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О возможном подавлении P -нечетных эффектов в тяжелых атомах

Рассмотрена $SU_2 \times U_1$ калибровочная теория слабого и электромагнитного взаимодействий, в которой нейтральный ток адронов содержит векторную и аксиальную части, а P - нечетные эффекты в тяжелых атомах, таких как ^{209}Bi и ^{133}Cs, подавлены. Показано, что в этой модели P -нечетная асимметрия в процессах глубоконеупругого рассеяния поляризованных лептонов нуклонами такого же порядка (10^{-4} q^2/M^2), как и в стандартной теории.

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On a Possible Suppression of the Parity Violation Effects in Heavy Atoms

An $SU_2 \times U_1$ gauge theory of weak and electromagnetic interactions is considered in which the hadron neutral current contains both vector and axial vector terms but the parity violation effects in heavy atoms (such as ^{209}Bi and ^{133}Cs) are suppressed. It is shown that the parity-violating asymmetry predicted by this model in the processes of deep inelastic scattering of polarized leptons on nuclei has the same order of magnitude ($10^{-4} q^2/M^2$) as that predicted by the standard theory.

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

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Recently, the first results of the experiments on possible parity violation effects in atomic tranzitions have been published /1/. For a linearly polarized light, the polarization plane rotation in atomic ^{209}Bi was measured in two distinct experiments. The results obtained for $R = \frac{Im\langle f|E_1|i\rangle}{\langle f|M_1|i\rangle}$ (the ratio of the parity non-conserving E_1-transition matrix element to M_1 - the normal one)

$$R_1^{exp} = -8 \pm 3 \cdot 10^{-8}$$

$$R_2^{exp} = 10 \pm 8 \cdot 10^{-8}$$

are smaller than those predicted /2/ by the Weinberg-Salam model /3/ with four leptons and as many quark flavours /5/ i.e.,

$$R_1^{w-s} = -3 \cdot 10^{-7}$$

$$R_2^{w-s} = -4 \cdot 10^{-7}$$

(the quoted statistical errors in $R_{1,2}^{exp}$ represent 2 s.d.), and within the systematic uncertainty ($\pm 10 \cdot 10^{-8}$) are each consistent with $R=0$.

On the other hand, the neutrino experiment data /4/ imply the existence of a vector as well as an axial vector term in the neutral hadron current.

In the present note we discuss whether the (V,A) structure of the neutral hadron current and the suppression of the parity violation effects in heavy atoms are compatible within the framework of the $SU_2 \times U_1$ unified gauge theories of weak and electromagnetic interactions.

The relevant part of the weak interaction effective Hamiltonian in $SU_2 \times U_1$ gauge theories has the following general form:

$$H = \frac{G}{\sqrt{2}} \kappa \, j^z_\alpha j^z_\alpha , \qquad (1)$$

where $\kappa = \frac{M_w^2}{M_z^2 \cos^2\theta_w}$ (M_w, M_z are the masses of the charged and neutral intermediate bosons respectively, θ_w is the Weinberg angle), and

$$j^z_\alpha = j^\ell_\alpha + j^h_\alpha ,$$

$$j^\ell = \sum_{\ell = e,\mu} \bar{\ell} \gamma_\alpha (v_\ell + a_\ell \gamma_5) \ell , \qquad (2)$$

$$j^h_\alpha = \sum_{q=u,d,..} \bar{q} \gamma_\alpha (v_q + a_q \gamma_5) q . \qquad (3)$$

The constants v_i and a_i depend on the choice of a particular model and u(d) denote the up (down) quarks. In the standard theory of weak and electromagnetic interactions [3,5] one has:

$$v_\ell = -\frac{1}{2} + 2\sin^2\theta_w , \quad a_\ell = -\frac{1}{2} (\ell = e, \mu),$$

$$v_u = \frac{1}{2} - \frac{4}{3}\sin^2\theta_w , \quad a_u = \frac{1}{2} ,$$

$$v_d = -\frac{1}{2} + \frac{2}{3}\sin^2\theta_w , \quad a_d = -\frac{1}{2}$$

and $\kappa = 1$.

