$SU(3)_C \times SU(3)_L \times U(1) \times U'(1)$ MODEL OF ELECTROWEAK INTERACTION AND ELECTRIC CHARGE QUANTIZATION

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The possibility of construction of the electroweak model based on spontaneously broken gauge $SU(3)_C \times SU(3)_L \times U(1) \times U'(1)$ group symmetry has been investigated. In case of arbitrary values of hypercharges of Higgs and fermion fields, expressions for gauge bosons masses, eigenstates of neutral fields, and expressions for the interactions among the charged vector fields with leptons and quarks are obtained. The expressions for charges of leptons and the quarks, testifying to the natural solving of the electric charge quantization problems in the considering model are obtained. Influence of Higgs fields on particles charges "formation" and on electric charge quantization are shown.

1. Introduction

The $SU(3)_C \times SU(2)_L \times U(1)_Y$ Standard Model (SM) [1] of the strong and electroweak interactions, with the $SU(2)_L \times U(1)_Q$ symmetry spontaneously broken down to the $U(1)_Q$ of electromagnetism, is an excellent description of the interactions of elementary particles down to distances in the order of $\sim 10^{-16}$cm.

Though the Standard Model is a good phenomenological theory and coincides very well with all experimental results [2], it leaves several unanswered questions which suggest that SM should be an effective model at low energies, originated from a more fundamental theory. Some of the unexplained aspects in SM are: the existence of three families [3, 4], the mass hierarchy problem [3, 4], the quantization of the electric charge, the large number of free parameters to fit the model, the absence of an explanation for the matter anti-matter asymmetry, the fact that the SM says nothing about the stability of the proton, gravity cannot be incorporated as a gauge theory it cannot account on the neutrino deficit problem etc.

A very common alternative to solve some of these problems consists of enlarging the group of gauge symmetry, where the larger group embeds properly the SM. For instance, the $SU(5)$ grand unification model [5] can unify the interactions and predicts the electric charge quantization, while the models based on E_6 group can also unify the interactions and might explain the masses of the neutrinos [6], and etc. [7]. Supersymmetric and superstring theories give the elegant solution of the hierarchy problem. Possibilities to solve the problem of electric charge quantization in the framework of SM are considered in [8]. A very interesting alternative to explain the origin of generations comes from the cancellation of chiral anomalies [9]. In particular, the models with gauge group $G_{331}= SU(3)_C \times SU(3)_L \times U(1)_X$, also called 3-3-1 models [10-13], arise as a possible solution to this puzzle, since some of such models require the three generations in order to cancel chiral anomalies completely. An additional motivation to study this kind of models comes from the fact that in these models there are some progress in the solving such of problems as lepton charge violation [10,14,15], the families problem [13,16,17], neutrino mass [18], electric charge quantization [19], P - parity violation in nuclear transitions [20].

In [21] it has been shown, that gauge group $E_8 \times E_8$ or $SO(32)$ is free from anomalies, and comprises all type of interactions, including gravitation. Further the group E_8 breakdowns to E_6 with $N=1$ local supersymmetry. In the low energy limit the group E_6 contains at least one additional $U(1)$ factor [22]. Hence, investigation of the electroweak interaction models with the additional $U(1)$ group symmetry represents interest.

Note, that the possibilities of construction of electroweak interaction models (both usual, and supersymmetric) based on $SU(2)_L \times U(1) \times U'(1)$ group symmetry have been considered in [23-31]. In this paper the possibility of construction of the electroweak model based on spontaneously broken gauge $SU(3)_C \times SU(3)_L \times U(1) \times U'(1)$ group symmetry has been investigated (3-3-1-1 – model). Taken into account the parity invariance of electromagnetic interaction, the expressions for charges of leptons and the quarks, testifying to the natural solving of the electric charge quantization problems in the considering model are obtained. Influence of Higgs fields to the particles charges "formation" and to the electric charge quantization are investigated.

2. Model structure

The electric charge is defined in general as a linear combination of the diagonal generators of $SU(3)_C \times SU(3)_L \times U(1) \times U'(1)$ group

$$\hat{Q} = \alpha \hat{T}_3 + \beta \hat{T}_8 + X\hat{I} + X'\hat{I} \ , \qquad (1)$$

with $T_3 = \frac{1}{2} diag(1,-1,0)$, $T_8 = \frac{1}{2\sqrt{3}} diag(1,1,-2)$ where the normalization chosen is $Tr\left(T_\alpha T_\beta\right) = \frac{1}{2}\delta_{\alpha\beta}$, $I=diag(1,1,1)$ is the identity matrix. The value of the α and β parameter determines the fermion assignment and it is customary to use this number to classify the different models (see, for example [32]).

The hypercharges of fermions as well as the Higgs fields are defined as

$$\hat{Y} = \beta \hat{T}_8 + X\hat{I}_3 + X'\hat{I}_3 \, . \qquad (2)$$

Some part this hypercharge (X) causes interaction with Maxwell field B_μ and other part (X') - with the another Maxwell field C_μ .

Lagrangian describing interacting Young – Mills fields $W_{a\mu}$, Maxwell fields B_μ, C_μ and Higgs fields look likes

$$L = L_{YM} + V, \tag{3}$$

where V- the part of lagrangian , responsible for the Higgs fields.

