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A.E.Dorokhov, N.I.Kochelev*

INSTANTONS AND EMC-EFFECT FOR SPIN-DEPENDENT FUNCTION $g_1^p(x)$

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*High Energy Physics Institute, Academy of Science of Kazakh SSR, SU-480082 Alma-Ata, USSR

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required from the angular momentum to the proton angular momentum $\Delta g \approx 8$, $L_z \approx -8$ which is also difficult to understand within the generally accepted composite quark model.

In this note we shell show that in fact a modification of Δq_i analogous to (7) takes place, it has a deep physical meaning and describes the contribution of the polarization of instanton vacuum of QCD to proton helicity.

It is well known[10] that instantons cause nonconservations of the axial current (6). Really, the results of computations carried out within the QCD sum rules[12], and bag model with taking account of the instanton interaction of quarks[13] have shown that the QCD vacuum model as the instanton liquid[14] may in principle explain the anomalously large mass of $\eta'-$meson related to the nonconservation of current (6).

Moreover, it is proved[13] that instantons give a dominant contribution to the spin-spin quark interaction inside hadrons. That is why we have pointed out possible instanton effects on the scattering of polarized particles[15]. To define the instanton contribution to (7), rewrite (8) in the form (see [16]):

$$\tilde{j}^{\mu}_{05} = \sum_{i=1}^{N_f} \bar{q}^i \gamma^\mu \gamma^5 q^i - 2K^\mu, \tag{9}$$

where the four-dimensional divergence K_μ is related with the topological charge ν by

$$\nu = \int d^4k \partial_\mu K^\mu. \tag{10}$$

Matrix elements of (9) over the proton state (p) is

$$< j_{05} >_p = \Delta q - 2N_f < \nu >_p, \tag{11}$$

where $< \nu >_p$ is the topological charge of a polarized proton: $< \nu >_p = \sin\theta \, n_0 \bar{Q}_5^{an}$.

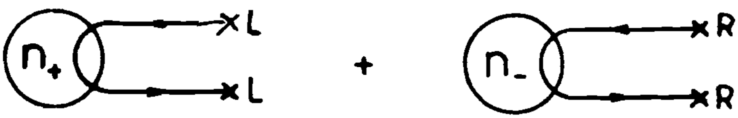

Figure 1: The contribution of vacuum polarization to the proton helicity. Crosses on fermion lines denote quarks from condensate.

If we assume the instanton configuration to dominate in QCD vacuum, eq. (11) may be rewritten as (7)

$$\frac{1}{2} = \frac{1}{2}\Delta q - \frac{1}{2}\ 2N_f < n_+ - n_- >_p V_p, \qquad (12)$$

where $n_+(n_-)$ is the number of instantons $\nu = 1$ (anti-instantons $\nu = -1$) in a polarized proton, V_p is the four-dimensional 'volume' of proton.

Eq. (12) has a simple physical meaning. A massless quark in the instanton field has a zero mode[10] and in scattering on this mode the quark changes helicity. So, the right quark (R) transforms into the left state (L) on the instanton, and the inverse process exists on the anti-instanton. As a result, the second term of eq. (12) corresponds to the contribution of diagrams of Fig. 1 to the proton helicity. Factor N_f in eq. (12) is the number of zero fermion modes in the instanton field, and two is due to antiquarks.

Note that $n_+ \neq n_-$ means polarization of the gluon condensate because the instanton density is proportional to the value of the gluon condensate[14]. The instanton medium may be polarized only due to the polarization of the quark condensate because instantons themselves do not carry the magnetic moment. Thus, the second term in (12) in fact results from the polarization of quarks being in the condensate inside a hadron.

So, our point of view is that the proton is not only a system of valence and sea quarks and gluons but also a system of quarks and gluons which are in condensate. By using eq. (12), the EMC result (1), hyperon decay data[4] and eq. (28) of[6] with the corrected coefficient of Δg [7]:

$$g_1^p = \frac{1}{2}\sum_{i=1}^{N_f} e_i^2 \Delta q_i + < e^2 > N_f \Delta n, \qquad (13)$$

where $< e^2 >= 2/9$, $\Delta n =< n_+ - n_- >_p$, we may estimate the contributions of partons of different species to the proton helicity:

$$\begin{aligned} \Delta\ \ u &= 0.84,\ \Delta d = -0.41,\ \Delta s = -0.13, \\ \Delta\ \ G^{vac} &= -2N_f\Delta n \approx 0.7. \end{aligned} \qquad (14)$$

Thus, the polarization of instanton vacuum gives 70% of the total amount of the proton helicity. This phenomenon is analogous to the origin of the baryon charge by a singular pion field within the soliton models of the nucleon[17]. In our case the singularity of the gluon field is defined by the instanton solution.

