ITEP - 131

INSTITUTE OF THEORETICAL
AND EXPERIMENTAL PHYSICS

E.P.Shabalin

THE ELECTRIC DIPOLE MOMENTS OF BARYONS IN THE KOBAYASHI-MASKAWA CP-NONINVARIANT THEORY

MOSCOW 1979

УДК 530.145:538.3 М-16

Abstract

The contribution of interquark forces into the electric dipole moment (e.d.m.) of baryons is considered. The account of these forces results in

$$\frac{D}{e} \sim 10^{-34}\ \text{см}$$

This value agrees with the estimate obtained by summation the e.d.m. of single quarks calculated with the account of strong interactions.

Шабалин Е.П.
Электрические дипольные моменты барионов в СР-неинвариантной теории Кобаяши-Маскавы
Работа поступила в ОНТИ 24/X-1979г.

Подписано к печати I/XI-79г. Т-2040I.Формат 70x108 I/16.
Печ.л.0,5.Тираж 260 экз.Заказ I3I.Цена 4коп.Индекс 3624.

Отдел научно-технической информации ИТЭФ,II7259,Москва

The measurement of the electric dipole moments (e.d.m.) of baryons, especially those of neutron can be a prominent step towards understanding the mechanism of CP violation.

Nowadays a very plausible seems the violation mechanism due to difference of the phase factors in some components of charged left-handed current in the six-quark SU(2)xU(1) scheme by Kobayashi- Maskawa [1] (in the following K-M scheme).

Since it is well known that the static characteristics of baryons are well reproduced by summation the characteristics of separate quarks, some authors [2-7] first studied the problem of the value of the quark e.d.m. within the K-M scheme. In doing so, in a number of publications [2-4] there was obtained an erroneous conclusion that already two-loop diagrams yield $D \neq 0$. A more accurate consideration revealed that in this order the e.d.m. of a quark treated as a free quasiparticle, is zero [5].

The question of quark e.d.m. value when strong interactions are taken into account was discussed in refs. [6,7]. It seems to me, that ref. [6] gives a wrong estimate of $D \sim m_q^3 / M_W^4$. As it was shown in ref. [7] such large terms do appear in some terms of the matrix elements of some graphs but they disappear in summing all the graphs so that the account of gluonic corrections if results in $D \neq 0$ the value of D is not more than

$$\left|\frac{D}{e}\right|_{u,d} \sim \frac{G_F^2 \alpha_s f_{K-M}^{Im} m_{u,d}}{16\pi^5 M_W^2 \tilde{m}^4} \cdot (m_c^2 - m_t^2)(m_d^2 - m_s^2)(m_s^2 - m_b^2)(m_d^2 - m_b^2) \tag{1}$$

where $m_{c,t,d,s,\ell}$ are the masses of the corresponding quarks, $\tilde{m}^2$ is the linear combination of m_d^2, m_s^2, m_ℓ^2 and

$$f_{K-M}^{Im} = \sin\delta \; c_1 c_2 c_3 \, s_1^2 \, s_2 \, s_3 \tag{2}$$

is the product of $c_i = \cos\theta_i$, $s_i = \sin\theta_i$, and $\sin\delta$ of the K-M scheme parameters.

With existing constraints on the parameters of the K-M-theory and the quark masses eq. (1) gives

$$\left|\frac{D}{e}\right|_{u,d} \leq 10^{-34} \text{ cm} \tag{3}$$

Taking the sum of single quark e.d.m. we get the same estimate for e.d.m. of baryon. It proves to be by ten orders of magnitude less than the existing experimental limit for the neutron e.d.m.

So it seems interesting whether the account of the exchange interquark forces (whose possible contribution was pointed out in ref. [5]) can lead to a larger result for the baryons. Recently there appeared two papers [9,10] which considered the role of the exchange forces and in which the following estimates for the neutron e.d.m. were obtained

$$\frac{D_N}{e} \sim 10^{-30} \text{ cm} \qquad [9]$$

$$\frac{D_N}{e} \sim 10^{-32} \text{ cm} \qquad [10]$$

In this paper we are studying the question of the exchange forces as well, the approach used being close to that used by the authors of ref. [10]. The formulae obtained give however the far less value of D_N.

Let us consider the contribution from the neutron e.d.m. of the graph of Fig. 1a, b. The fat point at these graphs corresponds itself to four one-loop graphs and is the renormalized vertex of $us\gamma$ or $ub\gamma$ transition. Using the technique developed in refs. [5,11] one can state that the renormalized vertex of transition $q_1 \to q_2\gamma$ where q_1 and q_2 are different in quantum numbers quarks, is of the form

$$-\Gamma^R_\mu(\bar q_2 q_1 \gamma) = A(q_1,q_2)(\hat p_2 - m_2)\gamma_\mu(1-\gamma_5)(\hat p_1 - m_1) +$$

$$+ i B(q_1,q_2)\,\varepsilon_{\mu\sigma\tau\nu}\gamma_\nu(1+\gamma_5)k_\sigma p_{1\tau} + \qquad (4)$$

+ (high order terms in powers of k)

where k is the photon momentum.