Let's consider the case when symmetry is broken by three fields

$$\chi = \begin{pmatrix} \chi'^{0} \\ \chi^{-} \\ \chi^{0} \end{pmatrix} \sim \left(1,3,X_\chi,X'_\chi\right),\ \rho = \begin{pmatrix} \rho^{+} \\ \rho^{0} \\ \rho'^{+} \end{pmatrix} \sim (1,3,X_\rho,X'_\rho),\ \eta = \begin{pmatrix} \eta^{0} \\ \eta^{-} \\ \eta'^{0} \end{pmatrix} \sim (1,3,X_\eta,X'_\eta). \tag{4}$$

In this case

$$V(\chi,\eta,\rho) = V_0 + V_{kin},$$

Where

$$V_{kin} = (D_\mu\chi)^+(D_\mu\chi) + (D_\mu\eta)^+(D_\mu\eta) + (D_\mu\rho)^+(D_\mu\rho). \tag{5}$$

The covariant derivative of the triplet is given by

$$D_\mu = \partial_\mu - igT_aW_{a\mu} - ig'T_9XB_\mu - ig''T_9X'C_\mu, \tag{6}$$

where T_a $(a=1,...,8)$ are the $SU(3)_L$ generators, and $T_9 = \frac{1}{\sqrt{6}}diag\left(1,1,1,1\right)$ are defined such that $Tr\left(T_aT_b\right) = \frac{1}{2}\delta_{ab}$, $(a,b = 1,2,...,9)$; g, g' and g'' – coupling constants.

Note, that similar structure of Higgs fields in the frameworks of $SU(3)_C \times SU(3)_L \times U(1)$ models have been considered in [33], where

$$\begin{aligned} V_0 = {} & \mu_1^2\eta^+\eta + \mu_2^2\rho^+\rho + \mu_3^2\chi^+\chi + \lambda_1(\eta^+\eta)^2 + \lambda_2(\rho^+\rho)^2 + \\ & + \lambda_3(\chi^+\chi)^2 + (\eta^+\eta)[\lambda_4(\rho^+\rho) + \lambda_5(\chi^+\chi)] + \lambda_6(\rho^+\rho)(\eta^+\eta) + \\ & + \lambda_7(\rho^+\eta)(\eta^+\rho) + \lambda_8(\chi^+\eta)(\eta^+\chi) + \lambda_9(\rho^+\chi)(\chi^+\rho) + \lambda_{10}(\chi^+\eta + \eta^+\chi)^2, \end{aligned} \tag{7}$$

where μ_i – and λ_i – coupling constants.

In this work, we choose the scalars to break the symmetry following the pattern,

$$\begin{gathered} SU(3)_C \times SU(3)_L \times U(1) \times U'(1) \\ \downarrow \\ SU(3)_C \times SU(2)_L \times U(1) \times U'(1) \\ \downarrow \\ SU(3)_C \times U(1) \times U'(1) \end{gathered} \tag{8}$$

and give, at the same time, masses to the fermion fields in the model. Then the minimally required scalars are:

$$<\chi> = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ 0 \\ V \end{pmatrix}, <\rho> = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ \upsilon \\ 0 \end{pmatrix}, <\eta> = \frac{1}{\sqrt{2}}\begin{pmatrix} u \\ 0 \\ 0 \end{pmatrix}, \tag{9}$$

here the VEV V is responsible for the first breakdown while υ and u are responsible for the second breakdown. So χ and η have the same quantum numbers but they get VEVs at different mass scales. Then the scalar χ breaks $SU(3)_C \times SU(3)_L \times U(1) \times U'(1)$ to $SU(3)_C \times SU(2)_L \times U(1) \times U'(1)$ and gives large masses to the new fermions as well as non-SM gauge bosons. The remaining scalars implement $SU(3)_C \times U(1) \times U'(1)$ breaking and give the realistic masses to the known fermions and bosons. To keep consistency with the effective theory, the VEVs in the model satisfy the constraint: $V >> \upsilon >> u$. This is also true to the present version. This issue has been studied in a number of papers [11], so we will not discuss it further.

For the lepton and quark fields we choose the following representations (we will consider one family of leptons and quarks without mixing):

$$\begin{gathered} \psi_{lL} = \begin{pmatrix} \nu \\ e \\ N \end{pmatrix}_L \sim (1,3,X,X'), \psi_{eR} = e_R \sim (1,1,X,X'), \psi_{NR} = N_R \sim (1,1,X,X'), \\ \psi_{QL} = \begin{pmatrix} u \\ d \\ U \end{pmatrix}_L \sim (3,3,X,X'), \psi_{uR} = u_R \sim (1,1,X,X'), \\ \psi_{dR} = d_R \sim (3,1,X,X'), \psi_{UR} = U_R \sim (3,1,X,X'). \end{gathered} \tag{10}$$

Multiplet structure and hypercharges of fermions and Higgs isomultiplets of considered model are listed in Table 1.

3. Masses of gauge bosons

The gauge bosons of this model form an octet $W_{a\mu}$ associated with $SU(3)_L$, an octet $G_{a\mu}$ (gluons) with $SU(3)_C$ and singlet B_μ and C_μ associated with $U(1)$ and $U'(1)$ accordingly. It is easy to see that the massless gauge bosons associated with $SU(3)_C$ group decouple from the neutral bosons mass matrix. Since that reason we neglect terms contain the $G_{a\mu}$ gauge bosons in the covariant derivative.

