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SEVDA RZAYEVA

Elctric-Charge Quantization and Higgs field

Institute of Physics, Azerbaijan National Academy of Sciences, Baku, Azerbaijan

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Conditions of electric charge quantization and fixation:

- The $U(1)_{em}$ gauge symmetry must remain exact;
- To guarantee the renormalizability and covariance of theory, gauge and gauge gravitational anomalies must be canceled;
- The masses of fermions must be generated by the Higgs mechanism.

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- Quantization of electric charge does not depend on the hypercharge of the Higgs field.
- In gauge models with right-handed neutrino, quantization of electric charge follows from the conditions of anomaly cancellation and nonvanishing fermions masses only if the neutrino is a Majorana particle.

Why ?

- It is known that only massive elementary particles have the electric charges (massless are neutral), so **the coupling of electric charge (quantization) with the mechanism of mass generation of elementary particles, it is obvious there is and should be investigated.**

- Definition and study of the relation of electric charges with the properties of Higgs bosons, finding conditions for an unambiguous definition (quantization) of these charges is certainly interesting.

It was shown that the [11 – 13]

1. Photon eigenstate and particle charges depend on the hypercharge of the Higgs fields.
2. In the issue of quantization of electric charge in the gauge models, it is possible to manage without an explicit accounting of the Higgs mechanism of mass generation, relying instead on the P invariance of the electromagnetic interaction.

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Electric charge quantization in SM and its extensions

Usual way	In this report
Y – from anomalies cancellation conditions. Electric charges from $Q = T_3 + \frac{Y}{2}$	Calculation of particles electric charges

1. Standard Model with right handed neutrino

2. $SU_C(3) x SU(3)_L x U(1)_X$

3. $SU_C(3) x SU(3)_L x U(1)_X x U^{'}(1)$

4. $SU_C(2) x SU(3)_L x U(1)_X x U^{'}(1)$

I. Electric charge quantization in the SM with right-handed neutrino

$$\psi_L = \begin{pmatrix} \nu \\ e^- \end{pmatrix}_L, \psi_R = e_R, \psi_{\nu R} = \nu_{R,} \psi_{QL} = \begin{pmatrix} u \\ d \end{pmatrix}_L, \psi_{uR} = u_R, \psi_{dR} = d_R$$

$$\varphi = \begin{pmatrix} \varphi^+ \\ \varphi^0 \end{pmatrix}$$

.

$$L = i\overline{\psi}_{fL} \hat{D} \psi_{fL} + i\overline{\psi}_{fR} \hat{D} \psi_{fR} + \left(D_\mu \varphi\right)^+ \left(D_\mu \varphi\right),$$

$$D_\mu = \partial_\mu - ig \frac{\vec{\tau} \vec{A}_\mu}{2} - ig' \frac{X}{2} B_\mu$$

$$X(\varphi) = x_\varphi, \quad X(\psi_L) = x_L \quad X(\psi_{eR}) = x_{eR}, \quad X(\psi_{\nu R}) = x_{\nu R},$$

$$X(\psi_{QL}) = x'_{QL}, \quad X(\psi_{uR}) = x_{uR}, \quad X(\psi_{dR}) = x_{dR}.$$

$$A_\mu^3 = A_\mu \sin\theta_i + Z_\mu \cos\theta_i,$$

$$B_\mu = A_\mu \cos\theta_i - Z_\mu \sin\theta_i.$$

$(D_\mu\varphi)^+(D_\mu\varphi)$	$\overline{\psi}_{fL}\hat{D}\psi_{fL}$	$\overline{\psi}_{QL}\hat{D}\psi_{QL}$
$\sin\theta_\varphi = \frac{x_\varphi g'}{\sqrt{g^2 + x_\varphi^2 g'^2}}$	$\sin\theta_L = -\frac{x_L g'}{\sqrt{g^2 + x_L^2 g'^2}}$	$\sin\theta_{QL} = \frac{x'_{QL} g'}{\sqrt{g^2 + x'^2_{QL} g'^2}}$

In general, there is no theoretical reason to require the equality of these angles. If these angles are equal

$$x_\varphi = -x_L, \quad x_\varphi = x'_{QL}, \quad x_L = -x'_{QL} \qquad (1)$$

In the SM, the quantity defining the interaction of the Higgs and fermionic fields with the field B_μ is the weak hypercharge (hereinafter hypercharge).

