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SPIN CRISIS AND NONPERTURBATIVE QCD DYNAMICS

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In the last time, the EMC results of measuring the first moment of the structure functions $g_1^p(x)$[1]

$$G_1^p = \int_0^1 dx\; g_1^p(x) = 0.126 \pm 0.010 \pm 0.015 \tag{1}$$

are intensively discussed.

By using the operator expansion (OPE) it was obtained that

$$\Delta\Sigma \equiv \Delta u + \Delta d + \Delta s = 0.12 \pm 0.20, \tag{2}$$

where $\Delta\Sigma$ is the difference of quark proton densities with different helicity. This result turned out to be quite unexpected (see f. i. the discussion in [2]) because within the quark model where the whole proton spin is due to quarks one should have

$$\Delta\Sigma = 0.7 \div 1\,.$$

To solve this discrepancy, it was supposed[3] that in the EMC experiment the value

$$\Delta q' = \Delta\Sigma - N_f \frac{\alpha_s}{2\pi} \Delta G, \tag{3}$$

was measured, where N_f is the number of quark flavour, and ΔG is the helicity carried by gluons. Appearence of the second term in (3) is related to the anomaly in the axial current divergence[4]

$$\partial_\mu j_\mu^{05} = \partial_\mu K_\mu, \tag{4}$$

where

$$K_\mu = N_f \frac{\alpha_s}{2\pi} \epsilon_{\nu\mu\sigma\rho} A_\mu^a (\partial_\sigma A_\rho^a - \frac{g}{3} f_{abc} A_\sigma^b A_\rho^c). \tag{5}$$

However, some later based on the general principles of guage invariance and analyticity it was shown that there was no any, calculated in QCD perturbative theory, anomalous contribution to $\Delta q'$[5]. As concerned the derivation of (3) in[3], the factorization procedure was incorrectly applied.

In works[6], it was pointed out that the second term in (3) may be due to the change of the topological properties of vacuum in a polarized proton because the divergency of current K_μ

$$\partial_\mu K_\mu \equiv Q, \tag{6}$$

is expressed through the topological charge density Q.

It was shown that[6]

$$\begin{aligned} \Delta q' &= \Delta\Sigma - 2N_f < p \mid n_+ - n_- \mid p > \approx \\ &\approx \Delta\Sigma - 2N_f n_0 V_4 \sin\theta_v^p, \end{aligned} \tag{7}$$

where $n_\pm$ is the instanton (antiinstanton) density in a polarized proton, n_0 is the equilibrium density of instantons, V_4 is the four-dimensional volume of a proton, θ_v^p is the vacuum angle determing CP breaking inside a polarized proton. Equation (7) follows from the fact that quarks in the instanton field have zero modes of different helicities[7].

We should note here that the anomaly in (4) is related with the $U_A(1)$–problem: the problem of anomalous large mass of a η'–meson[8]. Thus, in[8] it was shown that the η'–meson mass is also connected with the fluctuations of the topological charge

$$m_{\eta'}^2 = \frac{< 0 \mid T(QQ) \mid 0 >}{f_{\eta'}^2}. \tag{8}$$

The existence of this relation initiated the works[9,10] where the ghost pole contribution was considered which is due to the nonvanishing matrix element $< 0 \mid T(QQ) \mid 0 >$ in axial proton formfactor.

Namely, defining the matrix elements

$$\begin{aligned} < p' \mid j_\nu^5 \mid p > &= \bar{u}(p')[\gamma_\nu\gamma^5 G_1(q^2) + q_\nu\gamma^5 G_2(q^2)]u(p) \\ < p' \mid K_\nu \mid p > &= \bar{u}(p')[\gamma_\nu\gamma^5 \tilde{G}_1(q^2) + q_\nu\gamma^5 \tilde{G}_2(q^2)]u(p) \end{aligned} \tag{9}$$

one can obtain from (4) and (5)

$$2MG_1(q^2) + q^2 G_2(q^2) = 2m\tilde{G}_1(q^2) + q^2\tilde{G}_2(q^2). \tag{10}$$

By using the result [9]

$$\lim_{q^2 \to 0} q^2 \tilde{G}_2(q^2) = \sqrt{N_f} f_{\eta'} g_{\eta' NN} \tag{11}$$

from (10) we receive the quark contribution to the proton spin [10]

$$\Delta\Sigma = G_1(0) - \tilde{G}_1(0) = \frac{\sqrt{N_f} f_{\eta'}}{2M} g_{\eta' NN}, \tag{12}$$

where from (7)

$$\tilde{G}_1(0) = 2N_f n_0 V_4 \sin\theta_v^p. \tag{13}$$

Then,

$$\Delta\Sigma \approx 1.14 \pm 0.2, \tag{14}$$

and thus the discrepancy between the composed quark model and the EMC result (2) is resolved.

