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THE ROLE OF THE QUARK-ANTIQUARK PAIRS IN THE SPIN-FLIP EFFECTS IN QCD AT LARGE DISTANCES

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The experimental results obtained in the last years [1] show that the spin effects are essential in high-energy hadron reactions. The modern theory of strong interaction cannot explain now all observable effects. For example, the perturbative QCD leads to a small polarization at large momenta transfer [2]. This result is in contradiction with experiment.

There are no well grounded results for a small-angle scattering based on QCD. This is connected with the importance of the long-distances effects here. Up to now different dynamical models [3-5] play an important role in the investigation of high energy reactions at fixed momenta transfer. Some of them[4,5] lead to the spin effects which have a weak energy dependence. In the case of elastic scattering this means that the exchange with vacuum quantum numbers in the t--channel has a spin-flip part growing as s.

The nonperturbative properties of the theory can be important (see, e.g. [6]) in the vacuum amplitude which is connected in QCD with the gluons exchange [7] in the t-channel.

A model of that sort was used in [8] for the investigation of spin-flip effects in high energy qq scattering at small angles. It was shown that taking accoung of the full matrix structure of the 2-gluon exchange amplitude leads to the spin-flip amplitude growing as s:

$$\frac{|T_{flip}|}{|T_{non-lip}|} \sim \frac{m\sqrt{|t|}}{\ln s/s_0 \; a(m,t)}, \qquad (1)$$

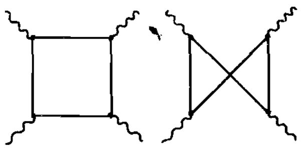
where m is a constituent quark mass, a is a function linearly dependent on $|t|$.

In this paper, using results from [8,9] we shall calculate the quark contribution to the high energy spin-flip amplitude at fixed momenta transfer. It is shown that the quark-loop effects in gluon--gluon interaction and the $q\bar{q}$ sea contributions lead to the spin-flip amplitude growing as s.

We shall be restricted to the investigation of QQ scattering, for simplicity. As in [6,8], we shall suppose that the quark and gluon propagators at small momenta transfer are determined by the nonperturbative parts. In this case we shall use the following representations:

$$\hat{G}^{q}(p)=i(\hat{p}+m)G(-p^2), \qquad G^{g}_{\alpha\beta}(q)=-ig_{\alpha\beta}F(-q^2). \quad (2)$$

In (2) we do not use any concrete form of functions $F(-q^2)$ and $G(-p^2)$ at small p^2 and q^2. The propagators (2) have a perturbative form at large momenta and they have a standard pole behaviour near the mass shell (see /6,10/). The questions connected with the normalization of F and the gauge invariance in this case are discussed in /10/.



a) b)

Fig. 1.
The quark loop contribution to the ladder gluon-gluon amplitude.

Let us consider the quark-loop contribution to the two-gluon ladder diagrams /8/. The contributions to the imaginary part come from the loop diagrams, fig.1. For the diagram, fig. 1a, with a definite flavor in the loop we have:

$$\mathrm{Im}T^{a}\sim C^{a}\frac{g^{8}}{2(2\pi)^{8}}\int d^4k\,d^4q\,d^4l\;\delta[(p-k)^2-m^2]\,\delta[(p'+l)^2-m^2]$$
$$\delta[(k+q)^2-\sigma^2]\,\delta[(q+l)^2-\sigma^2]\;H^{a}\,S^{a}_{\lambda\mu,\nu\sigma}\,N^{\lambda\mu,\nu\sigma}, \quad (3)$$

where m and σ are the masses of a constituent quark and a quark in the loop, respectively, C^{a} is a color factor,

$$H^{a}=F[-(k+r)^2]F[-(k-r)^2]F[-(l+r)^2]F[-(l-r)^2]$$
$$D[-(q+r)^2+\sigma^2]D[-(q-r)^2+\sigma^2],$$

$$S^{a}_{\lambda\mu,\nu\sigma}=\mathrm{Sp}\{\gamma_{\lambda}[\hat{q}+\hat{k}+\sigma]\gamma_{\mu}[\hat{q}-\hat{r}+\sigma]\gamma_{\sigma}[\hat{q}+\hat{l}+\sigma]\gamma_{\nu}[\hat{q}+\hat{r}+\sigma]\},$$
$$N^{\lambda\mu,\nu\sigma}=\bar{u}(p-r)\gamma^{\lambda}(\hat{p}-\hat{k}+m)\gamma^{\mu}u(p+r)\;\bar{u}(p'+r)\gamma^{\nu}(\hat{p}'+\hat{l}+m)\gamma^{\sigma}u(p'-r). \quad (4)$$

It is convenient to calculate (3) in the light-cone variables:

$$k=(xp_{+},k_{-},\vec{k}_{\perp}), \quad l=(yp_{+},l_{-},\vec{l}_{\perp}), \quad q=(-zp_{+},q_{-},\vec{q}_{\perp}),$$
$$p_{\pm}=p_0\pm p_z.$$

Integration over k_{-}, l_{-}, q_{-}, y is performed with the help of δ-functions in (3). This leads to the cut-off the integrals over transverse momenta in the upper limit: $q_{\perp}^2, k_{\perp}^2, l_{\perp}^2 \sim s$ /9/.

