Polarized lepton-nucleon scattering in frame of various gauge model

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1. Introduction

The Standard theory of electroweak interactions is verified for a long time. As a rule assumed that the Standard Model (SM) is only a low energy effective theory, which will be able to resolve several problems inherent to the Standard Model. Let us mention some of these difficulties: 1) the scalar structure of the SM: nature of the Higgs boson and origin of the electroweak symmetry breaking; 2) the huge number of SM free parameters to be fixed by experiments; 3) the origin of parity violation for weak interactions; 4) the origin of the SM three generation, etc. Besides, the ultimate unification of all particles and of all interactions is still an essential aim of particle physics. It is natural to have several models or theories which go beyond the Standard Model in order to satisfy this unification goal and to resolve some problems of the SM like those mentioned above. A common prediction to all these models is the existence of new Z' bosons.

The application of expanded gauge theories extends potentialities of the electroweak theory. The predictions of this gauge models can be conformed to experimental data with the widely changing parameters that are deviated from the Standard model. The experiments of scattering of polarized leptons by unpolarized nucleon target when the transfer momentum runs up to $\sim 10^{40}\text{GeV}^2$ and accordingly electroweak asymmetries are closed to several decades of percent [1] allow to verify predictions of different gauge models with an additional Z-boson.

There is important to consider the supplementary information about a structure of one electroweak group using investigation of deep inelastic scattering of polarized leptons and nucleons (see, for example, lepton-proton scattering at HERA [2, 3, 29]). The covariant method to calculate cross sections of processes where two (and more) polarized particles are interacted has great importance. This method allows us to do research not depending from concrete kinematics of different experiments. In the paper we have calculated the Lorentz-invariant differential cross section of electroweak deep inelastic scattering of polarized leptons by polarized nucleon target within the framework of gauge models with additional Z-boson.

2. The gauge models

2.1. The model $SU(3) \times U(1)$

The interaction between a polarized lepton and polarized nucleon in different gauge models can be described by following Feynman's diagrams in fig. 1

The electroweak interaction [3, 7] is

$$L^{NC} = \frac{g \cos \theta_W}{\sqrt{3 - 4 \sin \theta_W}} \{X^\mu \left( \frac{1}{2} \bar{\nu}_e \gamma^\mu (1 + \gamma_5) \nu_e ight. $$

$$- \frac{1}{2} \bar{e} \gamma^\mu (1 + \gamma_5) e - \bar{e} \gamma^\mu (1 - \gamma_5) e + \frac{1}{2} \bar{u} \gamma^\mu (1 + \gamma_5) u $$

$$- \frac{1}{2} \bar{d} \gamma^\mu (1 + \gamma_5) d - \bar{d} \gamma^\mu (1 - \gamma_5) d $$

$$+ \frac{1}{2} \tan \theta_W Z^\mu \left( \bar{\nu}_e \gamma^\mu (1 + \gamma_5) \nu_e - \bar{\nu}_e \gamma^\mu (1 + \gamma_5) e ight. $$

$$+ \bar{u} \gamma^\mu (1 + \gamma_5) u - \bar{d} \gamma^\mu (1 + \gamma_5) d - 2J_{e.m.} \right\}.$$

$X^\mu, Z^\mu$ – the neutral gauge bosons. The physical bosons are obtained with following orthog-
Fig. 1. The lepton-nucleon deep inelastic scattering

Transformation

\[ Z_1 = \cos \alpha Z - \sin \alpha X, \]
\[ Z_2 = \sin \alpha Z + \cos \alpha X, \]
\[ -\pi/2 \leq \alpha \leq \pi/2. \]  

Masses for \( Z_1 \) - and \( Z_2 \) - bosons are equal to
\[ M_1 = 80\text{GeV}, \]
\[ M_2 = 110\text{GeV}, \]
\[ M_2/M_1 \gtrsim 1.4, \]

at \( \alpha = -0.02\pi \),

accordingly.
\[ \sin \theta_W^2 = 0.18 \sim 0.30. \]

2.2. The model \( SU(2)_L \times SU(2)_R \times U(1) \)
In this model the electroweak interaction Langragian is defined like the latter in $SU(3) \times U(1)$ (see (1)).

