THE ELECTROWEAK ASYMMETRIES IN THE SEMI-INCLUSIVE DEEP-INELASTIC REACTIONS $l^{\mp}N \Rightarrow l^{\mp}BX$

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The investigation of the degree of longitudinal polarization of Λ-hyperon and electroweak asymmetries in semi-inclusive reactions $l^{\mp}N \Rightarrow l^{\mp}BX$ was carried out in the frameworks of the standard theory and quark-parton model. The expressions for the degree of longitudinal polarization of Λ-hyperon, left-right, polarized, charge-polarized and charge asymmetries have been obtained.

The standard model (SM) well describes the series of experiments, carried out in the different laboratories of the world. In particular, the one from the most its detailed checking was carried on e^-e^+-colliders SLC, LEP and TRISTAN, where the agreement with the experimental data is convincing. Along with e^-e^+-annihilations, the processes of the deep-inelastic scattering (DIS) of the leptons on the nucleons play the important role in SM checking and nowadays are experimentally investigated intensively [1-5].

Here the electroweak asymmetries in the semi-inclusive reactions are considered

$$l^{\mp}(\lambda)+N(h_N)\Rightarrow(\gamma^*,Z^0)\Rightarrow l^{\mp}+B(h_B)+X\ , \qquad (1)$$

in which the lepton and detailed inclusive hadron B are registered on the coincidence, and X is the system of the non-detected hadrons. Here λ is the lepton spirality (antilepton), h_N is longitudinal polarization of nucleon-target, h_B is longitudinal polarization of B baryon.

The differential cross-section of semi-inclusive reaction $l^-N \Rightarrow l^-BX$ in SM frameworks can be written in the following form:

$$\frac{d\sigma^{(-)}}{dxdydz}=\sum_{q,h_q} f_{q(h_q)}^{N(h_N)}(x,Q^2)\frac{d\hat{\sigma}}{dy}D_{q(h_q)}^{B(h_B)}(z,Q^2)\ , \qquad (2)$$

Here $f_{q(h_q)}^{N(h_N)}(x,Q^2)$ is distribution function of polarized quarks in the polarized nucleon, $D_{q(h_q)}^{B(h_B)}(z,Q^2)$ is fragmentation function of polarized quarks into the polarized baryon B; $\frac{d\sigma}{dy}$ is the differential cross-section of the elementary subprocess $l^-q \to l^-q$ ($l^-\bar{q} \to l^-\bar{q}$); x, y, z are common kinematic variables of DIS.

Taking under the consideration the exchange of γ and Z^0, It is easy to make sure, that the spiralities of quark and lepton should be saved separately in subprocess $l^-+q \to l^-+q$. That's why in this process only four spiral amplitudes F_{RR}, F_{LL}, F_{RL} and F_{LR}, which describe the following reactions

$$l_R^-+q_R \Rightarrow l_R^-+q_R\ ,\quad l_L^-+q_L \Rightarrow l_L^-+q_L$$
$$l_R^-+q_L \Rightarrow l_R^-+q_L\ ,\quad l_L^-+q_R \Rightarrow l_L^-+q_R$$

should be saved.

The spiral amplitudes in SM limits are defined by the expressions

$$F_{\alpha\beta}=\frac{Q_q}{yS}-\frac{g_\alpha^l g_\beta^q}{yS+M_Z^2} \qquad (\alpha,\beta=L;R)\ . \quad (3)$$

Where M_Z is mass of Z^0-boson, is the square of total energy of $l\bar{q}$-system in c.m.s., Q_q is quark electric charge q, g_R^l and g_L^l (g_R^q and g_L^q) are right and left neutral weak charges of lepton (quark):

$$g_R^l=\sqrt{\frac{x_W}{1-x_W}},\qquad g_L^l=\frac{-1/2+x_W}{\sqrt{x_W(1-x_W)}},$$
$$g_R^q=-Q_q\sqrt{\frac{x_W}{1-x_W}},\quad g_L^q=\frac{T_3-Q_q x_W}{\sqrt{x_W(1-x_W)}}. \qquad (4)$$

Here $\chi_W=\sin^2\theta_W$ is Weinberg parameter, T_3 is third projection of the weak isospin of q quark.