Let us calculate the spin-non-flip amplitude in the down quark line. The main contribution comes from the following term of the matrix element /8/:

$$N_{1}^{\nu\sigma}=\bar{u}^{+}(p'+r)\gamma^{\nu}(\hat{p}'+\hat{l}+m)\gamma^{\sigma}u^{+}(p'-r)\simeq 4p'^{\nu}p'^{\sigma}.$$

The spin-non-flip matrix element in the upper quark line has the same simple form. This permits one to calculate the corresponding amplitude without difficulties (see, e.g. /11/). The spin-flip matrix element has a more complicated structure. It can be calculated by (A3-A5) formulae from appendix. As a result, we have:

$$\langle S^{a}_{\lambda\mu,\nu\sigma}N^{\lambda\mu,\nu\sigma}\rangle_{flip}=-16m\Delta(z-y)s^2\{q_{\perp}^2[xz(1-z)/(x-z)-x(x-z)-2z]+$$
$$+k_{\perp}^2[-z(x-z)(1-2z)/(1-x)+xz(1-z)/(x-z)-2z(1-z)]+$$
$$+2(\vec{q}_{\perp}\vec{k}_{\perp})[xz(1-z)/(x-z)-2z(1-z)-xz]+\Delta^2/4\;(z^2-x^2)-$$
$$-m^2z(x-2z)(x-z)/(1-x)+\sigma^2[xz(1-z)/(x-z)-x(x-z)-2z(1+x)+2x]\}. \quad (5)$$

The corresponding integrals over $d^2k_{\perp}$, $d^2l_{\perp}$ are convergent in the upper limit. The main logarithmic asymptotic of (3) is connected with the integration over $d^2q_{\perp}$ near $q_{\perp}^2\sim s$. In this region the momenta squared in the quark loop are large, and we can use the asymptotic free quark propagators D. It is convenient to write (5) in the form:

$$\langle S^{a}_{\lambda\mu,\nu\sigma}\, N^{\lambda\mu,\nu\sigma}\rangle_{flip} = m\,\Delta\, s^2\,[a(x,z)\, q_\perp^2 + \Psi^a(x,z,q_\perp,k_\perp,\Delta)]. \qquad (6)$$

After integration we find:

$$\mathrm{Im}T^a_{flip} = 2N_f \frac{m\Delta\alpha_s^4 \pi s}{(2\pi)^4}\{\ln s/s_0 \int d^2 l_\perp\, F[-(\widetilde{l+r})^2]F[-(\widetilde{l-r})^2]$$
$$\int_y^1 \frac{dx}{x^2\,(1-x)} \int d^2k_\perp\, F[-(\widetilde{k+r})^2]F[-(\widetilde{k-r})^2] I^a(x) + (\text{non log terms})\}, \qquad (7)$$

where

$$I^a(x) = c^a \int_y^x \frac{dz\,(x-z)}{(z-y)}\, a(x,z). \qquad (8)$$

The gluon propagators in (7) depend on variables:

$$-(\widetilde{k\pm r})^2 = \{x^2m^2 + [\vec{k}_\perp \pm (1-x)\vec{r}_\perp]^2\}/(1-x);$$
$$-(\widetilde{l\pm r})^2 = (\vec{l}_\perp \pm \vec{r}_\perp)^2. \qquad (9)$$

Summation runs over quark flavors, and the antiquark loops are taken into account in (7).

For diagram 1b we obtain for the spin-flip matrix element the expression similar to (6):

$$\langle S^{b}_{\lambda\mu,\nu\sigma}\, N^{\lambda\mu,\nu\sigma}\rangle_{flip} = m\,\Delta\, s^2\,[b(x,z)\, q_\perp^2 + \Psi^b(x,z,q_\perp,k_\perp,\Delta)]. \qquad (10)$$

After calculations for the sum of diagrams fig. 1 we get the asymptotical behaviour in form (7) where expression (8) is changed to the integral:

$$I(x) = \int_y^x dz\,[4/27\; a(x,z)(x-z)/(z-y) - 1/54\; b(x,z)] =$$
$$= -16/27\; x^3[5/6 - 3x]. \qquad (11)$$

So we may conclude that the main logarithmic terms in diagrams, fig. 1, are connected with the integration region determined by short distances in quark propagators and long distances in gluon propagators. Really, during the integration of (11) over x , the region $x \sim$ const is essential. Here the gluon momenta squared (8) are small.