$$L_{NC} = \frac{g \cos \theta_W}{\sqrt{1 - 2 \sin \theta_W}} (X_\mu(\frac{1}{2} \bar{\nu}_e \gamma^\mu (1 - \gamma_5) \nu_e - \frac{1}{2} \bar{d} \gamma^\mu (1 - \gamma_5) d)
+ \frac{1}{2} \tan \theta_W W^\mu Z^\mu \bar{e} \gamma^\mu (1 + \gamma_5) \nu_e - \bar{e} \gamma^\mu (1 + \gamma_5) e
+ \bar{u} \gamma^\mu (1 + \gamma_5) u - \bar{d} \gamma^\mu (1 + \gamma_5) d - 2 J^\mu_{e.m.}).$$

Physical bosons masses are

$$M_1 = 96 GeV,$$
$$M_2 = 288 GeV,$$
$$M_2/M_1 \gtrsim 3.0,$$
$$at \alpha = -0.02 \pi.$$  

As one can see, the bosons become more massive in comparison with $SU(3) \times U(1)$, besides that, the range of Weinberg’s angle is expanded − $\sin \theta_W^2 = 0.16 \sim 0.34$.

### 2.3. The model $SU(2)_L \times SU(2)_R \times U(1)_L \times U(1)_R$

The model is more difficult for consideration because it has three massive neutral gauge bosons [23, 24]. We will investigate the special case of transforming the $SU(2)_R \times U(1)_R$ to the group $U(1)$ at low energy. In this model only two neutral massive boson exist. The Lagrangian of electroweak interaction is expressed as

$$L_{NC} = g \sin \theta_W Z^\mu_{1L}(\frac{2}{3} \bar{d} \gamma^\mu \gamma_5 d - \bar{u} \gamma^\mu \gamma_5 u + \frac{1}{3} \bar{e} \gamma^\mu \gamma_5 e)
+ \frac{g}{\sqrt{1 - 2 \sin \theta_W^2}} Z^\mu_{2L}(\frac{1}{2} \bar{\nu}_e \gamma^\mu (1 + \gamma_5) \nu_e
- \frac{1}{2} \bar{e} \gamma^\mu (1 + \gamma_5) e
+ \frac{1}{2} \bar{d} \gamma^\mu (1 + \gamma_5) d - 2 \sin \theta_W^2 \{ - \bar{e} \gamma^\mu (1 + \gamma_5) e
+ \bar{u} \gamma^\mu (1 + \gamma_5) u - \frac{1}{3} \bar{d} \gamma^\mu (1 + \gamma_5) d \}).$$

The masses are defined by formulae

$$M^2_W/M^2_1 = (1 - 2 \sin \theta_W^2)(1 + \sqrt{\frac{\sin \theta_W^2 \cos \alpha}{1 - 2 \sin \theta_W^2 \sin \alpha}}),$$
$$M^2_W/M^2_2 = (1 - 2 \sin \theta_W^2)(1 - \sqrt{\frac{\sin \theta_W^2 \sin \alpha}{1 - 2 \sin \theta_W^2 \cos \alpha}}).$$  

(7)
Using (7) one can obtain that boson masses are

\[
\begin{align*}
M_1 &= 98\text{GeV}, \\
M_2 &= 181\text{GeV}, \\
\text{at } \alpha &= -0.02. \\
\end{align*}
\] (8)

3. The deep inelastic scattering of polarized leptons on polarized nucleons. Born approximation

The expression for differential cross section \[\sigma\] of longitudinally-polarized leptons (with helicity \(P_l\)) in deep inelastic scattering (DIS) on polarized nucleons are given by

\[
\sigma^{\pm}(k_1, k_2) = \frac{2\alpha^2 M x}{S Q^6} \sum_q f_q^{\pm}(x) \sum_{i=1,2} \left\{ \frac{1}{2} f_q I_1 + 2 f_q r_i (v_i v_q + a_i a_q) P_V^{ij} I_1 + (v_i a_q + a_i v_q) P_A^{ij} I_2 \right\} + \\
+ \sum_{j=1,2} r_j r_j [v_j v_q + a_j a_q] P_V^{ij} I_1 + (v_j a_q + a_j v_q) P_A^{ij} I_2 \\
- \frac{4\alpha^2 M x}{S Q^6} \sum_q f_q^{-}(x) \sum_{i=1,2} \left\{ \frac{1}{2} f_q K \eta P Q^2 (K \eta) + 2 r_i f_q (a_i v_q + v_i a_q) P_V^{ij} I_1 + (v_i v_q + a_i a_q) P_A^{ij} Q^2 (K \eta) - \\
- 2 a_i a_q P_A^{ij} x I_2^2 + 2 x \varepsilon (\hat{p}_1 \eta \hat{k}_1 \hat{k}_2) (a_i v_q - v_i a_q) \right\},
\] (9)

