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NEW UPPER LIMITS OF THE T-INVARIANCE VIOLATION IN β-DECAY

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НОВОСИБИРСК

New Upper Limits on the T-Invariance Violation
in β-Decay

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ABSTRACT

Upper limits on the imaginary parts of the β-decay weak magnetism and weak electricity constants, which violate T-invariance, are obtained on the level 10^{-4}.

In recent paper [1] strict upper limits were established for some T-invariance violating β-decay parameters. Namely, for the tensor, scalar and pseudoscalar lepton-nucleon constants they are

$$\mathrm{Im}(C_T+C'_T)<0.5\cdot10^{-3},$$
$$\mathrm{Im}(C_S+C'_S)<4\cdot10^{-3}, \qquad (1)$$
$$\mathrm{Im}(C_P+C'_P)<0.3$$

(in the preprint mentioned these limits were explicitly given for the corresponding lepton-quark constants, but the reformulation of those limits for the lepton-nucleon ones is straightforward). Here we shall get the limits on the T-invariance violating imaginary parts of the weak magnetism and weak electricity constants g_m and g_e. At present there is no direct experimental information on these parameters. Recent experimental proposal [2] aims at the accuracy about 10^{-2} in the measurement of the corresponding T-odd correlations in A=8 β-decays.

Let us write down the corresponding lepton-quark β-decay interaction as

$$\frac{G}{\sqrt{2}}\frac{1}{2m_p}[\bar{e}\gamma_\mu(1+\gamma_5)\nu\cdot\bar{u}(\tilde{g}_m+\tilde{g}_e\gamma_5)\sigma_{\mu\lambda}k_\lambda d + \text{h.c.}] \qquad (2)$$

Here G is the Fermi weak interaction constant, m_p is the proton mass, e, ν, u, d are the operators of the corresponding lepton and quark fields. The lepton-quark constants $\tilde{g}_{m,e}$ are supplied with tildes to tell them from the lepton-nucleon ones.

Following the approach of Ref.[1], let us transform β-decay interaction (2) into an effective diagonal electron-quark one by means of W-exchange (see diagrams 1, 2). We do not attempt here at a consistent calculation of this radiative correction which is quite model-dependent. In particular, we shall assume in our estimates the simple Feynman form $\delta_{\mu\nu}/(q^2-M_W^2)$ for the W-boson propagator with the hope that the term $-q_\mu q_\nu/M_W^2$ in its nominator will somehow cancel out at more accurate calculations. In this way we come to the effective electron-quark interaction upper limits for which can be extracted from atomic experiments.

$\text{Im}\tilde{g}_e$ is evidently a close analog of the parameter q of the T-odd, P-even electron-quark interaction

$$\frac{G}{\sqrt{2}}\frac{q}{2m_p}\bar{e}\gamma_\mu\gamma_5 e\cdot\bar{q}i\gamma_5\sigma_{\mu\nu}k_\nu q \qquad (3)$$

discussed in Ref.[1]. Since the W-exchange is at least as effective as the Z-exchange exploited in that paper, the ratio of the effective T- and P-odd electron-quark constant

to $\text{Im}\tilde{g}_e$ is roughly the same

$$\sim\frac{\alpha}{\pi}\log\frac{\Lambda^2}{M_W^2}\frac{m_e}{m_p}, \qquad (4)$$

as the ratio of this constant to the parameter q of interaction (3) considered in Ref.[1]. Here α=1/137, M_W and m_e are the W and electron masses respectively, Λ is the cut-off parameter. Trying again to be as conservative as possible, we shall assume in our numerical estimates that $\log\Lambda^2/M_W^2\sim1$. Thus, we come to the same estimate for $\text{Im}\tilde{g}_e$, as that for q:

$$\text{Im}\tilde{g}_e<10. \qquad (5)$$

The same diagrams, but with different arrangement of the vector and axial vertices, γ_μ and $\gamma_\mu\gamma_5$, leads evidently to an analogous estimate for the upper limit on $\text{Im}\tilde{g}_m$:

$$\text{Im}\tilde{g}_m<10. \qquad (6)$$

The limits (5), (6) do not look very impressive. However, they can be improved essentially by passing over from one-loop diagrams 1, 2 which induce the effective T- and P-odd interactions, to the two-loop diagrams of the type 3 which induce the quark electric dipole moment (EDM). When evaluating such diagrams, we neglect the fermion masses. Then, to induce the chirality-changing EDM structure $\gamma_5\sigma_{\mu\nu}F_{\mu\nu}$, we have to place the chirality-changing vertex $(\tilde{g}_m+\tilde{g}_e\gamma_5)\sigma_{\mu\nu}k_\nu$ on the lower line. In other words, the leptons are propagating in the closed loop, and the lower line refers to quarks.