Note that in QCD the momentum dependence of the vertex functions leads to the logarithmic terms similar to (7) in diagrams of the fig.1 type with the gluon and ghost loops. The sum of all these ln s terms can vanish. (The investigation of this problem will be done elsewhere).

The contributions connected with short distances in quark propagators can disappear only as a result of this compensation. The remaining terms are determined completely by long distances in the t-channel propagators (nonlogarithmic terms in (7)). In this case we have the following behaviour for the spin flip amplitude, different from (7):

$$T_{flip} \sim im\,\Delta\, s\, \phi(t). \qquad (12)$$

Let us now investigate the effects connected with the $q\bar{q}$ sea contribution. These effects may lead to the spin-flip amplitude growing as s too /12/. There are some approaches which permit one to take into account the nonperturbative effects connected with the $q\bar{q}$ sea, e.g. the coupled channel framework /13/, the method of effective meson Lagrangians in low energy physics /14/. The latter method permits to replace in fig. 2 the s -channel gluon exchanges by the t -channel meson exchanges (fig.3).

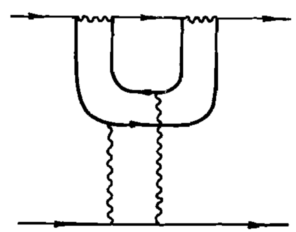


Fig. 2.
Diagram with the $q\bar{q}$ sea contribution.

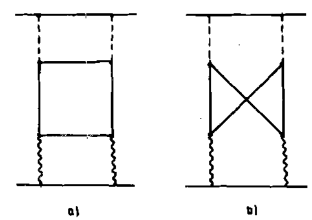


Fig.3. Effective diagrams with the meson exchanges in t -channel.

In the case of the meson contribution we can use the following lagrangian (without the isospin structure):

$$L_{\pi qq} = ig_\pi \bar{\Psi}^a \gamma_5 \Psi^a \pi. \qquad (13)$$

For the scattering amplitude we have the form (3) where we must do some replacement in coupling constants propagators, and so on. The calculations show that the main logarithmic terms in diagrams, fig 3a,b, cancel out. As a result, the asymptotical behaviour of the spin-flip scattering amplitude is determined by the nonlogarithmic terms in (7). Thus, in this simple model we obtain the behaviour (12) for the spin-flip amplitude. As mentioned previously, this behaviour is connected with the large-distance behaviour of all t -channel propagators.

Note that in the meson-cloud model /5/ based on the hypothesis that the sea effects dominate in the spin-flip amplitude, the results were obtained similar to the consequences of the model (fig.3).

A large magnitude of the meson coupling constant g_π in (13) permits us to conclude that similar contributions can be very important in the investigation of spin effects in high-energy hadron scattering. This can explain the success of the meson-cloud model in the description of the spin effects in hadron reactions /15/.

Thus, our analysis shows an essential role of the $q\bar{q}$ pair in spin effects in hadron interactions at high energies.

A more detailed calculation of the quark-quark scattering in the considered model which takes into account the $q\bar{q}$ sea effects is very important. However, to perform this, we must use information about the long-distances behaviour of quark and gluon propagators, This investigation will be done in future.

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Appendix

We shall here write some common formulae which are convenient for the calculation of the spin-flip matrix elements. Here we use the symmetric coordinate system /8/ in which the sum of quark momenta before and after scattering is directed along the Z -axis; and the moments transfer Δ , along the X axis.

The matrix element of the product:

$$N^{\lambda\mu}= \bar{u}(p-r)\gamma^{\lambda}(\hat{s}+m)\gamma^{\mu}u(p+r); \quad s=p-k; \quad \Delta=-2r \tag{A1}$$

can be decomposed in the sum of symmetric and antisymmetric parts:

$$N^{\lambda\mu}= \bar{u}\ [\hat{S}^{\lambda\mu}+\hat{A}^{\lambda\mu}]\ u,$$

$$\hat{S}^{\lambda\mu}\simeq s^{\lambda}\gamma^{\mu}+s^{\mu}\gamma^{\lambda}+g^{\lambda\mu}\hat{k}\ ,$$

$$\hat{A}^{\lambda\mu}=i\varepsilon^{\lambda\mu\delta\rho}s_{\delta}\gamma_{\rho}\gamma_{5}-im\ \sigma^{\lambda\mu}. \tag{A2}$$