This difficulty of the SM may be overcome by using the following three facts:

- The anomaly cancellation conditions from which it follows that

$$x'_{QL} = 3x_{QL} = 3Y^{CM}_{QL}$$

- The fact of equality of the Weinberg angle measured in purely leptonic, semileptonic and hadronic processes and assume

$$x'_{QL} = 3x_{QL} = 3Y^{CM}_{QL}$$

- Assumed that the ratios of left hypercharge of the quark and lepton fields to the hypercharge of the Higgs field are baryon and lepton quantum numbers, respectively (A. Abbas [9])

$$\frac{x_{QL}}{x_{\varphi}} = B, \quad \frac{x_L}{x_{\varphi}} = -L.$$

$$\boxed{x_{\varphi} = -x_L\,, \quad x_{\varphi} = 3x_{QL}\,, \quad x_L = -3x_{QL}} \qquad (2)$$

Electric charge quantization

$$L_{l\gamma} = \bar{\nu}\gamma_\mu \left(Q_\nu + Q'_\nu \gamma_5\right)\nu A_\mu + \bar{e}\gamma_\mu \left(Q_{0e} + Q'_{0e}\gamma_5\right) e A_\mu$$

$$L_{q\gamma} = \bar{u}\gamma_\mu \left(Q_{1u} + Q'_{1u}\gamma_5\right) u A_\mu + \bar{d}\gamma_\mu \left(Q_{2d} + Q'_{2d}\gamma_5\right) d A_\mu .$$

$$Q_\nu = \frac{g}{4}\left(1 + \frac{x_L + x_{\nu R}}{x_\varphi}\right)\sin\theta_\varphi, \qquad Q'_\nu = \frac{g}{4}\left(1 + \frac{x_L - x_{\nu R}}{x_\varphi}\right)\sin\theta_\varphi,$$

$$Q_{0e} = -\frac{g}{4}\left(1 - \frac{x_L + x_{eR}}{x_\varphi}\right)\sin\theta_\varphi, \qquad Q'_{0e} = -\frac{g}{4}\left(1 - \frac{x_L - x_{eR}}{x_\varphi}\right)\sin\theta_\varphi.$$

$$Q_{1u} = \frac{g}{4}\left(1 + \frac{x_{QL} + x_{uR}}{x_\varphi}\right)\sin\theta_\varphi, \qquad Q'_{1u} = \frac{g}{4}\left(1 + \frac{x_{QL} - x_{uR}}{x_\varphi}\right)\sin\theta_\varphi,$$

$$Q_{2d} = -\frac{g}{4}\left(1 - \frac{x_{QL} + x_{dR}}{x_\varphi}\right)\sin\theta_\varphi, \qquad Q'_{2d} = -\frac{g}{4}\left(1 - \frac{x_{QL} - x_{dR}}{x_\varphi}\right)\sin\theta_\varphi.$$

P invariance of electromagnetic interaction leads to

$$Q'_\nu = 0, \quad Q'_{0e} = 0 \quad Q'_{1u} = 0, \quad Q'_{2d} = 0$$

and

$$x_L = x_{\nu R} - x_\varphi, x_L = x_{eR} + x_\varphi$$
$$x_{QL} = x_{uR} - x_\varphi, \quad x_{QL} = x_{dR} - x_\varphi \qquad (3)$$

$$L^f_{mass} = f_e \overline{\Psi}_L \Psi_{eR}\varphi + f_\nu \overline{\Psi}_L \Psi_{\nu R}\varphi^c + f_d \overline{\Psi}_{QL} \Psi_{dR}\varphi + f_u \overline{\Psi}_{QL} \Psi_{uR}\varphi^c + h.c.,$$

$$Q_\nu = \frac{Q_e}{2}\left(1 + \frac{x_L}{x_\varphi}\right), Q_{0e} = -\frac{Q_e}{2}\left(1 - \frac{x_L}{x_\varphi}\right), \quad Q_u = \frac{Q_e}{2}\left(1 + \frac{x_{QL}}{x_\varphi}\right), \quad Q_d = -\frac{Q_e}{2}\left(1 - \frac{x_{QL}}{x_\varphi}\right)$$

$$Q_e = g\sin\theta_\varphi = x_\varphi g g' / \bar{g}_\varphi, \bar{g}_\varphi = \sqrt{g^2 + x_\varphi^2 g'^2}.$$

Taking into account (2) we have

$$Q_\nu = 0, \quad Q_{0e} = -Q_e, \quad Q_u = \frac{2}{3}Q_e, \quad Q_d = -\frac{1}{3}Q_e$$

Thus, we conclude that relations (2) and (3) are necessary conditions for the quantization of electric charge and, hence, without the presence of the Higgs field in this case there is no quantization of electric charge.

Interaction of the Higgs field with the fermion fields (or the condition of P invariance of electromagnetic interaction) also leads to the fixation of the hypercharges of right fields

$$x_{\nu R} = 0, \quad x_{eR} = -2x_{\varphi}, \quad x_{dR} = -\frac{2}{3}x_{\varphi}, \quad x_{uR} = \frac{4}{3}x_{\varphi}.$$

Conclusions

- In the considered models the conditions of P invariance of the electromagnetic interaction and gauge invariance of the Yukawa interaction (which generates the fermion masses) are identical. This fact leads us to consider Higgs fields as a possible mechanism explaining the parity conservation in electromagnetic interactions.

- The dependence of the quantization conditions and electric charges of particles from the hypercharge of the Higgs fields, the identity of electric charge quantization conditions, following from Lagrangians generating particle masses and from the P invariance of the electromagnetic interaction and the fact of the fixing of fermionic field hypercharges by the Higgs fields **can be interpreted as new properties of Higgs fields**.

Thank you for your attention