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A b s t r a c t

The hypothesis of the baryon chirality conservation in the processes with large momentum transfer is suggested and some arguments in its favour are made. Experimental implications of this assumption for weak and electromagnetic form factors of transitions in the baryon octet and of transitions $N \to \Delta$, $N \to \Sigma^*$ are considered.

As is well known the experimental ratio of cross sections of the deep inelastic $\bar{\nu}N$ and νN scattering $\sigma(\bar{\nu}N)/\sigma(\nu N) \simeq$ 1/3 means that at large momentum transfers Q^2 and not small $x=Q^2/2\nu$ the interference of axial and vector interaction is maximal. (It is supposed that the contribution of weak currents with $\Delta T\neq 1$ is small). Hence it follows that the processes of $\bar{\nu}N$ and νN scattering at large Q^2 and not small x are mainly contributed by states with left-handed chiralitites of initial nucleon and final baryon. (Unlike the processes at small Q^2 where e.g., in semileptonic hyperon decays, the experiment and the Cabibbo theory indicate an essential role of states with both chiralitites). It is very plausible that the conservation of the baryon chirality must also hold in the deep inelastic eN scattering *) .

The statement on the dominant role of finite states of the baryons with the left-handed chirality in inclusive processes of $\bar{\nu}N$ and νN scattering at large Q^2 and not small x would be interesting to check directly by measuring the final baryon chirality in such processes. It should be expected that at $Q^2 \to \infty$, $\nu \to \infty$, $Q^2/2\nu \sim 1$ the final baryon helicity (if the baryon does not emerge from the decay of some resonance) is $\lambda \to -\frac{1}{2}$. Perhaps, the most effective ways for experimental study of the final baryon helicity in inclusive processes of νN , $\bar{\nu}N$ scattering are 1) the observation of reaction $\bar{\nu}_\mu N \to \mu^+ \Sigma^+ +$ and all

*) We do not consider here the processes with the baryon-antibaryon pair production whose contribution into the total cross section is small.

and the measurement of Σ^{+} polarization by $\Sigma^{+} \to p\pi^{0}$ decay and 2) the measurement of reaction $\nu_\mu(\bar{\nu}_\mu)N \to \mu^{\mp}\Delta +$ all and the measurement of the pion angular distribution in Δ decay (see formula (6) below).

The hypothesis of the baryon chirality conservation in the deep inelastic weak and electromagnetic processes is natural to expand and to assume that : (A) the baryon chirality conservation hold in any (including exclusive) interactions at small distances (besides the processes with the baryon-antibaryon pair production).

The hypothesis (A) seems to be plausible since it means that at small distances the chiral symmetry (e.g., $SU_L(3)' \times SU_R(3)'$ in gluon theory) is exact. Within the model consideration the baryon chirality conservation may be obtained considering, for instance, the weak (or electromagnetic) baryon form factors which appear in the double logarithmic approximation due to the baryon interaction with vector gluons. In this case the masses in the virtual fermion propagators may be neglected and it seems that for large Q^2 the final baryon chirality will coincide with the chirality of initial one. For the theory with pseudoscalar gluons such a statement cannot be true in general.

The conservation of the baryon chirality at large Q^2 (i.e., invariance relative to γ_5 transformation) should be also expected in the vector gluon theories with the ultraviolet-stable fixed point when the amplitudes are determined by anomalous dimensions of the field operators and by the values of Lorenz invariants (relative to normalization points) but are independent of the particle masses. It is evident that in any model consideration the hypothesis (A) is equivalent to two assumptions: 1) at small distances the fermion interaction is due to the vector meson exchange; 2) in the processes with large momentum transfers the virtual fermion masses may be neglected. The latter assumption is confirmed by success of the "quark counting" rule [1,2] in determination of hadron form factors at large Q^2 where the masses in the fermion propagators are also neglected. The assumptions 1) and 2) are of sufficiently general character and have no direct relations with the guiding considerations based on the experimental value of the ratio $\sigma(\bar{\nu}N)/\sigma(\nu N)$. (In particular, they may be remained valid if at larger energies $\sigma(\bar{\nu}N)/\sigma(\nu N)$ will considerably differ from 1/3, e.g. due to the larger role of the sea of quark-antiquark pairs or of the V+A current contribution).

