The Spin of Nucleon in Lepton-Nucleon DIS

E. Timoshin, S. Timoshin

Gomel State Technical University

Abstract

The spin of nucleon in the processes deep inelastic scattering leptons on nucleons have been investigated.

PACS numbers: 13.88.+c, 13.15.+g , 13.40.Ks , 13.60.Hb , 14.20.Dh
Keywords: quark, nucleon spin, structure function, asymmetry

In present time is known that only about 30% of the nucleon spin is accounted by quarks and antiquarks. The quark contribution is dominated by the valence component [1, 2]. The polarization of strange quarks and antiquarks in the nucleon is not well known at present [3, 4, 5, 6].

In present report we propose to use a measurable quantities of lN-DIS with charged and neutral current (γ, Z *exchange*) for the extraction data about the contributions of the quarks in nucleon spin.

The cross sections of the inclusive DIS unpolarized leptons on polarized nucleons

$$l + N \xrightarrow{\gamma,Z} l + X \tag{1}$$

in Born approximation are

$$\sigma_{l^-,l^+} = \frac{4\pi\alpha^2 s}{Q^4}\left[\frac{y^+}{2}F_{2s} \mp \frac{y^-}{2}xF_{3s} + P_N x\Big(y^+ g_{6s} \mp y^- g_{1s}\Big)\right]. \tag{2}$$

Here $\sigma = d^2\sigma/dxdy$, $Q^2 = -q^2 = -(k-k')^2$, $s = 2pk$, $y^\pm = 1 \pm (1-y)^2$, $x = \frac{Q^2}{2p\cdot q}$, $y = \frac{p\cdot q}{p\cdot k}$, $k(k')$, $p - 4$ – momentum incoming (outcoming) lepton and nucleon respectively; P_N is the degree of the longitudinal polarization of nucleon; $F_{2s,3s}$ and $g_{1s,6s}$ are spin-average and spin-dependent structure functions (SF) of nucleon.

These SF give following expressions:

$$\begin{aligned} F_{2s} &= F_2^{\gamma} + \eta_{\gamma Z} g_V F_2^{\gamma Z} + \eta_Z (g_V^2 + g_A^2) F_2^Z, \\ F_{3s} &= -\eta_{\gamma Z} g_A F_3^{\gamma Z} - 2\eta_Z g_V g_A F_3^Z, \\ g_{1s} &= -\eta_{\gamma Z} g_A g_1^{\gamma Z} - 2\eta_Z g_V g_A g_1^Z, \\ g_{6s} &= \eta_{\gamma Z} g_V g_6^{\gamma Z} + \eta_Z (g_V^2 + g_A^2) g_6^Z. \end{aligned} \tag{3}$$

In (3) are
$\eta_{\gamma Z} = \frac{G m_Z^2}{2\sqrt{2}\pi\alpha} \cdot \frac{Q^2}{Q^2 + m_Z^2}$, $\eta_Z = \eta_{\gamma Z}^2$,
G is Fermi constant, m_Z is mass of Z-bozon; $g_V = -\frac{1}{2} + 2\sin^2\theta_W$, $g_A = -\frac{1}{2}$, θ_W is Weinberg angle. The expression for $F_2^{\gamma,\gamma Z,Z}$, $F_3^{\gamma Z,Z}$, $g_{1,6}^{\gamma Z,Z}$ are in [7].

The single spin asymmetries determine as following the combinations of the cross sections (2):

$$A^s_{l^-,l^+} = \frac{\sigma^{\uparrow}_{l^-,l^+} - \sigma^{\downarrow}_{l^-,l^+}}{\sigma^{\uparrow}_{l^-,l^+} + \sigma^{\downarrow}_{l^-,l^+}}, \tag{4}$$

where $\uparrow$ ($P_N = +1$) and $\downarrow$ ($P_N = -1$).

With help (2) from (4) obtain

$$A^s_{l^-,l^+} = \frac{2x\left(y^+ g_{6s} \mp y^- g_{1s}\right)}{y^+ F_{2s} \mp y^- x F_{3s}}. \tag{5}$$

From expressions (5) can to extract SF g_{1s} and g_{6s} through the single spin asymmetries $A^s_{l^-}$, $A^s_{l^+}$

$$\begin{aligned} g_{1s} &= \frac{1}{4xy^-}\Big[\big(A^s_{l^+} - A^s_{l^-}\big) y^+ F_{2s} + \big(A^s_{l^+} + A^s_{l^-}\big) y^- x F_{3s}\Big], \\ g_{6s} &= \frac{1}{4xy^+}\Big[\big(A^s_{l^+} + A^s_{l^-}\big) y^+ F_{2s} + \big(A^s_{l^+} - A^s_{l^-}\big) y^- x F_{3s}\Big]. \end{aligned} \tag{6}$$