The gauge boson mass matrix arises from the Higgs boson kinetic term (5). The covariant derivatives for the triplet of Higgs fields write down as

$$D_\mu\varphi_i = \partial_\mu\varphi_i - iP_\mu\varphi_i, \tag{11}$$

where φ_i - Higgs fields (4), and the matrix P_μ looks like

$$P_\mu = \frac{g}{2}\begin{pmatrix} W_{3\mu} + \frac{W_{8\mu}}{\sqrt{3}} + \sqrt{\frac{2}{3}}(tXB_\mu + t'X'C_\mu) & \sqrt{2}W_\mu^+ & \sqrt{2}X_\mu'^0 \\ \sqrt{2}W_\mu^- & -W_{3\mu} + \frac{W_{8\mu}}{\sqrt{3}} + \sqrt{\frac{2}{3}}(tXB_\mu + t'X'C_\mu) & \sqrt{2}Y_\mu'^- \\ \sqrt{2}X_\mu'^{0*} & \sqrt{2}Y_\mu'^+ & -\frac{2W_{8\mu}}{\sqrt{3}} + \sqrt{\frac{2}{3}}(tXB_\mu + t'X'C_\mu) \end{pmatrix}, \tag{12}$$

here $t = g'/g$, $t' = g''/g$ and

$$W_\mu^\pm = \frac{W_{1\mu} \mp iW_{2\mu}}{\sqrt{2}},\; Y_\mu'^\mp = \frac{W_{6\mu} \mp iW_{7\mu}}{\sqrt{2}},\; X_\mu'^0 = \frac{W_{4\mu} - iW_{5\mu}}{\sqrt{2}}. \tag{13}$$

In this case taking into account (4), (12) and (13) in (11) for the masses of gauge bosons we have

$$L_{mass} = M_X^2 X_\mu'^0 X_\mu'^{0*} + M_W^2 W_\mu^+ W_\mu^- + M_Y^2 Y_\mu'^+ Y_\mu'^- + \frac{g^2u^2}{8}\left(W_{3\mu} + \frac{1}{\sqrt{3}}W_{8\mu} + \sqrt{\frac{2}{3}}\left(tX_\eta B_\mu + t'X'_\eta C_\mu\right)\right)^2 +$$
$$+\frac{g^2\upsilon^2}{8}\left(-W_{3\mu} + \frac{1}{\sqrt{3}}W_{8\mu} + \sqrt{\frac{2}{3}}\left(tX_\rho B_\mu + t'X'_\rho C_\mu\right)\right)^2 + \frac{g^2V^2}{8}\left(-\frac{2}{\sqrt{3}}W_{8\mu} + \sqrt{\frac{2}{3}}\left(tX_\chi B_\mu + t'X'_\chi C_\mu\right)\right)^2, \tag{14}$$

where for the non – Hermitian gauge bosons we have the following masses

$$M_W^2 = \frac{g^2}{4}\left(\upsilon^2 + u^2\right), M_Y^2 = \frac{g^2}{4}\left(V^2 + \upsilon^2\right), M_X^2 = \frac{g^2}{4}\left(V^2 + u^2\right). \tag{15}$$

Taking into account $V >> \upsilon >> u$, from (15) we have M_X, $M_Y >> M_W$.

For a mass matrix of neutral fields in the $W_{3\mu}$, $W_{8\mu}$, B_μ, C_μ basis from (14), we have

$$M^2 = \frac{g^2}{4}\begin{pmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{12} & m_{22} & m_{23} & m_{24} \\ m_{13} & m_{23} & m_{33} & m_{34} \\ m_{14} & m_{24} & m_{34} & m_{44} \end{pmatrix}, \tag{16}$$

where

$$m_{11} = \left(u^2 + \upsilon^2\right),\; m_{12} = \frac{1}{\sqrt{3}}\left(u^2 - \upsilon^2\right), m_{13} = \frac{2}{\sqrt{6}}t\left(u^2X_\eta - \upsilon^2X_\rho\right),\; m_{14} = \frac{2}{\sqrt{6}}t'^2\left(u^2X'_\eta - \upsilon^2X'_\rho\right),$$

$$m_{22} = \frac{1}{3}\left(4V^2 + u^2 + \upsilon^2\right),\quad m_{23} = \frac{2}{3\sqrt{2}}t\left(u^2X_\eta + \upsilon^2X_\rho - 2V^2X_\chi\right),$$

$$m_{24} = \frac{2}{3\sqrt{2}}t'\left(u^2X'_\eta + \upsilon^2X'_\rho - 2V^2X'_\chi\right),\quad m_{33} = \frac{2}{3}t^2\left(u^2X_\eta^2 + \upsilon^2X_\rho^2 + V^2X_\chi^2\right),$$

$$m_{34} = \frac{2}{3}tt'\left(u^2X_\eta X'_\eta + \upsilon^2X_\rho X'_\rho + V^2X_\chi X'_\chi\right),\; m_{44} = \frac{2}{3}t'^2\left(u^2X'^2_\eta + \upsilon^2X'^2_\rho + V^2X'^2_\chi\right).$$

The interactions lagrangian, containing the mass of the neutral (Hermitian) gauge bosons in this case, looks like:

$$L_{mass}^{NG} = \frac{1}{2}V^TM^2V, \qquad V = (W_{3\mu}, W_{8\mu}, B_\mu, C_\mu). \tag{17}$$

For the mass lagrangian of the neutral gauge bosons we have (the field A_μ remains massless)

$$L^{NG}_{mass} = \frac{1}{2}(M^2_{Z_1} Z_{1\mu} Z_{1\mu} + M^2_{Z_2} Z_{2\mu} Z_{2\mu} + M^2_{Z_3} Z_{3\mu} Z_{3\mu}. \tag{18}$$

