LETTERS TO THE EDITOR

ARE THERE VALENCE GLUONS IN THE NUCLEON?*

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We interpret the SLAC result $W_1(\nu, Q^2) \sim (1-x_s)^4$ at large x_s as an evidence for there being three valence gluons (= "coquarks") in the nucleon.

It follows from the recent analysis [1] of the SLAC experiments on deep inelastic electron-nucleon scattering that the proton and neutron structure functions can be nicely fitted to the scaling forms

$$2F_1^{\mathrm{p}}(x_s^{\mathrm{p}}) = 3.2(1-x_s^{\mathrm{p}})^4, \quad 2F_1^{\mathrm{n}}(x_s^{\mathrm{n}}) = 2.2(1-x_s^{\mathrm{n}})^4 \tag{1}$$

for x_s^{p} and $x_s^{\mathrm{n}} \gtrsim 0.2$, where

$$x_s^{\mathrm{p}} = \frac{Q^2}{2M\nu+1.5\ \mathrm{GeV}^2}, \quad x_s^{\mathrm{n}} = \frac{Q^2}{2M\nu+0.6\ \mathrm{GeV}^2}. \tag{2}$$

At the present time, nothing safe can be said about the ratio $F_1^{\mathrm{n}}/F_1^{\mathrm{p}}$ in the "true" Bjorken limit, where x_s^{p} and x_s^{n} approach $x = Q^2/2M\nu$. However, if x_s^{p} and x_s^{n} are really good scaling variables, then (1) should be valid also in this limit, giving the ratio close to 2/3 for $x \gtrsim 0.2$. In particular, the value 1/4 suggested previously for $x \to 1$ would be no longer significant. Obviously, the value close to 2/3 for $x \gtrsim 0.2$ would be in agreement with the simplest conjecture that for $x \gtrsim 0.2$ the valence quarks dominate the nucleon structure and the u and α valence quarks have equal momentum distributions (cf. e. g. [2]).

In this note we would like to call the reader's attention to the power 4 in formulae (1) and its agreement with the simple nucleon model, proposed previously [3], which in fact predicted that in the "true" Bjorken limit the formulae

$$2F_1^{\mathrm{p}}(x) = \frac{A(\lambda)}{6}(1-x)^4, \quad 2F_1^{\mathrm{n}}(x) = \frac{A(\lambda)}{9}(1-x)^4 \tag{3}$$

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hold for $x \simeq 1$. Here $A(\lambda)$ is a given constant which depends on the model parameter $0 \leqslant \lambda \leqslant 1$ measuring the admixture of the sea configurations to the valence configuration. When $\lambda \to 0$, the nucleon $\to$ the valence configuration and the region of validity of formulae (3) is being extended to the whole range $0 \leqslant x \leqslant 1$. The values of $A(\lambda)/6$ are for instance

λ	0	0.25	0.5	0.75	1
$A(\lambda)/6$	5	4.02	3.36	2.88	2.53

(4)

if we estimate the configuration probability by a simple formula (cf. (10) later on).

Details of the model can be described as follows:

(*i*) Assume that the valence configuration in the nucleon consists of three usual fractional-charge quarks and three neutral gluons (= "coquarks") which all share statistically the nucleon longitudinal momentum (in the infinite momentum frame). Then the one-parton correlation functions are the same for all six partons and equal to

$$f_N(x) = (N-1)! \int_0^1 \ldots \int_0^1 dx_1 \ldots dx_N \delta\Big(\sum_{\beta=1}^{N} x_\beta - 1\Big)\delta(x_\alpha - x) = (N-1)(1-x)^{N-2}, \tag{5}$$

where in this case $N = 6$. Hence, the quark and gluon distributions in the valence configuration in the nucleon are

$$u^{(0)}(x) = 2f_6(x), \quad d^{(0)}(x) = f_6(x), \quad g^{(0)}(x) = 3f_6(x) \tag{6}$$

and, therefore, we get

$$F_2^{p(0)}(x) = 2xF_1^{p(0)}(x) = xf_6(x) = 5x(1-x)^4,$$

$$F_2^{n(0)}(x) = 2xF_1^{n(0)}(x) = \tfrac{2}{3}\, xf_6(x) = \tfrac{10}{3}\, x(1-x)^4. \tag{7}$$

So, we obtain formulae (3) with $A(\lambda)/6 = 5$. They are valid in the whole range $0 \leqslant x \leqslant 1$.

