Magnetic moment of a neutrino in a model with a flavor lepton symmetry

M. A. Stefanov
M. V. Lomonosov State University, Moscow

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A model for the generation of the magnetic moment of an electronic neutrino of order $10^{-10}\mu_B$, based on the flavor lepton SU(3) symmetry, is proposed. As a result, the processes involving a change in the aroma can be avoided. The experimental constraints on the constants of the model are examined.

To explain the relation between the number of sunspots and the solar neutrino flux, Voloshin *et al.*[1] assumed that neutrinos have an anomalously large magnetic moment:

$$\mu_{\nu_e} = (0.3-1)\times 10^{-10}\mu_B \quad \left(\mu_B = \frac{e}{2m_e} \ - \text{Bohr magneton}\right). \qquad (1)$$

The standard $SU(2)\times U(1)$ model of the electroweak interaction with a minimum scalar sector predicts a very small value[2] of μ_ν:

$$\mu_{\nu_e} = \frac{3eG_F}{8\sqrt{2}\pi^2}\, m_{\nu_e} = 3\times 10^{-19}\mu_B \times \frac{m_{\nu_e}}{1\ \text{eV}}\ . \qquad (2)$$

To explain the possible appearance of μ_ν of order (1), Fukugita and Yanagida[3] proposed a model in which the scalar sector is expanded as a result of addition of one charged particle η^- with an electric charge -1 and lepton number $+2$. The interaction of η^- with the leptons is described by

$$\sum_{ik} (g_{ik}\overline{\nu_L^{ci}}\, l_L^k + f_{ik}\overline{\nu_R^{ci}}\, l_R^k)\eta^+ + \text{H.c.}, \qquad (3)$$

where $i,k = 1,2,3$ (e, μ, τ) are the aroma indices.

Interaction (3), however, leads, in addition to the appearance of μ_ν, to the processes involving a change in the aroma ($\mu\to e\gamma$, $\tau\to e\gamma$, $\tau\to\nu_e e\nu_\mu$, etc.). To reconcile quantity (1) with the absence of decay $\mu\to e\gamma$ at the level $B\,(\mu\to e\gamma)\lesssim 10^{-10}$, we must assume that the constants in (3) differ markedly: $g_{13}\gtrsim 10^2 g_{23}$ (Ref. 3).

We propose a model in which the appearance of processes involving a change in the aroma can be avoided because of the flavor lepton SU(3) symmetry in the interaction with leptons of additional scalars η^i $(i = 1, 2, 3)$ which are introduced instead of a single scalar η^- as in the case of the model of Ref. 3:

$$\sum_{ikm} (g\overline{\nu_L^{ci}}\, l_L^k + f\overline{\nu_R^{ci}}\, l_R^k)\epsilon^{ikm}\eta^{+m} + \text{H.c.}, \qquad (4)$$

where $i,k,m = 1,2,3$ are the aroma indices. The magnetic moment of the neutrino in

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this case is

$$\mu_{\nu_i} = \sum_{k \neq i} e \frac{gf}{16\pi^2 M^2} m_k \left(\ln \frac{M^2}{m_k^2} - 1\right), \tag{5}$$

where M are the particle masses of the triplet η^i (for simplicity, it is assumed that $M_1 = M_2 = M_3 = M$), and m_k is the mass of the kth charged lepton. It thus follows that

$$\mu_{\nu_e} \approx \mu_{\nu_\mu} \approx e \frac{gf}{16\pi^2 M^2} m_\tau \left(\ln \frac{M^2}{m_\tau^2} - 1\right), \quad \mu_{\nu_\tau} \cong \frac{m_\mu}{m_\tau} \mu_{\nu_e}.$$

The magnetic moment (1) requires that

$$\frac{gf}{M^2} \approx (0{,}6 - 1{,}5) \times 10^{-6}\,\mathrm{GeV}^{-2} \approx (0{,}05 \pm 0{,}13)\, G_F, \tag{6}$$

if 40 GeV $\lesssim M \lesssim$ 1 TeV.

Let us consider the constraints imposed on the constants g and f. The contribution of interaction (4) to the g-factor of the kth charged lepton is $\delta(g_k - 2) = 2 \times (gf/16\pi^2 M^2) \times 2m_k^2/3$. Using $\delta(g_e - 2) \lesssim 10^{-10}$ and $\delta(g_\mu - 2) \lesssim 10^{-8}$, we obtain respectively $gf/M^2 \lesssim 5 \times 10^{-2}$ GeV^{-2} and $gf/M^2 \lesssim 10^{-4}$ GeV^{-2}: The constraints are very weak if we keep in mind the value required in (6).

