LIMIT ON $\mu^- \rightarrow e^+$ CONVERSION

Forbidden by total lepton number conservation.

$\sigma(\mu^- {}^{32}\mathrm{S} \rightarrow e^+ {}^{32}\mathrm{Si}^*)$ / $\sigma(\mu^- {}^{32}\mathrm{S} \rightarrow \nu_\mu {}^{32}\mathrm{P}^*)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<9 × 10⁻¹⁰	90	BADERT...	80	STRC	SIN
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<1.5 × 10⁻⁹	90	BADERT...	78	STRC	SIN

$\sigma(\mu^- {}^{127}\mathrm{I} \rightarrow e^+ {}^{127}\mathrm{Sb}^*)$ / $\sigma(\mu^- {}^{127}\mathrm{I} \rightarrow$ anything)

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<3 × 10⁻¹⁰	90	[20] ABELA	80	CNTR	Radiochemical tech.

[20] ABELA 80 is upper limit for $\mu^- e^+$ conversion leading to particle-stable states of ^{127}Sb. Limit for total conversion rate is higher by a factor less than 4 (G. Backenstoss, private communication).

$\sigma(\mu^-\,\mathrm{Cu} \rightarrow e^+\,\mathrm{Co})$ / $\sigma(\mu^-\,\mathrm{Cu} \rightarrow \nu_\mu\,\mathrm{Ni})$

VALUE	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<2.6 × 10⁻⁸	90	BRYMAN	72	SPEC
<2.2 × 10⁻⁷	90	CONFORTO	62	OSPK

$\sigma(\mu^-\,\mathrm{Ti} \rightarrow e^+\,\mathrm{Ca})$ / $\sigma(\mu^-\,\mathrm{Ti} \rightarrow$ capture)

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<8.9 × 10⁻¹¹	90	[21] DOHMEN	93	SPEC	SINDRUM II
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<4.3 × 10⁻¹²	90	[22] DOHMEN	93	SPEC	SINDRUM II
<1.7 × 10⁻¹⁰	90	[23] AHMAD	88	TPC	TRIUMF

[21] This DOHMEN 93 limit assumes a giant resonance excitation of the daughter Ca nucleus (mean energy and width both 20 MeV).

[22] This DOHMEN 93 limit assumes the daughter Ca nucleus is left in the ground state. However, the probability of this is unknown.

[23] Assuming a giant-resonance-excitation model.

LIMIT ON MUONIUM → ANTIMUONIUM CONVERSION

Forbidden by lepton family number conservation.

$R_g = G_C \,/\, G_F$

The effective Lagrangian for the $\mu^+ e^- \rightarrow \mu^- e^+$ conversion is assumed to be

$$\mathcal{L} = 2^{-1/2}\, G_C\, [\overline{\psi}_\mu \gamma_\lambda (1-\gamma_5)\, \psi_e]\, [\overline{\psi}_\mu \gamma_\lambda (1-\gamma_5)\, \psi_e] + \text{h.c.}$$

The experimental result is then an upper limit on G_C/G_F, where G_F is the Fermi coupling constant.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< 0.13	90	GORDEEV	93	SPEC	JINR phasotron
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 6.9	90	NI	93	CBOX	LAMPF
< 0.16	90	MATTHIAS	91	SPEC	LAMPF
< 0.29	90	HUBER	90B	CNTR	TRIUMF
< 0.88	90	HUBER	88	CNTR	See HUBER 90B
< 7.5	90	NI	87	CBOX	See NI 93
<20	95	BEER	86	CNTR	TRIUMF
<42	95	MARSHALL	82	CNTR	

NOTE ON MUON DECAY PARAMETERS

(by W. Fetscher and H.-J. Gerber, ETH Zürich)

All measurements in direct muon decay, $\mu^- \rightarrow e^- + 2$ neutrals, and its inverse, $\nu_\mu + e^- \rightarrow \mu^- +$ neutral, are successfully described by the "V–A interaction," which is a particular case of a local, derivative-free, lepton-number-conserving, four-fermion interaction [1]. The matrix element is given below. The V–A form and the nature of the neutrals (ν_μ and $\overline{\nu}_e$), and hence the doublet assignments $(\nu_e\; e^-)_L$ and $(\nu_\mu\; \mu^-)_L$, can be determined from experiments [2,3].

