

# The Quark Contributions in the Nucleon Spin from the Neutrino Experiments on the Polarized Deuterons

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The contributions of the quarks and the antiquarks in the nucleon spin were obtained from the polarized asymmetries of the inclusive and semi-inclusive DIS the neutrino and antineutrino on the polarized deuterons.

**PACS numbers:** 13.88.+c, 13.15.+g, 13.40.Ks, 13.60.Hb, 14.20.Dh

**Keywords:** quark, nucleon spin, structure function, asymmetry

The study of nucleon spin is important problem in the particle physics [1]. The lepton-nucleon polarization DIS experiments show that only 1/3 of the nucleon spin derives from the spins of quarks and antiquarks [2, 3].

The experiments at RHIC [4–6] showed for the first time nonzero polarization of gluons  $\Delta g$  in region  $x > 0,05$ .

The polarization of antiquarks (quark sea)  $\Delta\bar{u}, \Delta\bar{d}, \Delta\bar{s}$  were measured in the semi-inclusive DIS in the experiments HERMES, COMPASS [7], but the data have the essential uncertainties [8].

The neutrino experiments have the important significance for the study the spin structure of the nucleon as here it is possible separately to measure the contributions of the valence quarks and antiquarks.

We consider the inclusive

$$\nu(\bar{\nu}) + d \longrightarrow \nu(\bar{\nu}) + X \quad (1)$$

and the semi-inclusive with the production  $\pi$ -meson

$$\nu(\bar{\nu}) + d \longrightarrow \nu(\bar{\nu}) + \pi + X. \quad (2)$$

processes DIS the neutrino and the antineutrino on the polarized deuterons.

The cross sections of the inclusive processes (1) are

$$\sigma_{\nu,\bar{\nu}} = \sigma_{\nu,\bar{\nu}}^a + P_N \sigma_{\nu,\bar{\nu}}^p, \quad (3)$$

where  $\sigma = \frac{d^2\sigma}{dx dy}$ ,  $P_N = \pm 1$  is the degree of the longitudinal polarization of the nucleon.  $\sigma_{\nu,\bar{\nu}}^a$  and  $\sigma_{\nu,\bar{\nu}}^p$  are unpolarized and polarized cross sections.

The cross sections  $\sigma_{\nu,\bar{\nu}}^a, \sigma_{\nu,\bar{\nu}}^p$  are expressed cross sections scattering on protons ( $p$ ) and neutrons ( $n$ ) following

$$\begin{aligned} \sigma_{\nu,\bar{\nu}}^{ad} &= \frac{\sigma_{\nu,\bar{\nu}}^{ap} + \sigma_{\nu,\bar{\nu}}^{an}}{2}, \\ \sigma_{\nu,\bar{\nu}}^{pd} &= \frac{\sigma_{\nu,\bar{\nu}}^{pp} + \sigma_{\nu,\bar{\nu}}^{pn}}{2} (1 - 1.5\omega). \end{aligned} \quad (4)$$

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The cross sections scattering on protons  $\sigma^{ap}$ ,  $\sigma^{pp}$  and on neutrons  $\sigma^{an}$ ,  $\sigma^{pn}$  are obtained from the expressions for cross sections scattering on the nucleons

$$\sigma_{\nu,\bar{\nu}}^a = \frac{x\sigma_0}{2} \left[ \sum_q (y_1^+ a_q \pm 2y_1^- b_q) q(x) + \sum_q (y_1^+ a_q \mp 2y_1^- b_q) \bar{q}(x) \right], \quad (5)$$

$$\sigma_{\nu,\bar{\nu}}^p = \frac{x\sigma_0}{2} \left[ \sum_q (2y_1^+ b_q \pm y_1^- a_q) \Delta q(x) + \sum_q (-2y_1^+ b_q \pm y_1^- a_q) \Delta \bar{q}(x) \right], \quad (6)$$

$\sigma_0 = \frac{G^2}{\pi} ME$ ,  $a_q = (g_V^2 + g_A^2)_q$ ,  $b_q = (g_V g_A)_q$ ;  $q = u, d, s$ ;  $g_{V_u} = \frac{1}{2} - \frac{4}{3} \sin^2 \Theta_W$ ,  $g_{A_u} = \frac{1}{2}$ ,  $g_{V_d} = g_{V_s} = \frac{1}{2} + \frac{2}{3} \sin^2 \Theta_W$ ,  $g_{A_d} = g_{A_s} = -\frac{1}{2}$ ,  $\Theta_W$  is Weinberg angle.  $y_1^\pm = 1 \pm y_1^2$ ,  $y_1 = 1 - y$ ,  $M$  is target mass,  $E$  is energy of initial neutrino (antineutrino),  $G$  is Fermi constant;  $x, y$  are scaling variables;  $q(x)$  ( $\bar{q}(x)$ ) and  $\Delta q(x)$  ( $\Delta \bar{q}(x)$ ) are distribution functions unpolarized and polarized quarks (antiquarks) respectively.

