Past Experiments Exclude Light Majorana Neutrino States

(Lepton Photon 2017, August 7-12, Guangzhou; updated Mar 4, 2021)

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http://kirkmcd.princeton.edu/examples/majorana.pdf http://kirkmcd.princeton.edu/examples/majorana_170307.pptx

In 1937, Majorana gave a "symmetric theory of electrons and positrons," in which there might be no distinction between spin-1/2 particles and antiparticles. *E. Majorana, Nuovo Cimento **14**, 171 (1937)*

He noted that this theory doesn't apply to charged particles like electrons and positrons, but might apply to neutrinos.

However, in a gauge theory, interacting fermions and antifermions have different quantum numbers, and cannot form Majorana states (unless only electric-charge conjugation defines particles and antiparticles).

Charge:	Isotopic	Hyper	Electric
d_L	-1/2	+1/3	-1/3
e_L	-1/2	-1	-1
$(\nu_e)_L$	+1/2	-1	0
u_L	+1/2	-1/3	+2/3
d_R	0	+2/3	-1/3
e_R	0	-2	-1
$(\nu_e)_R$	0	0	0
u_R	0	+4/3	+2/3

(Weak isotopic charge) = (electric charge) − ½ (hypercharge)

In 1960, Glashow postulated a new symmetry, $SU(2)_T \otimes U(1)_Y$, based on weak isospin, T, and the conserved quantum numbers/charges T_3 and weak hypercharge, $Y_W = 2(Q - T_3)$. *S.L. Glashow, Nucl. Phys. **22**, 579 (1961)*

Antiparticles have the opposite quantum numbers of those in the table.

$$\bar{\nu}_R = C_W \nu_L^* \equiv \nu_L^{(C_W)}, \qquad \bar{\nu}_L = C_W \nu_R^* \equiv \nu_R^{(C_W)},$$
$$= C\nu_R^* = i\gamma^2 \nu_R^* \equiv \nu_R^{(C)}, \qquad = C\nu_L^* = i\gamma^2 \nu_L^* \equiv \nu_L^{(C)},$$

where $C_W = \gamma^5 C$ is the weak-hypercharge-conjugation operator.

Recall that in the $V-A$ *theory, and in the Glashow-Weinberg-Salam electroweak theory, only the neutrino states* ν_L *and* $\bar{\nu}_R$ *interact.*

The ν_R *and* $\bar{\nu}_L$ *are sterile neutrinos and could be Majorana states.* *B. Pontecorvo, Sov. J. Nucl. Phys. **26**, 984 (1968)*

Majorana Neutrino Chirality States?

Despite the incompatibility of Majorana states with Standard Model neutrinos of nonzero weak hypercharge, people consider two possibilities:

1. $\psi_L = \frac{\nu_L + \nu_L^{(C_W)}}{\sqrt{2}} = \frac{\nu_L + \bar{\nu}_R}{\sqrt{2}} = \psi_L^{(C_W)}, \qquad \psi_R = \frac{\nu_R + \nu_R^{(C_W)}}{\sqrt{2}} = \frac{\nu_R + \bar{\nu}_L}{\sqrt{2}} = \psi_R^{(C_W)},$ based on weak-hypercharge conjugation.

2. $\psi_L = \frac{\nu_L + \nu_L^{(C)}}{\sqrt{2}} = \frac{\nu_L + \bar{\nu}_L}{\sqrt{2}} = \psi_L^{(C)}, \qquad \psi_R = \frac{\nu_R + \nu_R^{(C)}}{\sqrt{2}} = \frac{\nu_R + \bar{\nu}_R}{\sqrt{2}} = \psi_R^{(C)},$ based on electric-charge conjugation.

Form 2 appears much more often in the literature than Form 1.

Confrontation of Form 1, $\psi_L = \frac{\nu_L + \bar{\nu}_R}{\sqrt{2}}$, with Experiment

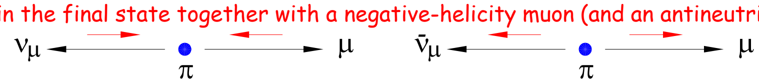
If the lefthanded-chirality neutrinos that participate in the V-A weak interaction had the form $\psi_L = \frac{\nu_L + \bar{\nu}_R}{\sqrt{2}}$, then many existing experiments exclude this.

A good place to start is the charged-pion decay, $\pi^+ \to \mu^+ \nu$, $\pi^- \to \mu^- \bar{\nu}$, where the muon is almost at rest in the pion frame, $KE_\mu \approx 4\ MeV$.

Here, a lefthanded chirality μ_L^- (or righthanded chirality μ_R^+) has essentially equal probability to be either positive or negative helicity.

The pion has spin zero, a lefthanded neutrino has almost pure negative helicity, and a righthanded antineutrino has almost pure positive helicity.

Hence, a neutrino can only appear in the final state together with a negative-helicity muon (and an antineutrino can appear only with a positive-helicity muon).



If Form 1 held, there would be essentially equal rates for the two decay modes $\pi^+ \to \mu_R^+ \nu$, $\pi^+ \to \mu_R^+ \bar{\nu}$, and also for the two modes $\pi^- \to \mu_L^- \bar{\nu}$, $\pi^- \to \mu_L^- \nu$.

Only the first of each pair is observed in experiment!

Confrontation of Form 2, $\psi_L = \frac{\nu_L + \bar{\nu}_L}{\sqrt{2}}$, with Experiment

Here, the supposed Majorana neutrino states are $\psi_L = \frac{\nu_L + (\nu_L)^C}{\sqrt{2}} = \frac{\nu_L + \bar{\nu}_L}{\sqrt{2}} = (\psi_L)^C$, $\qquad \psi_R = \frac{\nu_R + (\nu_R)^C}{\sqrt{2}} = \frac{\nu_R + \bar{\nu}_R}{\sqrt{2}} = (\psi_R)^C$.

Since the lefthanded antineutrino $\bar{\nu}_L$ does not participate in the V-A weak interaction, there is no physical difference in single-neutrino interactions of a Dirac lefthanded neutrino ν_L or the above Majorana state ψ_L, except for the normalization factor $1/\sqrt{2}$.

For Majorana states normalized with the factor $1/\sqrt{2}$, rates of single-neutrino interactions with a single internal W would be down by $\frac{1}{2}$ compared to those for Dirac neutrinos .

Can fix this by multiplying the electroweak coupling constant g by $\sqrt[4]{2}$.

But, then should also multiply g' by $\sqrt[4]{2}$ to keep the Weinberg angle $\theta_W = \tan^{-1} g'/g$ the same, which would increase the predicted decay width of the Z^0 by $\sqrt{2}$, in disagreement with experiment by $200\,\sigma$.

Existing data exclude both forms of light Majorana neutrino states! But, Majorana mass terms can exist.

The see-saw mechanism to explain the low mass of observed neutrinos (and neutrinoless double beta decay) requires Majorana mass terms not Majorana states. *H. Fritzsch, M. Gell-Mann and P. Minkowski, Phys. Lett. B **59**, 256 (1975)*