All results in direct muon decay (energy spectra, polarizations, and angular distributions) and in inverse muon decay (the reaction cross section) at energies well below $m_W c^2$ may be parametrized in terms of amplitudes $g^\gamma_{\varepsilon\mu}$ and the Fermi coupling constant G_F, using the matrix element

$$\frac{4G_F}{\sqrt{2}} \sum_{\substack{\gamma=S,V,T \\ \epsilon,\mu=R,L}} g^\gamma_{\epsilon\mu} \langle \overline{e}_\epsilon \,|\, \Gamma^\gamma \,|\, (\nu_e)_n \rangle \, \langle (\overline{\nu}_\mu)_m \,|\, \Gamma_\gamma \,|\, \mu_\mu \rangle \; . \qquad (1)$$

We use the notation of Fetscher *et al.* [2], who in turn use the sign conventions and definitions of Scheck [4]. Here $\gamma = S, V, T$ indicate a scalar, vector, or tensor interaction; and ε, $\mu = R, L$ indicate a right- or left-handed chirality of the electron or muon. The chiralities n and m of the ν_e and $\overline{\nu}_\mu$ are then determined by the values of γ, ε, and μ. The particles are represented by fields of definite chirality [5].

As shown by Langacker and London [6], explicit lepton-number nonconservation still leads to a matrix element equivalent to Eq. (1). They conclude that it is not possible, even in principle, to test lepton-number conservation in (leptonic) muon decay if the final neutrinos are massless and are not observed.

The ten complex amplitudes $g^\gamma_{\varepsilon\mu}$ (g^T_{RR} and g^T_{LL} are identically zero) and G_F constitute 19 independent (real) parameters to be determined by experiment. The V–A interaction corresponds to the single amplitude g^V_{LL} being unity and all the others being zero.

C. Jarlskog [7] has noted that certain experiments observing the decay electron are especially informative if they yield the V–A values. Indeed, all (direct) muon decay experiments are compatible with an arbitrary mix of the scalar and vector amplitudes g^S_{LL} and g^V_{LL}—in the extreme, even with the purely scalar $g^S_{LL} = 2$, $g^V_{LL} = 0$. The decision in favor of V–A comes from the quantitative observation of inverse muon decay, which would be forbidden for pure g^S_{LL} [2].

The differential decay probability to obtain an $e^\pm$ with (reduced) energy between x and $x + dx$, emitted in the direction $\hat{z}$ at an angle between θ and $\theta + d\theta$ with respect to the muon polarization vector $\vec{P}_\mu$, and with its spin pointing in the arbitrary direction $\hat{\zeta}$, is given by

$$\frac{d^2\Gamma}{dx\; d\cos\theta} = \frac{m_\mu}{4\pi^3} W^4_{e\mu} G^2_F \sqrt{x^2 - x^2_0} \times \Big(F_{IS}(x) \pm P_\mu \cos\theta\, F_{AS}(x) \Big) \times [1 + \vec{P}_e(x,\theta) \cdot \hat{\zeta}] \; .$$

Here $W_{e\mu} = \max(E_e) = (m^2_\mu + m^2_e)/2m_\mu$ is the maximum $e^\pm$ energy, $x = E_e/W_{e\mu}$ is the reduced energy, and $x_0 = m_e/W_{e\mu} = 9.67 \times 10^{-3}$. The quantity $P_\mu = |\vec{P}_\mu| \cdot \hat{\zeta}$ has the significance of the direction in which a perfect polarization-sensitive electron detector would be most sensitive. The isotropic part of the spectrum, $F_{IS}(x)$, the anisotropic part, $F_{AS}(x)$, and the electron polarization, $\vec{P}_e(x,\theta)$, depend on bilinear combinations—called decay parameters—of the coupling constants $g^\gamma_{\varepsilon\mu}$. Neglecting possible nonzero neutrino masses, we have, in terms of the decay parameters ρ, η, ξ, δ, etc.,

$$F_{IS}(x) = x(1-x) + \tfrac{2}{9}\rho(4x^2 - 3x - x^2_0) + \eta\, x_0(1-x)$$

$$F_{AS}(x) = \tfrac{1}{3}\xi \sqrt{x^2 - x^2_0} \times \Big[1 - x + \tfrac{2}{3}\delta \Big(4x - 3 - \big(\sqrt{1 - x^2_0} - 1\big) \Big) \Big]$$

$$\vec{P}_e(x,\theta) = P_{T_1}\,\hat{x} + P_{T_2}\,\hat{y} + P_L\,\hat{z} \; .$$