Neutral gauge bosons masses are

$$M^2_{Z_1} = \frac{g^2}{2}(f_0 cos\frac{\alpha}{3} + f_1), \qquad M^2_{Z_2, Z_3} = \frac{g^2}{2}[f_0 cos(\frac{\alpha}{3} \pm \frac{\pi}{3}) + f_1], \tag{19}$$

where

$$cos\frac{\alpha}{3} = \frac{f_2}{3f_0^3}, \tag{20}$$

and

$$f_0 = 2(x_0 + 4x_1 + x_2 - 2x_3 - 3x_4)^{1/2}/9, \quad f_1 = [2(V^2 + \upsilon^2 + u^2) + V^2 y_1 + u^2 y_2 + \upsilon^2 y_3]/9,$$
$$f_2 = \frac{8}{729}[(V^2 + u^2 + \upsilon^2)^2 + x_1][11(V^2u^2 + V^2\upsilon^2 + u^2\upsilon^2) - 8(V^4 + u^4 + \upsilon^4) - \tag{21}$$
$$- 8x_1 - 2x_2 + 9x_4 + 2x_5] - \frac{8}{9}x_6.$$

The expression of notations x_i and y_i are listed in Appendix A. In the case of $M_{Z_1} >> M_{Z_2} >> M_{Z_3}$, corresponding to the modern experimental data [2], for neutral bosons masses, we have

$$M^2_{Z_1} \approx \frac{g^2}{6}[V^2(2 + y_1) + u^2(2 + y_2) + \upsilon^2(2 + y_3)],$$
$$M^2_{Z_2} \approx \frac{g^2}{6}\frac{V^2\upsilon^2(3 + \eta_4) + V^2u^2(3 + \eta_5) + u^2\upsilon^2(3 + \eta_6)}{V^2(2 + y_1) + u^2(2 + y_2) + \upsilon^2(2 + y_3)}, \tag{22}$$
$$M^2_{Z_3} \approx \frac{g^2}{6}\frac{x_6}{V^2\upsilon^2(3 + \eta_4) + V^2u^2(3 + \eta_5) + u^2\upsilon^2(3 + \eta_6)},$$

where the expression of notations η_4, η_5 and η_6, are also listed in Appendix A. Taken into account the symmetry breaking pattern i.e. the condition $V >> \upsilon >> u$, from (22), we have

$$M^2_{Z_1} \approx \frac{g^2V^2(2 + y_1)}{6}, \quad M^2_{Z_2} \approx \frac{g^2\upsilon^2(3 + \eta_4)}{6(2 + y_1)}, \quad M^3_{Z_3} \approx \frac{gu^2}{2}x_7. \tag{23}$$

Note that in this case the neutral vector boson M_{Z_3} one can identify with SM boson, i.e.

$$M_{Z_3} \equiv M_Z. \tag{24}$$

4. Electric charge quantization

Transformation of neutral fields $W_{3\mu}$, $W_{8\mu}$, B_μ, C_μ to the physical photon field, write down in the form

$$A_\mu = a_1 W_{3\mu} + a_2 W_{8\mu} + a_3 B_\mu + a_4 C_\mu \tag{25}$$

The eigenstate with zero eigenvalue follow from the equation:

$$M^2 \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{pmatrix} = 0. \tag{26}$$

It can be checked that the matrix M^2 has a non-degenerate zero eigenvalue for the arbitrary values of considered model parameters. Therefore, the zero eigenvalue is identified with the photon mass, $M_\gamma^2 = 0$ and eigenstate with zero eigenvalue with photon field.

In the considered $SU(3)_C \times SU(3)_L \times U(1) \times U'(1)$ model the equation (26) leads to the following values for quantities:

$$a_1 = \frac{tt'}{\overline{g}}P;\; a_2 = \frac{\sqrt{3}tt'}{\overline{g}}P_1;\; a_3 = \frac{\sqrt{6}t'}{\overline{g}}P_2;\; a_4 = -\frac{\sqrt{6}t}{\overline{g}}P_3, \tag{27}$$

where

$$\overline{g} = \sqrt{t^2t'^2\left(P^2 + 3P_1^2\right) + 6t'^2P_2^2 + 6t^2P_3^2}\;; P = X_\chi\left(X'_\eta - X'_\rho\right) - X'_\chi\left(X_\eta - X_\rho\right) + 2\left(X_\rho X'_\eta - X_\eta X'_\rho\right);$$
$$P_1 = X_\chi\left(X'_\eta + X'_\rho\right) - X'_\chi\left(X_\eta + X_\rho\right);\; P_2 = X'_\chi + X'_\rho + X'_\eta;\; P_3 = X_\chi + X_\rho + X_\eta. \tag{28}$$

Hence, for any 3-3-1-1 – model, the photon eigenstate is independent on the VEVs structure. This is a natural consequence of the *U(1)* (and *U′(1)*) invariance – the conservation of the electric charge. However photon eigenstate depend from the Higgs fields hypercharges. Moreover, to be consistent with the QED based on the unbroken *U(1)* gauge group (in the considering case also on the unbroken *U′(1)* gauge group), the photon field has to keep the general properties of the electromagnetic interaction in the framework of the 3-3-1-1 model, such as the parity invariant nature [34]. These would help us to obtain some consequences related to quantities which are independent on VEVs structure.

