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Суперсимметричные модели слабых и электромагнитных взаимодействий

Рассмотрены примеры реалистичных суперкалибровочных лептонных моделей, основанных на группах $SU(2) \times U(1)$ и $SU(2) \times SU(2) \times U(1)$. Эти модели не противоречат современным экспериментальным данным, естественным образом объясняют механизм Хиггса и предсказывают существование тяжелых лептонов. Первая модель предсказывает сохранение четности, а вторая нарушение четности в атомных процессах.

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Supersymmetric Models of Weak And Electromagnetic Interactions

Examples of realistic supergauge lepton models based on the groups $SU(2) \times U(1)$ and $SU(2) \times SU(2) \times U(1)$ are considered.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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I. Introduction

With the accumulation of experimental data, it becomes clear that conventional Weinberg-Salam[1] model of weak and electromagnetic interaction is not sufficient to describe the real leptonic world. Larger number of particles and probably larger gauge groups must be considered, $SU(2) \times SU(2) \times U(1)$, $SU(3) \times U(1)$ groups were proposed as possible candidates[2,3]. Contrary to the W.-S. model which was more or less uniquely fixed by demanding that no other leptons except for electron, muon and corresponding neutrinos were present, there exist great arbitrariness in the choice of larger unified models. For that reason additional information which may diminish this ambiguity is desirable. Such information may be provided by postulating some extra symmetry of interaction which is more restrictive than ordinary gauge invariance. It seems that supersymmetry is able to play such a role. Indeed, supersymmetry implies severe constraints on the possible gauge models. At the same time it provides a natural explanation for the Higgs mechanism[4]: in supersymmetric theory leptons are necessarily accompanied by scalar mesons triggering spontaneous symmetry breaking.

Heavy leptons are also predicted by supersymmetric unified models. More precisly: if one insists on the (V-A) form of $\mu - e$ interaction than heavy leptons must be present. Their masses are correlated with the masses of W-mesons.

Using the mechanism of spontaneous supersymmetry breaking proposed by one of the present authors /4,5/ it was shown possible to construct realistic supersymmetric models of weak and electromagnetic interactions/4,6,7/.

In this paper we consider two models, based on $SU(2)\times U(1)$ and $SU(2)\times SU(2)\times U(1)$ groups, not contradicting experimental data. Everywhere throughout this paper we assume lepton number conservation. This conservation is associated with the transformation

$$\Phi_\pm(x,\theta) \to e^{i\beta_\pm}\,\Phi_\pm(x, e^{-\alpha\gamma_5}\theta)$$

$$\Psi(x,\theta) \to \Psi(x, e^{-\alpha\gamma_5}\theta) \tag{1.1}$$

or in terms of the components

$$\begin{pmatrix} A_\pm \\ \Psi_\pm \\ F_\pm \end{pmatrix} \to e^{i\beta_\pm}\begin{pmatrix} A_\pm \\ e^{\pm i\alpha}\,\Psi_\pm \\ e^{\pm 2i\alpha}\,F_\pm \end{pmatrix}$$

$$\begin{pmatrix} A_\nu \\ \lambda \\ \mathcal{D} \end{pmatrix} \to \begin{pmatrix} A_\nu \\ e^{\alpha\gamma_5}\,\lambda \\ \mathcal{D} \end{pmatrix} \tag{1.2}$$

Here $\Phi_\pm$ are chiral matter superfields and Ψ is the gauge superfield. The existence of zero mass neutrinos will follow from these conservation laws. The invariance with

respect to the transformations (1.1) restricts also possible mass terms and the vacuum expectation values (VEV) of the scalar components of superfields.

2. A $SU(2)\times U(1)$ Model.

As a first example we shall consider $SU(2)\times U(1)$ model with the additional contact matter field interaction. The simplest model reproducing reasonable lepton spectrum includes three chiral isodublets: $\Phi^i_{k\pm} = \{A^i_{k\pm}, \Psi^i_{k\pm}, F^i_{k\pm}\}$, $i = 1, 2, 3$; k is the isotopic index: $k = 1, 2$ and two Hermitian singlests: Φ^j_S, $\Phi^j_{S+} = (\Phi^j_{S-})^+$, $\Phi^j_{S\pm} = \{A^j_{S\pm}, \Psi^j_{S\pm}, F^j_{S\pm}\}$, $j = 1, 2$.

