Comment on Recent Argument That Neutrinos Are Not Majorana Particles*

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Abstract

Existing data on neutrino-electron scattering do not imply that neutrinos are not Majorana particles. The question of whether neutrinos are of Majorana or of Dirac character remains completely open.

Recently, it has been argued\[1\] that existing data imply that neutrinos are not Majorana particles. The argument is as follows:

1. If some neutrino is a Majorana particle, then its vector neutral current (NC) vanishes.

2. The CHARM II experiment has found that, at least at the $2\sigma$ level, the product of the vector NC couplings of a $\nu_\mu$ and an electron is nonzero\[2\]

3. If, as suggested by the CHARM II experiment, the $\nu_\mu$ vector NC coupling is really nonzero, then the $\nu_\mu$ cannot be a Majorana neutrino. In that case, the other neutrinos are probably not Majorana particles either.

This argument is not correct. In particular, the assertion in step (2) is not right. The CHARM II experiment studied the NC reactions $\nu_\mu^- e^+ \rightarrow \nu_\mu^- e^+$. As explained below, experiments on NC interactions between a $\nu_\mu$ (and $\bar{\nu}_\mu$) and some target cannot determine the $\nu_\mu$ NC vector coupling.

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In lowest order, the NC reactions $\nu + A \to \nu + B$ are, of course, due to Z boson exchange. Suppose the neutrino $\nu$ couples to the Z boson through the general V and A neutral current

$$J_\alpha^\nu = \bar{\nu}\gamma_{\alpha}(g_V^\nu + g_A^\nu\gamma_5)\nu. \quad (1)$$

Here, the neutrino field $\nu$ may be either a Dirac field or a Majorana one. If it is a Majorana field, then, as Ref. 4 correctly notes, the vector neutral current $\bar{\nu}\gamma_{\alpha}\nu$ vanishes.

The amplitudes for $\nu + A \to \nu + B$ and $\bar{\nu} + A \to \bar{\nu} + B$ involve the neutrino neutral current $J_\alpha^\nu$ only through the matrix elements $\langle \nu_f|J_\alpha^\nu|\nu_i \rangle$ and $\langle \bar{\nu}_f|J_\alpha^\nu|\bar{\nu}_i \rangle$, respectively. Here, the subscripts $i$ and $f$ refer to the initial and final neutrino momenta and helicities. Now, in practice, the neutrinos and antineutrinos in our experimental beams are highly relativistic. In addition, the particles we call neutrinos are left-handedly polarized, while the ones we call antineutrinos are right-handedly polarized. These polarizations are, of course, observed facts, and do not depend on whether neutrinos are Dirac or Majorana particles. For example, the muons from $\pi^+ \to \mu^+\nu_\mu$ are observed to be left-handed, from which it follows that the neutrinos are as well. For neutrinos and antineutrinos with the observed polarizations, the matrix elements of the current $J_\alpha^\nu$ of Eq. (1) are readily found to be:

$$\langle \nu_f|J_\alpha^\nu|\nu_i \rangle = c^\nu u_{iL}\gamma_{\alpha} u_{fL}. \quad (2.1)$$

$$\langle \bar{\nu}_f|J_\alpha^\nu|\bar{\nu}_i \rangle = -c^\nu v_{iR}\gamma_{\alpha} v_{fR}. \quad (2.2)$$

Here, $u$ and $v$ are the usual Dirac spinors, and the subscript $L(R)$ tells us that the particle described is left-handed (right-handed). In the Majorana case, $\langle \bar{\nu}_f|J_\alpha^\nu|\bar{\nu}_i \rangle$ and $\langle \nu_f|J_\alpha^\nu|\nu_i \rangle$ in Eq. (2.2) are just the right-handed neutral particles produced, for example, in $\pi^- \nu$ decay. Finally, the constant $c^\nu$ is given by

$$c^\nu = \begin{cases} 
  g_V^\nu + g_A^\nu & ; \quad \nu \text{ is a Dirac neutrino} \\
  2g_V^\nu & ; \quad \nu \text{ is a Majorana neutrino}
\end{cases} \quad (3)$$

(We have omitted from $c^\nu$ an irrelevant overall constant.)

From Eqs. (2), we see that the only thing the reactions $\nu + A \to \nu + B$ can teach us about the neutral current of $\nu$ is the value of the constant $c^\nu$. For a given value of this constant, the NC matrix elements of Eqs. (2) are identical in the Majorana and Dirac cases. (The spinors $\nu$ in Eq. (2.2) don’t know whether the particles they are being used to describe are really “antiparticles” or not. These spinors are exactly the same quantities in either case.) Thus, the reactions $\nu + A \to \nu + B$ cannot tell us whether $\nu$ is a Majorana particle or a Dirac one.

From Eq. (3), we see that the relation between $c^\nu$ and the underlying NC coupling constants $g_V^\nu$ and $g_A^\nu$ does depend on whether $\nu$ is a Dirac neutrino or a Majorana one. However, since experiments on $\nu + A \to \nu + B$ measure only $c^\nu$, they cannot determine $g_V^\nu$ or $g_A^\nu$ separately. In particular, they cannot tell us that $g_V^\nu \neq 0$. It should also be noted that a theoretical model can contain a nonvanishing $g_V^\nu$ even though $\nu$ is a Majorana neutrino. This is true because in the Majorana case, the vector current $\bar{\nu}\gamma_{\alpha}\nu$ which multiplies $g_V^\nu$ in the neutral current $J_\alpha^\nu$ vanishes, so that $g_V^\nu$ does not contribute to any measurable quantity.

Indeed, in the Standard Model (SM), a neutrino $\nu$ couples to the Z through a left-handed current. In the Sakurai gamma-matrix conventions which we are using here throughout, this
means that in the SM, $g^ν_V = g^ν_A = 1/2$. This is true whether the mass terms added to the “minimal” SM to give neutrinos masses make $ν$ a Dirac particle or a Majorana one.

One might have wondered whether the measured value of $c''$ can tell us whether $ν$ is of Dirac or Majorana character if we are willing to assume the SM. Clearly, even if we do assume the SM, the value of $c''$ cannot distinguish between the Majorana and Dirac cases. Indeed, from Eq. (3), we see that the SM predicts that $c'' = 1$, regardless of whether $ν$ is a Dirac neutrino or a Majorana one.

The argument of Ref. [1] seems to have grown out of one of those misunderstandings which occur from time to time. The CHARM II paper to which Ref. [1] refers can be read as saying that (disregarding the errors) the experiment has found that $g^ν_ν g^ν_ν \neq 0$. However, this paper refers in turn to an earlier one [4] which rather clearly talks about determining only an NC neutrino coupling $g''$ with no $V$ or $A$ subscript. That is absolutely right; as we have seen, NC experiments do not determine the $V, A$ content of the neutrino neutral current.

References

1. R. Plaga, Max-Planck-Institut preprint, hep-ph/9610543.

2. Here, the author of Ref. [1] refers to P. Vilain et al. (CHARM II Collaboration), Phys. Lett. B335, 246 (1994).

3. For further discussion of neutrino NC interactions and the Majorana-Dirac distinction, please see B. Kayser and R. Shrock, Phys. Lett. 112B, 137 (1982), and B. Kayser, F. Gibrat-Debu and F. Perrier, The Physics of Massive Neutrinos (World Scientific, Singapore, 1989), Chap. 4.

4. P. Vilain et al. (CHARM II Collaboration), Phys. Lett. B320, 203 (1994).