The single spin asymmetries can to determine also as the combinations simultaneously the cross sections
$\sigma^{\uparrow}_{l^-}$, $\sigma^{\uparrow}_{l^+}$, $\sigma^{\downarrow}_{l^-}$, $\sigma^{\downarrow}_{l^+}$:

$$A_{\pm}^{s} = \frac{\left(\sigma_{l-}^{\uparrow} \pm \sigma_{l+}^{\uparrow}\right) - \left(\sigma_{l-}^{\downarrow} \pm \sigma_{l+}^{\downarrow}\right)}{\left(\sigma_{l-}^{\uparrow} \pm \sigma_{l+}^{\uparrow}\right) + \left(\sigma_{l-}^{\downarrow} \pm \sigma_{l+}^{\downarrow}\right)}$$

or through the SF

$$A_{+}^{s} = \frac{2xg_{6s}}{F_{2s}}, \quad A_{-}^{s} = \frac{2g_{1s}}{F_{3s}}. \tag{7}$$

The expressions (7) give a possibility to obtain the polarized SF g_{1s}, g_{6s} from the single spin asymmetries A_{+}^{s}, A_{-}^{s}

$$g_{1s} = \frac{1}{2}F_{3s}A_{-}^{s},$$
$$g_{6s} = \frac{1}{2x}F_{2s}A_{+}^{s}.$$

For SF g_{1s} (3) in the quark-parton model (QPM) for case scattering on proton we obtain

$$g_{1s}^{p} = -a_u\left[\Delta u(x) + \Delta\overline{u}(x)\right] + a_d\Big[\left(\Delta d(x) + \Delta\overline{d}(x)\right) + \left(\Delta s(x) + \Delta\overline{s}(x)\right)\Big],$$

where

$$a_u = \frac{2}{3}g_A\eta_{\gamma Z}g_{V,u} - g_V g_A \eta_Z\left(g_{V,u}^2 + g_{A,u}^2\right),$$
$$a_d = \frac{1}{3}g_A\eta_{\gamma Z}g_{V,d} - g_V g_A \eta_Z\left(g_{V,d}^2 + g_{A,d}^2\right),$$
$$g_{V,u} = \frac{1}{2} - \frac{4}{3}\sin^2\theta_W, \quad g_{A,u} = \frac{1}{2},$$
$$g_{V,d} = -\frac{1}{2} + \frac{2}{3}\sin^2\theta_W, \quad g_{A,d} = -\frac{1}{2}.$$

The first moment SF g_{1s}^{p} is

$$\Gamma_{1s}^{p} = \int_0^1 g_{1s}^{p}dx = -a_u(\Delta u + \Delta\overline{u}) + a_d\left[(\Delta d + \Delta\overline{d}) + (\Delta s + \Delta\overline{s})\right], \tag{8}$$

where

$\Delta q(\Delta\overline{q}) = \int_0^1 \Delta q(x)\left(\Delta\overline{q}(x)\right)dx$ is the contribution quark q (antiquark $\overline{q}$) in nucleon spin.

For determination from (8) the contributions quark flavours (u, d, s) are necessary a complementary measurable quantities. For this goal can to use isovector axial charge a_3 $(a_3 = 1,2695 \pm 0,0029)$ and octet axial charge a_8 $(a_8 = 0,585 \pm 0,025)$ that have measure in neutron and hyperon β decay respectively. These measurable quantities in QPM are

$$\begin{aligned} a_3 &= (\Delta u + \Delta\overline{u}) - (\Delta d + \Delta\overline{d}), \\ a_8 &= (\Delta u + \Delta\overline{u}) + (\Delta d + \Delta\overline{d}) - 2(\Delta s + \Delta\overline{s}). \end{aligned} \tag{9}$$

Therefore from (8) and (9) obtain the contributions the quark flavours (u, d, s) in spin of nucleon

$$\begin{aligned} \Delta u + \Delta\overline{u} &= \frac{2\Gamma^p_{1s} + a_d(3a_3 + a_8)}{2(2a_d - a_u)}, \\ \Delta d + \Delta\overline{d} &= \frac{2\Gamma^p_{1s} + 2a_u a_3 + a_d(a_8 - a_3)}{2(2a_d - a_u)}, \\ \Delta s + \Delta\overline{s} &= \frac{2\Gamma^p_{1s} + a_u(a_8 + a_3) - a_d(a_8 - a_3)}{2(2a_d - a_u)}. \end{aligned} \tag{10}$$

The contributions the quark flavours can to obtain on other scheme if to use the first moments Γ_1, Γ_6 lp-DIS with charged current [8]

$$\begin{aligned} \Gamma_1^{l^-} + \Gamma_1^{l^+} &= (\Delta u + \Delta\overline{u}) + (\Delta d + \Delta\overline{d}) + (\Delta s + \Delta\overline{s}), \\ \Gamma_6^{l^-} - \Gamma_6^{l^+} &= (\Delta u + \Delta\overline{u}) - (\Delta d + \Delta\overline{d}) - (\Delta s + \Delta\overline{s}). \end{aligned}$$