This paper considers the consequences from hypothesis (A) for electromagnetic and weak form factors of baryons at large Q^2. The experimental confirmation of these consequences would be in favour of vector gluons in case of theories with gluons but undoubtedly would be of independent interest apart from the theoretical arguments which may be given now pro and con the hypothesis under consideration. Consequences concerning strong interaction processes with large momentum transfers will be considered elsewhere.

1. Electromagnetic Form Factors of Nucleons

The requirement of the chirality conservation applying to electromagnetic form factors of nucleons immediately leads to a conclusion that the magnetic (Pauli) form factor $F_2(Q^2)$ at $Q^2 \to \infty$ must decrease essentially faster than electric $F_1(Q^2)$ (at least $F_2(Q^2) \ll F_1(Q^2)/\sqrt{Q^2}$). Making use of of the connection between Pauli and Sachs form factors $G_E = F_1 - (Q^2/4m^2)F_2$, $G_M = F_1 + F_2$, and experimental relations for G_E, G_M at large Q^2 : $G_{Ep} = G_{Mp}/\mu_p = G_{Mn}/\mu_n = (1+Q^2/m_V^2)^{-2}$, $G_{En} \simeq 0$. ($m_V^2 = 0.71$ GeV^2 , μ_p , μ_n , are the total magnetic moments moments of proton and neutron) it can be easily seen that experimentally this is really the case: for proton and neutron $F_2(Q^2) \sim (1/Q^2)F_1(Q^2)$. (In approach [2] such relation between F_2 and F_1 was recently obtained by Ezawa [3]).

2. Weak Form Factors in the Octet of Baryons

Let us consider the weak interaction form factors in the octet of baryons which may be measured in the processes of neutrino (antineutrino) scattering on nucleons $\nu n \to \ell^- p$ (Ia), $\bar{\nu} n \to \ell^+ n$ (Ib), $\bar{\nu} p \to \ell^+ \Lambda^0$ (IIa) $\bar{\nu} n \to \ell^+ \Sigma^-$ (IIb) $\bar{\nu} p \to \ell^+ \Sigma^0$ (IIc).

In the framework of the hypothesis under consideration and supposing the V-A structure of the bare weak current it should be expected that at large Q^2 the matrix elements of processes(I),(II) will contain only states with the left-handed baryon chirality, and the form factors will be of the form

$$F_1(Q^2)\bar{u}_f \gamma_\mu (1+\gamma_5) u_i \qquad (1)$$

where u_f and u_i are spinors of final and initial baryons. For processes (I) hence it follows that at $Q^2 \to \infty$ the axial form factor $G_A(Q^2)$ equals the vector isovector $G_A(Q^2) = F_{1V}(Q^2) \simeq G_{Mp}(Q^2) - G_{Mn}(Q^2)$. So the usual parametrization of axial form factor $G_A(Q^2) = G_A(0)(1+Q^2/m_A^2)^{-2}$ with the constants $G_A(0) = 1.25$ and M_A is not quite good. If nevertheless we use such parametrization at large Q^2 then it should be expected that $M_A = m_V \left[(\mu_p - \mu_n)/G_A(0) \right]^{1/4} =$ $= 1.4\ m_V = 1.17$ GeV. This value does not contradict the experimental data available [4]. Our expectations for the axial form factor at large Q^2 are close (the difference is by a factor of $G_A(0)=1.25$) to predictions by Gordon and Peccei [5] but they are considerably different from those by Riazuddin and Fayyazuddin [6].