Let's consider interaction of fermions with gauge bosons. In the considered case the interaction lagrangian looks like

$$\begin{aligned} L = i\overline{\psi}_{lL}D_\mu\psi_{lL} + i\overline{\psi}_{eR}D_\mu\psi_{eR} + i\overline{\psi}_{NR}D_\mu\psi_{NR} + \\ i\overline{\psi}_{QL}D_\mu\psi_{QL} + i\overline{\psi}_{uR}D_\mu\psi_{uR} + i\overline{\psi}_{dR}D_\mu\psi_{dR} + i\overline{\psi}_{UR}D_\mu\psi_{UR}. \end{aligned} \tag{29}$$

At first consider interaction of leptons with the electromagnetic field. Taking into account (6) and (25) in (29), we have

$$L_{l\gamma} = Q_\nu\overline{\nu}\gamma_\mu(1+\gamma_5)\nu A_\mu + \overline{e}\gamma_\mu(Q_{0e} + Q'_{0e}\gamma_5)eA_\mu + \overline{N}\gamma_\mu(Q_N + Q'_N\gamma_5)NA_\mu, \tag{30}$$

where

$$\begin{aligned} Q_\nu &= \frac{g}{4}[a_1 + \frac{1}{\sqrt{3}}a_2 + \sqrt{\frac{2}{3}}\left(ta_3y_{lL} + t'a_4y'_{lL}\right) = 0, \\ Q_{0e} &= \frac{g}{4}[-a_1 + \frac{1}{\sqrt{3}}a_2 + \sqrt{\frac{2}{3}}ta_3\left(y_{lL} + y_{eR}\right) + \sqrt{\frac{2}{3}}t'a_4\left(y'_{lL} + y'_{eR}\right)], \\ Q'_{0e} &= \frac{g}{4}[-a_1 + \frac{1}{\sqrt{3}}a_2 + \sqrt{\frac{2}{3}}ta_3\left(y_{lL} - y_{eR}\right) + \sqrt{\frac{2}{3}}t'a_4\left(y'_{lL} - y'_{eR}\right)], \\ Q_N &= \frac{g}{4}[-\frac{2}{\sqrt{3}}a_2 + \sqrt{\frac{2}{3}}ta_3\left(y_{lL} + y_{NR}\right) + \sqrt{\frac{2}{3}}t'a_4\left(y'_{lL} + y'_{NR}\right)], \\ Q'_N &= \frac{g}{4}[-\frac{2}{\sqrt{3}}a_2 + \sqrt{\frac{2}{3}}ta_3\left(y_{lL} - y_{NR}\right) + \sqrt{\frac{2}{3}}t'a_4\left(y'_{lL} - y'_{NR}\right)]. \end{aligned} \tag{31}$$

From the expression (31) one can see that the interaction of neutrino with a photon differs from zero and there are terms proportional γ_5 in electron – photon and N – lepton – photon interactions. Taken into account the parity invariance of the electromagnetic interaction from (31) and (27), we have

$$Q_\nu = 0,\quad Q'_{0e} = 0,\quad Q'_N = 0,\quad Q_{0e} = -Q_e,\quad Q_N = \frac{3P_1 + P}{2P}Q_e, \tag{32}$$

where $Q_e = gtt'P/\overline{g}$.

Notice, that in the considered case when neutrino has not the right component the requirement parity invariance of electromagnetic interaction and the condition of neutrino charge equality to zero are equivalent. Besides, from the condition of parity invariance of electromagnetic interaction we have the relations between hypercharges of Higgs and lepton fields following from (30)

$$\begin{aligned} &P + P_1 + 2y_{lL}P_2 - 2y'_{lL}P_3 = 0, \\ &-P + P_1 + 2(y_{lL} - y_{eR})P_2 - 2(y'_{lL} - y'_{eR})P_3 = 0, \\ &-P + (y_{lL} - y_{NR})P_2 - (y'_{lL} - y'_{NR})P_3 = 0. \end{aligned} \tag{33}$$

Let's consider the interaction of quarks with the electromagnetic field. Taken into account (6) and (25) in (29), we have

$$L_{q\gamma} = \overline{u}\gamma_\mu(Q_u + Q'_u\gamma_5)uA_\mu + \overline{d}\gamma_\mu(Q_d + Q'_d\gamma_5)dA_\mu + \overline{U}\gamma_\mu(Q_U + Q'_U\gamma_5)UA_\mu, \tag{34}$$

where

$$
\begin{aligned}
Q_u &= \frac{g}{4}[a_1 + \frac{1}{\sqrt{3}}a_2 + \sqrt{\frac{2}{3}}ta_3(y_{QL} + y_{uR}) + \sqrt{\frac{2}{3}}t'a_4(y'_{QL} + y'_{uR})],\\
Q'_u &= \frac{g}{4}[a_1 + \frac{1}{\sqrt{3}}a_2 + \sqrt{\frac{2}{3}}ta_3(y_{QL} - y_{uR}) + \sqrt{\frac{2}{3}}t'a_4(y'_{QL} - y'_{uR})],\\
Q_d &= \frac{g}{4}[-a_1 + \frac{1}{\sqrt{3}}a_2 + \sqrt{\frac{2}{3}}ta_3(y_{QL} + y_{dR}) + \sqrt{\frac{2}{3}}t'a_4(y'_{QL} + y'_{dR})],\\
Q'_d &= \frac{g}{4}[-a_1 + \frac{1}{\sqrt{3}}a_2 + \sqrt{\frac{2}{3}}ta_3(y_{QL} - y_{dR}) + \sqrt{\frac{2}{3}}t'a_4(y'_{QL} - y'_{dR})],\\
Q_U &= \frac{g}{4}[-\frac{2}{\sqrt{3}}a_2 + \sqrt{\frac{2}{3}}ta_3(y_{QL} + y_{UR}) + \sqrt{\frac{2}{3}}t'a_4(y'_{QL} + y'_{UR})],\\
Q'_U &= \frac{g}{4}[-\frac{2}{\sqrt{3}}a_2 + \sqrt{\frac{2}{3}}ta_3(y_{QL} - y_{UR}) + \sqrt{\frac{2}{3}}t'a_4(y'_{QL} - y'_{UR})].
\end{aligned}
\tag{35}
$$

