THE SPIN STRUCTURE OF THE NUCLEON FROM $\ell p-$DIS

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1 Introduction

Deep Inelastic lepton-nucleon scattering is a powerful source of the information on spin structure of the nucleons (see, for example,[1]). According to the recent experimental data of HERMES and COMPASS [2]–[5] the quark and antiquark bear 33-35% of nucleon spin, light antiquarks $\bar{u}$, $\bar{d}$ contribution is near to zero and the strange quarks have the negative polarization – 5-10%. Gluon contribution to the spin of nucleon is not so big as it has been supposed at first and according experimental data is $\leq 0.3 - 0.4$. The nucleon spin problem requires the further experimental research of all contributions.

In the present work the possibilities of determination of the quark contributions to the nucleon spin based on observable asymmetries of lpsemi-inclusive deep inelastic scattering (SIDIS) with the charged weak current are considered.

2 The cross section and polarized asymmetries

Let us consider the process of semi-inclusive deep inelastic $lp-$scattering with charged weak current

$$\ell + p \to \nu + h + X. \tag{1}$$

The differential cross sections of the process (1) in the case of a lepton have the form

$$\sigma_{\ell^-} = 2\rho x \left\{ \sum_{q_i,q_j} q_i(x) D^h_{q_j}(z) + y_1^2 \sum_{\bar{q}_j,\bar{q}_i} \bar{q}_j(x) D^h_{\bar{q}_i}(z) + \right.$$
$$\left. + P_N \left(\sum_{q_i,q_j} \Delta q_i(x) D^h_{q_j}(z) - y_1^2 \sum_{\bar{q}_j,\bar{q}_i} \Delta \bar{q}_j(x) D^h_{\bar{q}_i}(z) \right) \right\}, \qquad (2)$$

where $q = u, c, t$, $\bar{q} = \bar{d}, \bar{s}, \bar{b}$.

In the case of an antilepton the cross sections look like

$$\sigma_{\ell^+} = 2\rho x \left\{ y_1^2 \sum_{q_i,q_j} q_i(x) D^h_{q_j}(z) + y_1^2 \sum_{\bar{q}_j,\bar{q}_i} \bar{q}_j(x) D^h_{\bar{q}_i}(z) + \right.$$
$$\left. + P_N \left(y_1^2 \sum_{q_i,q_j} \Delta q_i(x) D^h_{q_j}(z) - \sum_{\bar{q}_j,\bar{q}_i} \Delta \bar{q}_j(x) D^h_{\bar{q}_i}(z) \right) \right\}, \qquad (3)$$

where $q = d, s, b$, $\bar{q} = \bar{u}, \bar{c}, \bar{t}$.

Here $\sigma \equiv \dfrac{d^3\sigma}{dxdydz}$, $\rho = \dfrac{G^2 s}{2\pi} \left(\dfrac{m_w^2}{m_w^2 + Q^2} \right)^2$, $y_1 = 1 - y$, G is Fermi constant, m_w is the W-boson mass, $x = \dfrac{Q^2}{2p\cdot q}$, $y = \dfrac{p\cdot q}{p\cdot k}$, $Q^2 = -q^2 = -(k - k')^2$, $s = 2p\cdot k$, $k(k')$ and p are the initial (final) lepton and proton 4-momenta, respectively, P_N is the degree of longitudinal polarization of proton, $q(x)(\Delta q(x))/\bar{q}(x)(\Delta \bar{q}(x))$ are the unpolarized (polarized) quark/antiquark distribution functions, $D^h_q(z)(D^h_{\bar{q}}(z))$ are the fragmentation functions of quark (antiquark) with flavor q to the hadron h.

