INSTANTONS AND SINGLE SPIN ASYMMETRIES

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A new mechanism for single spin asymmetries in strong interaction is proposed. It is based on instanton–induced nonperturbative chromomagnetic quark–gluon interaction. We estimate the contribution of this interaction to single spin asymmetry in quark–quark scattering. It is shown, that interference between quark spin–flip amplitude induced by instantons and spin–nonflip amplitude, which is related to nonperturbative two gluon exchange, gives a large value for a single spin asymmetry. Due to strong increasing of the instanton–induced spin–flip amplitude with energy, this asymmetry does not vanish at high energies.

Recently, a new approach to the theory of polarized effects based upon nonperturbative QCD was proposed [1] (see also some applications of the instanton model to polarized DIS in [2]). In this approach the origin of the large polarized effects is the interaction of quarks with strong vacuum fluctuations of the gluon fields, so-called instantons [3].

In the recent paper [4] it was shown that instantons lead to a new type of the nonperturbative interaction, so–called chromomagnetic quark–gluon interaction. In [5] it was demonstrated that the contribution of this interaction to spin–dependent $g_1(x,Q^2)$ structure function is large and allow us to explain a most part of observed violation of the Ellis–Jaffe sum rule.

The fundamental feature of nonperturbative chromomagnetic quark–gluon interaction is its anomalous dependence on quark helicities. So, this interaction leads to the quark helicity flip, just as a usual perturbative quark–gluon vertex conserves the quark helicity. Therefore this nonperturbative interaction can be used as fundamental QCD mechanism to explain very large single spin asymmetries observed in hadron–hadron interaction.

The main goal of this article is to calculate the contribution of spin–flip chromomagnetic quark–gluon interaction induced by instantons to quark single spin asymmetries.

We will consider the case when the momentum transfer between quarks is small $p_\perp^2 \ll S$, where $S=(p_1+p_2)^2$, $t=(p_1'-p_1)^2=-p_\perp^2$ In this case the main contribution to quark–quark scattering amplitude gives Landshoff–Nachtmann (LN) pomeron which is based on the exchange of a pair of nonperturbative gluons [6].

In the framework of this model the nonperturbative gluon propagator reads

$$g^2D(p_\perp^2) = -\beta_0 a e^{-p_\perp^2/\mu_0^2}, \tag{1}$$

where $a = (4\pi^3)^{0.1}/\mu_0$, $\beta_0 \approx 2GeV^{-1}$, and $\mu_0 \approx 1.1GeV$.

The double gluon exchange with the perturbative quark-gluon interaction does not lead to quark spin-flip and gives rise to helicity amplitudes [7] $\Phi_1 = \Phi_3 \approx M_{+,+;+,+}$. In the framework of LN model these amplitudes are [6]

$$\Phi_1 = \Phi_3 = i2\beta^2(p_\perp^2)S, \tag{2}$$

where $\beta^2(p_\perp^2) = \beta_0^2 exp(-p_\perp^2/2\mu_0^2)$.

The additional contribution to the quark–quark scattering amplitude is related to the nonperturbative chromomagnetic quark–gluon interaction induced by instantons [4]

$$\Delta\mathcal{L}_A = -i\mu_a \sum_q \frac{g}{2m_q^*}\bar{q}\sigma_{\mu\nu}t^a q G^a_{\mu\nu}, \tag{3}$$

where $m_q^* = 2\pi^2\rho_c^2 < 0 \mid \bar{q}q \mid 0 > /3$ is a quark mass in the instanton vacuum.

The value of the quark anomalous chromomagnetic moment in the liquid instanton model [8] is

$$\mu_a = -\frac{f\pi}{2\alpha_s}, \tag{4}$$

where $f = n_c\pi^2\rho_c^4$ is the so–called packing fraction of instantons in vacuum. The value of n_c is connected with the value of the gluon condensate by the formula

$$n_c =< 0 \mid \alpha_s G^a_{\mu\nu}G^a_{\mu\nu} \mid 0 > /16\pi \approx 7.5\ 10^{-4}\ GeV^4. \tag{5}$$

The following estimate for the value of the anomalous quark chromomagnetic moment has been obtained for $\rho_c = 1.6GeV^{-1}$ in [4]

$$\mu_a = -0.2. \tag{6}$$

The quark-gluon chromomagnetic interaction gives rise to $\Phi_5 = M_{++;+-}$ spin–flip amplitude and straightforward calculation leads to the result

$$\Phi_5 = \frac{4\mu_a p_\perp g^2 D(p_\perp^2)S}{9m_q^*}F(p_\perp^2\rho_c^2), \tag{7}$$

where F(z) is the instanton form factor (see for example [9])

$$F(z) = \frac{4}{z}(1 - \frac{z}{2}K_2(\sqrt{z})). \tag{8}$$

The single spin asymmetry on the quark level can be written in the following form

$$A = \frac{2Im(\Phi_5(\Phi_1 + \Phi_3))}{|\Phi_1|^2 + |\Phi_3|^2 + 4|\Phi_5|^2}, \tag{9}$$

where we have neglected the contribution which comes from double spin-flip amplitudes Φ_2 and Φ_4, that are connected with high order instanton contributions.

The result of the calculation of the quark single spin asymmetry is that the value of the asymmetry is rather large $A \approx 10\%$ at $p_\perp \approx 1GeV$.

It should be mentioned also that due to the similar growth of both instanton–induced spin–flip amplitude 7 and of spin-nonflip LN amplitude 2 with energy, the single spin asymmetry turns out to be energy–independent. This result is supported by the experimental data on single spin asymmetries [11] and is opposite to the prediction of perturbative QCD, $A \approx m_q/\sqrt{S}$ [10].

In summary, the instanton–induced chromomagnetic quark–gluon interaction leads to a large quark single spin asymmetry at high energy. The magnitude of the single spin asymmetry is determined by the parameters of the instantons in the QCD vacuum. Therefore the investigation of the single spin asymmetries can give very important information on the structure of the QCD vacuum.

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