Therefore for cross sections (4) we obtained the following expressions

$$\begin{aligned} \sigma_{\nu,\bar{\nu}}^{pd} &= \frac{x\sigma_0}{4} \left[ 2y_1^+ (b_u + b_d) (\Delta u_V(x) + \Delta d_V(x)) \pm y_1^- \left( (a_u + a_d) (\Delta u(x) + \Delta \bar{u}(x) + \Delta d(x) + \Delta \bar{d}(x)) + 2a_s (\Delta s(x) + \Delta \bar{s}(x)) \right) \right] (1 - 1.5\omega), \\ \sigma_{\nu,\bar{\nu}}^{ad} &= \frac{x\sigma_0}{4} \left[ y_1^+ \left( (a_u + a_d) (u(x) + \bar{u}(x) + d(x) + \bar{d}(x)) + 2a_s (s(x) + \bar{s}(x)) \right) \pm \right. \\ &\quad \left. \pm 2y_1^- (b_u + b_d) (u_V(x) + d_V(x)) \right]. \end{aligned} \quad (7)$$

The polarization asymmetries we determine as the following combinations of the sections (3)

$$A_{\nu,\bar{\nu}} = \frac{\sigma_{\nu,\bar{\nu}}^{\downarrow\uparrow,\uparrow\uparrow} - \sigma_{\nu,\bar{\nu}}^{\downarrow\downarrow,\uparrow\downarrow}}{\sigma_{\nu,\bar{\nu}}^{\downarrow\uparrow,\uparrow\uparrow} + \sigma_{\nu,\bar{\nu}}^{\downarrow\downarrow,\uparrow\downarrow}}, \quad (8)$$

$$A_\pm = \frac{(\sigma_\nu^{\downarrow\uparrow} \pm \sigma_{\bar{\nu}}^{\uparrow\uparrow}) - (\sigma_\nu^{\downarrow\downarrow} \pm \sigma_{\bar{\nu}}^{\uparrow\downarrow})}{(\sigma_\nu^{\downarrow\uparrow} \pm \sigma_{\bar{\nu}}^{\uparrow\uparrow}) + (\sigma_\nu^{\downarrow\downarrow} \pm \sigma_{\bar{\nu}}^{\uparrow\downarrow})}. \quad (9)$$

The first arrow is the helicity neutrino ( $\downarrow$ ) or antineutrino ( $\uparrow$ ), the second arrow is spin of the target  $\uparrow$  ( $P_N = +1$ ) and  $\downarrow$  ( $P_N = -1$ ). Substituting in (6), (7) cross sections (3) we obtain for the asymmetries

$$A_{\nu,\bar{\nu}} = \frac{\sigma_{\nu,\bar{\nu}}^p}{\sigma_{\nu,\bar{\nu}}^a}, \quad (10)$$

$$A_\pm = \frac{\sigma_\nu^p \pm \sigma_{\bar{\nu}}^p}{\sigma_\nu^a \pm \sigma_{\bar{\nu}}^a}. \quad (11)$$

The inclusive polarization asymmetries  $A_{\nu d, \bar{\nu} d}$  (10) through (5) are

$$A_{\nu d, \bar{\nu} d} = \frac{2y_1^+ (b_u + b_d) (\Delta u_V(x) + \Delta d_V(x)) \pm y_1^- \left[ (a_u + a_d) (\Delta u(x) + \Delta \bar{u}(x) + \Delta d(x) + \Delta \bar{d}(x)) + 2a_s (\Delta s(x) + \Delta \bar{s}(x)) \right]}{y_1^+ \left[ (a_u + a_d) (u(x) + \bar{u}(x) + d(x) + \bar{d}(x)) + 2a_s (s(x) + \bar{s}(x)) \right] \pm 2y_1^- (b_u + b_d) (u_V(x) + d_V(x))} \cdot (1 - 1.5\omega). \quad (12)$$

