Muon-number nonconservation in models with Majorana neutrinos

B. V. Martem'yanov
Institute of Theoretical and Experimental Physics

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The processes $\mu \rightarrow e\gamma$ and $e^+e^- \rightarrow \mu^+e^-$ in models with Majorana neutrinos of nonzero mass are examined, and their probabilities are calculated.

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The possible existence of a Majorana neutrino of nonzero mass has recently been discussed widely in the literature. Renormalizability requires that the Majorana neutrino acquire a mass spontaneously, as a result of a spontaneous breaking of *B-L* symmetry.[1,2] The experimental consequences of this hypothesis, in particular, the existence and properties of a massless pseudoscalar particle—the Majorana—were discussed in Refs. 1, 2, and (in more detail) 3.

In this letter we are reporting some calculations of the probabilities for the processes $\mu \rightarrow e\gamma$ and $e^+e^- \rightarrow \mu^+e^-$ based on the models of Refs. 1 and 2. As will be seen

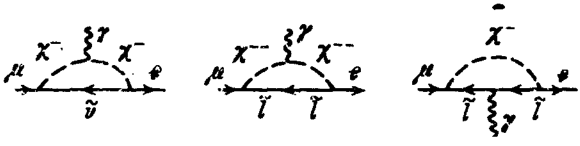

FIG. 1.

from the results, in certain cases the predictions of the models are close to the present experimental limitations, so that there is the hope of an experimental test in the near future.

In Gelmini and Roncadelli's model,[1] the left-hand Majorana mass of the neutrinos results from the vacuum expectation value $\langle \chi^0 \rangle$ of the neutral component of the triplet $(\chi^0, \chi^-, \chi^{--})$ of the Higgs fields of the weak group $SU(2)_L$. The $\mu \to e$ transition in this model is dominated by processes involving intermediate charged Higgs particles χ^- and χ^{--}. In the model of Mohapatra, Peccei, and Chikashige, the neutrino mass Lagrangian simultaneously contains Dirac and large right-hand Majorana terms. As a result, the mass spectrum of the diagonal neutrinos consists, in the case of three types of leptons, of three light and three superheavy states. In this situation it is interesting to examine the effect of the superheavy neutrinos on the processes under consideration here, $\mu \to e\gamma$ (Ref. 4) and $e^+e^- \to \mu^+e^-$.

We first consider the decay $\mu \to e\gamma$ in the model of Gelmini and Roncadelli, where the decay is described by the diagrams in Fig. 1. The amplitude $A(\mu \to e\gamma)$ calculated from these diagrams is

$$A(\mu \to e\gamma) = e\left(\frac{C}{12M^2_{\chi^-}} + \frac{C'}{6M^2_{\chi^{--}}}\right)\bar{u}_e \sigma_{\beta\alpha} k_\alpha m_\mu (1-\gamma_5) u_\mu A_\beta , \qquad (1)$$

where

$$C = \frac{i}{32\pi^2}(g_{\mu\mu}g^*_{\mu e} + g_{\mu e}g^*_{ee} + g_{\mu\tau}g^*_{\tau e}),$$

$$C' = \frac{i}{16\pi^2}(g_{\mu\mu}g^*_{\mu e} + g_{\mu e}g^*_{ee} + \frac{1}{2}g_{\mu\tau}g^*_{\tau e}),$$

the g's are the Yukawa coupling constants describing the coupling of the triplet χ with leptons, k_α is the photon momentum, and m_μ is the mass of the muon. To estimate the decay width, we adopt the following values for the constants g and the Higgs masses M_{χ^-} and $M_{\chi^{--}}$, found in Ref. 3 from data on 2β and $\mu \to 3e$ decays:

$$g \sim 10^{-3}, \quad M_{\chi^{--}} = \sqrt{2}M_{\chi^-} > 50\,\mathrm{GeV}. \qquad (2)$$

We then have $B(\mu \to e\gamma) < 10^{-12}$; this value is considerably larger than in the standard schemes,[5] but it is two orders of magnitude smaller than the experimental limit, $B(\mu \to e\gamma) < 1.9 \times 10^{-10}$ (Ref. 6).

The process $e^+e^- \to \mu^+e^-$, described by the diagram in Fig. 2, is also possible in the Born approximation in the model of Gelmini and Roncadelli. The cross section for this process for energies $\sqrt{s} \ll M_{\chi^{--}}$ is

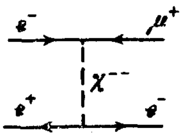

FIG. 2

$$\sigma = \frac{(g_{\mu e} g^*_{ee})^2 s}{192\pi M^4_{\chi^{--}}} \tag{3}$$

In the model of Mohapatra *et al.*, as we have already mentioned, the charged and neutral currents contain operators corresponding to superheavy neutrinos. The admixture of heavy neutrinos in these currents is generally small and proportional to $\sqrt{m_\nu/M_\nu}$, where m_ν and M_ν are the masses of the light and superheavy neutrinos, respectively.[2] In the processes under consideration here, however, this smallness is offset by the fact that under the conditions $m_\nu \ll M_W \ll M_\nu$ the GIM mechanism does not operate, and there is no suppression proportional to $m_\nu{}^2/M_W{}^2$ in the amplitudes $A(\mu \to e\gamma)$ and $A(e^+e^- \to \mu^+e^-)$. With $m_\nu \sim 1$ eV, $M_W \sim 100$ GeV, and $M_\nu \sim 10^6$ GeV there is thus an enhancement,

$$m_\nu/M_\nu \ : \ m_\nu^2/M_W^2 = 10^7$$

in comparison with the standard case of Dirac neutrinos.

A calculation of the amplitudes $A(\mu \to e\gamma)$ and $A(e^+e^- \to \mu^+e^-)$ for the $1S^0$ state of the e^+e^- pair yields

$$A(\mu \to e\gamma) = \frac{eG_F}{8\sqrt{2}\pi^2} U_{\mu\nu} U^+_{\nu e} \bar{u}_e \frac{\sigma_{\beta\alpha} k_\alpha}{2} m_\mu (1-\gamma_5) u_\mu A_\beta \ , \tag{4}$$

$$A(e^+e^- \to \mu^+e^-) = \frac{g^2 G_F}{8\sqrt{2}\pi^2} U_{\mu\nu} U^+_{\nu e} \frac{3}{8} \ln \frac{M_\nu^2}{M_W^2} \bar{e}\gamma_\mu (1+\gamma_5)\mu \bar{e}\gamma_\mu \gamma_5 e, \qquad \sqrt{s} \ll M_W \ , \tag{5}$$

where the index ν corresponds to superheavy neutrinos. As mentioned earlier, we have $U_{\mu\nu} U^+_{\nu e} \sim m_\nu/M_\nu$, so that the probabilities for the processes $\mu \to e\gamma$ and $e^+e^- \to \mu^+e^-$ under the condition $\sqrt{s} \ll M_W$ are numerically extremely small in comparison with the experimental limitations.

It can thus be seen from these results that the predictions of the Gelmini-Roncadelli model for $\mu \to e\gamma$ and $e^+e^- \to \mu^+e^-$ are relatively high, and it may be possible to test them in the near future.

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