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Р-нечетные эффекты в тяжелых атомах и знак константы слабого взаимодействия

На основе альтернативной модели Бьеркена рассмотрены Р-нечетные эффекты в тяжелых атомах. Характеризующий несохранение четности параметр $R = \mathrm{Im}\,\frac{E_1}{M_1}$ определяется в этой теории анапольным моментом электрона и знаком G. Показано, что измерение Р-нечетных эффектов в двух различных тяжелых атомах позволило бы определить как анапольный момент, так и знак G.

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Parity Violation Effects in Heavy Atoms and the Sign of the Weak Coupling Constant

Parity violation effects in heavy atoms are considered in the framework of the SU(2) invariant four-fermion theory. The parameter $R = \mathrm{Im}\,\frac{E_1}{M_1}$ which characterises the parity nonconservation is determined in this theory by the anapol momentum of the electron and the sign of the Fermi constant G. We have shown that the measurement of the magnitude of the parity violation effects for two different heavy atoms would make possible the determination of both these quantities.

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

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The unified gauge theories of weak and electromagnetic interactions permit one to describe a large amount of the existing data on weak processes. In particular, it was shown recently[1,2,3] that all the available data on weak neutral currents can be described satisfactorily by the standard theory of the weak interaction[4,5]. In this connection one may ask whether the experimental data exclude the four-fermion theory as a possible theory of the weak interaction.

In a recent paper[1] it was shown that all the neutral current data can be described successfully by an SU(2) invariant four-fermion Hamiltonian* provided the neutrino has an electromagnetic radius $\sim 10^{-16}$ cm. In the present note we shall discuss the parity violation effects in heavy atoms arising in such a theory. We will show that the experiments which are now in progress may be of great importance for testing this possibility.

The SU(2) invariant four-fermion Hamiltonian is given by the expression**:[1,6]

$$\mathcal{H} = \frac{G}{\sqrt{2}}\, j^k_a\, j^k_a\,, \tag{1}$$

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* The question as to whether the existing data exclude the four-fermion theory was discussed also by V.N.Gribov and L.B.Okun at a meeting on the "DUMAND" project (1977).

**Let us note that the symmetric neutral current was discussed[7] in the four-fermion theory a long time before the gauge theories were proposed.

where

$$j_\alpha^k = \sum_a \bar{\psi}_{aL} \gamma_\alpha \tau^k \psi_{aL} + \dots \qquad (2)$$

The SU(2) doublets ψ_a have the form:

$$\begin{pmatrix} \nu_e \\ e \end{pmatrix}, \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}, \dots ; \begin{pmatrix} u \\ d\cos\theta_C + s\sin\theta_C \end{pmatrix}, \begin{pmatrix} c \\ -d\sin\theta_C + s\cos\theta_C \end{pmatrix}, \dots \qquad (3)$$

We can rewrite the Hamiltonian (1) in the following way

$$\mathcal{H} = \frac{G}{\sqrt{2}} (j_\alpha \bar{j}_\alpha + j_\alpha^3 j_\alpha^3), \qquad (4)$$

where $j_\alpha = j_\alpha^1 + i j_\alpha^2$ is the charged weak current. The first term in this expression coincides with the relevant term of the effective Hamiltonian of the standard theory. The neutral current of the four-fermion interaction (4) differs considerably from the neutral currents arising in the gauge schemes. As is well known, neutral current of the standard SU(2)×U(1) theory has the form:

$$j_\alpha^z = j_\alpha^3 - 2\sin^2\theta_W \, j_\alpha^{em}, \qquad (5)$$

where j_α^{em} is the electromagnetic current and θ_W is the Weinberg angle. The structure of j_α^z is consistent /1-3/ with all neutral current data obtained so far in the high energy neutrino experiments.

In ref. /1/ it was assumed that the additional term in the neutral current might arise due to the electromagnetic interaction of the neutrino with the charged particles. The electromagnetic vertex of the two-component neutrino has the form:

$$\Gamma_\alpha(k', k) = -ie\,\bar{u}_L(k')\gamma_\alpha u_L(k) q^2 R(q^2), \qquad (6)$$

where k and k′ are the initial and final momenta of the neutrino, $q = k - k'$, e – is the charge of proton. If $\frac{G}{|G|} R(q^2) \simeq \frac{1}{\Lambda^2} = \text{const}$ for high q^2 ($q^2 \gtrsim 1\,\text{GeV}^2$) such a theory describes the existing data on weak neutral currents, the relation between Λ and $\sin^2\Theta_W$ being:

$$\frac{e^2}{\Lambda^2} = 4\frac{|G|}{\sqrt{2}} \sin^2\Theta_W. \qquad (7)$$

Note that for $\sin^2\Theta_W \simeq \frac{1}{3}$, $\Lambda \simeq 160$ GeV and $\frac{1}{\Lambda} \simeq 1.2 \cdot 10^{-16}$ cm.

