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ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ
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ПРЕПРИНТ 81-115

Новосибирск

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ABSTRACT

A new mechanism is considered due to which the neutron electric dipole moment $\mathcal{D}_n$ arises in the Kobayashi-Maskawa model. This mechanism leads to the estimate $\mathcal{D}_n \sim 2\cdot 10^{-32}$ e.cm, by two orders of magnitude larger than the contributions considered previously.

The search for the electric dipole moment(edm) of the neutron, being carried out for many years, have allowed to restrict essentially the class of possible models of CP-violation. Due to the well-known successes of the renormalizable theory of electromagnetic and weak interactions the attempts to describe CP-violation within the same approach appear to be the most natural. Now two schemes of this kind are discussed intensively. In one of them CP-violation arises in the Higgs sector of the model /1,2/, in another- in the fermion sector /3/.

The edm of the neutron in the most popular version of the model of the first type, suggested by Weinberg /2/,was considered in Refs./2,4-7/. In Ref./7/ the neutron edm D_n was shown to be due in this model mainly to the contribution of the strange quarks. The estimate $D_n \simeq -9\cdot 10^{-25}$ e·cm [1] obtained in this way, formally contradicts already the last experemential data /8/ $D_n = (2.3 \pm 2.3)10^{-25}$ e·cm. Due however to the ambiguities in the value of the model parameters which are extracted from the $K_L \to 2\pi$ decay, only order of magnitude of the theoretical estimate can be guaranteed, but not its sign. Nevertheless, the improvement of the accuracy of the experement on the neutron edm by 3-4 times(it can be expected within the next few months) would finally decide the fate of the Weinberg model of CP-violation /2/.

In the present work we discuss the value of the neutron edm

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[1] In the Ref./7/ we have made an error in the sign of the strange quarks contribution that has led to the estimate $D_n \simeq +7\cdot 10^{-25}$ e·cm.

in the Kobayashi-Maskawa (K-M.) model /3/. In the first papers on this topic /9-11/ it was realized that D_n does not arise here in the first order in the Fermi constant G_F. Then Shabalin /12/ has shown that a quark edm vanishes also in the two-loop approximation[2]. In Ref./12/ it was noted also that D_n can arise due to weak interaction between quarks constituting the neutron. The investigation of corresponding diagrams (see Fig.1) has led to the estimate $D_n \sim 10^{-34}$ e·cm./15/. Other, larger values for this contribution /16,17/ are overestimated.

In the present work another mechanism leading to the neutron edm and due to the interquark weak interaction is considered. Following the idea used in Ref./18/ to calculate the neutron edm in another model (see also Refs./19,7/), we shall look for the contribution to D_n singular in the chiral limit. This contribution, proportional to $\ln \frac{1}{m_\pi}$, arises from the diagrams $2^{a,b}$. The symbol O represents here the usual non-leptonic weak interaction described by the phenomenological Hamiltonian

$$H = i G_F m_\pi^2 \bar{u}_n (A + B\gamma_5) u_\Sigma \cdot \varphi_\pi \qquad (1)$$

$$A = -1.93(1), \quad B = -0.65(7)$$

We follow the convention on the signs of the amplitudes of non-leptonic decays adopted in Ref./20/.

As to the CP-odd $\pi n \Sigma$ interaction, represented at Figs. $2^{a,b}$ by the symbol $\otimes$, it is determined by the quark diagram 3 (here the dashed line refers to the gluon) where we only retain the structure

$$H_1 = i \frac{G_F}{\sqrt{2}} \sin\delta\, s_1 s_2 s_3 c_2 \frac{\alpha_s(\bar{m})}{12\pi} \Delta \cdot \ln \frac{m_t^2}{m_c^2} \bar{s} \gamma_\mu (1+\gamma_5) \lambda^a d \sum_{q=u,d} \bar{q} \gamma_\mu \lambda^a q \qquad (2)$$

$$m_c < \bar{m} < m_t$$

In the formula (2) we follow the convention on the K.-M. matrix adopted in Ref./21/. Note that at $\alpha_s(\bar{m}) = 0.2$ the correction factor Δ in the operator (2), arising due to strong interaction at small distances, constitutes $\Delta \simeq 1.3$. It only slightly deviates from unity since the characteristic virtual momenta are here large enough so that α_s is small. The operator (2) is essentially the well-known "penguin" diagram which was used for the first time in Ref./20/ in another connexion, for the description of non-leptonic decays of hyperons and kaons.