Let's reduce the subprocess cross-section $l^-q \to l^-q$ at the definite values of initial and final particles:

1. $l_R^-+q_R \Rightarrow l_R^-+q_R$:
$$\frac{d\sigma}{dy}=4\pi\alpha^2 sF_{RR}^2,$$
2. $l_L^-+q_L \Rightarrow l_L^-+q_L$:
$$\frac{d\sigma}{dy}=4\pi\alpha^2 sF_{LL}^2,$$
3. $l_R^-+q_L \Rightarrow l_R^-+q_L$:
$$\frac{d\sigma}{dy}=4\pi\alpha^2 s(1-y)^2F_{RL}^2, \qquad (5)$$
4. $l_L^-+q_R \Rightarrow l_L^-+q_R$:
$$\frac{d\sigma}{dy}=4\pi\alpha^2 s(1-y)^2F_{LR}^2.$$

The difference of y-dependencies of the above-mentioned cross-sections (5) connects with the difference of the total spriralities of the system l^-q:: for $l_R^-q_R$ and $l_L^-q_L$-collisions the total system spirality is equal to zero and y-dependence doesn't appear; for $l_R^- q_L$ and $l_L^- q_R$-collisions the sum spirality is equal to one that leads to the characteristic *y*-dependence.

The differential cross-section of the elementary subprocess $l^- q \Rightarrow l^- q$ with taking under the consideration of the spiralities of the initial units can be imagined in the form (the spiralities of the final particles are the same, as of the initial ones, i.e. the spiralities of lepton and quark are saved separately):

$$\frac{d\sigma}{dy} = \pi\alpha^2 s\left\{(1+\lambda)(1+h_q)F_{RR}^2 + (1-\lambda)(1-h_q)F_{LL}^2 + [(1+\lambda)(1-h_q)F_{RL}^2 + (1-\lambda)(1+h_q)F_{LR}^2](1-y)^2\right\}, \quad (6)$$

where h_q is spirality of the initial (or final) quark.

The differential cross-section of subprocess $l^- \bar{q} \Rightarrow l^- \bar{q}$ can be obtained from (6) with the help of the elementary changes: $F_{RR} \Rightarrow F_{RL}$, $F_{RL} \Rightarrow F_{RR}$, $F_{LR} \Rightarrow F_{LL}$, $F_{LL} \Rightarrow F_{LR}$.

On the base of formulas (2) and (6), the expression for the differential cross-section of semi-inclusive reactions $l^- N \Rightarrow l^- BX$ has been obtained:

$$\begin{aligned}\frac{d\sigma^{(-)}}{dxdydz} = \sum_q \Big\{ &\left[f_q^N(x,Q^2)\times D_q^B(z,Q^2) + h_N h_B \Delta f_q^N(x,Q^2)\Delta D_q^B(z,Q^2)\right]\times\left[(1+\lambda)(F_{RR}^2+(1-y)^2F_{RL}^2)+(1-\lambda)(F_{LL}^2+(1-y)^2F_{LR}^2)\right]+\\ +&\left[f_{\bar{q}}^N(x,Q^2)D_{\bar{q}}^B(z,Q^2) + h_N h_B \Delta f_{\bar{q}}^N(x,Q^2)\Delta D_{\bar{q}}^B(z,Q^2)\right]\times\left[(1+\lambda)(F_{RL}^2+(1-y)^2F_{RR}^2)+(1-\lambda)(F_{LR}^2+(1-y)^2F_{LL}^2)\right]+\\ +&\left[h_N \Delta f_q^N(x,Q^2)D_q^B(z,Q^2) + h_B f_q^N(x,Q^2)\Delta D_q^B(z,Q^2)\right]\times\left[(1+\lambda)(F_{RR}^2-(1-y)^2F_{RL}^2)-(1-\lambda)(F_{LL}^2-(1-y)^2F_{LR}^2)\right]+\\ +&\left[h_N \Delta f_{\bar{q}}^N(x,Q^2)D_{\bar{q}}^B(z,Q^2) + h_B f_{\bar{q}}^N(x,Q^2)\Delta D_{\bar{q}}^B(z,Q^2)\right]\times\left[(1+\lambda)(F_{RL}^2-(1-y)^2F_{RR}^2)-(1-\lambda)(F_{LR}^2-(1-y)^2F_{LL}^2)\right]\Big\}\end{aligned} \quad (7)$$

where

$$f_q^N(x,Q^2) = f_{q(+1)}^{N(+1)}(x,Q^2) + f_{q(-1)}^{N(+1)}(x,Q^2),$$
$$\Delta f_q^N(x,Q^2) = f_{q(+1)}^{N(+1)}(x,Q^2) - f_{q(-1)}^{N(+1)}(x,Q^2),$$
$$D_q^B(z,Q^2) = D_{q(+1)}^{B(+1)}(z,Q^2) + D_{q(-1)}^{B(+1)}(z,Q^2)$$
$$\Delta D_q^B(z,Q^2) = D_{q(+1)}^{B(+1)}(z,Q^2) - D_{q(-1)}^{B(+1)}(z,Q^2),$$

$f_q^N(x,Q^2)$ and $D_q^B(z,Q^2)$ present the usual function of quark distribution in nucleon and quark fragmentation function in baryon *B*.