The most general s.s. and gauge invariant Lagrangian /9/ looks as follows

$$\mathcal{L} = \{\Phi^{i+}_+ e^{g_1\Psi_1 + g\Psi^a\tau^a}\Phi^i_+ + \Phi^{i+}_- e^{-g_1\Psi_1 - g\Psi^a\tau^a}\Phi^i_-\}_{\mathcal{D}} +$$
$$+\{\Phi_{S+}\Phi_{S-}\}_{\mathcal{D}} - \{M_{ij}\Phi^{i+}_+\Phi^j_-\}_F - \tag{2.1}$$
$$-\{a^k_{ij}\Phi^k_{S+}\Phi^+_{-i}\Phi_{+j}\}_F + h.c. + \mathcal{L}_{YM} + \Delta\mathcal{L}.$$

Here $\Delta\mathcal{L}$ denotes a mass term generated by spontaneous supersymmetry breaking/10/. It looks as follows

$$\Delta\mathcal{L} = \xi^i_\pm A^{i+}_\pm A^i_\pm + \eta_{ij}(A^{i+}_+ A^j_- + A^{j+}_- A^i_+) + \xi^k_S A^k_{S+} A^k_{S-}. \tag{2.2}$$

We demand lepton charge conservation associated with the transformation

$$\Phi_{1,2+}(x,\theta) \to e^{-2i\alpha}\Phi_{1,2+}(x, e^{-\alpha\gamma_5}\theta)$$

$$\Phi_{3\pm}(x,\theta) \to \Phi_{3\pm}(x, e^{-\alpha\gamma_5}\theta)$$

$$\Phi_{1,2-}(x,\theta) \to \Phi_{1,2-}(x, e^{-\alpha\gamma_5}\theta)$$

$$\Phi^{1,2}_{S+}(x,\theta) \to \Phi^{1,2}_{S+}(x, e^{-\alpha\gamma_5}\theta) \ . \tag{2.3}$$

The lepton charges are specified as follows

$$\Psi^{1,2}_{\pm}(-1)\ ,\ \Psi^{3}_{\pm}(\pm 1)\ ,\ \Psi^{1,2}_{S+}(+1)\ .$$

We assume also separate electron and

$$\Phi_{1\pm} \to e^{i\beta}\Phi_{1\pm}\quad ,\quad \Phi^{1}_{S+} \to e^{-i\beta}\Phi_{S+}\ , \tag{2.4}$$

$$\Phi_{2\pm} \to e^{i\delta}\Phi_{2\pm}\quad ,\quad \Phi^{2}_{S+} \to e^{-i\delta}\Phi^{2}_{S+}\ . \tag{2.5}$$

These conservation laws lead to the following restrictions on the parameters M_{ij} , a^k_{ij} , η_{ij} . The only nonzero parameters are

$$M_{11} \equiv m_e\ ,\ M_{22} \equiv m_\mu\ ,\ \eta_{33} \equiv \eta\ ,\ a^1_{31} \equiv a_1\ ,\ a^2_{32} \equiv a_2\ . \tag{2.6}$$

One can easily verify that the effective potential generated by the Lagrangian (2.1) has a stable minimum at

$$\langle A^{1,2}\rangle_0 = \langle A_{S\pm}\rangle_0 = 0\ ,\ \langle A^3_{2\pm}\rangle_0 = \alpha_\pm(\eta,\varepsilon,g,g_1)\ . \tag{2.7}$$

Shifting the fields to zero expectation values we obtain the following mass spectrum:

Charged vector mesons $W_\pm$ acquire the masses

$$M^2_W = \frac{g^2}{2}(\alpha^2_+ + \alpha^2_-)\ . \tag{2.8}$$

Neutral vector mesons

$$Z_\mu = (g^2+g_1^2)^{-1/2}(g_1 A_\mu - g A^3_\mu)\ ,$$

$$M^2_Z = 2^{-1}(g^2+g_1^2)(\alpha^2_+ + \alpha^2_-) \tag{2.9}$$

$$a_\mu = (g^2+g_1^2)^{-1/2}(g A_\mu + g_1 A^3_\mu)\ ,\ M_a = 0\ .$$

Charged fermions

$$\Psi^1_1 = e\ ,\ m_e = M_{11}$$

$$\Psi^2_1 = \mu\ ,\ m_\mu = M_{22}$$

$$2^{-1/2}(\lambda_2 + i\lambda_1)_- + \Psi^3_{1+} = E_1\ ,\ M_{E_1} = g\alpha_+ \tag{2.10}$$

$$\Psi^3_{1-} + 2^{-1/2}(\lambda_2+i\lambda_1)_+ = E_2\ ,\ M_{E_2} = g\alpha_-\ .$$