where we use the definitions

\[
\sigma(k_1, k_2) = k_1^0 d^3 \sigma / d^3 K_2, \quad \alpha = e^2 / 4\pi,
\]

\[
r_i = Q^2 G_i / [4(Q^2 + M_i^2) \sin \theta_W^2 (1 - \sin \theta_W^2)],
\]

\[
G_V^{ij} = g_V^{ij} \pm P_l g_A^{ij}, \quad G_A^{ij} = \mp g_A^{ij} - P_l g_V^{ij},
\]

\[
P_V^{ij} = g_V^{ij} g_A^{ij} + g_A^{ij} g_V^{ij} \mp P_l (g_V^{ij} g_A^{ij} + g_A^{ij} g_V^{ij}),
\]

\[
P_A^{ij} = \mp (g_V^{ij} g_A^{ij} + g_A^{ij} g_V^{ij}) - P_l g_V^{ij} g_A^{ij} + g_A^{ij} g_V^{ij}
\]

\[
I_{1,2} = S^2 \pm X^2, \quad I_1^0 = S(k_{1,2} \eta) \pm X(k_{2,1} \eta),
\]

\[
K = k_1 + k_2, \quad Q = k_1 - k_2, \quad S = -2(p_1 k_2),
\]

\[
X = -2(p_1 k_2), \quad x = Q^2 / (S - X), \quad f_q^{\pm} = h_q^{\pm}(x) \pm h_q^{-}(x),
\]

\[
\varepsilon (\hat{p}_1 \eta \hat{k}_1 \hat{k}_2) = \varepsilon_{\alpha \beta \rho \sigma} p_1 \alpha \eta_\beta k_1 \rho k_2 \sigma.
\]

\((h_q^{\pm}) h_q^{-}\) is distribution functions of q-th quark that has a (anti)parallel to polarization of nucleon polarization, \(f_q\) is a charge q-th quark, \(k_1, p_1, (k_2, p_2)\) are 4-momenta for an initial (final) lepton and nucleon, \(\eta\) is 4-momentum of initial nucleon polarization, \(M\) – the nucleon mass, \(M_i\) – the \(Z_i\)-boson mass, \(g_A^{ij}, g_V^{ij}, v_i, a_i\) – parameters of discussed models. The last are given in tables 1 and 2.

The covariant expression for the differential cross sections of deep inelastic scattering within the framework of the nonminimal gauge models of electroweak interaction depends not only on kinematics variables, but on polarizations of interaction particles also. By means
of changing of these variables one can obtain electroweak asymmetries which are determined by the universal formula:

$$A^{\omega}(P_l, P_N, e_f, P_1, P_2, e_f) = \frac{\sigma^{e_f}(P_l, P_N) - \sigma^{e_f}(P_2, P_N)}{\sigma^{e_f}(P_l, P_N) + \sigma^{e_f}(P_2, P_N)}.$$  

(10)

Here $\sigma^{e_f}(P_l, P_N)$ is the differential cross section of scattering of leptons with helicity $P_l$ by a nucleon with longitudinal polarization $P_N$. 4-momentum of the nucleon's polarization is $\eta = P_N(k_1/E, 0)$, where $k_1$ - is momentum of a scattering nucleon, $E$ - its energy, $e_f$ - lepton's electric charge. Eq.(10) defines all asymmetries based on a bunch of the polarized particles, on a polarized target, and also on a study of interaction of two polarized particles. The last item allows us to build up the most extended succesion of electroweak asymmetries:

polarized asymmetries

$$A_p^{\pm} = \frac{\sigma^{e\pm}(1, 1) - \sigma^{e\pm}(-1, -1)}{\sigma^{e\pm}(1, 1) + \sigma^{e\pm}(-1, -1)},$$

$$A_a^{\pm} = \frac{\sigma^{e\pm}(1, -1) - \sigma^{e\pm}(-1, 1)}{\sigma^{e\pm}(1, -1) + \sigma^{e\pm}(-1, 1)}.$$  