The summation over *q* in (7) extends over all quarks and antiquarks which are in nucleon *N*.

The differential cross-section of semi-inclusive DIS antilepton on nucleon $l^+ N \Rightarrow l^+ B$ can be obtained from (7) with the help of the following exchanges:

$$\frac{d\sigma^{(+)}}{dxdydz} = \frac{d\sigma^{(-)}}{dxdydz} \quad (F_{RR} \Leftrightarrow F_{LR}, F_{Rl} \Leftrightarrow F_{LL}). \quad (8)$$

P-odd electroweak asymmetries DIS of longitudinal polarized leptons and antileptons can be defined by the unpolarized target by the following form:

$$A(l_L^- - l_R^-) = \left[\sigma_L^{(-)} - \sigma_R^{(-)}\right]/\left[\sigma_L^{(-)} + \sigma_R^{(-)}\right], \quad (9)$$
$$A(l_L^+ - l_R^+) = \left[\sigma_L^{(+)} - \sigma_R^{(+)}\right]/\left[\sigma_L^{(+)} + \sigma_R^{(+)}\right], \quad (10)$$
$$A(l_R^- - l_L^+) = \left[\sigma_R^{(-)} - \sigma_L^{(+)}\right]/\left[\sigma_R^{(-)} + \sigma_L^{(+)}\right], \quad (11)$$
$$A(l_L^- - l_R^+) = \left[\sigma_L^{(-)} - \sigma_R^{(+)}\right]/\left[\sigma_L^{(-)} + \sigma_R^{(+)}\right]. \quad (12).$$

Here $\sigma_L^{(-)} = \frac{d\sigma_L^{(-)}}{dxdydz}$ and $\sigma_R^{(-)} = \frac{d\sigma_R^{(-)}}{dxdydz}$ and $\sigma_R^{(+)}$ are differential cross-sections of semi-inclusive DIS right- and left-polarized lepton (antilepton) on nucleons.

At DIS of longitudinal polarized lepton (antilepton) the polarized asymmetries can be defined on the polarized nucleon

$$A_p^{(\mp)} = \left[\sigma_{RR}^{(\mp)} - \sigma_{LL}^{(\mp)}\right]/\left[\sigma_{RR}^{(\mp)} + \sigma_{LL}^{(\mp)}\right] \quad (13)$$
$$A_a^{(\mp)} = \left[\sigma_{RL}^{(\mp)} - \sigma_{LR}^{(\mp)}\right]/\left[\sigma_{RL}^{(\mp)} + \sigma_{LR}^{(\mp)}\right] \quad (14)$$

Charge-polarized asymmetries

$$B_p^{(\mp)} = \left[\sigma_{RR}^{(\mp)} - \sigma_{LL}^{(\pm)}\right]/\left[\sigma_{RR}^{(\mp)} + \sigma_{LL}^{(\pm)}\right] \quad (15)$$
$$B_a^{(\mp)} = \left[\sigma_{RL}^{(\mp)} - \sigma_{LR}^{(\pm)}\right]/\left[\sigma_{RL}^{(\mp)} + \sigma_{LR}^{(\pm)}\right] \quad (16)$$

and charge asymmetries

$$C_{\alpha\beta} = \left[\sigma_{\alpha\beta}^{(-)} - \sigma_{\alpha\beta}^{(+)}\right]/\left[\sigma_{\alpha\beta}^{(-)} + \sigma_{\alpha\beta}^{(+)}\right], \ (\alpha,\beta = R,L). \quad (17)$$

Here $\sigma_{RR}^{(\mp)}$, $\sigma_{LL}^{(\mp)}$, $\sigma_{RL}^{(\mp)}$ and $\sigma_{LR}^{(\mp)}$ are cross-sections of the processes (1) at the polarization of lepton (antilepton) and nucleon $\lambda = 1, h_N = 1$; $\lambda = -1, h_N = -1$, $\lambda = 1$, $h_N = -1$ and $\lambda = -1, h_N = 1$.