Due to invariance with respect to the transformations (2.3), (2.4), (2.5) four massless fermions exist

$$\nu_e = \frac{(M_{E_1}a_1 g^{-1})\Psi^1_{2-} - m_e\Psi^1_{S-}}{(m_e^2 + M^2_{E_1}a_1^2 g^{-2})^{1/2}}\ ,\ \nu_\mu = \frac{(M_{E_2}a_2 g^{-1})\Psi^2_{2-} - m_\mu\Psi^2_{S-}}{(m_\mu^2 + M^2_{E_2}a_2^2 g^{-2})^{1/2}}$$

$$\nu_1 = i\,\frac{(g\lambda + g_1\lambda_3)_-}{(g^2+g_1^2)^{1/2}}\quad ,\quad \nu_2 = \frac{M_{E_2}\Psi^3_{2-} - M_{E_1}\Psi^{3c}_{2+}}{(M^2_{E_1}+M^2_{E_2})^{1/2}}\ . \tag{2.11}$$

There are also three heavy neutral leptons with the masses

$$M_{N_1} = (M_{E_1}^2 a_1^2 g^{-2} + m_e^2)^{1/2}$$
$$M_{N_2} = (M_{E_2}^2 a_2^2 g^{-2} + m_\mu^2)^{1/2} \tag{2.12}$$
$$M_{N_3} = (g^2 + g_1^2)^{1/2} g^{-1} (M_{E_1}^2 + M_{E_2}^2)^{1/2} .$$

The masses of the heavy charged leptons are related to the intermediate vector meson mass by the sum rule

$$M_W^2 = \frac{1}{2}(M_{E_1}^2 + M_{E_2}^2) . \tag{2.13}$$

Therefore if one of these leptons is identified with the recently discovered τ particle ($M_\tau \approx 1.9$ GeV) than the second one has a very large mass.

Masses of the neutral leptons depend on the ratios $a_i g^{-1}$. Experimental lower limit $M_{N_i} > M_K$ leads to $a_1 g^{-1} \gtrsim 0.25$.

Scalar meson mass spectrum contains considerable arbitrariness. By the appropriate choice of the parameters ξ, η the masses of all scalar mesons can be done greater than the W mass. Consequently all the processes including scalar mesons are suppressed.

The explicit form of interaction can be easily found from eq. (2.1). The electron and muon part looks as follows

$$\mathcal{L} = g g_1 (g^2 + g_1^2)^{-1/2} a_\mu (\bar{e}\gamma^\mu e + \bar{\mu}\gamma^\mu \mu) +$$

$$+ 2^{-1}(g^2+g_1^2)^{-1/2} Z_\mu \{ (g^2 - g_1^2)(\bar{e}\gamma^\mu e + \bar{\mu}\gamma^\mu \mu) +$$
$$+ (g^2 + g_1^2)(\bar{\nu}_{eL}\gamma^\mu \nu_{eL} + \bar{\nu}_{\mu L}\gamma^\mu \nu_{\mu L}) \} +$$
$$+ 2^{-1/2} g_1 W_-^\alpha \{ M_{E_1} a_1 g^{-1} (M_{E_1}^2 a_1^2 g^{-2} + m_e^2)^{-1/2} \bar{e}_L \gamma_\alpha \nu_{eL} +$$
$$+ M_{E_2} a_2 g^{-1} (M_{E_2}^2 a_2^2 g^{-2} + m_\mu^2)^{-1/2} \bar{\mu}_L \gamma_\alpha \nu_{\mu L} \} + h.c. + \cdots \tag{2.14}$$

... denotes terms containing heavy leptons and scalars. This terms include axial vector contribution to the neutral current.

