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PARITY VIOLATION IN ATOMS IN A SUPERSYMMETRIC MODEL OF WEAK AND E.M. INTERACTIONS

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PARITY VIOLATION IN ATOMS IN A SUPERSYMMETRIC MODEL OF WEAK AND E.M. INTERACTIONS

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Нарушение четности в атомах в суперсимметричной модели слабых и электромагнитных взаимодействий

Изучены нарушающие четность эффекты в атомах и предсказания нейтральных токов в суперсимметричной калибровочной $SU(2)\times SU(2)\times U(1)$ модели. В легком лептонном секторе отклонения от предсказаний модели Вайнберга-Салама малы.

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Parity Violation in Atoms in a Supersymmetric Model of Weak and E.M. Interactions

Parity violation in atoms and neutral current predictions of a supersymmetric SU(2)xSU(")xU(1) gauge model are studied. For light leptonic sector deviations from predictions of Weinberg-Salam theory are small.

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

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1. INTRODUCTION

Recently A.Slavnov and the author of this article have proposed renormalizable supergauge unified models of the weak and electromagnetic interactions of leptons [1]. One of these models is based on the gauge group SU(2)x xU(1) and the other on $SU(2)_R \times SU(2)_L \times U(1)$. In the first model the electron and muon neutral currents are pure vector and therefore no parity violation in atomic physics is predicted, independently of the form of quark neutral currents [2]. On the contrary, the second $SU(2)_R \times SU(2)_L \times$ xU(1) model predicts parity violation in atomic physics because electron and muon neutral currents contain axial parts. The magnitude of parity-violating transitions in atoms depends on the form of quark neutral currents. We limit ourselves to models, where all quark charges are either $Q = 2/3$ or $Q = -1/3$. This constraint forces us to include quarks as left-and right-handed doublets under $SU(2)_L$ and $SU(2)_R$. The coupling constants of the hadronic neutral current are determined from neutrino hadron scattering experimental data [3]. This constraint together with the inequality $M_{Z_1} \ll M_{Z_2}$ leads to the same neutral current predictions (to within $M^2_{Z_1}/M^2_{Z_2} \ll 1$) for light leptonic sector as the Weinberg-Salam (W.-S.) theory. In particular, the order of parity violating effects is the same as in the W.-S. model, in agreement with the Novosibirsk data, which within the systematic uncertainty confirm the W.-S. model predictions of the parity-nonconserving optical rotation, R, in atomic bismuth [4]. Experimental situation here, however, is not quite clear, because the other measurements [5] didn't show parity violation in atoms.

2. *THE $SU(2)_R \times SU(2)_L \times U(1)$ SUPERSYMMETRIC MODEL*

In this section the author describes briefly the supergauge model proposed in article [1]. Matter fields are described by superfield quartets and doublets. The light leptons - electron, muon and their neutrinos - are arranged in superdoublets.

The left-handed light leptons are assigned to doublets under $SU(2)_L$ as follows (written only with fermionic components of superfields)

$$\begin{pmatrix} e \\ \nu_e \end{pmatrix}_L , \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix}_L$$

All the members of $SU(2)_L$ doublets are $SU(2)_R$ singlets. The right-handed light leptons are assigned to doublets of $SU(2)_R$ as follows

$$\begin{pmatrix} e \\ \nu_e \end{pmatrix}_R , \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix}_R$$

and are singlets under $SU(2)_L$.

There are, also, other leptons in the model arranged in superquartets and in the gauge superfields but they are heavier ($m \geq 1.9$ *GeV*) and do not bear on parity violation effects in atoms. For this reason they are not considered here.

Choosing appropriately symmetry breaking parameters, we can obtain a stable minimum of the potential at the following points

$$\langle A^3_+ \rangle = \begin{pmatrix} 0 \\ \gamma \end{pmatrix},$$

$$\langle A_\pm \rangle = \begin{pmatrix} \alpha_\pm & 0 \\ 0 & 0 \end{pmatrix} \qquad (2.1)$$

where A^3_+ is the scalar component of a (2.1) supermultiplet (transforming like a doublet under $SU(2)_R$ and a singlet under $SU(2)_L$) with $T_R A^3_+ = \frac{1}{2}\vec{\sigma} A^3_+$, $T_L A^3_+ = 0$, $SA^3_+ = \frac{1}{2} A^3_+$, and $A_\pm$ are the scalar components of (2.2) supermultiplets with $T_R A_\pm = \frac{1}{2}\vec{\sigma} A_\pm$, $T_L A_\pm = \frac{1}{2} A_\pm \vec{\sigma}$, $SA_\pm = 0$.