The study of the longitudinal polarization of baryon *B*, which can be measured on angle distribution of decay products in processes $B \Rightarrow N + \pi$ presents the special interest.

$$P_B^{(\mp)} = \left[\sigma^{(\mp)}(h_B = 1) - \sigma^{(\mp)}(h_B = -1)\right]/\left[\sigma^{(\mp)}(h_B = 1) + \sigma^{(\mp)}(h_B = -1)\right] \quad (18)$$

$$P_B^{(\mp)}(\lambda) = \left[\sigma^{(\mp)}(\lambda, h_B = 1) - \sigma^{(\mp)}(\lambda, h_B = -1)\right]/\left[\sigma^{(\mp)}(\lambda, h_B = 1) + \sigma^{(\mp)}(\lambda, h_B = -1)\right] \quad (19)$$

$$P_B^{(0)}(h_\ell)=\left|\sigma^{(0)}(h_\ell,h_B=1)-\sigma^{(0)}(h_\ell,h_B=-1)\right|/\left|\sigma^{(0)}(h_\ell,h_B=1)+\sigma^{(0)}(h_\ell,h_B=-1)\right|. \quad (20)$$

The electroweak asymmetries (9)-(17) and also the degree of longitudinal polarization of baryon (18)-(20) are expressed through spiral amplitudes $F_{\alpha\beta}$ and quark distribution and fragmentation functions. For example, the left-right asymmetry $A(l_L^- - l_R^+)$ and the degree of longitudinal polarization of baryon $P_B^{(-)}(\lambda=1)$ are defined by the expressions:

$$A(l_L^- - l_R^+) = \frac{1-(1-y)^2}{1+(1+y)^2}\left[\sum_q (F_{LL}^2 - F_{LR}^2)\times\left[f_q^N(x,Q^2)D_q^B(z,Q^2) - f_{\bar q}^N(x,Q^2)\times \times D_q^B(z,Q^2)\right]\right]\left[\sum_q (F_{LL}^2 + F_{LR}^2)\left[f_q^N(x,Q^2)\times D_q^B(z,Q^2) + f_{\bar q}^N(x,Q^2)D_{\bar q}^B(z,Q^2)\right]\right]^{-1} \quad (21)$$

$$P_B^{(-)}(\lambda=1)=\left[\sum_q f_q^N(x,Q^2)\Delta D_q^B(z,Q^2)(F_{RR}^2-(1-y)^2F_{RL}^2)+\sum_q f_q^N(x,Q^2)\Delta D_q^B(z,Q^2)(F_{RL}^2- -(1-y)^2F_{RR}^2)\right]\left[\sum_q f_q^N(x,Q^2)D_q^B(z,Q^2)(F_{RR}^2++(1-y)^2F_{RL}^2)+\sum_{\bar q} f_{\bar q}^N(x,Q^2)D_{\bar q}^B(z,Q^2)(F_{RL}^2++(1-y)^2F_{RR}^2)\right]^{-1} \quad (22)$$

In the expressions of the observed values the phenomenological parameters - distribution functions of quarks and antiquarks in polarized nucleons and fragmentation function of polarized quark (antiquark) into polarized baryon B, the values of which are defined from the experiment are present. In the literature there are set of distribution functions of quarks in nucleons [5-7]. The distribution functions of valence and sea polarized quarks (antiquarks) in nucleons, given in [6] have been considered by us for the numeral evaluations of asymmetries and polarizations.

The numeral calculations of the electroweak asymmetries and degree of longitudinal polarization of Λ^0-hyperons in semi-inclusive reactions $e^{\mp}p \to e^{\mp}\Lambda^0 X$ at energy $\sqrt{s}=300\,\mathrm{GeV}$ (*ep* - collider HERA), Weinberg parameter $\sin^2\theta_W=0.232$ are given by us.