Unlike another CP-odd structure, $\bar{s} \sigma_{\mu\nu} (1+\gamma_5) \lambda^a d\, G_{\mu\nu}^a$, arising from this diagram, here the cancelation between c-quark and t-quark contributions in the limit $m_c = m_t$ leads not to the factor $(m_t^2 - m_c^2)/m_W^2 \sim 10^{-1}$, but to $\ln \frac{m_t^2}{m_c^2}$ which at $m_t = 30$ GeV, $m_c = 1.5$ GeV is equal to 6.

The matrix element $\langle \Sigma^- \pi^+ | H_1 | n \rangle$ is calculated in the standard way by factorizing the pion. The result is

$$\langle \Sigma^- \pi^+ | H_1 | n \rangle = -\frac{G_F}{\sqrt{2}} \frac{\alpha_s \cdot \Delta}{12\pi} \sin\delta\, s_1 s_2 s_3 c_2 \ln \frac{m_t^2}{m_c^2} \cdot \frac{4}{9} \frac{f_\pi (m_\Sigma + m_n) m_\pi^2}{m_s (m_u + m_d)} \cdot \qquad (3)$$

$$\cdot\, \bar{u}_\Sigma \left[\frac{m_\Sigma - m_n}{m_\Sigma + m_n} + (2\alpha - 1) g_A \frac{m_K^2}{m_K^2 - q^2} \gamma_5 \right] u_n$$

Here $\alpha \simeq 0.64$ is the relative weight of D-coupling in the interaction of baryon and meson octets; $g_A = 1.25$; q is the pion momentum. One should pay attention to the factor $m_K^2/(m_K^2 - q^2)$ (m_K is the kaon mass) at the γ_5-structure. It is due to the effective pseudoscalar in axial current.

Using the expressions (1), (3), we find by standard calculati-

[2] Even taking into account strong-interaction radiative corrections, one cannot get a quark edm exceeding 10^{-34} e·cm /13/. Larger predictions /14/ for D_n obtained in this way are perhaps overestimated.

ons the contribution of the diagrams $2^{a,b}$ to the neutron edm:

$$D_n = -e\, G_F^2 \sin\delta\, s_1 s_2 s_3 c_2 \frac{\alpha_s(\bar m)\Delta}{\sqrt{2}\,2^7\pi^3} \ln\frac{m_t^2}{m_c^2} \frac{f_\pi m_\pi^4}{m_s(m_u+m_d)} A(2\alpha-1) g_A \ln\frac{m_K}{m_\pi} \quad (4)$$

We neglect in this expression the term $B\frac{m_\Sigma - m_N}{m_\Sigma + m_N} \simeq -0.08$ in comparison with $A(2\alpha-1)g_A \simeq -0.7$. The numerical estimate by the formula (4) at $c_2 s_2 s_3 \sin\delta = 10^{-3}$, $\alpha_s(\bar m) = 0.2$, $\Delta = 1.3$, $\ln\frac{m_K}{m_\pi} = 1$ gives $D_n \simeq 2\cdot 10^{-32}$ e·cm.

Calculating the contribution of the diagrams $2^{a,b}$, we have omitted the analogous diagrams with the $\pi^-\Sigma^+$ intermediate state. The reasons are as follows. The s-wave amplitude of the corresponding decay is very small, $A(\Sigma^+ \to n\pi^+) = 0.06(1)$, and can be neglected. But if in the CP-even vertex the amplitude B is retained only, in another vertex, CP-odd one, only the scalar structure is essential. The last structure turns to zero both in the limit of zero pion momentum, as can be checked by direct calculation of the corresponding commutator in PCAC technique, and in the pion factorization approach. The proof of the validity of these arguments is that they can be applied as well to the CP-even amplitude $A(\Sigma^+ \to n\pi^+)$ which is very small indeed.

It is useful to explain why our estimate for D_n is by two orders of magnitude larger than that obtained in Ref./15/. Firstly, as it was pointed above, the cancellation of the diagrams 3 with c- and t-quarks in the limit $m_c = m_t$ is guaranteed here by the factor $\ln\frac{m_t^2}{m_c^2} \simeq 6$ instead of $(m_t^2 - m_c^2)/m_W^2 \sim 10^{-1}$. Secondly, due to the presence of right-handed currents in the operator (2), the factor $m_\pi^2/f_\pi(m_u+m_d) \sim 12$ arises. And finally, there is a factor of the same order of magnitude in the amplitude A compensating in it the smallness of the Cabibbo angle. Taken together, they overweight with odds α_s and a small numerical factor arising due to the extra loop (Fig. $2^{a,b}$).

