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ABSTRACT

A simple scheme of renormalizable theory is presented in which μ-e universality is violated in the vector field interaction. It is shown that to check up the existence of the vector field interacting with the electronic and muonic charge in a different way the key ones are experiments on investigations of ν_e ($\bar{\nu}_e$) and ν_μ ($\bar{\nu}_\mu$) scattering on the electrons.

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о μ-e -универсальности

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The absence in experiment of $\mu \to e\gamma$ decays[1] and the experimentally observed orthogonality of the electron and muon neutrino[2] allows one to interprete the electronic and muonic neutrinos as particles with different charges L_e and L_μ. If these charges are related to the real gauge fields, the interaction of the electronic and muonic leptons must be different.

The possibility for existence of leptonic and muonic photons related to L_e and L_μ charges was considered by Okun'[3] who had established very low limits on the values of corresponding charges. And more previously, in connection with the μ-e problem, there was discussed the possibility of interaction of muonic leptons with the massive vector field[4-7]. At present of interest is the problem of the μ-e universality violation in the frame work of the gauge-invariant theory of weak and electromagnetic interactions. Examples of μ-e universality violation may be found in ref./8/where the SU(2)xU(1)xU'(1)xU''(1) symmetrical model is used and in ref.[9] where the electronic and muonic leptons are united in the multiplets of different dimension.

In this paper we give a simple scheme based on the introduction of massive vector field interaction with the charges L_e and L_μ and consider the methods of experimental checking of such gauge-invariant scheme.

1. Nonuniversal Interaction

The simplest gauge-invariant model of weak and electromagnetic interactions proposed by Weinberg and Salam[10,11] and generalized to hadrons in accordance with the four-quark scheme[12,13] does not contain triangle anomalies and is a completely renormalizable theory. It can be easily seen that the adding to the Weinberg Lagrangian[10] of the term

$$\mathcal{L}^{anom} = f\Big[\bar{e}\gamma_\alpha e + \frac{1}{2}\bar{\nu}_e\gamma_\alpha(1+\gamma_5)\nu_e - \bar{\mu}\gamma_\alpha\mu - \frac{1}{2}\bar{\nu}_\mu\gamma_\alpha(1+\gamma_5)\nu_\mu\Big]X_\alpha , \qquad (1)$$

in which X_α is the massive vector field interacting with electronic and muonic charges opposite in sign ($L_e = -L_\mu$), does not spoil renormalizability of the theory since: a) the field X_α is orthogonal to the system of the main field $\{W^\pm_\alpha, Z_\alpha, A_\alpha\}$; b) it interacts with conserved current; c) Lagrangian (1) does not lead to additional axial anomalies in the model[10]. Due to all of this the constant f and the mass of the field X_α are free parameters of the theory.

What can be said on the interaction of the field with quarks? If we take the four-quark scheme [10] then since n and λ are mixed and enter both left-handed doublets

$$\begin{pmatrix} p \\ n\cos\theta_c + \lambda\sin\theta_c \end{pmatrix}_L , \qquad \begin{pmatrix} c \\ -n\sin\theta_c + \lambda\cos\theta_c \end{pmatrix}_L$$

we must assign to both doublets one and the same charge of anomalous interaction. If this charge is not zero, then the orthogonality of the field X_α to the ground gauge fields Z_α and A_α breaks, so one must construct a more complicated scheme of the theory in which the field X_α is no more independent. If, however, there exist two groups of quarks

$$\begin{pmatrix} p & c \\ n & \lambda \end{pmatrix} , \qquad \begin{pmatrix} p' & c' \\ n' & \lambda' \end{pmatrix}$$

and there is no mixing between quarks of different groups then one may assign to these groups opposite charges fo anomalous interaction and the theory with included anomalous interaction keeps its simplicity though electronic and muonic leptons will interact with nucleons nonuniversally.