$\mu - e$ universality is exact only in the limit $m_e = m_\mu = 0$. $\bar{\mu}_L \nu_{\mu L}$ and $\bar{e}_L \nu_{eL}$ coupling constants differ by the factor

$$\frac{M_{E_1} a_1 g^{-1} (M_{E_2}^2 a_2^2 g^{-2} + m_\mu^2)^{1/2}}{(M_{E_1}^2 a_1^2 g^{-2} + m_e^2)^{1/2} M_{E_2} a_2 g^{-1}} . \tag{2.15}$$

However due to the fact that $m_e \ll M_{E_1}$, $m_\mu \ll M_{E_2}$ the deviation from universality is negligible.

The electron neutral current is pure vector and therefore no parity violation in atomic physics is predicted. Parity violating effects are absent also in the neutrino-e, μ scattering. Experimental situation here is not quite clear, and we shall not discuss it. As to the neutrino-hadron scattering where such effects are certainly present, it can be easily explained in the framework of the present model. Up to now we consider only leptonic sector. Quark weak interaction may be easily included. The peculiar feature of supersymmetry models is the absence of natural quark-lepton symmetry. Indeed leptons are constructed partially from chiral superfields Ψ_i and partially from gauge superfields λ_i. If the quarks are not mixed with the leptons than they must be described by only chiral superfields and vacuum expectation values of these superfields must be zero. (Otherwise the mass term would arise which mixes quarks and leptons). Therefore quark sector is completely independent on the lepton sector. Practically any quark model may be easily written in a supersymmetric form. In particular one can choose the quark neutral currents having axial part as well. Supersymmetry gives no essential new predictions for the quark weak interactions, apart from the existence of scalar particles accompanying quarks. For that reason we shall not discuss in this paper quark weak interactions.

3. $SU(2)\times SU(2)\times U(1)$ Model.

Now we will consider $SU(2)\times SU(2)\times U(1)$ model with doublets and quartets, but will assume that apart from minimal gauge coupling additional direct matter field interaction takes place. Matter fields are described by two quartets $\Phi_{ij\pm} = \{A_{ij\pm}, \Psi_{ij\pm}, F_{ij\pm}\}$ and six doublets

$$\Phi^{\alpha}_{i\pm} = \{A^{\alpha}_{i\pm}, \Psi^{\alpha}_{i\pm}, F^{\alpha}_{i\pm}\},\ \alpha = 1,2,3$$

$\Phi^{\alpha}_{+(-)}$ are doublets with respect to $SU(2)_1\ (SU(2)_2)$ and singlests with respect to $SU(2)_2\ (SU(2)_1)$.

The most general gauge invariant and supersymmetric Lagrangian for these fields looks as follows:

$$\mathcal{L} = Tr\{\Phi_+^+ e^{g_1\Psi_1}\Phi_+ e^{-g_2\Psi_2} + \Phi_-^+ e^{-g_1\Psi_1}\Phi_- e^{g_2\Psi_2}\}_{\mathcal{D}} +$$
$$+ Tr\{\Phi_+^{\alpha+} e^{g_1\Psi_1 + f\Psi}\Phi_+^{\alpha} + \Phi_-^{\alpha+} e^{g_2\Psi_2 - f\Psi}\Phi_-^{\alpha}\}_{\mathcal{D}} -$$
$$-\{h_{\alpha-}\Phi_+^{\alpha+}\Phi_-\Phi_-^{\alpha}\}_F + h.c. - m\{\Phi_+^+\Phi_- + \Phi_-^+\Phi_+\}_F + \quad (3.1)$$
$$+ \mathcal{L}_{YM} + \Delta\mathcal{L},$$

where $\Delta\mathcal{L}$ denotes a mass term for scalar fields generated by spontaneous supersymmetry breaking.

