Right-handed neutrinos in scalar leptonic interactions

M. Barroso, M. E. Magalhães, and J. A. Martins Simões
Universidade Federal do Rio de Janeiro, Instituto de Física, Cidade Universitária, 21910 Rio de Janeiro, Brasil

N. Fleury and J. Leite Lopes*
Université Louis Pasteur and Centre de Recherches Nucleaires, Strasbourg, France
(Received 17 October 1985; revised manuscript received 14 March 1986)

We propose that right-handed neutrinos can behave as singlets. Their interaction properties could be revealed through scalar couplings. Signatures and branching ratios for this hypothesis are discussed. In particular we discuss angular asymmetries in $\nu_\mu e \to \nu_e \mu$ due to scalar exchange and Z^0 decay in two scalars.

If the ITEP result[1] on $m_{\nu_e} \neq 0$ is confirmed, right-handed neutrinos must find their place in elementary-particle physics. But even if this result is to be disproved we can ask if the asymmetry between right and left components for the fermionic fields is definitive. Along this line of reasoning, many models have been proposed which include right-handed currents.[2] The most simple approach consists of an extension of the standard electroweak model[3] with a right-handed leptonic doublet.[4] Then, anomaly cancellation implies right-handed charged currents in the quark sector. But, so far, no signal for such an effect is known.[5]

In this paper we propose the inclusion of right-handed neutrinos in a different context. Our first step is to postulate a rigorous symmetry between quark and leptons in the following way. As quarks behave as

$$\begin{pmatrix} u \\ d' \end{pmatrix}_L , \quad u_R, \; d'_R , \tag{1}$$

we postulate that for leptons we have also

$$L \equiv \begin{pmatrix} \nu \\ e \end{pmatrix}_L , \quad e_R, \; \nu_R , \tag{2}$$

and so on for the other families. A strong objection to this model is that as a right-handed neutrino singlet has $Y=0$, it does not interact with the known gauge-vector bosons and would never be detected.

In order to avoid this difficulty, our second step is to consider that this kind of assignment for neutrinos can be meaningful in scalar interactions with very interesting signatures involving ν_R. Scalar (and pseudoscalar) interactions are well known to be suppressed relative to $V-A$ terms but we can still have residual contributions.[6] Scalars appear quite naturally in the Higgs mechanism and in some supersymmetric models.[7]

In our view, the most natural scenario for scalars is in composite models. If the presently known fermions and bosons are to be composite we expect states with spin $\frac{3}{2}$ for fermions[8] and spin 0 for bosons.[9,10]

We consider in this paper scalar isodoublets. This hypothesis is theoretically very appealing since it is known that it maintains the ratio of effective low-energy charged to neutral interactions.[11] In the composite approach[9] we expect that the same coupling constants appear for all the families in the case of the scalar interactions since we have universality for the vector interactions.

For the weak-isospin doublet ϕ and the conjugate $\tilde{\phi}$ (see Ref. 12, for the notations and conventions employed here) the most general scalar-interaction Lagrangian for the assignment indicated in Eq. (2) is

$$\mathscr{L} = g_1(\bar{L}\phi e_R + \bar{e}_R \phi^\dagger L) + g_2(\bar{L}\tilde{\phi}\nu_R + \bar{\nu}_R \tilde{\phi}^\dagger L) . \tag{3}$$

In the composite approach[9] we have then three scalar states ϕ^+, ϕ^0, ϕ^- corresponding to the vectors W^+, Z^0, W^- and the possibility of one scalar singlet χ^0 corresponding to the photon. As the neutral vector boson and the photon have a large mass difference we expect the same behavior for $m_{\phi^0} - m_{\chi^0}$. Of course we cannot directly couple a scalar singlet to the assignment (2). But if a neutral mixing can occur (as in the neutral vector sector) this can be done. However this mixing must be of the type developed in the old Feldman-Matthews mechanism[13] and more recently applied by Sakurai[14] in the γ-Z^0 mixing. This mechanism allows the possibility of $m_{\phi^\pm} \neq m_{\phi^0}$ and $m_{\phi^0} \gg m_{\chi^0}$ but as we have one more mixing parameter, no bounds on the neutral masses are available. A similar scalar interaction was considered recently by Ng[10] with no ν_R terms, which implies different phenomenological consequences.