Thus, anomalous interaction of electrons and muons with hadrons is in principle possible but not compulsory. So we first consider some consequences involved by anomalous interaction in leptonic part. First of all (1) somewhat changes the electrodynamics predictions since photon propagator is modified as follows

$$\frac{1}{q^2} \longrightarrow \frac{1}{q^2}\left[1+\frac{f^2}{e^2}\,\frac{q^2}{q^2-M_x^2}\right] \tag{3}$$

The test of the validity of quantum electrodynamics in the processes

$$e^+e^- \to e^+e^-\,,\ \mu^+\mu^-$$

showed that when photon propagator is parametrized as

$$\frac{1}{q^2}\left[1+\frac{q^2}{q^2-\Lambda^2}\right]$$

the parameter $\Lambda > 35$ Gev [14]. Hence assuming $M_x^2 \gg |q^2|_{eff}$ we get the following bound for f^2/M_x^2 which characterizes the strength of the 4-fermion anomalous interaction

$$\frac{f^2}{M_x^2} < \frac{6.6\cdot 10^{-5}}{m_p^2}\,. \tag{4}$$

Thus, the nonuniversal interaction, even it it exists, in the order of magnitude must be more than the weak interaction. The same conclusion results from analysis of corrections due to interaction (1) to magnetic moment of muon though the restrictions appear to be somewhat weaker.

The difference (neglecting (1)) between theoretical and experimental value of a_μ comprises [15]

$$a_\mu^{exp} - a_\mu^{theor} = \begin{cases} (31 \pm 29)\cdot 10^{-9} \\ (26 \pm 29)\cdot 10^{-9}. \end{cases} \tag{5}$$

Putting $\Delta a_\mu < 60.10^{-9}$ and making use of the well known formulae [7,16] for the contribution of anomalous interaction into a_μ we get

$$\frac{f^2}{M_x^2} < \frac{56\cdot 10^{-5}}{m_p^2}\,. \tag{6}$$

Consequently, the expected effects of μ-e universality violation must be of order or less than those induced by weak interaction. Therefore the anomalous interaction effects can appear completely but not as radiation corrections in the processes with neutrino neutral currents which we will consider now.

2. Anomalous Interaction in Leptonic Processes

Interaction (1) violates the universal theory predictions for reactions

$$\nu_e + e \rightarrow \nu_e + e, \tag{7a}$$

$$\bar{\nu}_e + e \rightarrow \bar{\nu}_e + e, \tag{7b}$$

$$\nu_\mu + e \rightarrow \nu_\mu + e, \tag{7c}$$

$$\bar{\nu}_\mu + e \rightarrow \bar{\nu}_\mu + e, \tag{7d}$$

$$\nu_e(\bar{\nu}_e) + \mu \rightarrow \nu_e(\bar{\nu}_e) + \mu, \tag{8a}$$

$$\nu_\mu(\bar{\nu}_\mu) + \mu \rightarrow \nu_\mu(\bar{\nu}_\mu) + \mu. \tag{8b}$$

Because of the absence of muonic target reactions (8) may be studied experimentally only in the indirect way, namely, by measuring the parameters of processes

$$\nu_e(\bar{\nu}_e) + Z \rightarrow \nu_e(\bar{\nu}_e) + \mu + \bar{\mu} + Z,$$

$$\nu_\mu(\bar{\nu}_\mu) + Z \rightarrow \nu_\mu(\bar{\nu}_\mu) + \mu + \bar{\mu} + Z.$$

occuring in the nuclear Coulomb field for which the vector interaction constant must be different if interaction (1) exists.