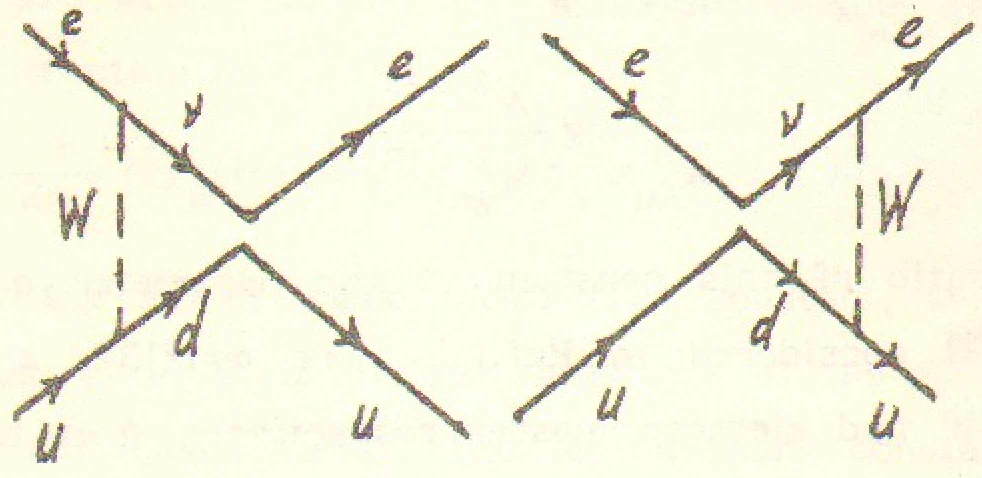

Fig. 1.

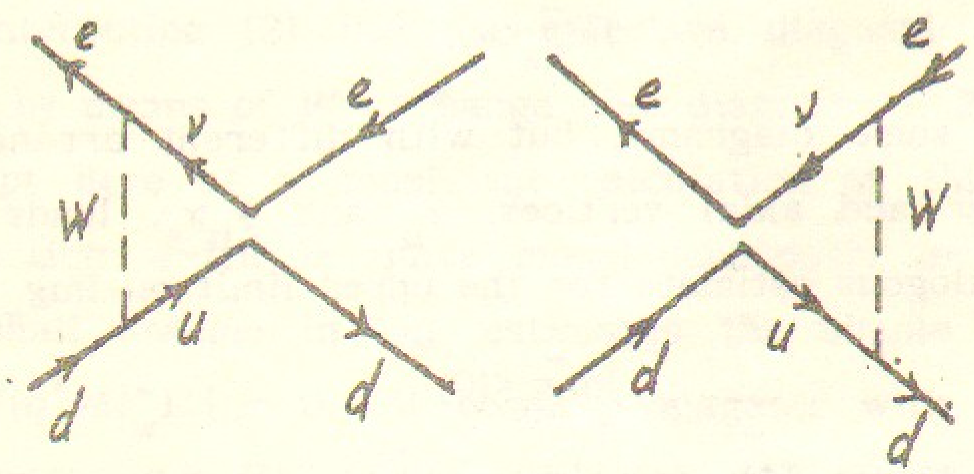

Fig. 2.