It is well known [6,7] that the main contribution to the parity violation effects in heavy atoms (^{209}Bi, ^{133}Cs) is given by the product of the axial vector part of the electron neutral current and the vector part of the hadron neutral current. In the non-relativistic approximation the corresponding term of the effective Hamiltonian has the following form [6]:

$$H_{pv}(\vec{x}) = \frac{G}{\sqrt{2}} 2\kappa Q \frac{1}{2m_e} \{ \vec{\sigma} \cdot \vec{p}_e \, \delta(\vec{x}) + \delta(\vec{x}) \vec{\sigma} \cdot \vec{p}_e \}$$

where

$$Q = -a_e [(2v_u + v_d) Z + (v_u + 2v_d) N]$$

(Z(N) is the number of protons (neutrons) in the atom), and m_e, $\vec{\sigma}$, $\vec{p}_e$ are the mass, spin operator and momentum operator of the electron respectively.

If the charged lepton neutral current has a pure vector structure ($a_e = 0$), then the parity violation effects are strongly suppressed in heavy atoms (which is possibly indicated by the experimental results [1]). In an $SU_2 \times U_1$ gauge theory the neutral current of charged leptons can be a pure vector in that case only when the theory includes both left-handed and right-handed doublets. We shall consider just such a scheme in the present note.

Suppose that the doublets of the $SU_2 \times U_1$ gauge theory of weak and electromagnetic interactions are as follows [8]:

$$\begin{pmatrix} \nu_e \\ e \end{pmatrix}_L , \quad \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L , \quad \begin{pmatrix} N_e \\ e \end{pmatrix}_R , \quad \begin{pmatrix} N_\mu \\ \mu \end{pmatrix}_R .$$

$$\begin{pmatrix} u \\ d_c \end{pmatrix}_L , \quad \begin{pmatrix} c \\ s_c \end{pmatrix}_L , \quad \begin{pmatrix} u \\ b \end{pmatrix}_R , \quad \begin{pmatrix} c \\ t \end{pmatrix}_R .$$

Here N_e and N_μ are the field operators of two heavy neutral leptons, b and r are the field operators of two heavy quarks with charges (-1/3), $d_c = d\cos\theta_c + s\sin\theta_c$, $s_c = -d\sin\theta_c + s\cos\theta_c$ (θ_c is the Cabibbo angle). Obviously, the masses of the leptons N_e and N_μ must be greater than the kaon mass. The neutral currents of the charged leptons and hadrons in this scheme have the form (2) and (3) respectively with

$$v_\ell = -1 + 2\sin^2\theta_w, \quad a_\ell = 0,$$
$$v_u = 1 - \frac{4}{3}\sin^2\theta_w, \quad a_u = 0, \qquad (4)$$
$$v_d = -\frac{1}{2} + \frac{2}{3}\sin^2\theta_w, \quad a_d = -\frac{1}{2}.$$

Note that the neutral hadron current has the following structure:

$$j^h_\alpha = \frac{3}{2} V^3_\alpha + \frac{1}{2} A^3_\alpha - 2\sin^2\theta_w J^{em}_\alpha + J^s_\alpha,$$

where $V^3_\alpha (A^3_\alpha)$ is the third component of the vector (axial vector) isovector current, J^{em}_α is the electromagnetic hadron current and J^s_α is the isoscalar current.

Let us list the basic features of the model.

1. The weak interaction Hamiltonian contains a right-handed charged hadron current in addition to the left-handed one of the standard theory. As is shown in ref.[9], the presence of such a current allows one to explain the so-called "high y-anomaly"[10] in the process $\bar\nu_\mu N \to \mu^+ X$ and the growth[11] with energy of the ratio of the antineutrino and neutrino total cross sections

$$\frac{\sigma(\bar\nu_\mu N \to \mu^+ X)}{\sigma(\nu_\mu N \to \mu^- X)}.$$

2. The neutral hadron current contains both vector and axial vector terms what is in agreement with the neutrino experiment data[4].

3. If a lepton mixing takes place in the present model then the decays $\mu \to e\gamma$, $\mu \to 3e$, etc., can occur. For the heavy lepton masses of order of a few GeV the $\mu \to e\gamma$ decay rate might be close[12] to its experimental upper bound.

4. The neutral current of the charged leptons is a pure vector. This implies that the cross sections for $\nu_\mu - e$ and $\bar\nu_\mu - e$ elastic scattering processes are equal

$$\sigma_{\nu_\mu e} = \sigma_{\bar\nu_\mu e} \qquad (5)$$

(note that the corresponding differential cross sections are equal too). The experimental check of equality (5) can serve as one of the basic tests of the theory under consideration.

Further on, the charged lepton weak interaction Hamiltonian conservs parity. So the parity violation effects in the leptonic processes

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

are absent in this scheme.