We postulate lepton number conservation associated with the transformation

$$\begin{aligned}
&\Phi^{\alpha}_-(x,\theta) \to e^{2ia}\Phi^{\alpha}_-(x, e^{-a\gamma_5}\theta)\\
&\Phi^{\alpha}_+(x,\theta) \to \Phi^{\alpha}_+(x, e^{-a\gamma_5}\theta),\ \alpha = 1,2,3\\
&\Phi_{\pm}(x,\theta) \to \Phi_{\pm}(x, e^{-a\gamma_5}\theta) \qquad (3.2)\\
&\Psi_{1,2}(x,\theta) \to \Psi_{1,2}(x, e^{-a\gamma_5}\theta)\\
&\Psi(x,\theta) \to \Psi(x, e^{-a\gamma_5}\theta)
\end{aligned}$$

and also separate conservation of doublet leptonic charges (electron, muon, etc.). The later is associated with the transformations

$$\Phi^{\alpha}_{\pm} \to e^{i\beta_\alpha}\Phi^{\alpha}_{\pm}\ , \quad \alpha = 1,2\ . \tag{3.3}$$

Invariance with respect to these transformations leads to equations $m = 0$,

$$\Delta\mathcal{L} = -\xi^{\alpha}_{+} A^{\alpha +}_{+} A^{\alpha}_{+} - \xi^{\alpha}_{-} A^{\alpha +}_{-} A^{\alpha}_{-} - Tr\{\eta(A^{+}_{+}A_{-} + A^{+}_{-}A_{+}) + \\ + \eta_{+} A^{+}_{+}A_{+} + \eta_{-} A^{+}_{-} A_{-}\}\ . \tag{3.4}$$

It can be shown that choosing appropriately symmetry breaking parameters we can obtain a stable extrenum at the following points

$$\langle A_{ij\pm}\rangle = \begin{pmatrix} \alpha_\pm & 0 \\ 0 & 0 \end{pmatrix}\ , \quad \langle A^{\alpha}_{\pm}\rangle = 0\ , \quad \alpha = 1,2$$

$$\langle A^{3}_{+}\rangle = \begin{pmatrix} 0 \\ \gamma \end{pmatrix}\ , \quad \langle A^{3}_{-}\rangle = 0\ . \tag{3.5}$$

Shifting the fields to zero expectation values one obtains the following mass spectrum charged vector mesons:

$$W_{1\pm} = 2^{-1/2}(V^{1}_{1\mu} \mp iV^{2}_{1\mu})\ , \quad M^{2}_{1} = \frac{g_1^2}{2}(\alpha_+^2 + \alpha_-^2 + \gamma^2) \\ W_{2\pm} = 2^{-1/2}(V^{1}_{2\mu} \mp iV^{2}_{2\mu})\ , \quad M^{2}_{2} = \frac{g_2^2}{2}(\alpha_+^2 + \alpha_-^2)\ . \tag{3.6}$$

Neutral vector mesons and photon

$$Z_{1\mu} = z_1(a_1 V^{3}_{1\mu} + V^{3}_{2\mu} + b_1 \mathcal{U}_\mu)$$

$$Z_{2\mu} = z_2(a_2 V^{3}_{1\mu} + V^{3}_{2\mu} + b_2 \mathcal{U}_\mu)$$

$$A_\mu = \frac{1}{(f^2 g_1^2 + f^2 g_2^2 + g_1^2 g_2^2)^{1/2}}(f g_2 V^{3}_{1\mu} - f g_1 V^{3}_{2\mu} + g_1 g_2 \mathcal{U}_\mu)$$

$$M^{2}_{Z_1(Z_2)} = \frac{\alpha^2(g_1^2+g_2^2) + \gamma^2(f^2+g_1^2)}{4} \mp \\ \mp \frac{1}{4}\{[\alpha^2(g_1^2+g_2^2) + \gamma^2(f^2+g_1^2)]^2 - 4\alpha^2\gamma^2(f^2 g_1^2 + f^2 g_2^2 + g_1^2 g_2^2)\}^{1/2}\ , \tag{3.7}$$

where

$$z_i = (1 + a_i^2 + b_i^2)^{-1/2}\ , \quad \alpha^2 = \alpha_+^2 + \alpha_-^2$$

$$a_i = \frac{2M^2_{Z_i} - g_2^2\alpha^2}{g_1 g_2 \alpha^2}\ , \quad b_i = \frac{(2M^2_{Z_i} - g_2^2\alpha^2) f\gamma^2}{g_2\alpha^2(f^2\gamma^2 - 2M_i^2)}\ .$$