Parity invariance of electromagnetic interaction leads to

$$
\begin{aligned}
&Q'_u = 0, \quad Q'_d = 0, \quad Q'_U = 0, \quad Q_u = \frac{P + P_1 + 2(P_2 y_{QL} - P_3 y'_{QL})}{2P} Q_e,\\
&Q_d = -\frac{P - P_1 - 2(P_2 y_{QL} - P_3 y'_{QL})}{2P} Q_e, \quad Q_U = -\frac{P_1 - P_2 y_{QL} + P_3 y'_{QL}}{P} Q_e.
\end{aligned}
\tag{36}
$$

Besides, we have following relations

$$
\begin{aligned}
P_2 y_{uR} - P_3 y'_{uR} &= P_2 y_{QL} - P_3 y'_{QL} + \frac{1}{2}(P + P_1),\\
P_2 y_{dR} - P_3 y'_{dR} &= P_2 y_{QL} - P_3 y'_{QL} - \frac{1}{2}(P - P_1),\\
P_2 y_{UR} - P_3 y'_{UR} &= P_2 y_{QL} - P_3 y'_{QL} - P.
\end{aligned}
\tag{37}
$$

Note that in generally the neutrino and N – lepton, as well as the u– and U– quarks charges can be different. If in the considering model there are no leptons with exotic charges ($Q_\nu = Q_N$), from (32) we have

$$3P_1 + P = 0. \tag{38}$$

In this case taken into account (38) in (36) for quarks charges we have

$$Q_u = Q_U = \frac{Q_e}{3}[1 - \frac{P_2 y_{QL} - P_3 y'_{QL}}{P_1}], \quad Q_d = -\frac{Q_e}{3}[2 + \frac{P_2 y_{QL} - P_3 y'_{QL}}{P_1}]. \tag{39}$$

Hence, we obtain that if in the considered model there are no leptons with exotic charges there are no also quarks with exotic charges. Fixing of the charge of one particle leads to fixing of the charge of other particle. It leads to the conclusion, that the model predicts a quark – lepton symmetry.

The obtained expressions (32) and (36) can be considered as the evidence of electric charge quantization of leptons and quarks. However the expressions (36) and (39) do not define numerical values of quarks charges (in terms of electron charge). For obtaining of numerical values of quarks, it is necessary to have the additional relations between quarks field hypercharges. Such of relations can be obtained from anomaly cancellation conditions.

In conclusion of this part note that in the SM (see work of authors in [8]) and various extended models of electroweak interaction photon eigenstate does not contain vacuum averages of Higgs fields, but depends on the hypercharges of Higgs fields. It leads in turn to dependence of electron charge from hypercharges of Higgs fields. Dependence of the particles charge from the hypercharges of Higgs fields leads to the conclusion that the Higgs fields influence on the particles charge "formation". Thus, Higgs fields are responsible not only for occurrence of particles mass and also for the formation of their charges hence for particles electric charge quantization. Certainly, the further and detailed studies of this problem are necessary.

5. The Charged and Neutral currents

Diagonalization the mass matrix of neutral fields gives the mass eigenstates $Z_{1\mu}$, $Z_{2\mu}$ and $Z_{3\mu}$

$$
\begin{aligned}
Z_{1\mu} &= b_1 W_{3\mu} + b_2 W_{8\mu} + b_3 B_\mu + b_4 C_\mu,\\
Z_{2\mu} &= c_1 W_{3\mu} + c_2 W_{8\mu} + c_3 B_\mu + c_4 C_\mu,\\
Z_{3\mu} &= d_1 W_{3\mu} + d_2 W_{8\mu} + d_3 B_\mu + d_4 C_\mu.
\end{aligned}
\tag{40}
$$

where

$$b_1 = \frac{2\sqrt{2}tt'R}{g_{Z_1}};\ b_2 = \frac{2\sqrt{6}tt'R_1}{g_{Z_1}};\ b_3 = \frac{\sqrt{3}t'R_2}{g_{Z_1}};\ b_4 = \frac{2\sqrt{3}tR_3}{g_{Z_1}}. \quad (41)$$

The expressions of quantities b_i ($i=1\div4$) are listed in Appendix B. Note that the expressions of c_i and d_i ($i=1\div4$) can be obtained from corresponding expressions b_i by replacement $Z_1 \to Z_2$ and $Z_1 \to Z_3$.

In most general form the interaction lagrangian of fermions with gauge bosons has the following form:

$$\begin{aligned} L_{int} &= i\overline{\psi}_L\gamma_\mu(\partial_\mu - ig\sum_{a=1}^{8}T_a W_{a\mu} - ig'T_9 XB_\mu - ig''T_9 X'C_\mu)\psi_L + \\ &+ i\overline{\psi}_R\gamma_\mu(\partial_\mu - ig'XB_\mu - ig''X'C\mu)\psi_R, \end{aligned} \quad (42)$$

where ψ_L, ψ_R – left and right fermion fields.

Taken into account (13) and (42), the interactions among the charged vector fields with leptons and quarks are

$$L_f^{CC} = \frac{g}{2}(\overline{v}W_\mu e_L + \overline{N}_L Y'_\mu e_L + \overline{v}_L X'_\mu N_L + \overline{d}_L W_\mu u_L + \overline{U}_L Y'_\mu d_L + \overline{u}X'_\mu U_L + h.c.). \quad (43)$$

We can see that the interactions with Y'_μ and X'_μ bosons violate the lepton number (see Eq.(43)) and the weak isospin.