Processes (7) give a direct information. To simplify the analysis let us suppose that $M_x^2 \gg m_p^2$ so when deriving formulae for differential and total cross sections one may use the local effective Lagrangian of the 4-fermion interaction. At $s/M^2_{x,w,z}$ Lagrangian (1) plus Weinberg Lagrangian [10] reduces to effective Lagrangian

$$\mathcal{L}_{eff} = -\frac{G}{\sqrt{2}}\Big\{\bar{\nu}_e\gamma_\alpha(1+\gamma_5)\nu_e\cdot\Big[\bar{e}\gamma_\alpha\Big(\frac{1}{2}+ 2\sin^2\theta_W+\delta+\frac{1}{2}\gamma_5\Big)e+\bar{\mu}\gamma_\alpha\Big(-\frac{1}{2}+2\sin^2\theta_W-\delta- \frac{1}{2}\gamma_5\Big)\mu\Big]+\bar{\nu}_\mu\gamma_\alpha(1+\gamma_5)\nu_\mu\cdot\Big[\bar{e}\gamma_\alpha\Big(-\frac{1}{2}+ 2\sin^2\theta_W-\delta-\frac{1}{2}\gamma_5\Big)e+\bar{\mu}\gamma_\alpha\Big(\frac{1}{2}+2\sin^2\theta_W+\delta+\frac{1}{2}\gamma_5\Big)\mu\Big]\Big\}. \qquad (9)$$

where $\delta = f^2/\sqrt{2}\,G M_x^2$.

If the processes (7) are studied in acceleraous neutrino beams, i.e. the condition

$$\frac{m}{E_\nu} \ll 1$$

is fulfilled, the differential cross section of any of the processes (7a-d) is written as

$$\frac{d\sigma}{dE} = \frac{G^2 m}{2\pi}\Big[A + B\Big(1-\frac{E}{E_\nu}\Big)^2\Big] \qquad (10)$$

where E is the recoil electron energy in lab.system and coefficient A and B are different for different reactions (a-d) and given in Table I.

With the account of anomalous interaction the relations between cross sections of different processes obtained by Sehgal /17/ assuming μ-e universality,change and take the following form

$$\big[\sigma(\nu_e e)-\sigma(\nu_\mu e)\big]-3\big[\sigma(\bar{\nu}_e e)-\sigma(\bar{\nu}_\mu e)\big]=-\frac{32}{3}\delta\sin^2\theta_W\frac{G^2 m E_\nu}{\pi}, \qquad (11)$$

$$\Big|\sqrt{\sigma(\nu_e e)-\frac{1}{3}\sigma(\bar{\nu}_e e)}-\sqrt{\sigma(\nu_\mu e)-\frac{1}{3}\sigma(\bar{\nu}_\mu e)}\Big| = \frac{4}{3}(1+\delta)\sqrt{\frac{G^2 m E_\nu}{\pi}}. \qquad (12)$$

In the theory with universal μ-e interaction the right-handed part of eq.(11) is equal to zero. Therefore the exact measurement of processes (7a-d) will allow one to make definite conclusions on anomalous interaction especially as the quantity δ characterising the strength of anomalous interaction enters formula (11) with the coefficient of about 10.

At present the data are available only on the cross sections of processes (7b-d). As usual these data are analysed aiming to determine the Weinberg theory parameter $\sin^2\theta_W$. Our model of universality violation, as is seen from Table I, applying to the Weinberg theory supposes the following changes:

for $\nu_e\,(\bar{\nu}_e)$ scattering on the electrons

$$\sin^2\theta_W \to \left(\sin^2\theta_W + \tfrac{1}{2}\delta\right),$$

for $\nu_\mu\,(\bar{\nu}_\mu)$ scattering on the electrons

$$\sin^2\theta_W \to \left(\sin^2\theta_W - \tfrac{1}{2}\delta\right).$$

From the data on reaction (7b) obtained on a beam of reactor antineutrinos within two energy ranges of the recoil electrons, it follows [18]

$$\left(\sin^2\theta_W + \frac{\delta}{2}\right) = 0{,}26 \begin{matrix} +0{,}05 \\ -0{,}06 \end{matrix} \qquad 1{,}5\ \text{Mev} < E_e < 3\ \text{Mev},$$

$$\left(\sin^2\theta_W + \frac{\delta}{2}\right) = 0{,}32 \pm 0{,}05 \qquad 3\ \text{Mev} < E_e < 4{,}5\ \text{Mev} \tag{13}$$

the data on reactions (7c) and (7d) are very poor and one may only conclude from them that

$$0{,}1 < \left(\sin^2\theta_W - \frac{\delta}{2}\right) < 0{,}6, \text{ reaction (7c)}, \quad [19]$$

$$0{,}1 < \left(\sin^2\theta_W - \frac{\delta}{2}\right) < 0{,}4, \text{ reaction (7d)}. \quad [20] \tag{14}$$