The parity violation effects in atomic transitions are due to the contribution of the axial vector part of the neutral hadron current and hence for the heavy atoms ($Z > 50$) they are considerably smaller[6] (approximately by two orders of magnitude) than the effects predicted by the standard theory.

So we see that if the discussed form of the charged lepton neutral current is actually realized in nature the role of the experiments searching for a possible parity violation effects in high-energy electron (muon)-hadron processes essentially increases.

We shall consider briefly the processes of deep inelastic scattering of polarized leptons on nucleons*:

$$\ell + N \to \ell + X. \qquad (6)$$

The parity violation effects in these processes have been considered in detail in ref. /15/. They are due to the interference of the contributions of the diagrams with exchange of a virtual photon and a virtual Z^o -boson and have order of magnitude

$$\frac{G}{\sqrt{2}}\,\frac{q^2}{4\pi\alpha} \sim 10^{-4}\,\frac{q^2}{M^2},$$

M being the proton mass and q^2 – the square of the momentum transferred to hadrons. In the CERN-Dubna-München-Saclay experiment on deep inelastic scattering of muons on protons /16/ which is under preparation the values of $q^2 \sim 500$ GeV^2 are to be reached. For these values of q^2 the parity - violating asymmetry is expected to be of order of a few per cent.

The cross section of deep inelastic scattering of leptons with longitudinal polarization λ on unpolarized nucleons has the following form:

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*The first experimental study of reaction (6) with polarized electron /13/ and muon /14/ beams performed recently has given the upper bound of the parity-violating asymmetry approximately by an order of magnitude greater than the value predicted by the standard theory.

$$\frac{d^2\sigma}{dq^2\,d\nu} = \left(\frac{d^2\sigma}{dq^2\,d\nu}\right)_0 (1+\lambda A).$$

Here $\left(\frac{d^2\sigma}{dq^2\,d\nu}\right)_0$ is the cross section for scattering of unpolarized particles, and A is a parity-violating asymmetry (ν is the energy transferred to the hadrons in the laboratory frame). In the case under consideration the lepton neutral current is a vector so it is obvious that

$A_+ = A_-$,

where A_+ is the asymmetry in the reaction

$$e^+(\mu^+) + N \to e^+(\mu^+) + X$$

and A_- is the corresponding one in the reaction

$$e^-(\mu^-) + N \to e^-(\mu^-) + X.$$

The asymmetry A for the case of ℓ –p scattering in the quark-parton approximation is given by:

$$A = \frac{G}{\sqrt{2}}\,\kappa\,\frac{q^2}{2\pi\alpha}\,\frac{M_z^2}{M_z^2+q^2}\,(-1+2\sin^2\theta_w) \times \qquad (7)$$
$$\times \frac{3y(2-y)}{[1+(1-y)^2]}\,\frac{d(x)}{[4u(x)+d(x)]}$$

($u(x)$ and $d(x)$ are u and d quark density distribution functions in a proton, $x = \frac{q^2}{2M\nu}$, $y = \frac{\nu}{E}$, E is the initial lepton energy in the lab. frame; note that the quark sea contribution to the asymmetry is neglected).

We shall write down also the expression for the asymmetry $\mathcal{A}$ for fixed q^2 (the integration over ν is carried out) for scattering of leptons on nuclei with equal number of protons and neutrons. As follows from (7) $\mathcal{A}$ has the form:

$$\mathcal{A} = \frac{3}{10}\,\frac{G}{\sqrt{2}}\,\frac{q^2}{2\pi\alpha}\,\kappa\,\frac{M_z^2}{M_z^2+q^2}(-1+2\sin^2\theta_w).$$

For $\kappa = 1$ and $q^2 \ll M_z^2$ we get:

$$\mathcal{A} \sim 0.5\times10^{-4}\,\frac{q^2}{M^2}(-1+2\sin^2\theta_w).$$

So far the case of two charged leptons has been considered. In the case when more than two charged leptons are present /7/ the charged lepton neutral current is a vector if the field of each of them enters both into the left-handed and right-handed doublet of the $SU_2\times U_1$ gauge group. All stated above applies equally to that case.

In conclusion we would like to emphasize that in the model we have discussed the weak interaction Hamiltonian of the charged leptons and hadrons does not conserve parity. However, the parity violation effects in heavy atoms, such as ^{209}Bi and ^{133}Cs, are considerably smaller than those calculated on the basis of the standard theory. The parity-violating asymmetry predicted by the model in the processes of deep inelastic scattering of polarized leptons on nucleons is of the same order of magnitude as the asymmetry predicted by the standard theory.

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