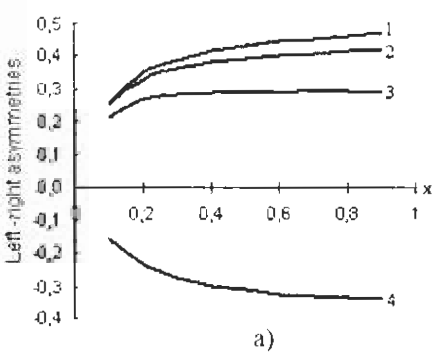
According to the refs [9,10], the spin functions of quark fragmentation into Λ^0-hyperon are parameterized in the form

$$\Delta D_S^{\Lambda}(z,Q^2) = z^{\alpha}D_S^{\Lambda}(z,Q^2),$$
$$\Delta D_U^{\Lambda}(z,Q^2) = \Delta D_d^{\Lambda}(z,Q^2) = N_U\Delta D_S^{\Lambda}(z,Q^2), \quad (23)$$

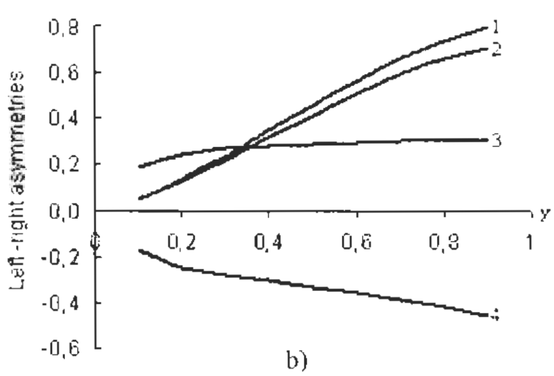
α and N_U parameters are chosen in three variants

Parameter	Variant 1	Variant 2	Variant 3
α	0.62	0.27	1.66
N_U	0	-0.2	1

The dependency of electroweak asymmetries $A(e_R^- - e_L^+)$, $A(e_L^- - e_R^+)$, $A(e_L - e_R)$, $A(e_L^+ - l_R^+)$ on x variable at the fixed value y=0,5 and on y variable at the fixed value x=0,7 is given on the figures 1. a) and b).



a)



b)

Fig.1. The dependence of the asymmetries $A(e_R^- - e_L^+)$, $A(e_L^- - e_R^+)$, and $A(e_L^- - e_R^-)$ and $A(e_L^+ - e_R^+)$ (curves 1, 2, 3 and 4 correspondingly) on x at y=0,5 and on y at x=0,7.

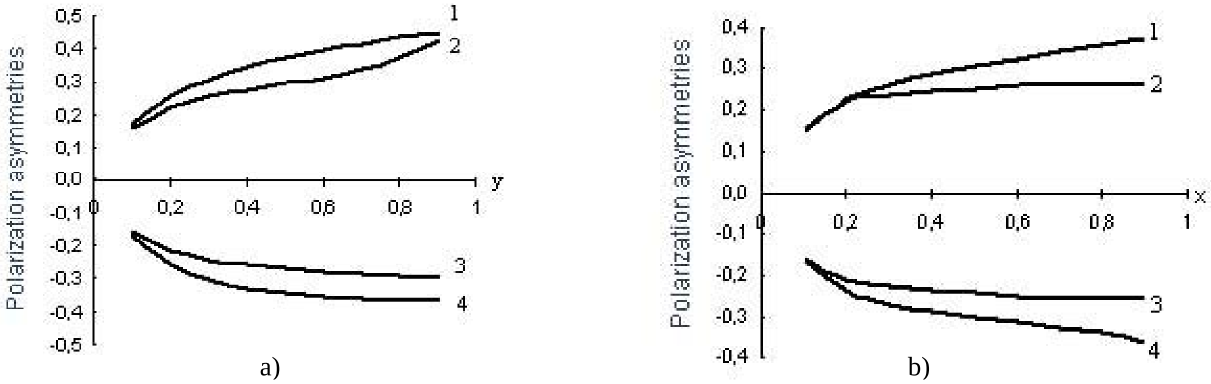


Fig.2. The dependence of the asymmetries $A_p^{(+)}$, $A_a^{(+)}$, $A_p^{(-)}$ and $A_a^{(-)}$ (curves 1, 2, 3 and 4 correspondingly) on *x* at *y*=0,3 and on *y* at *x* =0,5.