Imaginary parts of the coefficients A and B for the transitions of interest have the form

$$\mathrm{Jm}\begin{Bmatrix} A(d,s) \\ B(d,s) \end{Bmatrix} = -\frac{S_3}{C_3}\,\mathrm{Jm}\begin{Bmatrix} A(d,b) \\ B(d,b) \end{Bmatrix} = S_1 S_2 S_3 C_2 \frac{\sin\delta\, G_F\, e\,(m_t^2 - m_c^2)}{8\sqrt{2}\,\pi^2 M^2}\begin{Bmatrix} \frac{2}{3} \\ -\frac{1}{6} \end{Bmatrix} \qquad (5)$$

$$\mathrm{Jm}\begin{Bmatrix} A(u,c) \\ B(u,c) \end{Bmatrix} = -\frac{C_2}{S_2}\,\mathrm{Jm}\begin{Bmatrix} A(u,t) \\ B(u,t) \end{Bmatrix} = S_1 S_2 S_3 C_3 \frac{\sin\delta\, G_F\, e\,(m_s^2 - m_b^2)}{8\sqrt{2}\,\pi^2 M^2}\begin{Bmatrix} -\frac{4}{3} \\ \frac{5}{6} \end{Bmatrix}$$

Taking into account the coefficients at another vertices of graphs a and b one can easily see that the first term of the formula (4) after summing over all the intermediate states does not contribute to the e.d.m. of diquark independently of the quark being on or off-mass shell. Therefore the matrix element corresponding to the graph of Fig. 1a has the form

$$\mathcal{M}(1a) = A_\mu \frac{e G_F^2 (m_t^2 - m_c^2)}{16\pi^2 M^2} f_{K-M}^{Im} \left(-\frac{7}{6}\right) i \varepsilon_{\mu\sigma\tau\eta} K_\sigma p_{1\tau} \cdot$$
$$\cdot i \int \frac{d^4 q}{(2\pi)^4 (q^2 - M^2)} \bar{u}_1(p_1) \frac{\hat{p}_1 - \hat{q} + m}{2m} \gamma_\alpha (1+\gamma_5) \cdot$$
$$\cdot \frac{\hat{p}_1 (m_s^2 - m_t^2)}{(p_1^2 - m_s^2)(p_1^2 - m_t^2)} \gamma_\eta (1+\gamma_5) d_1(p_1) \cdot \tag{6}$$
$$\cdot \bar{d}_2(p_2) \frac{\hat{p}_2 + \hat{q} + m}{2m} \cdot \frac{\hat{p}_2 + \hat{q} + m}{(p_2+q)^2 - m^2} \gamma_\alpha (1+\gamma_5) u(p_2)$$

where m is the mass of u- or d-quark ($m_u = m_d = m$). Supposing the presence of strong interactions between quarks to result in the cutting off $|q^2|$ at $m_0^2 \sim m_\rho^2$ we get

$$\mathcal{M}(1a) \approx A_\mu \frac{e G_F^2 (m_t^2 - m_c^2)(m_s^2 - m_t^2) f_{K-M}^{Im} m_0^4}{2^9 \pi^4 M^2 m (m^2 - m_s^2)(m^2 - m_t^2)} \cdot \frac{1}{2} \tag{7}$$
$$\cdot i \varepsilon_{\mu\sigma\tau\eta} K_\sigma p_{1\tau} \bar{u}_1(p_1) \gamma_\alpha \hat{p}_1 \gamma_\eta (1+\gamma_5) d_1(p_1) \cdot$$
$$\cdot \bar{d}_2(p_2) \gamma_\alpha (1+\gamma_5) u_2(p_2).$$

Substituting the explicit expressions for spinors as

$$u(p) = \sqrt{\frac{E+m}{2E}} \begin{pmatrix} \varphi \\ \frac{\vec{\sigma}\vec{p}}{E+m}\varphi \end{pmatrix}$$

and noting as well that the electric field

$$\mathcal{E}_n = i\,(k_0 \mathcal{A}_n - k_n \mathcal{A}_0)$$

we get that the interaction of diquark (ud) in its rest system with the electric field is

$$\mathcal{M}(1a) + \mathcal{M}(1b) =$$

$$= \frac{5e\, G_F^2 (m_t^2 - m_c^2)(m_s^2 - m_b^2)\, f_{K-M}^{Im}\, m_0^4\, \vec{p}^{\,2}}{2^9 \pi^4 M^2 (m^2 - m_s^2)(m^2 - m_b^2)\, E} \cdot \frac{7}{15} \cdot \qquad (8)$$

$$\cdot\, \vec{\mathcal{E}} \left[\vec{s} - \frac{\vec{p}\,(\vec{p}\vec{s})}{\vec{p}^{\,2}} \right]$$

where $\vec{s}$ is the diquark spin, m the affective mass of quark and E and p are energy and momentum of one quark in the rest system of diquark.