(11)

charge-polarized asymmetries

$$B_p^{\pm} = \frac{\sigma^{e\pm}(1, 1) - \sigma^{e\mp}(-1, -1)}{\sigma^{e\pm}(1, 1) + \sigma^{e\mp}(-1, -1)},$$

$$B_a^{\pm} = \frac{\sigma^{e\pm}(1, -1) - \sigma^{e\mp}(-1, 1)}{\sigma^{e\pm}(1, -1) + \sigma^{e\mp}(-1, 1)}.$$  

(12)

and charged asymmetries

$$C_{RR} = \frac{\sigma^{e^+}(1, 1) - \sigma^{e^-}(1, 1)}{\sigma^{e^+}(1, 1) + \sigma^{e^-}(1, 1)},$$

$$C_{LL} = \frac{\sigma^{e^+}(-1, -1) - \sigma^{e^-}(-1, -1)}{\sigma^{e^+}(-1, -1) + \sigma^{e^-}(-1, -1)},$$

$$C_{RL} = \frac{\sigma^{e^+}(1, -1) - \sigma^{e^-}(1, -1)}{\sigma^{e^+}(1, -1) + \sigma^{e^-}(1, -1)},$$

$$C_{LR} = \frac{\sigma^{e^+}(-1, 1) - \sigma^{e^-}(-1, 1)}{\sigma^{e^+}(-1, 1) + \sigma^{e^-}(-1, 1)}.$$  

(13)

where $\sigma^{e\pm}(1, 1)$, $\sigma^{e\pm}(1, -1)$, $\sigma^{e\pm}(-1, 1)$, $\sigma^{e\pm}(-1, -1)$ - the differential cross section of electroweak deep inelastic scattering of leptons by nucleons with following values of polarizations of particles in the process: $P_l = 1$, $P_N = 1$; $P_l = 1$, $P_N = -1$; $P_l = -1$, $P_N = 1$; $P_l = -1$, $P_N = -1$.

The analysis of the electroweak asymmetries at $E = 10 - 40$ GeV in the ep-DIS and at $E = 100 - 2000$ GeV in the $\mu$p-DIS in the framework of the quark-parton model was made to estimate the magnitude and behavior of the electroweak asymmetries are calculated using the different extended gauge models, and to compare their values with experimental data.

Some results of the electroweak asymmetries for the various gauge models are presented in figures 2 – 5. All asymmetries are distinguished as functions of the scaling variable $y$ at the fixed $x$. They are equal to several percent at $E = 100$ GeV and several tens of percent as energy of scattered lepton goes up to 2000 GeV and they have trend to increase...
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in the region of maximum $x$ and $y$. So value of asymmetries $A^\pm_p$ reach 3% at $E = 100$ GeV and 15% at $E = 1$ TeV but asymmetries $A^\pm_A$ - 2% and 10% accordingly. In the case of scattering of leptons with positive and negative electric charge the asymmetries $A^\pm_p$ and $A^\pm_u$ have opposite signs, with $|A^-_p|$ exceeding $|A^+_p|$ throughout kinematic region, and $|A^-_A| > |A^+_A|$. Exceptions of these inequalities are results obtained in the framework of the Standard Models of electroweak interaction where $|A^-_A| > |A^+_A|$. The asymmetries significantly depend on longitudinal projections signs of spins $P_l$ (in case of a lepton) and $P_N$ (in case of a nucleon). Absolute values of asymmetries with parallel combination of lepton and nucleon spins exceed that of asymmetries $A^\pm_A$ over whole kinematic region. Comparison of different models' predictions for the electroweak polarized asymmetries indicates the results obtained in the frame of $SU(3) \times U(1)$ and $SU(2)_L \times SU(2)_R \times U(1)$ gauge models are closed to each other and greatly differ from values of the asymmetries in other gauge models (see fig.2, fig.3). It is particularly seen in the case of $\mu^- p$-DIS where they can be two times
differed in the region $y \geq 0.6$ and $x \leq 0.7$. The Standard Model has distinguished functional dependence of asymmetries on $y$. At the same time asymmetries $A^\pm_A$ reach maximum values in the $SU(2) \times U(1) \times [SU(2)]'$ model and $A^\pm_p$ - in the $SU(3) \times U(1)$ one. Replacement of scattering of a positive muon by scattering of a negative muon leads to the great change of the $y$-dependence of all asymmetries. It is particularly evident in the $SU(2) \times U(1) \times [U(1)]'$ gauge model.