It would be interesting to verify (1) for the hyperon production processes (II) and especially (IIb,c) since as it follows from the Cabibbo theory and from experiment, at small Q^2 the form factors of these processes are of the form considerably different from (I): $G_A(0)=-0.37$ for (IIb,c) $G_A(0) = 0.7$ for (IIa). If in the process (IIb,c) the polarization of the final hyperon will be measured, the following picture would appear: at small Q^2 the hyperon is longitudinally polarized along the momentum (P $\sim$ 50-100% depending on the scattering angle, see, e.g. [7]) with Q^2 increasing the polarization changes its sign and at large Q^2 the hyperon appears to be totally polarized opposite to the momentum. Unfortunately, a direct measurement of Σ^- polarization by $\Sigma^- \to n\pi^-$ decay is practically impossible because of a small asymmetry coefficient in this decay. Perhaps, the most promising would be the observation of the process $\bar{\nu}_\mu p \to \mu^+ \Sigma^0$, $\Sigma^0 \to \Lambda\gamma$ with the measurement of Λ polarization from asymmetry of its decay $\Lambda \to p\pi^-$ (Λ polarization $\vec{P}_\Lambda$ in $\Sigma^0 \to \Lambda\gamma$ decay is related to Σ^0 polarization $\vec{P}_{\Sigma^0}$ by $\vec{P}_\Lambda = -\vec{P}_{\Sigma^0} \cos^2\theta$ where θ is the angle between $\vec{P}_{\Sigma^0}$ and γ momentum in the Σ rest system).

3. Isobar Electroproduction Form Factors

The form factor of electromagnetic transition $N \to \Delta$ was studied from theoretical point of view in a number of papers [8-13]. For our aims it is convenient to make use of the Rarita-Schwinger formalism for a particle with spin 3/2 and in the notations of [13] to write the form factor as

$$\langle \Delta | j_\mu | N \rangle = \bar{u}_\beta(P_\Delta)\left[G_1(Q^2)H^{(1)}_{\beta\mu} + G_2(Q^2)H^{(2)}_{\beta\mu} + G_3(Q^2)H^{(3)}_{\beta\mu}\right]u(P) \tag{2}$$

where

$$\begin{aligned} H^{(1)}_{\beta\mu} &= (q_\beta \gamma_\mu - \hat{q}\,\delta_{\beta\mu})\gamma_5 \\ H^{(2)}_{\beta\mu} &= (q_\beta P_\mu - (qP)\delta_{\beta\mu})\gamma_5 \\ H^{(3)}_{\beta\mu} &= (q_\beta q_\mu - q^2 \delta_{\beta\mu})\gamma_5 \end{aligned} \tag{3}$$

$P = (p_\Delta + p)/2$, $q = p_\Delta - p$, $q^2 = -Q^2$, p_Δ and p are the isobar and nucleon momenta. From requirement of γ_5 invariance it follows that at large Q^2 only form factor $G_1(Q^2)$ survive and

$$G_2(Q^2)/G_1(Q^2) \to 0, \quad G_3(Q^2)/G_1(Q^2) \to 0 \tag{4}$$

at $Q^2 \to \infty$. By analogy with the nucleon form factors it may be thought that $G_2(Q^2)/G_1(Q^2) \lesssim 1/Q^2$, $G_3(Q^2)/G_1(Q^2) \lesssim 1/Q^2$ though directly from (2),(3) it follows only a more weak restriction $G_2/G_1 \ll 1/(Q^2)^{1/2}$, $G_3/G_1 \ll 1/(Q^2)^{1/2}$. The restrictions obtained can be easily formulated in term of the helicity amplitudes and of usually used magnetic dipole G^*_M, electric quadrupole G^*_E and Columob G^*_c form factors (the notations of Ref. [13]). For helicity amplitudes $\langle \lambda_\Delta | j | \lambda_\gamma, \lambda_N \rangle$ at $Q^2 \to \infty$ we have

$$\langle -\tfrac{1}{2}|j|-1,-\tfrac{1}{2}\rangle = \langle \tfrac{1}{2}|j|0,-\tfrac{1}{2}\rangle = i\frac{(Q^2)^{3/2}}{\sqrt{3}M_\Delta}G_1(Q^2)$$

$$\langle \tfrac{3}{2}|j|+1,-\tfrac{1}{2}\rangle / \langle -\tfrac{1}{2}|j|-1,-\tfrac{1}{2}\rangle \to 0 \qquad (5)$$