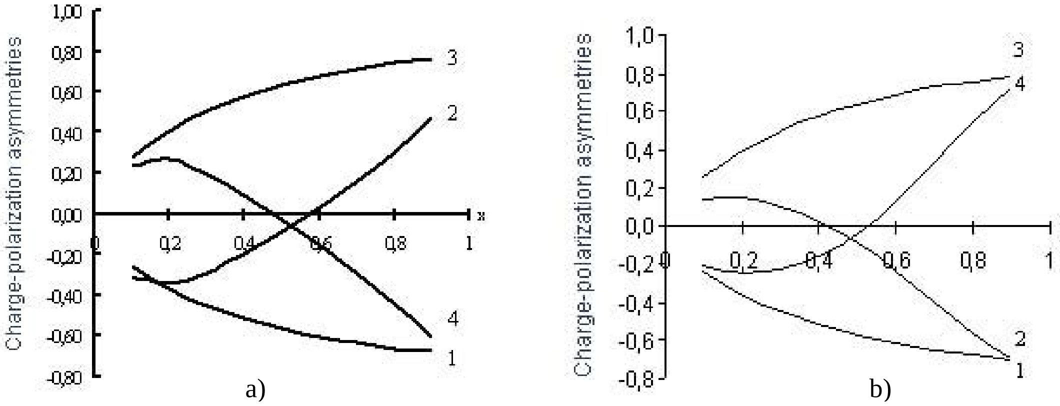


Fig.3. The dependence of the asymmetries $B_p^{(+)}$, $B_a^{(+)}$, $B_p^{(-)}$ and $B_a^{(-)}$ (curves 1, 2, 3 and 4 correspondingly) on *x* at *y*=0,5 and on *y* at *x*=0,5.

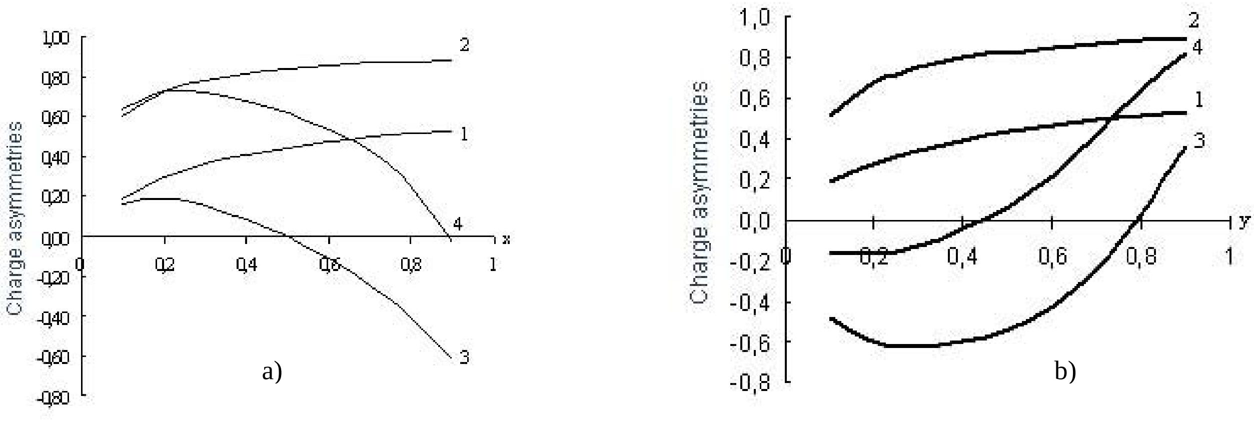


Fig.4. The dependence of the asymmetries C_{RR}, C_{LL}, C_{RL} and C_{LR} (curves 1, 2, 3 and 4 correspondingly) on *x* at *y*=0,7 and on *y* at *x*=0,7.