The charge-polarized electroweak asymmetries $B^\pm_p$ and $B^\pm_A$ are very sensitive to signs of longitudinal spins of leptons and nucleons as well as asymmetries $A^\pm_p$ and $A^\pm_A$ greatly depend on scaling variables. So $|B^\pm_p|$ grows as a linear function while $y$ increases, but $|B^\pm_p|$ falls with $y$ decreasing, and then, changes its sign and begins grow. It again approaches the minimum value at $y \to 0$. The absolute value of $B^\pm_p$ exceeds that of $B^\pm_u$ in the region of $x \leq 0.7$ and $y \geq 0.8$.

Fig. 2. The asymmetries $A^+_A$ in frame of various models.

Fig. 3. The asymmetries $B^+_p$ in frame of various models.
In the case of $\mu^+p$- and $\mu^-p$-DIS throughout kinematic region the asymmetries $B_p$ and $B_A$ nearly identically depend on $y$, but they have opposite signs. Values of asymmetries in the case of $\mu^+p$–DIS exceed values of asymmetries in the case of $\mu^-p$–DIS. In the case of $\mu^+p$–DIS the asymmetries obtained in the discussed gauge models differ from results obtained in the framework of the Standard Model greatly. This difference particularly increases at high energy of scattering particles and in the region where $x$ and $y$ are maximal.

Behavior of the charge electroweak asymmetries for scattering of particles with the parallel spin configuration $C_{RR}, C_{LL}$ are similar to behavior according to the antiparallel spin configuration $C_{RL}, C_{LR}$. The asymmetries for the parallel spin configuration ($C_{RR}, C_{LL}$) decrease while $y$ fall to zero then they become negative and begin increase. These asymmetries are minimal at $y \to 0$. The charge asymmetries for the antiparallel spin configuration are almost linear functions of $y$. In the case of $P_t \leq 0$ the charge electroweak asymmetries $C_{LL}, C_{LR}$ greatly exceed values of the asymmetries $C_{RR}$ and $C_{RL}$ in the whole kinematic region (for instance, $C_{LL} - 6$ and 35 %, $C_{LR} - 4$ and 20 % at lepton’s energy $E = 100$ and 1000 GeV accordingly), but $C_{RL}$ and $C_{RR}$ increase from 2 to 12 % at these values of energy.

The charge asymmetries depend on the gauge model choice (see fig. 4, fig. 5). The predictions of $SU(3) \times U(1)$ and $SU(2)_L \times SU(2)_R \times U(1)$ are close, and the difference of their asymmetries from asymmetries in the Standard Model is several tens of percent. Exception is the asymmetry $C_{RR}$, which has region of values $0.3 \leq y \leq 0.6$ for this difference, the asymmetry $C_{RL}$ also has close values in the framework of nonminimal gauge models. The charge asymmetries reach the maximum in the models $SU(2) \times U(1) \times [U(1)']$ and $SU(2) \times U(1) \times [SU(2)]'$ with result for all alternative models (except $SU(3) \times U(1)$ and $SU(2)_L \times SU(2)_R \times U(1)$) greatly differing from each other. This difference surpasses 10% in the significant part of the kinematic region.

All noted characteristics of the asymmetries behavior are kept in case of scattered elec-
trons (positrons) with energy up to 40 GeV, although their values decrease about ten times.

Thus, the analysis of the asymmetries $^{(11)} - ^{(13)}$ allows to discriminate gauge models of electroweak interaction. The experimental research of gauge models are complicated because of the fact that the differences between these gauge models have significant values near the border of the kinematic region. Nevertheless the analysis of all possible corrections to cross sections and asymmetries giving the basis for investigation of gauge models, allowed to definite the complementary asymmetries:

\[
D_1^\pm = \frac{\sigma_e^\pm(0,1) - \sigma_e^\pm(0,-1)}{\sigma_e^\pm(1,1) - \sigma_e^\pm(1,-1)},
\]
\[
D_2^\pm = \frac{\sigma_e^\pm(0,1) - \sigma_e^\pm(0,-1)}{\sigma_e^\pm(-1,1) - \sigma_e^\pm(-1,-1)},
\]
\[
F_1^\pm = \frac{\sigma_e^\pm(1,0) - \sigma_e^\pm(-1,0)}{\sigma_e^\pm(1,1) - \sigma_e^\pm(-1,1)},
\]
\[
F_2^\pm = \frac{\sigma_e^\pm(1,0) - \sigma_e^\pm(-1,0)}{\sigma_e^\pm(1,-1) - \sigma_e^\pm(-1,-1)},
\]

which give the greatly distinguishing values in the large part of the kinematic region. Their values are differed significantly from that of the other models mentioned above throughout kinematic region as well. The results of the models $SU(2)_L \times SU(2)_R \times U(1)$ and $SU(3) \times U(1)$ are very close to each other. All asymmetries significantly decrease at high $\sqrt{S}$.