We would like to notice first that instead of the parameter $2\sin^2\Theta_W$ of the standard theory in the matrix element of the hadron neutral current in the case of the four-fermion theory under consideration there appears $\frac{e^2}{\sqrt{2}\,G} R(q^2)$. One would expect the strongest q^2-dependence of the form factor $R(q^2)$ to hold /8/ at low q^2 (of an order of several hundred MeV^2). Therefore the experiments with neutrino beams from meson factories might permit one to test this theory. Note also that at low q^2 the electromagnetic form factors of ν_μ and ν_e may differ considerably /8/. In this connection it would be desirable to perform meson factory experiments that would give information about the scattering of both ν_μ and ν_e on nucleons.

The most fundamental difference between the four-fermion theory and the gauge theories is due to the sign of the weak coupling constant G. Such a sign can be positive as well as negative* in the four-fermion theory whereas in the gauge theories the effective constant G is definitely positive:

$$\frac{G}{\sqrt{2}} = \frac{e^2}{8 m_W^2 \sin^2\Theta_W} > 0. \qquad (8)$$

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* Let us note that the theory developed in ref. /6/ requires $G > 0$.

The sign of G can be determined in experiments where the effects due to the interference of weak electromagnetic amplitudes are investigated /10,11/. Such are the parity violation effects in atomic transitions and in deep-inelastic scattering of polarized charged leptons on nucleons, etc. Here we shall consider only the effects of parity nonconservation in heavy atoms. As is well known, the main contribution to these effects is given by the product of the axial part of the electron neutral current and the vector part of the hadron neutral current. In the four-fermion theory under consideration by analogy with the neutrino case, we must take into account the anapol momentum of the electron /10,12/, which might be induced by the weak interaction. The anapol term in the electron electromagnetic vertex has the form:

$$\Gamma_{\alpha}^{a}(k',k) = -ieq^{2}A(q^{2})\bar{u}(k')(\gamma_{\alpha} - \frac{q_{\alpha}\hat{q}}{q^{2}})\gamma_{5}u(k), \qquad (9)$$

where k and k′ are the initial and final momenta of the electron, and $q = k - k'$. In the nonrelativistic approximation, the leading parity nonconserving term of the electron-nucleus potential in which the contribution of the anapol momentum of the electron has been taken into account is given by the expression:

$$V_{PV}(\vec{x}) = \frac{|G|}{2\sqrt{2}} Q_{W} \frac{1}{2m_{e}} \vec{\sigma}\cdot p\delta(\vec{x}), \qquad (10)$$

where m_e, $\vec{\sigma}$ and $\vec{p}$ are respectively the mass, spin and momentum operators of the electron and

$$Q_{W} = -(N - Z(1-4a))\frac{G}{|G|}. \qquad (11)$$

Here N(Z) is the number of neutrons (protons) in the nucleus and

$$a = \frac{e^{2}}{\sqrt{2}\,G} A(0). \qquad (12)$$

For comparison, we shall write down also the expression for the weak charge Q_W in the Weinberg-Salam theory:

$$(Q_{W})_{W-S} = -(N - Z(1-4\sin^{2}\Theta_{W})). \qquad (13)$$

If the relation (7) holds for the value of $\sin^2\Theta_W$ in the interval 0.25÷0.35 (as implied by experiments) the parameter a in general does not lie in the same interval. (Arguments in favour of this possibility come, for example, from the analysis /10/ of the diagrams which give contributions to the electromagnetic formfactor of the neutrino and to the anapol momentum of the electron). Therefore, it should be expected that the parity violation effects in heavy atoms arising in the SU(2)-invariant four-fermion theory may be different from the effects predicted on the basis of the standard theory (in particular, the parity violation effects in ^{209}Bi are strongly suppressed for $a \simeq -0.13$). The parity violation effects in these two theories may differ not only in magnitude but also in sign.

In order to determine both the magnitude of the anapol momentum a and the sign of the constant G, it is necessary to measure the value of the parameter $R = \mathrm{Im}\frac{E_1^*}{M_1}$, which characterized the parity nonconservation, at least, for two different heavy atoms (^{209}Bi, ^{133}Cs, ^{205}Te, etc.). Such experiments, as is well-known, are in progress at present.

At the end of 1977 there were published the first results of two experiments in which the rotation of the polarization plane of a polarized light

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[*] The definition of this parameter can be found, for example, in the review article: A.N.Moskalyov, R.M.Ryndin and I.B.Khriplovich Sov.Journ.Uspekhi Fizicheskih Nauk, 118, 407 (1976).

traversing bismuth vapour was measured. In ref.[13,14] the following values of the parameter R were reported, respectively: $-0.7\pm3.2\cdot10^{-8}$ ($\lambda = 8757$ Å) and $2.7\pm4.7\cdot10^{-8}$ ($\lambda = 6480$ Å). The corresponding values of R calculated within the Weinberg-Salam theory in ref.[15] are equal to $-16\cdot10^{-8}$ and $-21\cdot10^{-8}$, respectively.

Recently, the first data of the Novosibirsk group which also are measuring the parity violation effects in ^{209}Bi, have been published[16]. The preliminary result obtained by this group is: $\frac{R_{exp}}{R_{W-S}} = (1.4\pm0.3)\times(1\pm0.5)$ (R_{W-S} is the Weinberg-Salam value of the parameter R calculated in ref.[15]).

It is quite clear that the clarification of the experimental situation concerning the parity violation effects in ^{209}Bi as well as the measurement of P-odd effects in other heavy atoms would be of great importance for understanding the nature of the weak interaction.

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