We define the polarization asymmetries in the form of [7]

$$A^{h^+-h^-}_{\ell^-,\ell^+} = \frac{\sigma^{\downarrow\uparrow,\uparrow\uparrow}_{\ell^-,\ell^+} - \sigma^{\downarrow\downarrow,\uparrow\downarrow}_{\ell^-,\ell^+}}{\sigma^{\downarrow\uparrow,\uparrow\uparrow}_{\ell^-,\ell^+} + \sigma^{\downarrow\downarrow,\uparrow\downarrow}_{\ell^-,\ell^+}}, \qquad (4)$$

$$A^{h^+-h^-}_{\pm} = \frac{\left(\sigma^{\downarrow\uparrow}_{\ell^-} \pm \sigma^{\uparrow\uparrow}_{\ell^+}\right) - \left(\sigma^{\downarrow\downarrow}_{\ell^-} \pm \sigma^{\uparrow\downarrow}_{\ell^+}\right)}{\left(\sigma^{\downarrow\uparrow}_{\ell^-} \pm \sigma^{\uparrow\uparrow}_{\ell^+}\right) + \left(\sigma^{\downarrow\downarrow}_{\ell^-} \pm \sigma^{\uparrow\downarrow}_{\ell^+}\right)} \qquad (5)$$

The first arrow corresponds to the helicity of the initial lepton ($\downarrow$) or antilepton ($\uparrow$) and the second – to the polarization degree of the proton: $\uparrow$ ($P_N = +1$), $\downarrow$ ($P_N = -1$).

Let us consider the case $h = \pi^+$. From equations (4), (5) for the case of a proton targets for asymmetry we have

$$A_{\ell^-}^{\pi^+-\pi^-} = \frac{\Delta u(x) D_d^{\pi^+-\pi^-}(z) - y_1^2 \Delta\bar{d}(x) D_{\bar{u}}^{\pi^+-\pi^-}(z)}{u(x) D_d^{\pi^+-\pi^-}(z) + y_1^2 \bar{d}(x) D_{\bar{u}}^{\pi^+-\pi^-}(z)}, \tag{6}$$

$$A_{\ell^+}^{\pi^+-\pi^-} = \frac{y_1^2 \Delta d(x) D_u^{\pi^+-\pi^-}(z) - \Delta\bar{u}(x) D_{\bar{d}}^{\pi^+-\pi^-}(z)}{y_1^2 d(x) D_u^{\pi^+-\pi^-}(z) + \bar{u}(x) D_{\bar{d}}^{\pi^+-\pi^-}(z)}, \tag{7}$$

$$\begin{aligned} A_{+,p}^{\pi^+-\pi^-} = & \Big\{\Delta u(x) D_d^{\pi^+-\pi^-}(z) - y_1^2(\Delta\bar{d}(x) D_{\bar{u}}^{\pi^+-\pi^-}(z) + \\ & + \Delta d(x) D_u^{\pi^+-\pi^-}(z)) + \Delta\bar{u} D_{\bar{d}}^{\pi^+-\pi^-}(z)\Big\} \Big/ \\ & \Big/ \Big\{u(x) D_d^{\pi^+-\pi^-}(z) + y_1^2(\bar{d}(x) D_{\bar{u}}^{\pi^+-\pi^-}(z) - \\ & - d(x) D_u^{\pi^+-\pi^-}(z)) - \bar{u}(x) D_{\bar{d}}^{\pi^+-\pi^-}(z)\Big\}, \end{aligned} \tag{8}$$

$$\begin{aligned} A_{-,p}^{\pi^+-\pi^-} = & \Big\{\Delta u(x) D_d^{\pi^+-\pi^-}(z) - y_1^2(\Delta\bar{d}(x) D_{\bar{u}}^{\pi^+-\pi^-}(z) - \\ & - \Delta d(x) D_u^{\pi^+-\pi^-}(z)) - \Delta\bar{u} D_{\bar{d}}^{\pi^+-\pi^-}(z)\Big\} \Big/ \\ & \Big/ \Big\{u(x) D_d^{\pi^+-\pi^-}(z) + y_1^2(\bar{d}(x) D_{\bar{u}}^{\pi^+-\pi^-}(z) + \\ & + d(x) D_u^{\pi^+-\pi^-}(z)) + \bar{u}(x) D_{\bar{d}}^{\pi^+-\pi^-}(z)\Big\}. \end{aligned} \tag{9}$$