The above mentioned features of electroweak asymmetries give a chance to check the Standard theory of electroweak interaction in processes of deep inelastic scattering of polarized particles. The asymmetries at high energy in different models are substaintially distinguished, and that allows to observe difference between nonminimal gauge models by experimental way.

**4. The radiative corrections to asymmetries of lN-deep inelastic scattering**

Radiative corrections can be sizeable in comparison with a contribution of the additional gauge boson in the kinematic region where electroweak asymmetries are only a few percent. In the case of high energy radiative corrections to lN-DIS processes must be taken into account. Therefore radiative effects are considered in the whole kinematic region.

Electroweak asymmetries $^{(13)}$ with the lowest-order correction are presented in the following form:

\[
A_e^\omega = \frac{\sigma_0^- + \sigma_V^- + \sigma_R^- + \sigma_{el}^-}{\sigma_0^+ + \sigma_V^+ + \sigma_R^+ + \sigma_{el}^+},
\]

Here $\sigma_0$, $\sigma_V$, $\sigma_R$, $\sigma_{el}$ are contributions to the cross section of lN-scattering according to a tree level cross section, exchange of an additional virtual photon, radiative effects of the deep inelastic scattering and the elastic peak. The signs +(-) indicate the sum (subtraction) of cross sections of different spin configurations in asymmetries. The electroweak correction to the asymmetry $^{(13)}$ of lp-DIS is expressed as

\[
\delta A = A_e^{\omega} - A_0^{\omega} = \delta A_{V\omega} + \delta A_{R\omega} + \delta A_{el\omega}.
\]
where $A_0^{e\omega}$ is defined by equation (10). The main contribution in wide kinematic region to the correction is given by $\delta A_i$. In frame of leading log approximation [25, 26] the radiative correction to asymmetry can be obtained as

$$\delta A_i = \frac{\alpha}{2\pi} \ln\left(\frac{Q^2}{M^2}\right) \sum_{i=1,2} \int_{z_i}^{1} dz \frac{1 + z^2 x_i \sigma_0^{-}(x_i, y_i, E_i)}{1 - z} x \sigma_0(x, y, E) \times [A_0^{e\omega}(x_i, y_i, E_i) - A_0(x, y, E)],$$

where

$$x_1 = zx_2, x_2 = (xy)/(z - 1 + y),$$
$$E_2 = E, E_1 = zE,$$
$$z_1 = 1 - y - xy, z_2 = (1 - y)/(1 - xy),$$
$$y_1 = y_2(z - 1 + y)/(z), Q^2 = (k_1 - k_2)^2.$$
(P_{l_1}P_{N_1} - P_{l_2}P_{N_2})$) that dismiss the electromagnetic correction in the asymmetry. The cross section $\sigma_{el}^+$ are defined by cross section of elastic scattering averaged on the spins of interaction particles. The most compact form of the differential cross section in approach of leading log is:

$$\frac{d\sigma}{dxdy} = \frac{\alpha^3}{2} \frac{1 + (1 - y)^2}{1 - y} f\left[\frac{x^2}{4(1-x)}\right],$$

(16)

where

$$f(x) = \int_x^\infty d\tau [2(A_1(\tau))/\tau - (A_2(\tau))/\tau^2 - (A_2(\tau))/x\tau],$$

$A_1(\tau), A_2(\tau)$ are expressed by electromagnetic nucleon form-factors $G_E, G_M$ as

$$A_1(t) = G_M^2(t), \ A_2(t) = (G_E^2(t) + \tau G_M^2(t))/(1 + t), \ \tau = t/4M^2.$$
Fig. 10. The $B_A$ asymmetry in the Born approximation (solid line) and next to the Born approximation (dotted line)

Fig. 11. The $B_A$ asymmetry in the Born approximation (solid line) and next to the Born approximation (dotted line)

Fig. 12. The $B_A$ asymmetry in the Born approximation (solid line) and next to the Born approximation (dotted line)

Fig. 13. The $B_A$ asymmetry in the Born approximation (solid line) and next to the Born approximation (dotted line)
values in the kinematic region for nonminimal gauge models.