Charged fermions

$$\begin{aligned} &E_{1+} = \chi_{1+}, \quad E_{1-} = \Psi^{c}_{21+}, && m_1 = |g_1\alpha_+| \\ &E_{2+} = \Psi_{12+}, \quad E_{2-} = \chi_{2-}, && m_2 = |g_2\alpha_+| \\ &E_{3+} = \chi_{2+}, \quad E_{3-} = \Psi_{12-}, && m_3 = |g_2\alpha_-| \\ &E_{4+} = (\alpha_-\Psi^{c}_{21-} - \gamma\Psi^{3}_{1+})(\alpha_-^2+\gamma^2)^{-1/2}, \quad E_{4-} = \chi_{1-}, && m_4 = g_1(\alpha_-^2+\gamma^2)^{1/2} \end{aligned} \tag{3.8}$$

$$
\left.\begin{aligned}
E_{5+} &= (\gamma\psi^{c}_{21-} + \alpha_-\psi^{3}_{1+})(\alpha_-^2+\gamma^2)^{-1/2} \\
E_{5-} &= \psi^{3}_{1-}
\end{aligned}\right\}, \quad m_5 = h_3(\alpha_-^2+\gamma^2)^{-1/2}
$$

$$
\left.\begin{aligned}
e_- &= \psi^{1}_{1-} \\
e_+ &= \psi^{1}_{1+}
\end{aligned}\right\}, \ m_e = |h_1\alpha_-|, \quad
\left.\begin{aligned}
\mu_- &= \psi^{2}_{1-} \\
\mu_+ &= \psi^{2}_{1+}
\end{aligned}\right\}, \ m_\mu = |h_2\alpha_-| \tag{3.9}
$$

$$
\chi_1 = 2^{1/2}(\lambda_2 - i\lambda_1), \quad \chi_2 = 2^{1/2}(\lambda_5 - i\lambda_4).
$$

Neutral massive fermions N_i

There are three neutral massive fermions. The masses of two of them are related to the masses of neutral vector mesons.

$$
\begin{aligned}
M^2_{N_1} &= M^2_{Z_2} \\
M^2_{N_2} &= M^2_{Z_1}
\end{aligned} \tag{3.10}
$$

$$
\left.\begin{aligned}
N_{3-} &= \psi^{1}_{2-} \\
N_{3+} &= \psi^{c}_{22-}
\end{aligned}\right\}, \quad M_{N_3} = |h_3\gamma|
$$

Jf $|\gamma| \gg |\alpha_-|$

$$
M^2_{N_1} \approx \gamma^2(f^2+g_1^2)/2, \quad M_{N_3} \approx m_5
$$

$$
M^2_{N_2} \approx (\alpha_+^2+\alpha_-^2)(f^2g_1^2 + f^2g_2^2 + g_1^2g_2^2)/2(f^2+g_1^2).
$$

Neutral massless fermions

$$
\nu_{0L} \equiv i(f^2g_1^2 + f^2g_2^2 + g_1^2g_2^2)^{-1/2}(fg_2\lambda^3_{1-} - fg_1\lambda^3_{2-} + g_1g_2\lambda_-)
$$

$$
\nu_{1L} \equiv (\alpha_-^2+\alpha_+^2)^{-1/2}(\alpha_-\psi^{c}_{11+} + \alpha_+\psi_{11-}) \tag{3.11}
$$

$$
\nu_{2L} \equiv -\psi^{c}_{22+}
$$

$$
\nu_{eL} = \psi^{1}_{2-}, \quad \nu_{eR} = \psi^{1}_{2+}
$$

$$
\nu_{\mu L} = \psi^{2}_{2-}, \quad \nu_{\mu R} = \psi^{2}_{2+}.
$$

We assume that ordinary electron and muon weak interaction is mediated by W_2 meson, associated with the $SU(2)_2$ group, and that the other intermediate meson W_1, is much heavier. That means $|\gamma| \gg |\alpha_+|, |\alpha_-|$. Than the charged W_{2-} current has a form