A stringent bound on charged-scalar coupling comes from ordinary muon decay. An analysis of residual scalar interactions[6] implies the bound

$$\frac{{g_1}^2}{{m_{\phi^+}}^2} < 10^{-5}\ \text{GeV}^{-2} . \tag{4}$$

Contributions to the gyromagnetic factor[15] do not improve this bound. Using the Mark J data on Bhabha scattering we have the bound[10]

$$\frac{{g_1}^2}{{m_{\phi^0}}^2} < 10^{-6}\ \text{GeV}^{-2} . \tag{5}$$

Perhaps the clearest signature for a scalar is in electron-positron annihilation. Neutral-scalar exchange occurs in $e^+e^- \to \mu^-\mu^+$ with cross sections given by many authors.[9,10]

Concerning branching ratios we estimate $B(\phi^0 \to \text{all } \bar{\nu}\nu)$ to be 0.14 since we have at present only three families. This high branching ratio can only be meaningful in a model with right-handed neutrinos. If no ν_R exists we can still look for other channels as $\mu^+\mu^-$. In this case $B(\phi^0 \to \mu^-\mu^+)=0.05$.

If $m_{Z^0} > m_{\phi^0}$ we can have decays as

$$Z^0 \to \chi^0 \phi^0 \quad (\chi^0 \to \text{jet},\ \phi^0 \to \nu\bar{\nu}) \tag{6}$$

which appear as events of the type jet + missing energy. This can be the case for the UA1 events $p\bar{p} \to jet + E_{\text{mis}}$. The hypothesis of a Z^0 decay in two scalars has been recently proposed by Rosner.[16] The general features such as the number of events and angular distributions are discussed in Ref. 16 but no detail of scalar decays are given. In our model, as we have $B(\phi^0 \to q\bar{q}) \simeq 5\%$ and $B(Z^0 \to \chi^0\phi^0)$ is not to be larger than 5% (Ref. 17), we have

$$B(Z^0 \to \text{one jet } + E_{\text{mis}}) \simeq 10002 \ .$$

This model is similar to the Glashow-Manohar model[18] with the important difference that we do not have a stable scalar if $m_{\chi^0} > m_{\nu/2}$. Some of the fermionic channels may be suppressed depending on the m_{χ^0} mass and the branching ratio $B(Z^0 \to \text{one jet } + E_{\text{mis}})$ could be higher than 1%.

There is recent experimental interest in testing the Glashow-Manohar model in $e^+e^- \to \text{one jet } + E_{\text{mis}}$ (Ref. 19). As our χ^0 can decay into $\nu\bar{\nu}$, the bound on scalar masses could be significantly higher [for $\Gamma(Z^0 \to \chi^0\phi^0)/\Gamma(Z^0 \to \mu^-\mu^+) \simeq 1$].

Scalar exchange also occurs in neutrino-lepton scattering. Some of these effects were discussed in Ref. 10. We point out that an important process which allows the separation between vector and scalar contributions is $\nu_\mu e^- \to \nu_e \mu^-$. As is well known, in the center-of-mass system the charged-lepton angular distribution is isotropic for vector exchange.

But if scalar exchange also happens then this isotropy is destroyed. If we consider the forward-backward asymmetry

$$A = \frac{\sigma(0 \to \pi/2) - \sigma(\pi/2 \to \pi)}{\sigma(0 \to \pi/2) + \sigma(\pi/2 \to \pi)} \ , \tag{7}$$

then only scalar exchange contributes.

TABLE I. Asymmetry in the reaction $\nu_\mu e^- \to \nu_e \mu^-$. With no scalar interactions the reaction is isotropic. With charged scalar exchange and no ν_R, the second line gives the upper bound for S-P interactions. The highest upper bound is for scalar exchange and ν_R production.

Model	Asymmetry
No scalars	0
Scalar + ν_L	-0.5%
Scalar + ν_R	-2.3%

In the limit $s \gg m_e^2, m_\mu^2$ but $s \ll m_\phi^2, m_W^2$ the angular distribution is

$$\frac{d\sigma}{d\Omega} = \frac{s}{(2\pi)^2} G_F^2 \times \left[1 + \left[\frac{\sqrt{2}(g_+^2 + g_-^2)}{4G_F m_\phi^2} \right]^2 \tfrac{1}{16}(1-\cos\theta)^2 \right] \ . \tag{8}$$

where $g_+ = g_1 + g_2$ and $g_- = g_1 - g_2$. The asymmetry is then

$$A = -\frac{1}{16} \left[\frac{\sqrt{2}(g_+^2 + g_-^2)}{4G_F m_\phi^2} \right]^2 \ . \tag{9}$$

With the upper bound given by Eq. (4), we show results in Table I where we consider $g_1 = g_2$ in the case of the right-handed neutrinos.