The investigation of the the electroweak asymmetries dependence from the choice of the Weinberg angle revealed that the result obtained in the Standard Model are slightly changed under the $\sin^2 \theta_W$ variation which is accorded by the experimental data. The difference of asymmetries values under the same $\sin^2 \theta_W$ variation in the nonminimal models can exceed 10% and at maximum $x,y$ can become more than the asymmetries values, with the sign of asymmetries changing in the case $A_{p,a}, C_{RR}, C_{RL}$.

5. Conclusion

The cross section for deep inelastic lepton-nucleon scattering with arbitrary polarized initial fermions have been calculated within the electroweak Standard Model and non-minimal gauge models with additional neutral boson. The Lorentz-invariant formulas for cross section and all types of electroweak asymmetries, polarized, charge-polarized, charged, including the first-order electroweak radiative correction have been obtained. We have presented a detailed numerical discussion of the radiative corrections to different kinds of electroweak asymmetries. The difference in the results minimal and nonminimal gauge models increases significantly with the energy of incident leptons and reaches the maximum for largest of scaling variable $y$, where radiative corrections is important for precision analysis of experimental data.

The properties of the electroweak asymmetries considered here in the different gauge models give the possibility to verify the Standard theory of the electroweak interaction and to define how one can use the alternative gauge models. For these purposes the analysis of the new experiment data from the DIS of the polarized particles are used.

6. Appendix

All parameters for the discussed nonminimal gauge model are presented in the following tables.

Table 1. The coupling constant in $SU(2) \times U(1)$ and $SU(3) \times U(1)$ models.

| Parameters | $SU(2) \times U(1)$ model | $SU(3) \times U(1)$ model |
|------------|---------------------------|---------------------------|
| $g_Z$      | $e/\sin 2\theta_W$       | $e/\sin 2\theta_W$       |
| $g_1$      | 1                         | $\cos \alpha$           |
| $g_V$      | $-1/2 + 2 \sin \theta_W^2$ | $-1/2 + 2 \sin \theta_W^2 - A(-1/2 + 3/2 \tan \theta_W^2)$ |
| $g_A$      | $-1/2$                    | $-1/2 + A(-3/2 + 1/2 \tan \theta_W^2)$ |
| $Q_{u,V}^i$| $1/2(1 - 8/3 \sin \theta_W^2)$ | $1/2(1 - 8/3 \sin \theta_W^2) - A(1/2 - 5/6 \tan \theta_W^2)$ |
| $Q_{u,A}^i$| $-1/2$                    | $-1/2 - A(-1/2 - 1/2 \tan \theta_W^2)$ |
| $Q_{d,V}^i$| $1/2(-1 + 4/3 \sin \theta_W^2)$ | $1/2(-1 + 4/3 \sin \theta_W^2) - A(-1/2 + 1/6 \tan \theta_W^2)$ |
| $Q_{d,A}^i$| $1/2$                     | $1/2 - A(-3/2 + 1/2 \tan \theta_W^2)$ |
Table 2. The coupling constants in $SU(2) \times SU(2) \times U(1) \times U(1)$ and $SU(2) \times SU(2) \times U(1)$ models.

| Parameters | $SU(2) \times SU(2) \times U(1) \times U(1)$ model | $SU(2) \times SU(2) \times U(1)$ model |
|------------|-------------------------------------------------|--------------------------------------|
| $g_2$      | ...                                              | $\sin \alpha$                       |
| $A$        | ...                                              | $\tan \alpha \cos^2 \theta_W / (3 - 4 \sin \theta_W^2)^{1/2}$ |
| $g_Y^2$    | ...                                              | $-1/2 + 2 \sin \theta_W^2 + B(-1/2 + 3/2 \tan \theta_W^2)$ |
| $g_Y^3$    | ...                                              | $-1/2 - B(-3/2 + 1/2 \tan \theta_W^2)$ |
| $Q_{u,V}^2$| ...                                              | $1/2(1 - 8/3 \sin \theta_W^2) + B(1/2 - 5/6 \tan \theta_W^2)$ |
| $Q_{u,A}^2$| ...                                              | $-1/2 + B(-1/2 - 1/2 \tan \theta_W^2)$ |
| $Q_{d,V}^2$| ...                                              | $1/2(-1 + 4/3 \sin \theta_W^2) + B(-1/2 + 1/6 \tan \theta_W^2)$ |
| $Q_{d,A}^2$| ...                                              | $1/2 + B(-3/2 + 1/2 \tan \theta_W^2)$ |
| $B$        | ...                                              | $\cot \alpha \cos^2 \theta_W / (3 - 4 \sin \theta_W^2)^{1/2}$ |