The inclusive asymmetries (11) are

$$A_{+d} = \frac{2(b_u + b_d) [\Delta u_V(x) + \Delta d_V(x)]}{(a_u + a_d) [u(x) + \bar{u}(x) + d(x) + \bar{d}(x)] + 2a_s [s(x) + \bar{s}(x)]} (1 - 1.5\omega), \quad (13)$$

$$A_{-d} = \frac{(a_u + a_d)[\Delta u(x) + \Delta \bar{u}(x) + \Delta d(x) + \Delta \bar{d}(x)] + 2a_s[\Delta s(x) + \Delta \bar{s}(x)]}{2(b_u + b_d)[u_V(x) + d_V(x)]} (1 - 1.5\omega). \quad (14)$$

The cross sections semi-inclusive processes (2) are obtained from (4), (5), (6) through replacements

$$\begin{aligned} \Delta q(x)(\Delta \bar{q}(x)) &\longrightarrow \Delta q(x)D_{q(z)}^{\pi^+-\pi^-}(\Delta \bar{q}(x)D_{\bar{q}(z)}^{\pi^+-\pi^-}), \\ q(x)(\bar{q}(x)) &\longrightarrow q(x)D_{q(z)}^{\pi^+-\pi^-}(\bar{q}(x)D_{\bar{q}(z)}^{\pi^+-\pi^-}), \end{aligned}$$

$\sigma \rightarrow \sigma^{\pi^+-\pi^-} = \sigma^{\pi^+} - \sigma^{\pi^-}$ , where  $\sigma = d^3\sigma/dx dy dz$ ,  $D_{q,\bar{q}(z)}^{\pi^+-\pi^-} = D_{q,\bar{q}(z)}^{\pi^+} - D_{q,\bar{q}(z)}^{\pi^-}$ ,  $D_{q,\bar{q}(z)}^{\pi}$  is the fragmentation function (anti) quark  $q(\bar{q})$  in  $\pi$ -meson.

Then for this cross sections we have

$$\begin{aligned} \sigma_{\nu d, \bar{\nu} d}^{p(\pi^+-\pi^-)} &= \frac{x\sigma_0}{4} \left[ 2y_1^+(b_u - b_d)(\Delta u(x) + \Delta \bar{u}(x) + \Delta d(x) + \Delta \bar{d}(x)) \pm \right. \\ &\quad \left. \pm y_1^-(a_u - a_d)(\Delta u_V(x) + \Delta d_V(x)) \right] \cdot D_{u(z)}^{\pi^+-\pi^-} (1 - 1.5\omega), \\ \sigma_{\nu d, \bar{\nu} d}^{a(\pi^+-\pi^-)} &= \frac{x\sigma_0}{4} \left[ y_1^+(a_u - a_d)(u_V(x) + d_V(x)) \pm 2y_1^-(b_u - b_d)(u(x) + \right. \\ &\quad \left. + \bar{u}(x) + d(x) + \bar{d}(x)) \right] \cdot D_{u(z)}^{\pi^+-\pi^-}. \end{aligned} \quad (15)$$

By obtained (15) were used the correlations

$$\begin{aligned} D_{\bar{d}}^{\pi^+-\pi^-} &= D_u^{\pi^+-\pi^-}, \quad D_{\bar{u}}^{\pi^+-\pi^-} = D_d^{\pi^+-\pi^-}, \quad D_u^{\pi^+-\pi^-} = -D_{\bar{d}}^{\pi^+-\pi^-}, \\ D_u^{\pi^+-\pi^-} &= -D_{\bar{u}}^{\pi^+-\pi^-}, \quad D_s^{\pi^+-\pi^-} = D_{\bar{s}}^{\pi^+-\pi^-} = 0. \end{aligned}$$

The semi-inclusive asymmetries (10) equal

$$A_{\nu d, \bar{\nu} d}^{\pi^+-\pi^-} = \frac{2y_1^+(b_u - b_d)(\Delta u(x) + \Delta \bar{u}(x) + \Delta d(x) + \Delta \bar{d}(x))}{y_1^+(a_u - a_d)(u_V(x) + d_V(x)) \pm 2y_1^-(b_u - b_d)(u(x) + d(x) + \bar{u}(x) + \bar{d}(x))} \cdot (1 - 1.5\omega). \quad (16)$$