We have also a neutral-scalar contribution (besides the Z^0), to $\nu_\mu + e^- + e^- \to \nu_\mu + e^-$ which gives

$$\frac{d\sigma}{dy} = \frac{G_F^2 m_e E_\nu}{8\pi} \left[(g_V + g_A)^2 + (1-y)(g_V - g_A)^2 + \frac{g_1^2 g_2^2}{G_F^2 m_{\phi^0}^4} y^2 \right] , \tag{10}$$

where as usual (Ref. 12) $y = E_e/E_\nu$, $g_V = -1 + 4\sin^2\theta_W$, and $g_A = -1$. For antineutrinos we simply change $(g_V + g_A) \leftrightarrow (g_V - g_A)$ in Eq. (10).

Scalars can be produced in $e^-e^+ \to \chi^0\phi^0$ but with a small cross section. The reaction $e^+e^- \to \chi^0\gamma$ is also possible but it is suppressed at present available energies.

In conclusion, the hypothesis of scalar interactions, combined with ν_R singlets leads to very interesting experimental signatures as in $p\bar{p} \to Z^0 \to \chi^0\phi^0$, a high branching ratio for $(\chi^0, \phi^0) \to \bar{\nu}\nu$ and asymmetries in neutrino-lepton scattering. We stress the fact that our assignment for ν_R leads to no new vector currents.

*Centro Brasileiro de Pesquisas Físicas, Rua Dr. Xavier Sigaud, 150, 22290 Rio de Janeiro, Brasil.

[1]V. A. Lubimov, in *Proceedings of the 22nd International Conference on High Energy Physics, Leipzig 1984,* edited by A. Meyer and E. Wieczorek (Akademie der Wissenschaften der DDR, Zeuthen, East Germany, 1984), Vol. II, p. 108.

[2]R. N. Mohapatra, in *Quarks, Leptons, and Beyond,* Proceedings of the NATO Advanced Study Institute, Munich, 1983, edited by H. Fritzsch, R. D. Peccei, H. Saller, and F. Wagner (Plenum, New York, 1985).

[3]S. Weinberg, Rev. Mod. Phys. **52**, 515 (1982); A. Salam, *ibid.* **52**, 525 (1982); S. Glashow, *ibid.* **52**, 539 (1982).

[4]P. Cheng and L. Li Phys. Rev. Lett. **38**, 381 (1977).

[5]P. Langacker, in *Proceedings of the 22nd International Conference on High Energy Physics,* Ref. 1, Vol. II, p. 215.

[6]K. Mursula, M. Roos, and F. Scheck, Nucl. Phys. **B219**, 321 (1983).

[7]H. P. Nilles Phys. Rep. **110**, 1 (1984).

[8]J. Leite Lopes, D. Spehler, and J. A. Martins Simões, Phys. Lett. **94B**, 367 (1980); Phys. Rev. D **23**, 797 (1981); **25**, 1854 (1982).

[9]U. Baur, H. Fritzch, and H. Faissner, Phys. Lett. **135B**, 313 (1984); W. Hollik, F. Schrempp, and B. Schrempp, *ibid.* **140B**, 424 (1984).

[10]J. Ng, Phys. Rev. D **31**, 464 (1985).

[11]L. Maiani, École d'Été de Physique des Particules, Gif-sur-Yvette, 1979 (unpublished).

[12]J. Leite Lopes, *Gauge Field Theories* (Pergamon, New York, 1981).

[13]G. Feldman and P. T. Matthews, Phys. Rev. **132**, 823 (1963).

[14]J. J. Sakurai, in *Proceedings of the XVIIth Rencontre de Moriond, Les Arcs, France, 1982,* edited by J. Tran Thanh Van (Editions Frontières, Gif-sur-Yvette, 1982).

[15]F. Del Aguila, A. Mendez, and R. Pascual, Phys. Lett. **140B**, 431 (1984).

[16]J. L. Rosner, Phys. Lett. **154B**, 86 (1985).

[17]N. G. Deshpande, X. Tata, and D. A. Dicus, Phys. Rev. D **29**, 1527 (1984).

[18]S. L. Glashow and A. Manohar, Phys. Rev. Lett. **54**, 526 (1985).

[19]G. J. Feldman *et al.*, Phys. Rev. Lett. **54**, 2289 (1986).