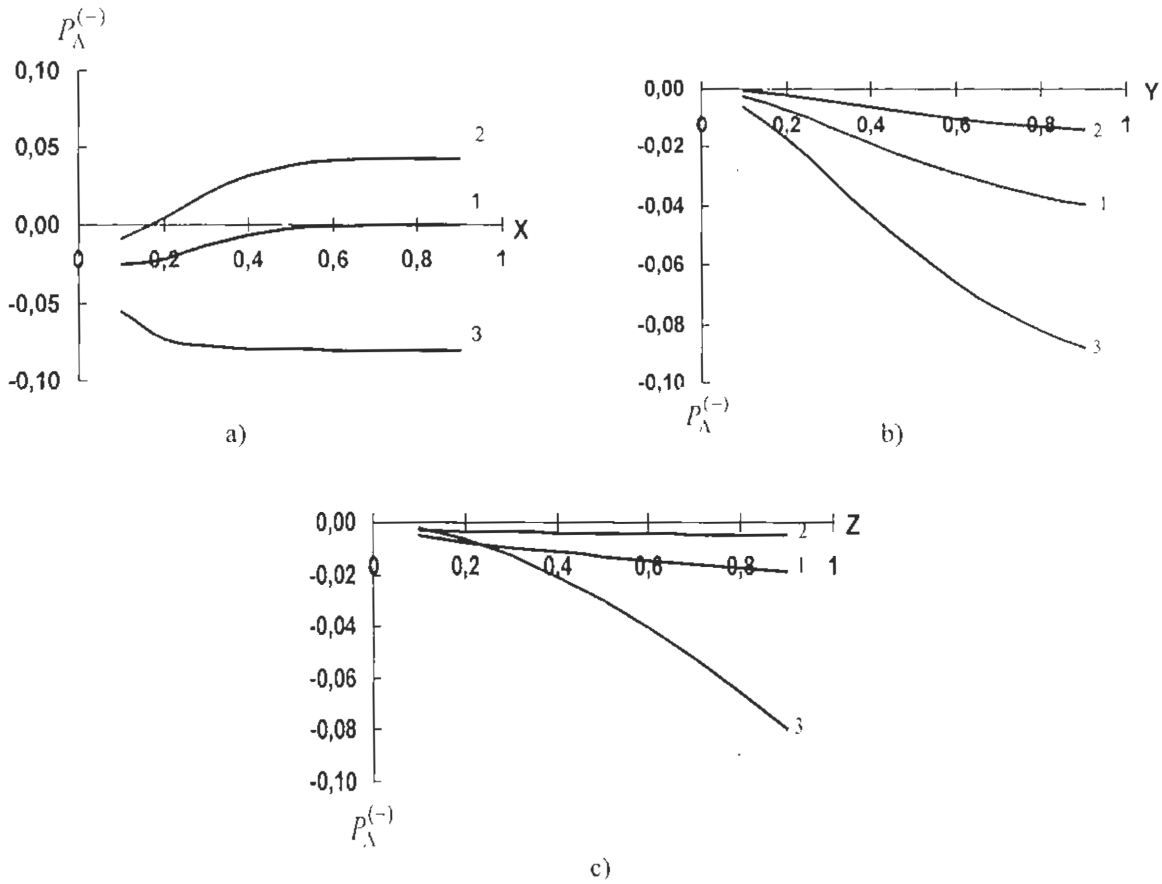


Fig 5. The dependence of $P_\Lambda^{(-)}$ on x at $y=0,5$, $z=0,5$ (a); on y at $x=0,1$, $z=0,5$ (b) and on z at $x=0,1$, $y=0,3$ (c).