The semi-inclusive asymmetries (11) we obtained in form

$$A_{-d}^{\pi^+-\pi^-} = \frac{(a_u - a_d)(\Delta u_V(x) + \Delta d_V(x))}{2(b_u - b_d)(u(x) + \bar{u}(x) + d(x) + \bar{d}(x))} \cdot (1 - 1.5\omega), \quad (17)$$

$$A_{+d}^{\pi^+-\pi^-} = \frac{2(b_u - b_d)(\Delta u(x) + \Delta \bar{u}(x) + \Delta d(x) + \Delta \bar{d}(x))}{(a_u - a_d)(u_V(x) + d_V(x))} \cdot (1 - 1.5\omega). \quad (18)$$

The interest represents the region small  $y$  ( $y \rightarrow 0$ ), where the experimental statistic are the best. From (12) the inclusive asymmetries at  $y \rightarrow 0$  take the form

$$A_{\nu d} = A_{\bar{\nu} d} = \frac{2(b_u + b_d)[\Delta u_V(x) + \Delta d_V(x)]}{(a_u + a_d)[u(x) + \bar{u}(x) + d(x) + \bar{d}(x)] + 2a_s[s(x) + \bar{s}(x)]} \cdot (1 - 1.5\omega). \quad (19)$$

The semi-inclusive asymmetries (16) at  $y \rightarrow 0$  equal

$$A_{\nu d}^{\pi^+-\pi^-} = A_{\bar{\nu} d}^{\pi^+-\pi^-} = \frac{2(b_u - b_d)[\Delta u(x) + \Delta \bar{u}(x) + \Delta d(x) + \Delta \bar{d}(x)]}{(a_u - a_d)[u_V(x) + d_V(x)]} \cdot (1 - 1.5\omega). \quad (20)$$

From (19) we obtain the contribution of the valence quarks in nucleon spin

$$\begin{aligned} \Delta u_V + \Delta d_V &= \\ &= \frac{a_u + a_d}{2(b_u + b_d)(1 - 1.5\omega)} \int_0^1 A_{\nu d}(A_{\bar{\nu}d}) \cdot [u(x) + \bar{u}(x) + d(x) + \bar{d}(x) + 2a_s(s(x) + \bar{s}(x))] dx. \end{aligned}$$

From the semi-inclusive asymmetries (20) and the measurable the axial charges  $a_3 = (\Delta u + \Delta \bar{u}) - (\Delta d + \Delta \bar{d})$  and  $a_8 = (\Delta u + \Delta \bar{u}) + (\Delta d + \Delta \bar{d}) - 2(\Delta s + \Delta \bar{s})$  can to extract the contributions of quarks and antiquarks separately on flavours

$$\Delta u + \Delta \bar{u} = \int_0^1 \frac{(a_u - a_d)[u_V(x) + d_V(x)] A_{\nu d}^{\pi^+ - \pi^-} (A_{\bar{\nu}d}^{\pi^+ - \pi^-}) dx}{4(b_u - b_d)(1 - 1.5\omega)} + \frac{a_3}{2},$$

$$\Delta d + \Delta \bar{d} = \int_0^1 \frac{(a_u - a_d)[u_V(x) + d_V(x)] A_{\nu d}^{\pi^+ - \pi^-} (A_{\bar{\nu}d}^{\pi^+ - \pi^-}) dx}{4(b_u - b_d)(1 - 1.5\omega)} - \frac{a_3}{2},$$

$$\Delta s + \Delta \bar{s} = \int_0^1 \frac{(a_u - a_d)[u_V(x) + d_V(x)] A_{\nu d}^{\pi^+ - \pi^-} (A_{\bar{\nu}d}^{\pi^+ - \pi^-}) dx}{4(b_u - b_d)(1 - 1.5\omega)} - \frac{a_8}{2},$$

Thus, the expressions were obtained for the polarization asymmetries the inclusive and semi-inclusive DIS (anti) neutrino on the polarized deuterons at  $y \rightarrow 0$ . In this region the contributions we obtained for the quarks and antiquarks ( $\Delta u + \Delta \bar{u}$ ,  $\Delta d + \Delta \bar{d}$ ,  $\Delta s + \Delta \bar{s}$ ) and the valence quarks ( $\Delta u_V + \Delta d_V$ ) in nucleon spin.

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