$$
\begin{aligned}
j_{ch} = g_2 2^{-1/2}\{ &\bar\nu_{eL}\gamma^\mu e_L + \bar\nu_{\mu L}\gamma^\mu\mu_L + \bar\nu_{2L}\gamma^\mu E_{1L} + \\
&+ 2^{1/2} f g_1 (f^2g_1^2 + f^2g_2^2 + g_1^2g_2^2)^{-1/2}\bar\nu_{0L}\gamma^\mu E_{2L} + \alpha_+(\alpha_+^2+\alpha_-^2)^{-1/2}\bar\nu_{1L}\gamma^\mu E_{3L} \\
&+ \alpha_-(\alpha_+^2+\alpha_-^2)^{-1/2}\overline{\nu^c_{1L}}\gamma^\mu E_{2R} - 2^{1/2} f g_1 (f^2g_1^2 + f^2g_2^2 + g_1^2g_2^2)^{-1/2} \cdot \\
&\overline{\nu^c_{0L}}\gamma^\mu E_{3R} + \dots
\end{aligned} \tag{3.12}
$$

... denotes terms containing heavy leptons (charged and neutral).

In the same appproximation neutral current interacting with the lighter neutral meson Z_1 looks as follows

$$
\begin{aligned}
j_{Z_1} = \frac{(f^2+g_1^2)^{1/2}}{2(f^2g_1^2 + f^2g_2^2 + g_1^2g_2^2)^{1/2}} \Big\{ &\frac{f^2g_1^2 + f^2g_2^2 + g_1^2g_2^2}{f^2+g_1^2}(\bar\nu_{eL}\gamma^\mu\nu_{eL} + \bar\nu_{\mu L}\gamma^\mu\nu_{\mu L}) \\
&+ \frac{\alpha_+^2-\alpha_-^2}{\alpha_+^2+\alpha_-^2}\bar\nu_{1L}\gamma^\mu\nu_{1L} + \bar\nu_{2L}\gamma^\mu\nu_{2L}) + \frac{2f^2g_1^2}{f^2+g_1^2}(\bar e_R\gamma^\mu e_R + \bar\mu_R\gamma^\mu\mu_R + \\
&+ \bar E_{1R}\gamma^\mu E_{1R} + \bar E_4\gamma^\mu E_4) + \frac{f^2(g_1^2-g_2^2) - g_1^2g_2^2}{f^2+g_1^2}(\bar e_L\gamma^\mu e_L + \bar\mu_L\gamma^\mu\mu_L \\
&+ \bar E_{1L}\gamma^\mu E_{1L} + \bar E_{2R}\gamma^\mu E_{2R} + \bar E_{3L}\gamma^\mu E_{3L}) + g_2^2(\bar E_{2L}\gamma^\mu E_{2L} + \bar E_{3R}\gamma^\mu E_{3R})\Big\}.
\end{aligned} \tag{3.13}
$$

Electromagnetic coupling constant is

$$e = \frac{f g_1 g_2}{(f^2 g_1^2 + f^2 g_2^2 + g_1^2 g_2^2)^{1/2}} \quad . \tag{3.14}$$

Electron and muon charged currents interaction is exactly universal and has a standard form. As to the heavy leptons one of them E_1 also has universal $V-A$ interaction, but others interact differently. In particular right handed currents are present. Identification of one of these leptons with τ -particle is somewhat arbitrary because at present we know little about it's interaction. One of the possibilities is $\tau \equiv E_1$.

Electron and muon neutral currents contain axial part, and therefore parity violation in atomic physics is predicted. So if the absence of parity violation in atoms will be confirmed this model should be considered as unsatisfactory. As in the previous model quark sector may be introduced quite independently and will not be discussed here.

Discussion

Examples considered in the previous sections show that unified lepton models may be formulated in a supersymmetric way. Supersymmetry implies severe restrictions on the possible models and leads in particular to the existence of sum rules between the masses of leptons and W -mesons. However, we found impossible to describe the existing experimental situation in the framework of minimal supersymmetric gauge coupling. Perhaps more complicated gauge

groups should be considered. Minimal models certainly are more appealing from the aesthetical point of view and are more predictive. If one abandons the requirement of minimality and considers direct matter field interaction of the type Φ^3, then "standard" gauge groups, i.e., $SU(2) \times U(1)$, $SU(2) \times SU(2) \times U(1)$ are acceptable. In comparison with ordinary gauge models supersymmetric lepton models give additional predictions concerning mass spectrum and the form of interaction.

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