smaller than that given by the 1986 CODATA adjustment, quoted in the Table of Physical Constants (Section 1). The conversion to MeV via the factor 931.49432(28) MeV/u is more uncertain because of the electron charge uncertainty. Our value in MeV differs slightly from the 1986 CODATA result.

[*b*] This is the best "electron disappearance" limit. The best limit for the mode $e^- \rightarrow \nu\gamma$ is $> 2.35 \times 10^{25}$ yr (CL=68%).

[*c*] The muon mass is most precisely known in u (unified atomic mass units). The conversion factor to MeV via the factor 931.49432(28) MeV/u is more uncertain because of the electron charge uncertainty.

[*d*] See the "Note on Muon Decay Parameters" in the μ Particle Listings for definitions and details.

[*e*] P_μ is the longitudinal polarization of the muon from pion decay. In standard $V{-}A$ theory, $P_\mu = 1$ and $\rho = \delta = 3/4$.

[*f*] This only includes events with the γ energy $>$ 10 MeV. Since the $e^- \overline{\nu}_e \nu_\mu$ and $e^- \overline{\nu}_e \nu_\mu \gamma$ modes cannot be clearly separated, we regard the latter mode as a subset of the former.

[*g*] See the μ Particle Listings for the energy limits used in this measurement.

[*h*] A test of additive vs. multiplicative lepton family number conservation.

[*i*] Basis mode for the τ.