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The Deep Inelastic Scattering the Leptons off the Polarized Neutrons and Deuterons

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An expressions for a contributions of the quark flavours, the valence quarks in the nucleon spin with help the first moments of the electroweak structure functions of the DIS the leptons off the polarized neutrons and deuterons are obtained.

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The beams polarized the deuterons and ^3He can will to obtain on Electron Ion Collider (EIC). The polarization data for neutrons and deuterons allows essentially to widen an analysis the spin structure of the nucleon together with data for the protons.

We consider the deep inelastic scattering (DIS) the unpolarized leptons off the longitudinally polarized nucleons

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

The cross sections in Born approximation are [1, 2]

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

Here $\sigma = d^2\sigma/dxdy$, $Q^2 = -q^2 = -(k-k')^2$, $s = 2pk$, $y^\pm = 1 \pm (1-y)^2$, $x = \frac{Q^2}{2p\cdot q}$, $y = \frac{p\cdot q}{p\cdot k}$, $k(k')$, $p - 4$ is the 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.

For SF g_{1s} in the quark-parton model for case scattering on proton we obtain [1, 2]

$$g^p_{1s} = -a^s_u\big[\Delta u(x) + \Delta\overline{u}(x)\big] + a^s_d\big(\Delta d(x) + \Delta\overline{d}(x)\big) + a^s_s\big(\Delta s(x) + \Delta\overline{s}(x)\big), \tag{3}$$

where

$$a^s_u = \frac{2}{3}g_A\eta_{\gamma Z}g_{V,u} - g_V g_A\eta_Z\big(g^2_V + g^2_A\big)_u,$$
$$a^s_{d,s} = \frac{1}{3}g_A\eta_{\gamma Z}g_{V(d,s)} - g_V g_A\eta_Z\big(g^2_V + g^2_A\big)_{d,s};$$
$$g_{V,u} = \frac{1}{2} - \frac{4}{3}\sin^2\theta_W, \quad g_{A,u} = \frac{1}{2},$$
$$g_{V(d,s)} = -\frac{1}{2} + \frac{2}{3}\sin^2\theta_W, \quad g_{A(d,s)} = -\frac{1}{2};$$
$$\eta_{\gamma Z} = \frac{Gm^2_Z}{2\sqrt{2}\pi\alpha}\cdot\frac{Q^2}{Q^2+m^2_Z}, \quad \eta_Z = \eta^2_{\gamma Z}$$

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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 first moment SF g_{1s}^p is

$$\Gamma_{1s}^p = \int_0^1 g_{1s}^p(x)dx = -a_u^s(\Delta u + \Delta\overline{u}) + a_d^s(\Delta d + \Delta\overline{d}) + a_s^s(\Delta s + \Delta\overline{s}), \tag{4}$$

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.

Now we consider the processes (1) in the case of the scattering on the polarized neutrons. The first moment Γ_{1s}^n is

$$\Gamma_{1s}^n = a_d^s(\Delta u + \Delta\overline{u}) - a_u^s(\Delta d + \Delta\overline{d}) + a_s^s(\Delta s + \Delta\overline{s}). \tag{5}$$

The first moments of the proton Γ_{1s}^p (4) and the neutron Γ_{1s}^n (5) can to perform

$$\Gamma_{1s}^{p,n} = \frac{1}{3}(a_d^s - a_u^s + a_s^s)a_0 \mp \frac{1}{2}(a_u^s + a_d^s)a_3 + \frac{1}{6}\left(a_d^s - a_u^s - 2a_s^s\right)a_8, \tag{6}$$

where

$$a_0 \overset{\overline{MS}}{=} \Delta\Sigma = \Delta u + \Delta\overline{u} + \Delta d + \Delta\overline{d} + \Delta s + \Delta\overline{s} \tag{7}$$

is the total contribution the quarks and the antiquarks in the nucleon spin;

$$\begin{aligned} a_3 &= (\Delta u + \Delta\overline{u}) - (\Delta d + \Delta\overline{d}), \\ a_8 &= (\Delta u + \Delta\overline{u}) + (\Delta d + \Delta\overline{d}) - 2(\Delta s + \Delta\overline{s}). \end{aligned} \tag{8}$$

The isovector axial charge a_3 ($a_3 = 1,2695 \pm 0,0029$) and octet axial charge a_8 ($a_8 = 0,585 \pm 0,025$) have measure in neutron and hyperon β decay respectively. From (6) it follows, that the measurements of the Γ_{1s}^n allow to determinate a_0 (see(7)) in leading order independently from a data DIS on the polarized protons. This scheme can to generalize on any order $\alpha_s(Q^2)$, since (6) in $\overline{MS}$ scheme is

$$\Gamma_{1s}^{p,n} = \frac{1}{3}(a_d^s - a_u^s + a_s^s)a_0\Delta C_s(\alpha_s) \mp \frac{1}{2}(a_u^s + a_d^s)a_3\Delta C_{Ns}(\alpha_s) + \frac{1}{6}(a_d^s - a_u^s - 2a_s^s)a_8\Delta C_{Ns}(\alpha_s), \tag{9}$$

where $\Delta C_s(\alpha_s), \Delta C_{Ns}(\alpha_s)$ are Wilson coefficients [3].

