# Roles of chiral constituent quarks in nucleon spin structure

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Constituent quark model provides a simple picture of the nucleon and its predictions for static hadron properties are quite consistent with experiments, although this model involves artificial assumptions and adjustable parameters. However, a clear connection has not been established yet between the constituent quark picture and the parton distribution functions measured in deep inelastic lepton nucleon scattering. In ref. [1] it was pointed out that the structure of the constituent quark itself may be important to describe the nucleon structure function. At large Bjorken-$x$ the nucleon is simply described as a bound state of three constituent quarks. At middle $x \sim 0.3$, other degrees of freedom such as meson clouds are essential rather than the simple valence quarks. The Reggeon which may be governed by the non-perturbative gluon dynamics plays a major role in the structure function at small-$x$. Significance of such contributions to the unpolarized structure function was demonstrated in ref. [1]. We naturally extend our model to the polarized structure functions, $g_1(x)$ and $h_1(x)$[2]. Here, we are interested in only the meson cloud contributions. Study of the Reggeon contribution to the polarized structure functions will be discussed in subsequent publications.

We dress the constituent quark by introducing the Goldstone bosons based on the chiral quark model of Manohar and Georgi [3]. Let $\psi = (u, d, s)$ be the quark field with $N_f = 3$ flavours. The effective interaction Lagrangian in leading order is given by

$$\mathcal{L}_{\rm int} = -\frac{g_A}{f}\bar{\psi}\gamma^\mu\gamma^5\left(\partial_\mu \Pi\right)\psi \tag{1}$$

with $\Pi$ being the standard octet GS boson matrix field. The physical $u$-quark state is written by the following form;

$$|U\rangle \;=\; \sqrt{Z}\,|u_0\rangle + a_\pi\,|d\pi^+\rangle + \frac{a_\pi}{2}\left|u\pi^0\right\rangle + a_K\,|sK^+\rangle + \frac{a_\eta}{6}\,|u\eta\rangle \;\;, \tag{2}$$

where $Z$ is the renormalization constant for a "bare" constituent quark $|u_0\rangle$ and $|a_i|^2$ are probabilities to find GS bosons in the dressed constituent quark states, which are calculated within the chiral quark model. Similar expressions can be written for $d, s$-quarks. We use the Infinite Momentum Frame with the time-ordered perturbation theory to calculate these probabilities. For example, the unpolarized splitting function $P(y)_{j\,\alpha/i}$ which gives the probability to find a constituent quark $j$ carrying the light-cone momentum fraction $y$ together with a spectator GS boson ($\alpha = \pi, K, \eta$), both of which coming from a parent constituent quark $i$, is expressed as

$$P(y)_{j\,\alpha/i} = \frac{1}{8\pi^2}\left(\frac{g_A\,\bar{m}}{f}\right)^2 \int dk_T^2 \frac{(m_j - m_i y)^2 + k_T^2}{y^2(1-y)\left[m_i^2 - M_{j\alpha}^2\right]^2} \;\;, \tag{3}$$

where $m_i, m_j, m_\alpha$ are the masses of the $i, j$- constituent quarks and the pseudoscalar meson $\alpha$, respectively. $M_{j\,\alpha}^2 = \frac{m_j^2+k_T^2}{y} + \frac{m_\alpha^2+k_T^2}{1-y}$ is the invariant mass squared of the final state. We have also given an estimate of two-pion Fock state contributions, which is of order of a few % and could be negligible.

The Goldstone boson fluctuations produce a flavor asymmetry of the quark distribution in the nucleon in agreement with experimental data. They also generate significant depolarization effects which reduce the fraction of the nucleon spin carried by quarks. This is because the GS boson emission converts part of the spin of the constituent quark into ($P$-wave) angular momentum of the meson cloud due to the axial-vector coupling of the chiral Lagrangian. Results are shown in Table 1 for the axial-charge and tensor charge, which are the first moments of the helicity distribution $g_1(x)$ and transversity distribution $h_1(x)$, respectively. Here, we use the relativistic constituent quark model to obtain the input 'bare' values. Reduction for the quark spin fraction $\Delta u, \Delta d$ is considerable but not enough to reproduce the experimental data. Hence we conclude that the nucleon spin problem is not solved by the GS boson dressing alone, in contrast to the previous naive estimates[4]. On the other hand, the calculated depolarization in the present study (30-40%) is quite consistent with the recent decomposition of the nucleon spin[5] when identified with the contribution from the quark orbital angular momentum. We have also studied possible other contributions to the nucleon spin structure[2]. When combined with other contributions, namely the axial $U(1)$ anomaly and the meson cloud effects, to be identified with the disconnected contributions on the lattice QCD simulations, the present results go altogether into the right direction of providing a reasonable description of the nucleon spin structure.

Corrections to the chiral-odd transversity spin structure function $h_1(x)$ is also interesting. In comparison with the correction for $g_1(x)$, where the CQ-GS boson splitting function $\Delta P$ is negative, we find a positive contribution to the $h_1(x)$ structure function (Fig.1). With inclusion of the renormalization effect, the transversity spin structure function for the $d$-quark is shown to be reduced significantly. In particular we find a large reduction (40%) of the $d$-quark tensor charge $\delta d$, which is consistent with recent lattice calculations (Table 1).

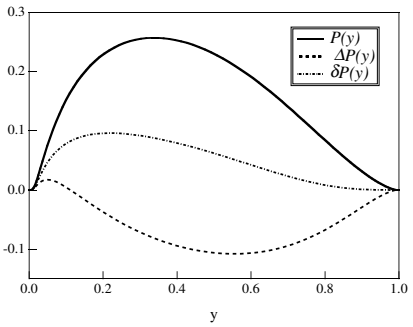

Figure 1: GS boson splitting functions

Table 1: 1st moments of the spin structure functions with GS bosons

| | $\Delta u$ | $\Delta d$ | $\delta u$ | $\delta d$ |
|---|---|---|---|---|
| Bare | 1.01 | −0.25 | 1.17 | −0.29 |
| CQ | 0.65 | −0.22 | 0.80 | −0.15 |
| Lattice | 0.76 | −0.35 | 0.84 | −0.23 |

In closing we mention that, recently, considerable interest has been focused on the possible experimental observation of such a "soft" pion cloud surrounding the nucleon. Semi-inclusive deep inelastic scattering processes with pions in the final state is studied as promising option[6].

## References


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