Here T_L, T_R, S are the generators of the groups $SU(2)_L$, $SU(2)_R$, $U(1)$.

There are other meson multiplets which don't develop nonzero vacuum expectation values but they do not effect the gauge structure of the theory, thus we ignore them here. Shifting the fields to zero expectation values one obtains the following mass spectrum of charged vector mesons:

$$W_{1\pm} = 2^{-1/2}(V^1_{1\mu} \mp iV^2_{1\mu}), \quad M_1^2 = \frac{g_1^2}{2}(\alpha_+^2 + \alpha_-^2 + \gamma^2),$$

$$W_{2\pm} = 2^{-1/2}(V^1_{2\mu} \mp iV^2_{2\mu}), \quad M_2^2 = \frac{g_2^2}{2}(\alpha_+^2 + \alpha_-^2). \qquad (2.2)$$

Neutral vector mesons and photon are:

$$Z_1, \quad M^2_{Z_1} \approx \frac{(\alpha_+^2 + \alpha_-^2)(f^2 g_1^2 + f^2 g_2^2 + g_1^2 g_2^2)}{2(f^2 + g_1^2)},$$

$$Z_2, \quad M^2_{Z_2} = \frac{\gamma^2 (f^2 + g_1^2)}{2},$$

$$A_\mu = \frac{(fg_2V^3_{1\mu} - fg_1V^3_{2\mu} + g_1g_2U_\mu)}{(f^2g_1^2 + f^2g_2^2 + g_1^2g_2^2)^{1/2}}, \quad M_A = 0, \tag{2.3}$$

where $\vec{V}_{1\mu}$, $\vec{V}_{2\mu}$, U_μ are gauge fields g_1, g_2, f are gauge couplings associated with groups $SU(2)_R$, $SU(2)_L$, U(1) and the masses $M^2_{Z_1}$, $M^2_{Z_2}$ are evaluated under condition $\gamma^2 \gg \alpha_+^2 + \alpha_-^2$.

As a result of spontaneous breaking of gauge symmetry, the electron and muon receive masses

$$m_e = |h_1\alpha_-|, \quad m_\mu = |h_2\alpha_-|, \tag{2.4}$$

where h_1, h_2 are the couplings of a supersymmetric interactions of type Φ^3.

The charged current for light leptons interacting with W_{2-} looks as follows

$$j^W_\lambda = 2^{-1/2} g_2(\bar{\nu}_{eL}\gamma_\lambda e_L + \bar{\nu}_{\mu L}\gamma_\lambda \mu_L). \tag{2.5}$$

Using (2.2) for the effective Fermi coupling constant one has

$$2^{-1/2}G = \frac{g_2^2}{8M_2^2} = \frac{1}{4(\alpha_+^2 + \alpha_-^2)},$$

$$G = \frac{10^{-5}}{m_p^2}. \tag{2.6}$$

The neutral current interacting with the lighter neutral meson (Z_1) is

$$j^{Z_1}_\lambda = 2^{5/4}G^{1/2}M_{Z_1}[(-\frac{1}{2} + \sin^2\theta)(\bar{e}_L\gamma_\lambda e_L + \bar{\mu}_L\gamma_\lambda\mu_L) +$$

$$+ \sin^2\theta(\bar{e}_R\gamma_\lambda e_R + \bar{\mu}_R\gamma_\lambda\mu_R) + \frac{1}{2}(\bar{\nu}_{eL}\gamma_\lambda\nu_{eL} + \bar{\nu}_{\mu L}\gamma_\lambda\nu_{\mu L})], \tag{2.7}$$

with

$$\sin^2\theta = \frac{f^2g_1^2}{(f^2g_1^2 + f^2g_2^2 + g_1^2g_2^2)}, \quad M^2 = \frac{M_2^2}{\cos^2\theta}. \tag{2.8}$$

There are neutral leptons and scalar particles, in the model, also, but they are heavy enough to be not observed in the present day experiments.

3. *QUARK SECTOR*

Leptons in our model are constructed partially from fermionic components of chiral superfields and partially from fermionic components of gauge superfields.

We limit ourselves to models with $Q=\frac{2}{3}$, $Q=-\frac{1}{3}$ non-integer quark charges and consequently the quarks are not mixed with the leptons. Then quarks must be described by only chiral superfields and vacuum expectation values of these superfields must be zero. Therefore the quark sector is completely independent of the lepton sector.