(*ii*) Assume further that also in the sea configurations quarks plus antiquarks and gluons appear in equal numbers and share statistically the nucleon longitudinal momentum. Then for each N-parton configuration in the nucleon formula (5) holds, where

$$N = 6 + 4n \quad (n = 0, 1, 2, \ldots). \tag{8}$$

Hence, the quark plus antiquark and gluon distribution in the nucleon are

$$u(x) = \sum_N P_N \left(2 + \frac{2n}{3}\right) f_N(x), \quad d(x) = \sum_N P_N \left(1 + \frac{2n}{3}\right) f_N(x),$$

$$s(x) = \sum_N P_N \frac{2n}{3} f_N(x), \quad g(x) = \sum_N P_N (3 + 2n) f_N(x), \tag{9}$$

where we take the sea as an SU(3) scalar consisting of $u\bar{u}$, $d\bar{d}$ and $s\bar{s}$ pairs. Here P_N denotes the probability of there being in the nucleon an N-parton configuration.

(*iii*) Assume eventually, just for a rough estimate, that the probability P_N is equal to (cf. [4])

$$P_N = \frac{A(\lambda)}{N(N-1)} \begin{cases} 1 \text{ for } N = 6 \\ \lambda \text{ for } N > 6 \end{cases} \quad (N = 6+4n), \tag{10}$$

where $0 \leqslant \lambda \leqslant 1$ is a free parameter. In this case from the normalization condition $\sum_N P_N = 1$ we get

$$\frac{1}{A(\lambda)} = \frac{1-\lambda}{30} + \frac{\lambda}{4}\left(\ln 2 + \frac{\pi}{2} - 2\right). \tag{11}$$

Then the series can be summed to give

$$u(x) = 2V(x) + \tfrac{2}{3}S(x), \quad d(x) = V(x) + \tfrac{2}{3}S(x), \tag{12}$$

$$s(x) = \tfrac{2}{3}S(x), \quad g(x) = 3V(x) + 2S(x),$$

where

$$V(x) = A(\lambda)\left\{\frac{1-\lambda}{6}(1-x)^4 + \frac{\lambda}{4}\left[\frac{\ln\dfrac{1+(1-x)^2}{1-(1-x)^2}}{(1-x)^2} - 2\right]\right\},$$

$$S(x) = \frac{A(\lambda)\lambda}{4}\left\{\frac{(1-x)^4}{1-(1-x)^4} - \frac{3}{2}\left[\frac{\ln\dfrac{1+(1-x)^2}{1-(1-x)^2}}{(1-x)^2} - 2\right]\right\}. \tag{13}$$

The proton and neutron structure functions can be expressed via (13) as follows:

$$F_2^p(x) = 2xF_1^p(x) = xV(x) + \tfrac{4}{9}xS(x),$$

$$F_2^n(x) = 2xF_1^n(x) = \tfrac{2}{3}xV(x) + \tfrac{4}{9}xS(x). \tag{14}$$

For $x \simeq 1$ we obtain from (13) and (14) formulae (3) with $A(\lambda)$ given by (11). The values (4) follow just from formula (11) which must be considered here as a rough estimate of the coefficient $A(\lambda)$ in equations (3). The agreement of our model results (3) with the experimental fit (1) (extrapolated to the "true" Bjorken limit) seems to be significant. Notice that the Drell-Yan-West relation applied to (3) gives for the nucleon elastic form-factor the asymptotic behaviour $1/Q^5$ which is certainly not worse, from the experimental point of view [1], than the usually accepted $1/Q^4$ (which is correlated rather with $(1-x)^3$). For $x \simeq 0$ we get from (13) and (14) the asymptotic formulae

$$F_2^p(x) \simeq F_2^n(x) \simeq \tfrac{4}{9}xS(x) \simeq \frac{A(\lambda)\lambda}{36} \tag{15}$$

which relate asymptotic behaviours of the structure functions and the sea distribution.

The detailed comparison of the model with global electron and neutrino data (from SLAC and CERN, respectively) was presented elsewhere [3], showing up very good consistency. Now, it seems that the local electron data for large x become also consistent with this model.

Finally, let us notice that, if (in analogy to the nucleon) the pion consists of a quark and an antiquark and two gluons, its structure functions behave for $x \simeq 1$ as $(1-x)^2$ (cf. (5)). Similarly, the structure function of the possible cluster (inside the nucleon) consisting of a quark and a gluon would behave for $x \simeq 1$ as $(1-x)^0 = 1$ (cf. (5)). Applying in the latter case the Drell-Yan-West relation one gets for the elastic form-factor of this cluster the asymptotic behaviour $1/\sqrt{Q^2}$ [5] which in the model of hard cluster-cluster collisions leads to the correct dependence $1/Q^8 \sim 1/p_\perp^8$ for the inclusive reaction $pp \to \pi X$.

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