Taking into account the correlations [8],[9] for π−meson fragmentation functions

$$D_d^{\pi^+-\pi^-} = -D_u^{\pi^+-\pi^-}, \quad D_u^{\pi^+-\pi^-} = -D_{\bar{u}}^{\pi^+-\pi^-}$$

asymmetries (6)-(9) have the form

$$A_{\ell^-}^{\pi^+-\pi^-} = \frac{\Delta u(x) - y_1^2 \Delta\bar{d}(x)}{u(x) + y_1^2 \bar{d}(x)}, \tag{10}$$

$$A_{\ell^+}^{\pi^+-\pi^-} = \frac{y_1^2 \Delta d(x) - \Delta\bar{u}(x)}{y_1^2 d(x) + \bar{u}(x)}, \tag{11}$$

$$A_{+,p}^{\pi^+-\pi^-} = \frac{\Delta u(x) + \Delta\bar{u}(x) - y_1^2(\Delta d(x) + \Delta\bar{d}(x))}{u_V(x) - y_1^2 d_V(x)}, \tag{12}$$

$$A_{-,p}^{\pi^+-\pi^-} = \frac{\Delta u_V(x) + y_1^2 \Delta d_V(x)}{u(x) + \bar{u}(x) + y_1^2(d(x) + \bar{d}(x)}, \tag{13}$$

where $u_V(x) = u(x) - \bar{u}(x)$, $d_V(x) = d(x) - \bar{d}(x)$.

Similarly we receive the asymmetries for the case $h^+ = K^+$. For $K-$meson fragmentation function $D_d^{K^+-K^-}$ the asymmetries (4), (5) look like

$$A_{\ell-}^{K^+-K^-} = -\frac{\Delta\bar{d}(x)}{\bar{d}(x)}, \tag{14}$$

$$A_{\ell+}^{K^+-K^-} = \frac{\Delta d(x)}{d(x)}, \tag{15}$$

$$A_{+,p}^{K^+-K^-} = -\frac{\Delta d_V(x)}{d_V(x)}, \tag{16}$$

$$A_{-,p}^{K^+-K^-} = \frac{\Delta d_V(x)}{d(x) + \bar{d}(x)}, \tag{17}$$

where $\Delta d_V(x) = \Delta d(x) - \Delta\bar{d}(x)$.

3 Determination of the quark flavours contribution to the nucleon spin

For nucleon spin structure analysis we introduce the first parton distributions moments as follows

$$\Delta q(\Delta\bar{q}) = \int_0^1 \Delta q(x)(\Delta\bar{q}(x))dx, \tag{18}$$

which correspond to the quark q(antiquark $\bar{q}$) contributions to the spin of nucleon.

Then from the asymmetries (14) and (15) the d quark contribution to the nucleon spin can be defined as

$$\Delta d = \int_0^1 d(x) A_{\ell+}^{K^+-K^-} dx, \tag{19}$$

$$\Delta\bar{d} = -\int_0^1 \bar{d}(x) A_{\ell-}^{K^+-K^-} dx. \tag{20}$$

We received Δu and $\Delta\bar{u}$ from asymmetries (10), (14) and (11), (15) respectively:

$$\Delta u = \int_0^1 \left(A_{\ell-}^{\pi^+-\pi^-}(u(x) - y_1^2\bar{d}(x)) + y_1^2 A_{\ell-}^{K^+-K^-}\bar{d}(x)\right)dx, \tag{21}$$

$$\Delta\bar{u} = \int_0^1 \left(-A_{\ell+}^{\pi^+-\pi^-}(y_1^2 d(x) + \bar{u}(x)) + y_1^2 A_{\ell+}^{K^+-K^-} d(x)\right)dx. \tag{22}$$

Evidently, that from equations (19)–(22) can be find the $(\Delta u+\Delta\bar{u})$, $(\Delta d+\Delta\bar{d})$. Also the quarks contributions $(\Delta u + \Delta\bar{u})$, $(\Delta d + \Delta\bar{d})$, $(\Delta s + \Delta\bar{s})$ can be determined using the asymmetry $A^{\pi^+-\pi^-}_{+,p}$ and additional observable quantities – axial charges a_3 and a_8 (see, for example, [10])

$$\begin{aligned} a_3 &= (\Delta u + \Delta\bar{u}) - (\Delta d + \Delta\bar{d}), \\ a_8 &= (\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) - 2(\Delta s + \Delta\bar{s}). \qquad (23) \end{aligned}$$