However, result (14) leads to two important questions: first, only 30% of the proton spin is carried by quarks and therefore the reason of success becomes unclear of the generally accepted quark model of hadrons as the system of valence quarks in describing such spin-dependent quantities as magnetic moments of hadrons, and so on. Second, which mechanism is responsible for the polarization of strange sea against the proton spin[18]?

To answer the first question, let us divide eq. (14) into valence and sea parts :

$$\Delta u = \Delta u^v + \Delta u^s,\ \Delta d = \Delta d^v + \Delta d^s,\ \Delta s = \Delta s^s.$$

Under $SU(3)$ flavour symmetry of the sea we obtain

$$\begin{aligned} \Delta u^v &= 0.97,\ \Delta d^v = -0.28, \\ \Delta u^s &= \Delta d^s = \Delta s^s = -0.13. \end{aligned} \qquad (15)$$

But with the data[19] which point out strong $SU_f(3)$ asymmetry of the sea

$$R_s = \frac{2\bar{s}}{\bar{u} + \bar{d}} = 0.52 \pm 0.09,$$

one has

$$\Delta q^v = \Delta u^v + \Delta d^v \approx 1,\ \Delta q^s = \Delta u^s + \Delta d^s + \Delta s^s \approx -0.7. \qquad (16)$$

Then it follows that the contributions of sea quarks and the polarization of vacuum condensates to the hadron helicity are cancelled and the proton spin is really defined by the spin of valence quarks!

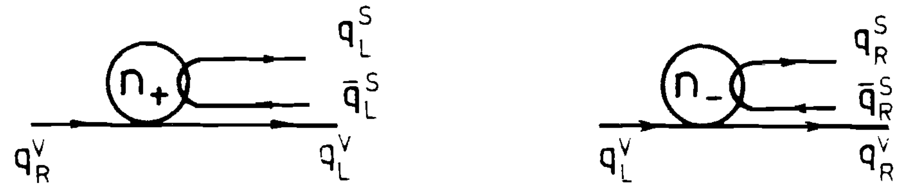

Figure 2: Polarization of sea quarks. $q^v_{R,L}$-valence quarks.

As to the sign of sea polarization (16), let us turn to the form of the instanton - induced quark Lagrangian[10]. Within the model of QCD vacuum as the instanton liquid[14] it has the form[13]:

$$\mathcal{L} \ = \ -\frac{1}{2}\sum_{i\neq j}\eta_{ij}\{\bar{q}_{iR}q_{iL}\bar{q}_{jR}q_{jL} + \frac{3}{32}(\bar{q}_{iR}\lambda^a q_{iL}\bar{q}_{jR}\lambda^a q_{jL} - \qquad (17)$$

$$-\frac{3}{4}\bar{q}_{iR}\lambda^a\sigma_{\mu\nu}q_{iL}\bar{q}_{jR}\lambda^a\sigma_{\mu\nu}q_{jL}) + (R \leftrightarrow L)\},$$

where summation runs over the quark species $(i,j = u,d,s)$, $q_{R,L} = 1/2(1 \pm \gamma_5)q$,

$$\eta_{ud} = \frac{4\pi^2\rho_c^2}{3}, \ \eta_{us} \approx 0.6\eta_{ud},$$

$\rho_c \approx 1.6\ Gev^{-1}$ is an average size of the instanton in QCD vacuum.

If one assumes that this interaction does define the mixing of sea quarks in the proton wave function (Fig.2) (this statement is natural because the one-gluon exchange gives insignificant contribution to the quark-quark potential[13]), then from (17) it immediately follows that the sea has to be polarized against the valence quark polarization (Fig. 2). So, we have shown that the EMC results may be easily interpreted by the polarization of instanton vacuum of QCD.[1]

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[1]After this note has been completed we learned about the work by S. Forte [20], where one of the most important results of our article equation (12) was independently derived. There , the origin of that formula was justified , but in our work we give a more carefully physical interpretation of this phenomenon.

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