(The amplitude $\langle \tfrac{1}{2}|j|0,-\tfrac{1}{2}\rangle$ does not vanish in accordance with the general theorem [14] but $\sigma_L/\sigma_T \to 0$). Hence $G_M^* \approx -G_E^*$ and $G_C^*/G_M^* \lesssim O(1/Q^2)$. Since according to (5) the isobar in the electroproduction process at large Q^2 is produced aligned with the helicity $\lambda_\Delta = \pm\tfrac{1}{2}$, then the pion angular distribution in its decay is proportional to

$$dw/d\cos\vartheta \sim 1 + 3\cos^2\vartheta \qquad (6)$$

where ϑ is the angle between $\vec{p}_\Delta$ and the pion momentum in the Δ rest system. Experimentally, the isobar electroproduction cross section is measured up to $Q^2 \approx 6$ GeV^2 (see, e.g. review [13,16]). At Q^2=2-6 GeV^2 there are only single-arm spectrometer experiments where G_M^* and G_E^* cannot be determined separately. At $Q^2 < 2$ GeV^2 in the isobar electroproduction of importance is the magnetic form factor G_M^* while G_E^*/G_M^* is small, $\sim$ 5%. These data accounting for kinematic factors can be put in accordance with our expectations. In the light of the mentioned above the isobar electroproduction measurement at large Q^2 together with the pion registration into coincidence with electron would be of great interest.

4. Σ^* and Δ Production in the Neutrino Experiment

From assumption (A) and from the V-A structure of weak hadronic current it directly follows that in the neutrino experiment in the processes $\bar{\nu}_\mu p \to \mu^+ \Sigma^{*0}$,

$\bar{\nu}_\mu n \to \mu^+ \Sigma^{*-}$ at large Q^2 Σ^* must be produced with the helicity $\lambda_{\Sigma^*} = -\frac{1}{2}$. Σ^* polarization leads to that Λ -hyperons resulting from $\Sigma^{*0} \to \Lambda \pi^0$, $\Sigma^{*-} \to \Lambda \pi^-$ decays appear to be also polarized. The projection of Λ polarization $\vec{P}_\Lambda$ to the direction of the momentum Σ^* is

$$\vec{P}_\Lambda \vec{n}_{\Sigma^*} = -(5 \cos^2\vartheta - 1)/(3\cos^2\vartheta + 1) \qquad (7)$$

where $\vec{n}_{\Sigma^*}$ is a unit vector in the direction of the momentum Σ^*, ϑ is the angle between Λ momentum and $\vec{n}_{\Sigma^*}$ in the Σ^* rest frame. Analogously, in reaction $\nu(\bar{\nu}) N \to e^{\mp} \Delta$ at high Q^2 the isobar Δ must be produced with the helicity $\lambda_\Delta = -\frac{1}{2}$, the pion angular distribution in its decay will be determined by formula (6) and the ratio $d\sigma(\bar{\nu}N \to e^+\Delta)/d\sigma(\nu N \to e^-\Delta) \approx (1-Q^2/s)^2$, $s = 2mE_\nu$. The threshold effects in Δ and Σ^* production must be probably more prolonged than in elastic scattering eN $\to$ eN, so the applicability region of relations (4)-(7) is at larger Q^2 than in case of the nucleon electromagnetic form factor (it seems, Q^2 4÷5 GeV^2). It should be also remarked that if for some dynamical reasons the form factor G_1 is suppressed (has a small numerical coefficient) then the asymptotic regime would appear at larger values of Q^2 .

Note in conclusion that the hypothesis under consideration may be extended to the process of e^+e^- annihilation into hadrons, particularly, it may be expected that in inclusive reactions $e^+e^- \to \bar{B}_1 B_2$ + all or exclusive $e^+e^- \to \bar{B}_1 B_2$ at large Q^2 the baryon B_2 and the antibaryon $\bar{B}_1$ will have opposite chiralities.

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