References

[1] Ruck R. //Phys. Lett. 1983. v.B129. p. 363 - 387; Nucl. Phys. 1984. v.B234. p. 91 - 107.

[2] Cashmore R.J. et al. //Phys. Rep. 1985. v.122. p. 275 - 297.

[3] Martyn H.U. 1987. HERA Workshop. p. 801 - 876.

[4] Kukhto(Shishkina) T.V., Slumeiko N.M. //Sov.J.P. 1984. Vol. 40. N.5(11). p. 1235 - 1242.
[5] Lee B.W., Weinberg S. //Phys. Rev. Lett. 1977. v.36 N 22. p. 1237 - 1240.
[6] Inoue K. et al. //Progr. Theor. Phys. 1977. v.58. N 6. p. 1914 - 1926.
[7] Lee B.W., Shrock R.E. //Phys. Rev. 1978. v.D17. N 9. p. 2410 - 2448.
[8] Fritzch M., Minkowski P. //Nucl. Phys. v.B103. N 1. p. 61 - 66.
[9] Mohapatra R.N., Sidhu D.P. //Phys. Lett. 1977. v.38. N 13. p. 667 - 670.
[10] De Rujule A. et al. //Ann. Phys. 1977. v.109. N 1. p. 242 - 257.
[11] De Groot E.H. et al. //Z. Phys. 1980. v.C5. N 2. p. 127 - 146.
[12] De Groot E.H. et al. //Phys. Lett. 1979. v.B85. N 4. p. 399 - 403.
[13] De Groot E.H. et al. //Phys. Lett. 1980. v.B90. N 4. p. 427 - 436.
[14] Barger V. et al. //Phys. Rev. Lett. 1980. v.44. N 18. p. 1169 - 1172.
[15] Barger V. et al. //Phys. Rev. Lett. 1980. v.D22. N 3. p. 727 - 737.
[16] Barger V. et al. //Phys. Rev. Lett. 1980. v.D94. N 3. p. 377 - 380.
[17] Barger V. et al. //Phys. Rev. Lett. 1981. v.46. N 23. p. 1501 - 1503.
[18] Hayashi M. et al. //Nuovo Cim. 1983. v.A77. N 1. p. 76 - 98.
[19] Barger V. et al. //Phys. Rev. Lett. 1985. v.D25. N 5. p. 1384 - 1399.
[20] Liaofu V., Gang Z. //Lett. Nuovo Cim. 1985. v.44. p. 319 - 327.
[21] Cvetic M., Lynn B.W. //Phys. Rev. 1987. v.D35. N 1. p. 51 - 69.
[22] Olechowski M. //Z. Phys. 1988. v. C37. N 3. p. 401 - 406.
[23] Pati J.C. et al. Imperial College. 1977. (Preprint ICTP 176/II).
[24] Elias V. et al. University of Maryland. 1977. (Technical reports. N 78 - 043, N 78 - 041).
[25] Kukhto(Shiskina) T.V. et al. //J. Phys. G: Nucl. and Part. Phys. 1992. v.18. N 4. p. 771 - 781.
[26] Akushevich I.V., Kukhto(Shishkina)T.V. //Sov J.P. 1990. vol.52 N.5. p. 1442 - 1446; The questions of atomic science and technics. Vol. Nuclear–physical investigation (theory and experiment). 1990. N. 1. p. 91 - 93.
[27] Altarelli G., Parizi G. //Nucl. Phys. 1977. v.B126 N 2. p. 298 - 318.
[28] Altarelli G. //Phys. Rep. 1982. v.81. N 1. p. 1 - 129
[29] Foster B. //Int.J.Mod.Phys. 1998. v.A13. p. 1543-1622

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