The neutral current interactions can be written in the form

$$\begin{aligned} L_f^{NC} &= \frac{\sqrt{2}tt'}{g_{Z_1}}\sum_f \bar{f}\gamma_\mu(g_{Vf} + g_{Af}\gamma_5)fZ_{1\mu} + \frac{\sqrt{2}tt'}{g_{Z_2}}\sum_f \bar{f}\gamma_\mu(g'_{Vf} + g'_{Af}\gamma_5)fZ_{2\mu} + \\ &+ \frac{\sqrt{2}tt'}{g_{Z_3}}\sum_f \bar{f}\gamma_\mu(g''_{Vf} + g''_{Af}\gamma_5)fZ_{3\mu}, \end{aligned} \quad (44)$$

The values of vector and axial coupling are listed in the Appendix C.

Table 1

Fermions and Higgs fields	X	X'
$\psi_{lL} = \begin{pmatrix} \nu \\ e \\ N \end{pmatrix}_L$	y_{eL}	y'_{eL}
$\psi_{eR} = e_R$	y_{eR}	y'_{eR}
$\psi_{NR} = N_R$	y_{NL}	y'_{NL}
$\psi_{QL} = \begin{pmatrix} u \\ d \\ U \end{pmatrix}_L$	y_{QL}	y'_{QL}
$\psi_{uR} = u_R$	y_{uR}	y'_{uR}
$\psi_{dR} = d_R$	y_{dR}	y'_{dR}
$\psi_{UR} = U_R$	y_{UR}	y'_{UR}
$\chi = \begin{pmatrix} \chi'^0 \\ \chi^- \\ \chi^0 \end{pmatrix}$	X_χ	X'_χ
$\rho = \begin{pmatrix} \rho^+ \\ \rho^0 \\ \rho'^+ \end{pmatrix}$	X_ρ	X'_ρ
$\eta = \begin{pmatrix} \eta^0 \\ \eta^- \\ \eta'^0 \end{pmatrix}$	X_η	X'_η

6. The Conclusion

Taking into account the arbitrary values of fermions and Higgs fields hypercharges the possibility of construction of electroweak interactions model, based on spontaneously broken $SU(3)_C \times SU(3)_L \times U(1) \times U'(1)$ symmetry group by three Higgs fields have been investigated. Masses of gauge bosons, arising in the considered model are calculated. Diagonalization of mass matrix of neutral fields has been performed and expressions for eigenstates of neutral fields are obtained. Expressions for fermions charges, testifying the electric charge quantization are obtained. Dependence of the particles charges from the hypercharges of Higgs fields can be interpreted as new property of Higgs fields. Higgs fields influence on particles charges "formation", and on particles electric charge quantization. Higgs fields are responsible not only for occurrence particles mass and also for the formation of their charges. In the considered model fixing N - lepton charge leads to fixing U-quark charge, i.e. the model predicts presence a quark - lepton symmetry. Expressions for the interactions of gauge bosons with fermions and vector and axial coupling constants of interactions of neutral vector bosons with fermions are calculated.

Appendix A

Expression of quantities x_i and y_i, in neutral $M^2_{Z_1}$, $M^2_{Z_2}$ and $M^2_{Z_3}$ bosons masses have the form:

$$x_0 = 4(V^4 + u^4 + \upsilon^4) - [V^2(u^2+\upsilon^2) + u^2\upsilon^2\},$$
$$x_1 = V^4 y_1 + u^4 y_2 + \upsilon^4 y_3,$$
$$x_2 = V^4 y_1^2 + u^4 y_2^2 + \upsilon^4 y_3^2,$$
$$x_3 = V^2u^2(y_1 + y_2 - y_1y_2) + V^2\upsilon^2(y_1 + y_3 - y_1y_3) + u^2\upsilon^2(y_2 + y_3 - y_2y_3),$$
$$x_4 = u^2\upsilon^2\eta_1 + V^2\upsilon^2\eta_2 + V^2\upsilon^2\eta_3,$$
$$x_5 = V^2u^2(5y_1 + 5y_2 - 2y_1y_2) + V^2\upsilon^2(5y_1 + 5y_3 - 2y_1y_3) + u^2\upsilon^2(5y_2 + 5y_3 - 2y_2y_3),$$
$$x_6 = V^2u^2\upsilon^2 x_7,$$
$$x_7 = \frac{2t^2t'^2}{3}[z_1(z_1+z_2) + z_2(z_2+z_3) + z_3(z_3 - z_1)] + t^2P_3^2 + t'^2P_2^2,$$

where

$$y_1 = t^2X_\chi^2 + t'^2X_\chi'^2, \quad y_2 = t^2X_\eta^2 + t'^2X_\eta'^2, \quad y_3 = t^2X_\rho^2 + t'^2X_\rho'^2,$$
$$z_1 = X_\rho X_\eta' - X_\rho' X_\eta, \quad z_2 = X_\chi X_\eta' - X_\chi' X_\eta, \quad z_3 = X_\chi X_\rho' - X_\chi' X_\rho,$$
$$\eta_1 = t^2t'^2z_1^2 + 2t^2X_\rho X_\eta + 2t'^2X_\rho' X_\eta', \quad \eta_2 = t^2t'^2z_2^2 + 2t^2X_\chi X_\eta + 2t'^2X_\chi' X_\eta',$$
$$\eta_3 = t^2t'^2z_3^2 + 2t^2X_\chi X_\rho + 2t'^2X_\chi' X_\rho', \quad \eta_4 = \eta_3 + 2t^2(X_\rho^2 + X_\chi^2) + 2t'^2(X_\rho'^2 + X_\chi'),$$
$$\eta_5 = \eta_2 + 2t^2(X_\eta^2 + X_\chi^2) + 2t'^2(X_\eta'^2 + X_\chi'^2), \quad \eta_6 = \eta_1 + 2t^2(X_\rho^2 + X_\eta^2) + 2t'^2(X_\rho'^2 + X_\eta'^2).$$