Then using (12), (23) the quarks contributions are

$$\begin{aligned} \Delta u + \Delta\bar{u} &= \frac{1}{1-y_1^2}\Big(\int_0^1 A^{\pi^+-\pi^-}_{+,p}(u_V(x) - y_1^2 d_V(x))dx - y_1^2 a_3\Big), \qquad (24) \\ \Delta d + \Delta\bar{d} &= \frac{1}{1-y_1^2}\Big(\int_0^1 A^{\pi^+-\pi^-}_{+,p}(u_V(x) - y_1^2 d_V(x))dx - a_3\Big), \qquad (25) \\ \Delta s + \Delta\bar{s} &= \frac{1}{1-y_1^2}\Big(\int_0^1 A^{\pi^+-\pi^-}_{+,p}(u_V(x) - y_1^2 d_V(x))dx - \\ &\quad -2a_3(1+y_1^2)\Big) - 2a_8. \qquad (26) \end{aligned}$$

Valence $d-$, $u-$ quarks contribution can be determined from (13) and (16) as

$$\begin{aligned} \Delta d_V &= \int_0^1 d_V(x) A^{K^+-K^-}_{+,p} dx, \qquad (27) \\ \Delta u_V &= \int_0^1 \Big(\Big(u(x) + \bar{u}(x) + y_1^2(d(x) + \bar{d}(x))\Big) A^{\pi^+-\pi^-}_{-,p} + \\ &\quad + y_1^2 d_V(x) A^{K^+-K^-}_{+,p}\Big) dx. \qquad (28) \end{aligned}$$

4 Conclusions

1. The polarization asymmetries $A^{h^+-h^-}_{\ell\pm}$,$A^{h^+-h^-}_{\pm,p}$ for the $\pi-$, $K-$ meson production in SIDIS with charged weak current do not depend from the fragmentation functions.

2. The separate contributions of quarks and antiquarks via observable asymmetries and unpolarized parton distributions have been determined.

3. The contributions of valence quarks Δu_V,Δd_V have been obtained.

4. The contribution of strange quarks has been determined in our approach via asymmetries and additional quantities – axial charges.

References

[1] Burkardt, M [et al.] Spin-polarized high-energy scattering of charged leptons on nucleons, - 2008. – 103 p. (ArXiv: hep-ph/ 0812.2208)

[2] Kuhn, S.E. [et al.] The spin structure of the nucleon – status and recent results, - 2008. - 69 p. (ArXiv: hep-ph/0812.3535)

[3] M. Hirai and S. Kumano [Asymmetry Analysis Collaboration], preprint hep-ph/0808.0413

[4] A. Airapetian et al. [HERMES Collaboration], preprint hep-ex/0803.2993

[5] D. de Florian, R.Sassot, M.Stratmann and W.Vogelsang, preprint hep-ph/0804.0422

[6] Ashman, J. et al. // Nuclear Physics B.-1989. - Vol. 328, 1.- P.1-35

[7] Timoshin S.I. The spin and electroweak effects in the lepton-nucleon scattering: Gomel : GSTU , 2002. – 121 p

[8] Christova E., Leader E. A model independent approach to semi-inclusive deep inelastic scattering / E. Christova, E. Leader. 2004. 5p. (ArXiv: hep-ph/0412150)

[9] Sissakian A.N. et al. NLO QCD procedure of the SIDIS data analysis with respect to light quark polarized sea / A.N. Sissakian et al. 2004. – 20p. (ArXiv: hep-ph/0312084)

[10] Bass S.D., Aidala C.A. Towards an understanding of nucleon spin structure: from hard to soft scales / S.D. Bass, C.A. Aidala. 2006. 19p. (ArXiv: hep-ph/0606269)