Because of supersymmetry, there exist scalar particles accompanying quarks. Using the mechanism of spontaneous supersymmetry breaking proposed by A.Slavnov /6/ the masses of these scalar bosons can be made large enough to be not seen in the present day experiments /1/, and are ignored. The parity violating effects in atoms are due to "u", "d" quarks, and the author considers only them. Other quarks are incorporated analogously. The left-handed (right-handed) quarks are doublets (singlets) under $SU(2)_L$ and singlets (doublets) under $SU(2)_R$. They are arranged in doublets as follows

$$\begin{pmatrix} d \\ u \end{pmatrix}_L, \quad \begin{pmatrix} d \\ u \end{pmatrix}_R .$$

The abelian gauge coupling of quarks is $\frac{2}{3}\frac{1}{3}f$, then the electromagnetic charges of "u", "d" are $\frac{2}{3}$, $-\frac{1}{3}$, respectively.

The charged quark current interacting with the lighter charmed vector-meson W_2 has the "standard" form

$$j_\lambda^W = 2^{-1/2} g_2 u_L \gamma_\lambda d_L + \dots, \quad g_2 = e/\sin\theta, \tag{3.1}$$

... denotes other quarks.

The quark neutral current interacting with the lighter neutral vector-meson Z_1 looks as follows

$$j_\lambda^{Z_1} = 2^{5/4} G^{1/2} M_{Z_1} [(\frac{1}{2} - \frac{2}{3}\sin^2\theta)\bar{u}_L \gamma_\lambda u_L - \frac{2}{3}\sin^2\theta \bar{u}_R \gamma_\lambda u_R + (-\frac{1}{2} + \frac{1}{3}\sin^2\theta)\bar{d}_L \gamma_\lambda d_L + \frac{1}{3}\sin^2\theta \bar{d}_R \gamma_\lambda d_R]. \tag{3.2}$$

The coupling constants of hadronic neutral current can be determined from inclusive, semi-inclusive and exclusive neutrino processes /3/. Neglecting strange and charged quarks, the most general neutral current interaction for neutrino hadron scattering is

$$\mathcal{L} = 2^{3/2} G \bar{\nu}_L \gamma^\lambda \nu_L \mathcal{J}_\lambda^{NC} \tag{3.3}$$

with

$$\mathcal{J}_\lambda^{NC} = (a_L \bar{u}_L \gamma_\lambda u_L + a_R \bar{u}_R \gamma_\lambda u_R) + (b_L \bar{d}_L \gamma_\lambda d_L + b_R \bar{d}_R \gamma_\lambda d_R). \tag{3.4}$$

There is a certain information on neutrino hadron processes and it is in good agreement with the Weinberg values of parameters

$$a_L = \frac{1}{2} - \frac{2}{3}\sin^2\theta_w, \quad b_L = -\frac{1}{2} + \frac{1}{3}\sin^2\theta_w, \quad a_R = -\frac{2}{3}\sin^2\theta_w, \quad b_R = \frac{1}{3}\sin^2\theta_w, \tag{3.5}$$

with $\sin^2\theta_w \approx 0.3$.

Equations (2.7), (3.2), (3.3) give for θ

$$\sin^2\theta \approx \sin^2\theta_w \approx 0.3,$$

hence leptonic neutral current (2.7) and hadronic one (3.2) are identical with W.-S. neutral currents and neutral current predictions (in particular, parity violating effects in atoms) of our supersymmetric gauge model coincide with predictions of the W.-S. model. This is true only in the limit $M_{Z_2}^2 \to \infty$. For finite $M_{Z_2}^2$ there are small deviations from W.-S. neutral current predictions. These deviations are estimated by the ratio $M_{Z_1}^2 / M_{Z_2}^2$

$$\frac{M_{Z_1}^2}{M_{Z_2}^2} \sim \frac{M_{W_1}^2}{M_{W_2}^2} \sim \frac{\text{"left-handed currents"}}{\text{"right-handed currents"}} \ll 1$$

and are undetectable in the present-day experiments.

4. CONCLUSIONS

I have studied the neutral current predictions of the sypersymmetric SU(2)xSU(2)xU(1) gauge model proposed in article /1/. In the light leptonic sector (e, μ, ν_e, ν_μ) they coincide (to within 1%) with predictions of the W.-S. theory.

The main differences between our supersymmetric model and standard W.-S. model lie in heavier leptonic sector. Our model provides a natural explanation for Higgs mechanism, predicts heavy leptons (charged and neutral) and gives a sum rule between the masses of heavy charged leptons and intermediate vector-meson masses.

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