There is a problem of the contribution of the diagrams $4^{a,b}$ where the symbol ⊗ refers to a CP-odd scalar vertex of the second order in G_F, and the dot refers to the usual strong πNN vertex. It contains also the factors $\ln\frac{m_t^2}{m_c^2}$ and $m_\pi^2/f_\pi(m_u+m_d)$; the absence of the last large factor is compensated numerically by a large value of the constant $g_{\pi NN} \simeq 13$. However, we do not see any grounds to expect that such a contribution should cancel out that obtained above.

Therefore, we arrive at the estimate for the neutron edm in the K.-M. model:

$$D_n \simeq 2\cdot 10^{-32}\,\text{e}\cdot\text{cm} \quad (5)$$

We consider this estimate as a conservative one. In particular, account for renormalization group corrections due to gluons of virtuality from m_c^2 to $\mu^2 \simeq (0.2\ \text{GeV})^2$ leads to the increase of the estimate (5) by about two times.

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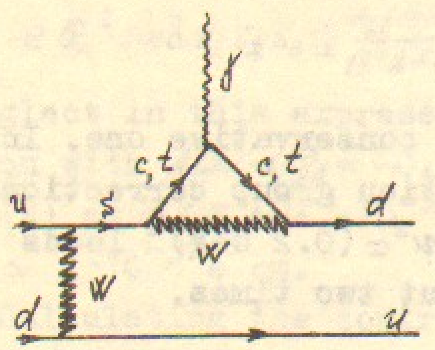

Fig 1.

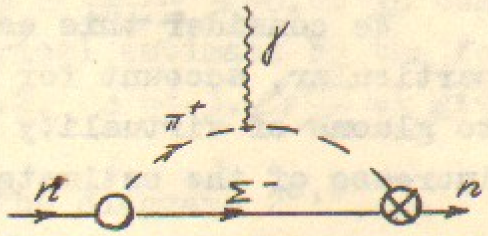

Fig 2a.

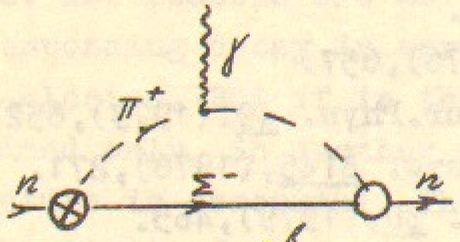

Fig 2b.

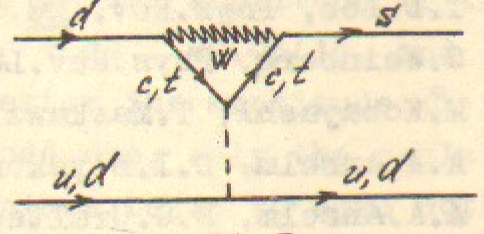

Fig 3.

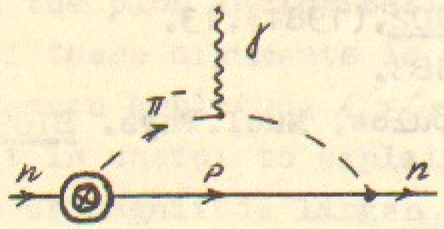

Fig 4a.

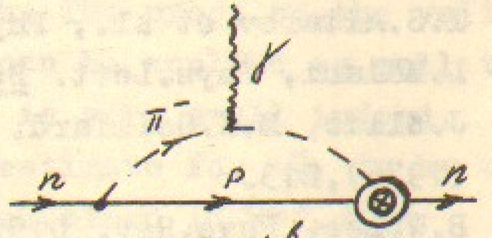

Fig 4b.

Работа поступила - 5 октября 1981 г.

Ответственный за выпуск - С.Г.Попов
Подписано к печати 12.10-1981г. МН 03458
Усл. 0,5 печ.л., 0,4 учетно-изд.л.
Тираж 290 экз. Бесплатно
Заказ № 115.

Отпечатано на ротапринте ИЯФ СО АН СССР