The account of graphs in which the photon is tied to the u-quark line, leads to an inessential correction

$$-\frac{5}{7}\,\frac{(m^2 - m_s^2)(m^2 - m_b^2)}{(m^2 - m_c^2)(m^2 - m_t^2)}\,.$$

To get the value of D for the baryon one must determine in the formula (8) the values of the parameters m, m_0 and $|\vec{p}|$. The experimental data on magnetic moments of baryons show that $m_{u,d}$ within static characteristics are

$$m_{u,d} = m \approx \frac{m_N}{3} \tag{9}$$

Then

$$(m_s^2 - m^2) \approx (m_\Lambda - m_N)\left(m_\Lambda - \frac{m_N}{3}\right) \tag{10}$$

Putting further

$$|\vec{p}| \sim \frac{1}{R_N} \approx m_\rho \qquad \text{and} \qquad m_o \approx m_\rho \tag{11}$$

making in (8) angle averaging and using SU(6) nonrelativistic quark functions for neutron and proton we obtain

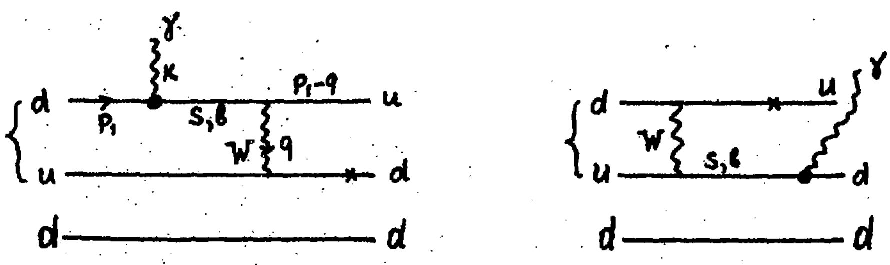
$$\left|\frac{D_N}{e}\right| \approx \left|\frac{D_P}{e}\right| \approx \frac{1}{2}\left(\frac{m_t}{M_W}\right)^2 f_{K-M}^{\mathrm{Im}} \cdot 10^{-28}\ \text{cm} \tag{12}$$

With $\frac{m_t}{M_W} = \frac{1}{6}$ and $f_{K-M}^{\mathrm{Im}} \approx 5 \cdot 10^{-5}$ we get

$$\left|\frac{D_N}{e}\right| \approx 0.75 \cdot 10^{-34}\ \text{cm} \tag{13}$$

This value is by two orders of magnitude less than in ref. [10] and by four orders of magnitude less than in [9]. One of course can raise an objection that the cut off parameter m_o and the value of $\vec{p}^{\,2}$ are not determined accurately enough meanwhile they enter the formula for D_N in a high enough degree. However, it seems not occasional that the result (13) coincides with the estimate D_N according to formula (1) and (3). Though the constant α_s did not enter explicitly the

the calculation of the exchange forces,without strong interactions we would not get the cut off of the integral in formula (6) at $|q^2| \ll M_W^2$. And without such a cut off the whole effect would be immediately reduced to the value by $\frac{m_\ell^2 - m_s^2}{M^2}$ less. So, in both cases i.e. in case of the single quark e.d.m. summation or in case of estimating D_N due to exchange effect strong interactions are essentially present and the choice in the formula (1) $\alpha_s \approx 1$ is in a certain degree equivalent to the choice $|\vec{p}| \approx m_\rho \approx m_\rho$ in the formula (8).



a) b)

Fig.1

References

1. M.Kobayashi, K.Maskawa. Prog.Theor.Phys. 49, 652, 1973.
2. L.Maiani. Phys.Lett. 62B, 183, 1976.
3. J.Ellis, M.K.Gaillard, D.V.Nanopoulos. Nucl.Phys. B109, 213, 1976.
4. B.W.Lee. Phys.Rev. D15, 3394, 1977.
5. E.P.Shabalin. Yadernaya Phys. 28, 151, 1978.
6. J.Ellis, M.K.Gaillard. Nucl.Phys. B150, 141, 1979.
7. E.P.Shabalin. Preprint ITEP-87, Moscow, 1979.
8. N.F.Ramsey. Bull.Am.Phys.Soc. 21, 61, 1976; Altarev et al., Pisma ZhETF 29, 794, 1979.
9. B.F.Morel. Preprint HUTP-79/A009, 1979.
10. D.V.Nanopoulos, A.Yildiz, P.H.Cox. Preprint HUTP-79/A024, 1979.

ИНДЕКС 3624