However, the question about the value of the r. h. side of (2) remains open. In this connection, we should note that by using (6) equation (10) can be continued as follows

$$\begin{aligned} 2MG_1(q^2) + q^2 G_2(q^2) &= 2M\tilde{G}_1(q^2) + q^2\tilde{G}_2(q^2) = \\ &= < p' \mid Q \mid p >. \end{aligned} \tag{15}$$

The matrix element of total topological charge over the proton state may be estimated analogously (7) (see[6])

$$< p \mid Q \mid p > \approx 2M2N_f n_0 V_4 \sin\theta_v, \tag{16}$$

where θ_v is the QCD vacuum angle. Substituting the value of the equilibrium density of instantons in the QCD vacuum $n_0 \simeq 8\ 10^{-4}\ Gev^4$ [11] and $V_4 \simeq 1\ fm^3/M_p$ we obtain

$$G_1(0) \approx 2N_f \sin\theta_v. \tag{17}$$

This is the central point of our work.

It is experimentally known that $\mid\theta_v\mid \leq 10^{-9}$ and thus

$$G_1(0) \leq 6 \cdot 10^{-9}. \tag{18}$$

We should stress the analogy between the results (12),(13),(17) and the appearance mechanism of a baryon charge in hybrid chiral bag models with external mesonic fields[12]. In these models, the baryon number is expressed as a sum of the charge of quarks inside a baryon and the charge induced by external mesonic fields. Then, though the charge is redistributed between internal and external regions of the bag-baryon, the total charge remains equal to one.

Analogously, equation (18) means that the zero topological proton charge is summed from intercompensating contributions of the charge inside a polarized proton (13) and the charge induced by the external η'–mesonic field (12).

Now, let us estimate different contributions to the proton spin. The result (12) was obtained in the chiral limit at $m_u = m_d = m_s = 0$. Here, we estimate mass corrections. From equation (4) with $m_u \neq m_d \neq m_s \neq 0$.

$$\partial_\mu j^{05}_\mu = \partial_\mu K^\mu + 2i\sum_i m_i \bar{q}_i \gamma_5 q_i$$

we get

$$\Delta\Sigma = f_{\eta'}\frac{\sqrt{N_f}}{2M} g_{\eta' NN} - \frac{1}{2}(3 - 4\frac{D}{F+D})g_A, \qquad (19)$$

where the equation

$$\partial_\mu j^{85}_\mu = 2i(m_u \bar{u}\gamma_5 u + m_d \bar{d}\gamma_5 d - 2m_s \bar{s}\gamma_5 s)$$

and the supposition of equality of the axial densities

$$< p \mid \bar{u}\gamma_5 u \mid p > \approx < p \mid \bar{d}\gamma_5 d \mid p > \approx < p \mid \bar{s}\gamma_5 s \mid p >$$

are used. The latter supposition is evidently correct within the models where a sea is caused by chiral invariant four-fermion Lagrangians such as the Lagrangian induced by instantons[13]. There, it should be

$$\frac{2 < p \mid \bar{s}\gamma_5 s \mid p >}{< p \mid \bar{u}\gamma_5 u + \bar{d}\gamma_5 d \mid p >} \approx \frac{2 < p \mid \bar{s}s \mid p >}{< p \mid \bar{u}u + \bar{d}d \mid p >} . \qquad (20)$$

Then, by using the experimental value for the pion-nucleon $\sigma_{\pi N}$−term (for a review see[14]), we have

$$\frac{2 < p \mid \bar{s}\gamma_5 s \mid p >}{< p \mid \bar{u}\gamma_5 u + \bar{d}\gamma_5 d \mid p >} \approx 0.47.$$

From (19) by using the values $f_{\eta'} = 1.26 f_\pi$; $g_{\eta' NN} = 7.5 \pm\ 1.5$[15] and $F = 0.47 \pm\ 0.04$, $D = 0.81 \pm\ 0.03$[2], $g_A = 1.24$[16] we get

$$\Delta\Sigma = 0.8 \pm\ 0.2 \qquad (21)$$

that somewhat differs from the result in[10]. From (12) the value of a strange sea contribution becomes

$$\Delta s = \frac{1}{3} f_{\eta'}\frac{\sqrt{N_f}}{2M} g_{\eta' NN} - \frac{1}{2}(3 - 4\frac{D}{F+D})g_A = 0.0 \pm\ 0.1.$$

Thus, by using (18), we find the strange sea value measured in the νp elastic scattering[10]

$$\Delta\tilde{s} = \Delta s - \frac{1}{3}\Delta\Sigma = -0.26 \pm\ 0.2.$$

This should be compared with the experiment[17]

$$\Delta\tilde{s} = -0.15 \pm\ 0.09\ .$$

So, we have shown that the EMC result means equality to zero of the QCD vacuum angle θ_v. The equality to zero of the topological charge of a proton is explained by the compensation of the QCD vacuum polarization inside a proton by the topological charge induced by the external η'−mesonic field.

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Дорохов А.Е., Кочелев Н.И. E2-89-858
Спиновый кризис и непертурбативная
динамика КХД

Получено соотношение между вакуумным углом КХД θ_v и первым моментом синглетной части структурной функции протона $g_1^p(x)$: $G_1(0) \approx 2N_f \sin\theta_v$.

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Dorokhov A.E., Kochelev N.I. E2-89-858
Spin Crisis and Nonperturbative
QCD Dynamics

The relation between the QCD vacuum angle value θ_v and the first moment of the singlet part of the proton structure function $g_1^p(x)$ is obtained: $G_1(0) \approx 2N_f \sin\theta_v$.

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

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