Then from set the measurable quantities $(\Gamma_1^{l^-} + \Gamma_1^{l^+},\ \Gamma^p_{1s},\ a_3)$ or $(\Gamma_6^{l^-} - \Gamma_6^{l^+},\ \Gamma^p_{1s},\ a_3)$ obtain $(\Delta u + \Delta\overline{u})$, $(\Delta d + \Delta\overline{d})$ and $(\Delta s + \Delta\overline{s})$

$$\begin{aligned} \Delta u + \Delta\overline{u} &= \frac{a_d\left(\Gamma_1^{l^-} + \Gamma_1^{l^+}\right) - \Gamma^p_{1s}}{a_u + a_d}, \\ \Delta d + \Delta\overline{d} &= \frac{a_d\left(\Gamma_1^{l^-} + \Gamma_1^{l^+}\right) - \Gamma^p_{1s} - a_3(a_u + a_d)}{a_u + a_d}, \\ \Delta s + \Delta\overline{s} &= \frac{2\Gamma^p_{1s} - (a_d - a_u)\left(\Gamma_1^{l^-} + \Gamma_1^{l^+}\right) + a_3(a_u + a_d)}{a_u + a_d}. \end{aligned}$$

Analogously from set $\left(\Gamma_6^{l^-} - \Gamma_6^{l^+}, \Gamma^p_{1s}, a_3\right)$.

Now consider the second SF g_{6s}. In QPM for g_{6s}^p obtain

$$g_{6s}^p = b_u \Delta u_V(x) + b_d \Delta d_V(x), \tag{11}$$

where

$$b_u = \frac{2}{3} g_V \eta_{\gamma Z} g_{A,u} + (g_V^2 + g_A^2) \eta_Z g_{V,u} g_{A,u},$$

$$b_d = -\frac{1}{3} g_V \eta_{\gamma Z} g_{A,d} + (g_V^2 + g_A^2) \eta_Z g_{V,d} g_{A,d};$$

$$\Delta q_V(x) = \Delta q(x) - \Delta \bar{q}(x) \quad (q = u, d)$$

is the distributions of valence quarks.

The first moment SF g_{6s}^p is

$$\Gamma_{6s}^p = \int_0^1 g_{6s}^p dx = b_u \Delta u_V + b_d \Delta d_V, \tag{12}$$

where $q_V = \int_0^1 \Delta q_V(x) dx; \quad q = u, d$ respective the contributions the valence quarks in nucleon spin.

Obviously the extraction Δu_V and Δd_V from (12) is possible by presence still one any correlation between them.

For that we use the following correlations between $\Gamma_{1,6}^{l-}$ and $\Gamma_{1,6}^{l+}$ from [8] in case charged current

$$\begin{aligned} \Gamma_1^{l-} - \Gamma_1^{l+} &= \Delta u_V - \Delta d_V, \\ \Gamma_6^{l-} + \Gamma_6^{l+} &= \Delta u_V + \Delta d_V. \end{aligned} \tag{13}$$

Then from (12) and (13) obtain the contributions the valence quarks in nucleon spin

$$\Delta u_V = \frac{\Gamma_{6s}^p - b_d(\Gamma_6^{l-} + \Gamma_6^{l+})}{b_u - b_d},$$

$$\Delta d_V = \frac{\Gamma_{6s}^p - b_u(\Gamma_6^{l-} + \Gamma_6^{l+})}{b_d - b_u}.$$

Analogously with $(\Gamma_1^{l-} - \Gamma_1^{l+})$.

Thus the contributions the quark flavours $(\Delta u + \Delta \bar{u})$, $(\Delta d + \Delta \bar{d})$, $(\Delta s + \Delta \bar{s})$ and the valence quarks $\Delta u_V, \Delta d_V$ in nucleon spin obtained through the first moments Γ_1, Γ_6 the polarized SF $g_{1,6}$ of lepton-nucleon DIS with charged and neutral current.

References

[1] Kuhn S.E. et al. Prog. Nucl. Part. Phys. 63 (2009). p.1.

[2] Burkardt M. et al. Rept. Prog. Phys. 73 (2010).P.016201.

[3] Airapetian A. et al. (The HERMES Collaboration). ArXiv: 0803.2993 [hep-ex].

[4] Leader E. et al. ArXiv: 1010.0574 [hep-ex].

[5] Alekseev M.G. et al. (The COMPASS Collaboration). ArXiv: 1007.4061 [hep-ex].

[6] Leader E. et al. ArXiv: 1103.5979 [hep-ex].

[7] Maksimenko N.V., Timoshin E.S.// Proc. of the National Academy of Sciences of Belarus. Ser. of Phys.-Math.sciences. 2009, №1.P.59.

[8] Maksimenko N.V., Timoshin E.S.// Proc. of the National Academy of Sciences of Belarus. Ser. of Phys.-Math.sciences. 2008, №2.P.73.