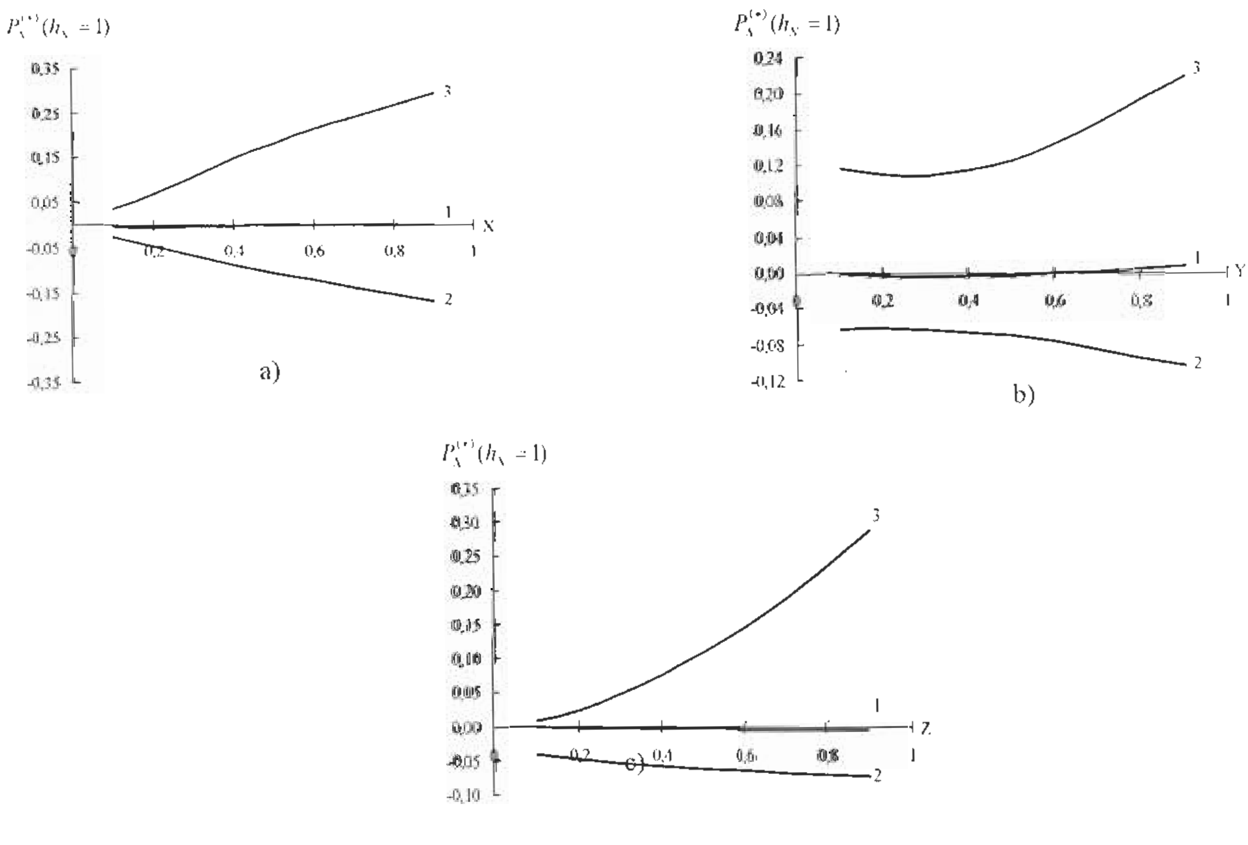


Fig.6. The dependence of the degree of longitudinal polarization $P_\Lambda^{(+)}(h_N=1)$ on x at $y=0,3$, $z=0,5$ (a); on y at $x=0,3$, $z=0,5$ (b) and on z at $x=0,3$, $y=0,3$ (c).

The analogical behavior is observed for x- and y-dependencies of electroweak asymmetries $A_p^{(\mp)}, A_a^{(\mp)}, B_p^{(\mp)}, B_a^{(\mp)}, C_{RR}, C_{LL}, C_{RL}$ and C_{LR} ((see fig.2-4. a) and b)). It is need to note, that the electroweak asymmetries don`t depend on z variable at the choice of quark fragmentation function into Λ^0-hyperon in the form (23).

The dependence of degree of longitudinal polarization of Λ^0-hyperon $P_\Lambda^{(-)}$ in reactions $e^{\mp}p \to e^{\mp}\Lambda^0 X$ on x, y, z variables is given on the fig.5. As it is seen in 1 and 2 variants the degree of longitudinal polarization of Λ-hyperon is small and weakly depends on x, y, z variables. In 3 variant polarization is negative and with the decrease of x, y or z, it weakly increase on module. The figure 6 illustrates the dependence of longitudinal polarization of Λ^0-hyperon $e^{\mp}p \to e^{\mp}\Lambda^0 X$ with polarized nucleon $h_N = +1$. In 1 model the polarization is almost zero, and in 2 and 3 models it achieves to several percents.

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$l^{\mp}N \Rightarrow l^{\mp}BX$ YARIMİNKLYUZİV DƏRİN QEYRİ ELASTİKİ REAKSİYALARDA ELEKTROZƏİF PROSESLƏR

Standart nəzəriyyə çərçivəsində və kvark-parton modelində Λ-heperonun uzununa polyarizasiyası və yarıminklyuziv $l^{\mp}N \Rightarrow l^{\mp}\Lambda X$ reaksiyalarda elektrozəif asimmetriyalar tədqiq edilmişdir. Λ-heperonun uzununa polyarizasiya dərəcəsinin, sol-sağ polyarizasiyalarının, yük polyarizasiyasının və yük asimmetriyasının analitik ifadələri hesablanmış və analizi verilmişdir.

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ЭЛЕКТРОСЛАБЫЕ АСИММЕТРИИ В ПОЛУИНКЛЮЗИВНЫХ ГЛУБОКОНЕУПРУГИХ РЕАКЦИЯХ $l^{\mp}N \Rightarrow l^{\mp}BX$

В рамках стандартной теории и в кварк-партонной модели проведено исследование степени продольной поляризации Λ- гиперона и электрослабых асимметрий в полуинклюзивных реакциях $l^{\mp}N \Rightarrow l^{\mp}\Lambda X$. Получены выражения для степени продольной поляризации Λ-гиперона, лево-правых, поляризационных, зарядово-поляризационных и зарядовых асимметрий.

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