Using expressions from /8/ we can calculate the spin-flip matrix elements of $\hat{S}^{\lambda\mu}$ (The light-cone variables are used):

$$<\hat{S}^{\lambda\mu}a_{\lambda}v_{\mu}>_{flip}= m\Delta\ [(sa)v_{+}/p_{+}+(sv)a_{+}/p_{+}+(av)k_{+}/p_{+}],$$

$$<\hat{S}^{\lambda\mu}g_{\lambda\mu}>_{flip}= 2m\Delta\ [1+k_{+}/p_{+}]. \tag{A3}$$

For the matrix element from $\hat{A}^{\lambda\mu}$ we have:

$$<\hat{A}^{\lambda\mu}q_{\lambda}b_{\mu}>_{flip}=m\ \{k_{x}[(q_{+}b_{-})-(b_{+}q_{-})]+k_{+}[q_{-}b_{x}-b_{-}q_{x}]+$$

$$+[b_{x}q_{+}/p_{+}-q_{x}b_{+}/p_{+}](\Delta^{2}/2\ -p_{+}k_{-})\}. \tag{A4}$$

The quantities $a,\ v,\ b,\ q$ in (A3, A4) are some vectors.

Let us now write some formulae which follow from (A4). They are needed for the calculation of the diagram of fig. 1a:

$$<\hat{A}^{\lambda\mu}q_{\lambda}\ p'_{\mu}>_{flip}= m\ [k_{x}(q_{+}p_{+})-q_{x}(k_{+}p_{+})],$$

$$<\hat{A}^{\lambda\mu}r_{\lambda}\ p'_{\mu}>_{flip}= m\Delta/2\ (k_{+}p_{+}),$$

$$<\hat{A}^{\lambda\mu}r_{\lambda}\ q_{\mu}>_{flip}=-m\Delta/2[(q_{+}k_{-})-(k_{+}q_{-})-q_{+}/p_{+}\ \Delta^{2}/2]. \tag{A5}$$

Expressions (A3-A5) are more convenient for calculations than the formulae from /8/.

References

1. Nurushev S.B. In:Proc. of the II Int.Workshop on High Energy Spin Physics, Protvino, 1984, p.5.
   Krish A.D. In:Proc. of the 6-th Intern.Symp. on High Energy Spin Phys., Marseille, 1984, p.C2-511.
2. Brodsky S.J., Lepage G.P. Phys.Rev., 1981, v.D24, p.2848.
3. Bourrely C., Leader E., Soffer J. Phys.Rep., 1980, v.59. p.95.
   Kamran M. Phys.Rep., 1984, v.108, p.272.
4. Pumplin J., Kane G.L. Phys.Rev., 1975, v.D11, p.1183.
   Soloviev L.D., Shchelkachov A.V. Particles and Nuclei, 1975, v.6, p.571.
   Troshin S.M., Tyurin N.E. Pis'ma Zh.Eksp.Teor. Fiz., 1976,v.23, p.716.
   Bourrely C., Soffer J., Wu T.T. Phys.Rev., 1979, v.D19, p.3249.

5. Goloskokov S.V., Kuleshov S.P., Selyugin O.V. Particles and Nuclei, 1987, v.18, p.39.
6. Landshoff P.V., Nachtmann O.Z. Phys.C., 1987, v.35. p.405.
7. Low F.E.Phys.Rev., 1975, V,D12, p.163;
Nussinov S. Phys.Rev.Lett., 1975, v.34, p.1286.
8. Goloskokov S.V. Yad.Fiz., 1989, V.49. p.1427.
9. Goloskokov S.V. Pr. BARY-TH/89-47, BARY, 1989.
10. Ross D.A. J.Phys.G.Nucl.Part Phys. 1989, v.15, p.1175.
11. Cheng H., Wu T.T. Phys.Rev., 1970, v.D1, p.2775.
12. Goloskokov S.V. In:Proc. of the 8-th Int.Symp. on High Energy Spin Phys., Minneapolis, 1988.
13. Zenczykowski P., Törnqvist N.A. Phys.Rev. 1984, v.D29, p.2139 .
14. Volkov M.K. Particles and Nuclei, 1986, v.17. p. 433.
15. Goloskokov S.V., Kuleshov S.P., Selyugin O.V. Yad.Fiz. 1989, v.50, p.779.

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Роль кварк-антикварковых пар в эффектах с переворотом спина в КХД на больших расстояниях

В модели, учитывающей свойства КХД на больших расстояниях, показано, что кварковые петли в t-канальном обмене и вклады $q\bar{q}$ моря приводят к амплитуде с переворотом спина, растущей как S при высоких энергиях и фиксированных переданных импульсах.

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Goloskokov S.V. E2-89-736

The Role of the Quark-Antiquark Pairs in the Spin-Flip Effects in QCD at Large Distances

In the model with taking account of the long-distance properties of QCD it is shown that the quark loops in the t-channel exchange and the $q\bar{q}$ sea contributions lead to the spin-flip amplitude growing as S at high energies and fixed momenta transfer.

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

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