On the other hand, in the generalization of the Weinberg model here considered, as was mentioned above, anomalous interaction must not give a contribution to semileptonic processes

$$\nu_\mu\,(\bar{\nu}_\mu) + N \to \nu_\mu\,(\bar{\nu}_\mu) + \text{hadrons} \tag{15}$$

so that these processes are determined only by the parameter $\sin^2\theta_W$.

The most of the data on reactions (15) gives for

$\sin^2\theta_W$ the value lying within the interval

$$0.28 < \sin^2\theta_W < 0.38. \qquad (16)$$

Thus, assuming the validity of the Weinberg model and permitting the μ-e -nonuniversality in the form (1) from the data of (13-16) one may conclude that

$$\delta \equiv \frac{f^2}{\sqrt{2}GM_x^2} \lesssim 0.16.$$

So, the considered interaction violating the μ-e -universality in the model with four quarks and with four leptons must be weaker than usual weak one. This conclusion remain valid even in a more general case when there are more quarks and anomalous interaction of leptons with hadrons is possible. The expected difference between cross sections of ep- and μp - scattering is characterized by the factor $\lesssim Gq^2$ where q is the momentum transfer (it is supposed that $|q^2|_{exp} \ll M_x^2$) and possible difference in cross sections of the processes (15) must be characterized by the value of order δ.

3. Conclusions

Initial attempts to introduce anomalous interaction for muons were made aiming to explain the mass difference of muon and electron. It can be easily seen that the μ-e universality violation scheme here proposed does not allow one to get different additions to muon and electron masses due to interaction with the field X_α. This, however, is not required at the nowadays level of constructing gauge -invariant models where the nonuniversality of interaction with scalar Higgs fields provides the mass difference of fermions. In this case the interactions of fermions with the vector fields are universal and what has been done in this paper is that we have demonstrated the possibility of nonuniversality due to the difference of electronic and muonic charges interacting with the vector field the introduction of which does not spoil the renormalizability of initial gauge-invariant theory.

The question whether such anomalous interaction is real will be answered when it will be possible to improve the accuracy of measurement of the processes connected with the interactions of neutral currents. Another decisive experiment would be the observation of $\mu \to e\gamma$ (or $\mu \to ee\bar{e}$) decay since in this case e and μ cannot be characterized by conserving quantum numbers L_e, L_μ and, consequently, there are no logical grounds for introduction of anomalous interaction. Note that in the framework of gauge-invariant models the $\mu \to e\gamma$ decays at a level of 10^{-9}-10^{11} from the total width are possible only in the case of expanding the leptonic sector by addition of heavy leptons [21,22].

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Table I

The coefficients A and B in formula (10)
for a different reactions

Reaction	A	B
$\nu_e + e \to \nu_e + e$	$(1+2\sin^2\theta_W+\delta)^2$	$(2\sin^2\theta_W+\delta)^2$
$\bar{\nu}_e + e \to \bar{\nu}_e + e$	$(2\sin^2\theta_W+\delta)^2$	$(1+2\sin^2\theta_W+\delta)^2$
$\nu_\mu + e \to \nu_\mu + e$	$(1-2\sin^2\theta_W+\delta)^2$	$(-2\sin^2\theta_W+\delta)^2$
$\bar{\nu}_\mu + e \to \bar{\nu}_\mu + e$	$(-2\sin^2\theta_W+\delta)^2$	$(1-2\sin^2\theta_W+\delta)^2$

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