Interaction (4) in the low-energy limit leads to an effective four-fermion interaction

$$\sum_{ikmn} \frac{1}{M^2} \overline{\nu^{ci}} (gP_L + fP_R) l^k \bar{l}^m (gP_R + fP_L) \nu^{cn} (\delta^{im}\delta^{kn} - \delta^{in}\delta^{km}), \tag{7}$$

where $P_L = \frac{1 + \gamma_5}{2}$ and $P_R = \frac{1 - \gamma_5}{2}$ are chiral projectors. For further discussion, we define $h^2 = \frac{1}{2}(g^2 + f^2)$ and $\epsilon = (g^2 - f^2/g^2 + f^2)$.

Let us consider the contribution of interaction (7) to the decay of a polarized muon. The interference term between the amplitude it generates and the ordinary Fermi amplitude is absent if the neutrino mass is ignored. The differential width of the polarized muon, normalized to the differential width of the unpolarized muon, can thus be written as

$$R(E, \cos\theta) = 1 + \frac{m_\mu - 4E}{3m_\mu - 4E} \frac{\Gamma + \Delta\Gamma \cdot \epsilon}{\Gamma + \Delta\Gamma} \cos\theta, \tag{8}$$

where E is the energy of the emitted electron, θ is the angle between the direction of the muon spin and the electron momentum, and $\Delta\Gamma = \frac{1}{8}(h^4/M^4) m_\mu^5/192\pi^3$ is the contribution to the total width $\Gamma = G_F^2(m_\mu^5/192\pi^3)$. Consequently, the asymmetry parameter is

$$\alpha \approx 1 - \frac{\Delta\Gamma}{\Gamma}(1-\epsilon), \qquad (9)$$

Stoker *et al.*[4] obtained a constraint on α by the muon-spin-rotation method: $\alpha > 0.9966$. Interaction (4) has no effect on the muon polarization in Ref. 4. Using (8) and (9), we then find the constraint

$$f\sqrt{g^2+f^2} < 0.23 M^2 G_F. \qquad (10)$$

This constraint, the strongest one, as can be seen in Fig. 1, is compatible with (6).

Interaction (7) also increases the muon width by $\Delta\Gamma$. This means that the "true" constant G_F is smaller than the measured constant in the muon decay. As a result, the theoretical estimates of the masses of W and Z (Refs. 5 and 6) should be increased: $\Delta m/m = \Delta G_F/2G_F = \Delta\Gamma/4\Gamma = 1/32[(h^2/M^2G_F)]^2$. This expression takes into account that interaction (4) has no effect on the other quantities (e, $\sin\theta_W$) appearing in the equations for m_W and m_Z. If it is assumed that the theoretical and experimental uncertainties of the masses of W and Z do not exceed 2% (Refs. 5 and 6), we find the constraint (see Fig. 1)

$$\sqrt{g^2+f^2} < 1.3\sqrt{M^2 G_F}. \qquad (11)$$

The model proposed by us is therefore consistent (see Fig. 1) with the experimental constraints considered here. We repeat that transitions involving a change in the aroma are absent in the model in all orders in g and f because of the flavor symmetry

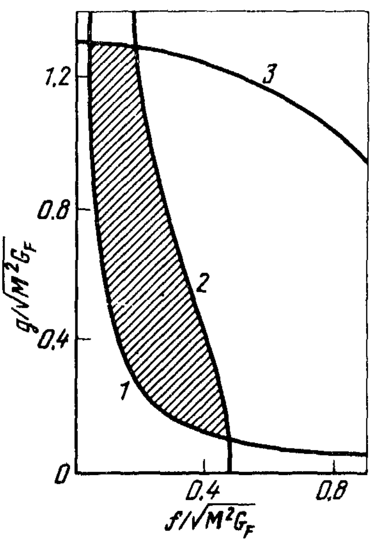

FIG. 1. Experimental constraints imposed on the constants g and f. Curve 1 limits the region where $\mu_{\nu_e} > 10^{-10}\,\mu_B$; curves 2 and 3 limit the regions of inequalities (10) and (11), respectively. Hatched region—possible values of the constants which are compatible with $\mu_{\nu_e} > 10^{-10}\,\mu_B$.

of the interaction (4). Despite the fact that this symmetry is broken in nature ($m_e \neq m_\mu \neq m_\tau$ and, possibly, $M_1 \neq M_2 \neq M_3$), there are still no transitions in any order in Δm if the mass matrix is diagonal in the aroma space.

Interaction (4) is considered here only in the lepton sector. Clearly, η^i cannot be linked with quarks. Consequently, $\sin\theta_W$, which is measured in experiments with neutral currents, and the muon polarization in the π-meson decay remain the same. This factor was taken into account in our model.

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