For determination from (5) the contributions quark flavours (u, s, d) are necessary a complementary measurable quantities. For this goal can to use the axial charges a_3 and a_8 in form (8).

Therefore from (5) and (8) we obtain the contributions every the quark flavour in the nucleon spin

$$\begin{aligned} \Delta u + \Delta\overline{u} &= \frac{2(\Gamma_{1s}^n - a_3a_u^s) + (a_3 + a_8)a_s^s}{2(a_d^s - a_u^s + a_s^s)}, \\ \Delta d + \Delta\overline{d} &= \frac{2(\Gamma_{1s}^n - a_3a_d^s) + a_s^s(a_8 - a_3)}{2(a_d^s - a_u^s + a_s^s)}, \\ \Delta s + \Delta\overline{s} &= \frac{2(\Gamma_{1s}^n - a_3a_d^s) - (a_d^s - a_u^s)(a_8 - a_3)}{2(a_d^s - a_u^s + a_s^s)}. \end{aligned}$$

The first moments the polarization SF g_{1s}, g_{6s} for the deuteron are

$$\Gamma^d_{1s,6s} = \frac{\Gamma^p_{1s,6s} + \Gamma^n_{1s,6s}}{2}(1 - 1.5\omega), \tag{10}$$

where $\omega \simeq 0.05$ is the probability D-state in the wave function of deuteron.

From (9), (10) we obtain

$$\Gamma^d_{1s} = \left(1 - \frac{3}{2}\omega\right)\frac{1}{6}\left[2(a^s_d - a^s_u + a^s_s)a_0\Delta C_s(\alpha_s) + (a^s_d - a^s_u - 2a^s_s)a_8\Delta C_{Ns}(\alpha_s)\right].$$

Hence the total contribution of the quarks and antiquarks in the nucleon spin is

$$a_0 = \frac{1}{2(a^s_d - a^s_u + a^s_s)\Delta C_s}\left[\frac{6\Gamma^d_{1s}}{1 - \frac{3}{2}\omega} - (a^s_d - a^s_u - 2a^s_s)a_8\Delta C_{Ns}\right].$$

Using (6), (7), (8) for Γ^d_{1s} (10) have

$$\frac{2\Gamma^d_{1s}}{1 - 1,5\omega} = (a^s_d - a^s_u)(\Delta u + \Delta\overline{u}) + (a^s_d - a^s_u)(\Delta d + \Delta\overline{d}) + 2a^s_s(\Delta s + \Delta\overline{s}). \tag{11}$$

Therefore from (8) and (11) we obtain the contributions of the quark flavours (u, d, s) on basis the deuteron data

$$\Delta u + \Delta\overline{u} = \frac{\frac{2\Gamma^d_{1s}}{1-1,5\omega} + a^s_s a_8 + a_3(a^s_d - a^s_u + a^s_s)}{2(a^s_d - a^s_u + a^s_s)},$$

$$\Delta d + \Delta\overline{d} = \frac{\frac{2\Gamma^d_{1s}}{1-1,5\omega} + a^s_s a_8 - a_3(a^s_d - a^s_u + a^s_s)}{2(a^s_d - a^s_u + a^s_s)},$$

$$\Delta s + \Delta\overline{s} = \frac{\frac{2\Gamma^d_{1s}}{1-1,5\omega} - a_8(a^s_d - a^s_u)}{2(a^s_d - a^s_u + a^s_s)}.$$

For first moment the violating parity SF g_6 of deuteron we obtain

$$\Gamma^d_{6s} = \frac{\Gamma^p_{6s} + \Gamma^n_{6s}}{2}(1 - 1,5\omega) = \frac{1}{2}(b^s_u + b^s_d)(\Delta u_V + \Delta d_V)(1 - 1,5\omega).$$

where

$$b^s_u = \frac{2}{3}g_V\eta_{\gamma Z}g_{A,u} + (g^2_V + g^2_A)\eta_Z g_{V,u}g_{A,u},$$

$$b^s_d = -\frac{1}{3}g_V\eta_{\gamma Z}g_{A,d} + (g^2_V + g^2_A)\eta_Z g_{V,d}g_{A,d}.$$

Hence it follow, that a measurement Γ^d_{6s} gives the access to the contribution of the valence quarks $(\Delta u_V + \Delta d_V)$ in DIS unpolarized leptons on polarized deuterons:

$$\Delta u_V + \Delta d_V = \frac{2\Gamma^d_{6s}}{(b^s_u + b^s_d)(1 - 1,5\omega)}.$$

Thus we obtain the expressions for $(\Delta q + \Delta\overline{q})$, $q = u, d, s$ with the help measurable quantities the first moments of the polarized SF DIS the unpolarized leptons on the polarized neutrons and deuterons. From data at deuteron Γ^d_{6s} can to obtain the contribution the valence quarks $(\Delta u_V + \Delta d_V)$ in the spin of nucleon without the complementary measurable quantities.

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