Appendix B

Expression of notations in eigenstates of neutral fields $Z_{1\mu}$, $Z_{2\mu}$ and $Z_{3\mu}$, are

$$\bar{g}_{Z_1} = \sqrt{8t^2t'^2\left(3R^2 + R_1^2\right) + 3t'^2R_2 + 12t^2R_4^2},$$

where

$$R = 4r_1 - 2m_{Z_1}(r_3 - 3r_5/t^2) + 3m_{Z_1}^2 r_7/t^2,$$
$$R_1 = 4r_2 - 6m_{Z_1}(r_4 - r_6/t^2) + 9m_{Z_1}^2 r_8/t^2,$$
$$R_2 = [R(2r_6 + 3r_8m_{Z_1}) - R_1(2r_5 + r_7m_{Z_1})]/r_{10},$$
$$R_3 = r_9R_2/2, \quad R_4 = [R_1m_{Z_1} - u^2(R+R_1) - \upsilon^2(R_1 - R) - R_3]/r_8,$$

$$r_1 = V^2 u^2 \upsilon^2 P_3(z_2 + z_3), \quad r_2 = V^2 u^2 \upsilon^2 P_3(2z_1 + z_2 - z_3),$$
$$r_3 = V^2 u^2 z_2(2X_\eta + X_\chi) + V^2 \upsilon^2 z_3(2X_\rho + X_\chi) - u^2 \upsilon^2 z_1(X_\rho - X_\eta),$$
$$r_4 = V^2 u^2 z_2 X_\chi - V^2 \upsilon^2 z_3 X_\chi + u^2 \upsilon^2 z_1(X_\rho + X_\eta), \quad r_5 = -u^2 \upsilon^2 (X'_\rho + X'_\eta) + V^2(u^2 + \upsilon^2)X'_\chi,$$
$$r_6 = u^2 \upsilon^2 (X'_\rho - X'_\eta) - V^2(u^2 - \upsilon^2)X'_\chi - 2V^2(u^2 X'_\eta - \upsilon^2 X'_\rho), \quad r_7 = u^2 X'_\eta + \upsilon^2 X'_\rho - 2V^2 X'_\chi,$$
$$r_8 = u^2 X'_\eta - \upsilon^2 X'_\rho, \quad r_9 = u^2 X_\eta - \upsilon^2 X_\rho, \quad r_{10} = u^2 \upsilon^2 z_1 - V^2(u^2 z_2 - \upsilon^2 z_3).$$
$$m_{Z_1} = M^2_{Z_1} \big/ 4g^2 .$$

Appendix C

Values of vector and axial coupling constants in neutral current interactions are

$$g_{V\nu} = g_{A\nu} = R + R_1 + R_2 y_{lL}/2 + R_4 y'_{lL},$$
$$g_{Ve} = R - R_1 + R_2(y_{lL} + y_{eR})/2 + R_4(y'_{lL} + y'_{eR}),\; g_{Ae} = R - R_1 + R_2(y_{lL} - y_{eR})/2 + R_4(y'_{lL} - y'_{eR}),$$
$$g_{VN} = -2R + R_2(y_{lL} + y_{NR})/2 + R_4(y'_{lL} + y'_{NR}),\; g_{AN} = -2R + R_2(y_{lL} - y_{NR})/2 + R_4(y'_{lL} - y'_{NR}),$$
$$g_{Vu} = R + R_1 + R_2(y_{QL} + y_{uR})/2 + R_4(y'_{QL} + y'_{uR}),\; g_{Au} = R + R_1 + R_2(y_{QL} - y_{uR})/2 + R_4(y'_{QL} - y'_{uR}),$$
$$g_{Vd} = R - R_1 + R_2(y_{QL} + y_{dR})/2 + R_4(y'_{QL} + y'_{dR}),\; g_{Ad} = R - R_1 + R_2(y_{QL} - y_{dR})/2 + R_4(y'_{QL} - y'_{dR}),$$
$$g_{VU} = -2R + R_2(y_{QL} + y_{UR})/2 + R_4(y'_{QL} + y'_{UR}),\; g_{AU} = -2R + R_2(y_{QL} - y_{UR})/2 + R_4(y'_{QL} - y'_{UR}).$$

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ELEKTROZƏİF QARŞILIQLI TƏSİRLƏRİN $SU(3)_C \times SU(3)_L \times U(1) \times U'(1)$ MODELİ VƏ ELEKTRİK YÜKÜNÜN KVANTLANMASI

İşdə elektrozəif qarşılıqlı təsirlərin $SU(3)_C \times SU(3)_L \times U(1) \times U'(1)$ modeli qurulmuşdur. Lepton və kvarkların yükləri hesablanmış və zərrəciklərin elektrik yükünün kvantlanması probleminin təbii həlli göstərilmişdir. Xiqqs sahələrinin zərrəciklərin yükünün “formalaşmasına” və zərrəciklərin elektrik yükünün kvantlanmasına təsiri göstərilmişdir.

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$SU(3)_C \times SU(3)_L \times U(1) \times U'(1)$ МОДЕЛЬ И КВАНТОВАНИЕ ЭЛЕКТРИЧЕСКОГО ЗАРЯДА

Настоящая работа посвящена исследованию возможности построения модели электрослабого взаимодействия, основанной на спонтанно нарушенной $SU(3)_C \times SU(3)_L \times U(1) \times U'(1)$ группе симметрии. Вычислены выражения для зарядов лептонов и кварков, свидетельствующие о естественном решении проблемы квантования электрического заряда в предложенной модели. Показано влияние Хиггсовских полей на «формирование» зарядов частиц и на квантование электрического заряда частиц.

Received: 03.11.08