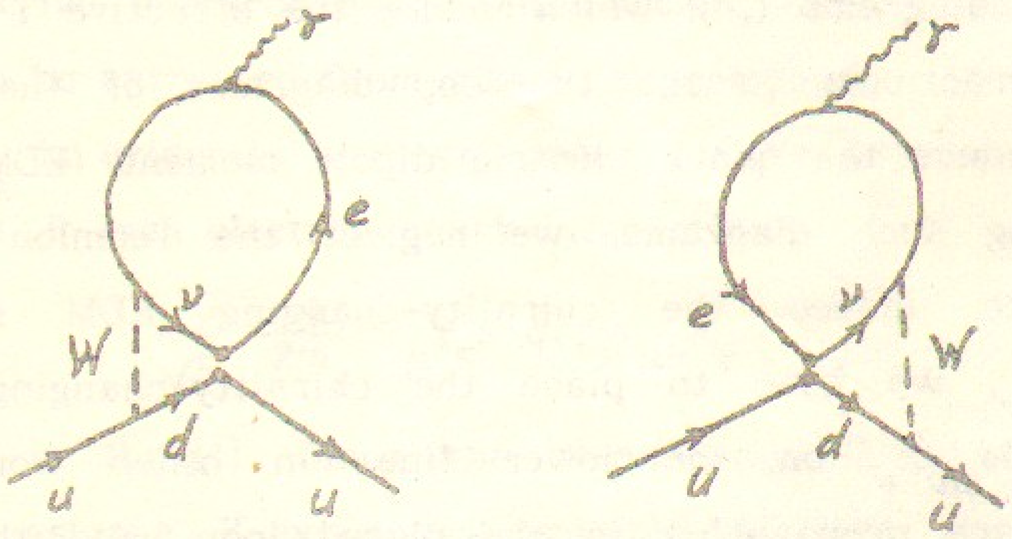

Fig. 3.

The simple estimate for the quark EDM induced in this way is

$$d/e \sim \frac{G\Lambda^2}{\sqrt{2}} \frac{\alpha}{a\pi^3} \frac{1}{m_p} \mathrm{Im}(\tilde{g}_m \pm \tilde{g}_e). \qquad (7)$$

Here Λ is the cut-off parameter; we neglect again possible enhancement factors $\log\Lambda^2/M_W^2$. Two-loop diagrams contain as geometrical suppression factor not only $1/\pi^3$, but as well a small number $1/a$ which, according to the experience with the calculations of such diagrams, is close to 10^{-2}. In the expression $\mathrm{Im}(\tilde{g}_m \pm \tilde{g}_e)$ the upper sign refers to the u-quark EDM, the lower one to the d-quark dipole moment.

Simple dimensional arguments show that the neutron EDM induced by the quark dipole moment, is of the same order of magnitude as the latter. In other words, we get roughly the same estimate (7) for the neutron EDM. But we do not know exactly the relative weight of the *u*- and *d*-quark contributions to the neutron dipole moment, and therefore the relative weight of $\mathrm{Im}\tilde{g}_m$ and $\mathrm{Im}\tilde{g}_e$ in the latter. We shall assume however that there is no strong cancellation between the contributions of $\mathrm{Im}\tilde{g}_m$ and $\mathrm{Im}\tilde{g}_e$ to the neutron EDM d_n. Then, comparing estimate (7) with the latest experimental result [3]

$$d_n/e < 1.2 \cdot 10^{-25}\,\mathrm{cm}, \qquad (8)$$

we arrive at the following upper limit

$$\mathrm{Im}\tilde{g}_{m,e} < 10^{-4} \qquad (9)$$

even under quite modest assumption $\Lambda \sim 100\mathrm{GeV}$. Dimensional arguments show that the same limits as (9) for the quark-lepton β-decay constants refer also for the induced in this way nucleon weak current parameters:

$$\mathrm{Im}g_{m,e} < 10^{-4}. \qquad (10)$$

As to the possible contributions to the T-odd constants $\mathrm{Im}g_{m,e}$ in the nucleon weak current from the T-invariance violation in the hadronic interactions, they should be even much smaller than (10). Indeed, the atomic experiments [4, 5] put the upper limit on the T- and P-odd nucleon-nucleon interaction on the level $0.1G$ [6]. A rough estimate for the corresponding relative contribution to the hadronic matrix elements is $0.1Gm_{\pi}^{2} \sim 10^{-8}$ (m_{π} is the π-meson mass). As to the T-odd, P-even nucleon-nucleon interaction, the upper limits obtained in Ref.[1] constitute $10G$ and $10^{-4}G$ for the one-loop and two-loop approaches respectively, which corresponds to the relative admixtures on the level 10^{-6} and 10^{-11}.

Let us note in the conclusion that the explicit dependence of interaction (2) on the momenta (this operator being of the dimension 7, but not 6) is crucial for the improvement of the limits from (5), (6) to (9) when passing from the one-loop approach to the two-loop one. No such improvement takes place for the T-odd β-decay interactions without derivatives, i.e., for the constants $\mathrm{Im}C_{T,S,P}$.

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НОВЫЕ ОГРАНИЧЕНИЯ НА НАРУШЕНИЕ Т-ИНВАРИАНТНОСТИ В β -РАСПАДЕ

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