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ЛАБОРАТОРИЯ ТЕОРЕТИЧЕСКОЙ ФИЗИКИ

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A possible mechanism of CP-violation in the interaction of particles with electromagnetic field is discussed in this note. The coupling constant of the interaction is Ge where G is the weak interaction coupling constant and e – the electron charge. As a guide we exploit considerations of the geometric model of weak interactions[1] (details of the model to be published elsewhere). Four leptons are described in this approach by the unified superspinor Ψ_L and eight baryons – by superspinor Ψ_B, these fields together with electromagnetic field defining the space-time structure (the curvature, the torsion etc.). In the lowest approximations (quasi-euclidean approximation[1]) the geometric theory gives the effective lagrangians of the electromagnetic ($\sim e$) and of the weak ($\sim G$) interactions. CPT, CP and γ_5-invariances are valid in these orders.

In the next approximation ($\sim Ge$) the torsion of the space-time may be significant. Following the spirit of the unified field theories of Einstein[2] and Schroedinger[3] we connect electromagnetic field $F_{mn} = \partial_m A_n - \partial_n A_m$ with the antisymmetric part $g_{[mn]}$ of the metric tensor g_{mn} ($g_{[mn]}$ defines the torsion). Using dimensionality considerations (g_{mn} is dimensionless) we set $g_{[mn]} = \lambda Ge F_{mn}$, λ being a number. Now it can be easily seen that the kinetic part $i g_{mn} \gamma_m \partial_n \psi$ of the Dirac equation for a particle ψ gives rise to the interaction Lagrangian

$$\frac{i}{2} \lambda\, Ge (\bar{\psi} \gamma_m \partial_n \psi - \partial_n \bar{\psi} \gamma_m \psi) F_{mn} . \tag{1}$$

This interaction violates CP but conserves parity P. In general, the geometric theory may lead, however, to the more complicated interaction of the superspinors Ψ_ρ $(\rho = L,B)$ with F_{mn}:

$$L_\rho = \frac{1}{2} \lambda\, Ge (\bar{\Psi}_\rho O_m \Gamma_\rho \partial_n \Psi_\rho - \partial_n \bar{\Psi}_\rho O_m \Gamma_\rho \Psi_\rho) F_{mn} . \tag{2}$$

Here Γ_ρ are hermitian matrices operating on the particles as a whole and commuting with the operator of the electric charge; $O_m = a\gamma_m + b\gamma_m\gamma_5$.
If γ_5-invariance is additionally required, we find $O_m = \gamma_m (1+\gamma_5) \equiv V_m - A_m$.

Lagrangian (2) changes its sign under CP-transformation. Its part with V_m is P-invariant, whereas the part with A_m is C-invariant. It is evident that the whole Lagrangian is invariant under CPT. The conservation of the muonic charge, at least in Ge order, is proved by the absence of $\mu \to e\gamma$ transition[4]. Thus, Γ_L should commute with the muonic charge and so it is diagonal[1]. The matrix Γ_B may have both diagonal ($\Delta Y=0$) matrix elements and nondiagonal $(\Delta Y \neq 0)$ · ones, the latter corresponding to $|\Delta Y| = 1$. The transitions with $|\Delta Y| > 1$ are excluded experimentally[5].

We will discuss possible experimental consequences of the interaction (2), bearing in mind the mentioned general restrictions on Γ_ρ. It can be easily found that the diagonal terms in (2) give the electric dipole moment of the i-th particle

$$\bar{d}_i = 2\lambda G m_i^2 \Gamma_{ii} \left(\frac{e}{2m_i}\right)\bar{\sigma} = 2\lambda \Gamma_{ii}\, 10^{-5} \left(\frac{m_i}{m}\right)^2 \left(\frac{e}{2m_i}\right)\bar{\sigma} . \qquad (3)$$

From the experimental upper bound for the neutron e.d.m.[6] $d_n < 2.3 \cdot 10^{-6} \left(\frac{e}{2m}\right)$ we have $\lambda \Gamma_{nn} \lesssim 0,.1$. The search for e.d.m. of various particles, especially of the neutron, seems to be extremely important for the test of the CP-violating mechanism.

The effects of CP-violation having a relative order of e^2 in weak nonleptonic decays are caused by an exchange of a virtual photon, emitted from the Ge vertex (2) and absorbed in the usual vertex. This gives, in particular, the qualitative explanation of the magnitude of the CP-violation $(\epsilon \approx \frac{\alpha}{\pi})$ in the decay $K_2^0 \to 2\pi$ [7]. In calculations it may be helpful to use the phenomenological $K\pi\gamma$ interaction Lagrangian (other interactions can be written in the same way):

$$L = \frac{\lambda'}{2} Ge \left[(\partial_m K\, \partial_n \pi^* - \partial_n K\, \partial_m \pi^*) + h.c. \right] F_{mn} . \qquad (4)$$

Note that the interaction vanishes for identical particles. The constant λ' may differ from λ.

The important consequence of our mechanism is the absence of CP-violation effects in leptonic decay modes of all particles (the effect being of the order Ge^2 in comparison with weak interaction). This does not contradict to the present experimental evidence[8].

The mechanism under consideration predicts strong effects (≈ 1) in radiative decays of baryons with $|\Delta Y| = 1$ ($\Sigma^+ \to p\gamma$, $\Lambda \to n\gamma$ etc). One should expect the same for the radiative decay modes of K-mesons. The necessity of taking into account the interaction of pions in the final state complicates, however, the interpretation of the latter effect. The search for the $K^{\pm}$-decays with internal conversion of the photon ($K^{\pm} \to \pi^{\pm} e^+ e^-$, $\pi^{\pm}\mu^+\mu^-$) is of great interest. The investigation of this process would allow one to define the coupling constant λ' in (4).

Our mechanism gives some interesting consequences for scattering processes involving leptons. Especially important is the search for polarizations in e-e scattering, which are forbidden by CP-invariance. Some CP-violation effects are possible in the scattering of leptons by protons, the amplitude being of the order Ge^2 (due to the one-photon exchange).

A direct test of CP and C-violation in hardon decays may be provided by the measurement of partial decay widths of particles and antiparticles (see e.g.[9]). The most significant effect can be found in weak radiative decays. For instance, the partial widths of the charge conjugated reactions of K^+ and K^- in the processes $K^{\pm} \to \pi^{\pm}\pi^0\gamma$; $K^{\pm} \to \pi^{\pm}\pi^+\pi^-\gamma$, $\pi^{\pm}\pi^0\pi^0\gamma$ may be quite different. The same is true for weak radiative decays of baryons and antibaryons. The partial decay widths in processes without radiation may differ in terms of the order e^2. Of course, the CPT invariance provides the compensation of all these effects in the total width.

Our CP-violating mechanism can be experimentally distinguished from other hypotheses in which the photons play an essential role[10,11]. In this sense the test as to whether there are any CP-violation effects in leptonic decays is the most important.

The possibility of the CP-violating interaction of photons and hadrons with coupling constant of the order Ge was independently pointed out by L.Okun. Without specifying the mechanism of this interaction, he discussed its possible experimental consequences for weak radiative decays of hadrons. Considerations based on the geometric model of weak interactions allow one to find the form of such an interaction quite naturally. The appealing feature of the new interaction proposed here is the possibility to connect the CP-violation with the space-time torsion, vanishing in the absence of interactions.

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