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MULTIQUARK STATES IN DEEP-INELASTIC MUON-NUCLEUS SCATTERING

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1. Investigation of the deep-inelastic muon-nucleus scattering at a large value of the Bjorken scale variable $x>1$ (where $x=Q^2/2M\nu$; $t=-Q^2$ is a four-momentum transfer, $\nu=E_\mu-E_{\mu'}$ is the energy transfer, and M is the nucleon mass) permits us to clarify the principal question of modern high energy physics on the existence of multiquark states and to determine their quark-parton structure function. Up to now all attempts to find multiquark states in nuclei concerned the cumulative particle production at a large momentum transfer. However, the interpretation of these reactions is ambiguous because of a great number of the competing mechanisms. This ambiguity is absent in the muon-nuclei reaction, and therefore the events with large $x(x>1.2)$ should be a consequence of the interaction of an incident muon with the multiquark system of a nucleus. Since the mass of the multiquark system is several time as large as the nucleon mass: $M_f(k)\approx kM$ (where $3k$ is the number of quarks in the system), the corresponding Bjorken scale variable $x_k=x/k$. This means that in deep-inelastic muon-nucleus scattering x is charged in the region $0\le x<k$ (in principle, k may be equal to the atomic weight A). To establish the dynamics of the multiquark system, deep-inelastic muon-nuclei data are required over a large range of Q^2, nearly in the same interval where the nucleon structure function has been measured.

Below we present a theoretical prediction of a nucleus quark-parton structure function based on the idea of the existence of the multiquark (six-quark) configurations in nuclei and the modern understanding of the quark-parton structure of hadrons.

2. The cross section of deep-inelastic $\mu p\to\mu' X$ scattering in the small-angle limit ($\theta\ll 1$) takes the form:

$$\frac{d^2\sigma}{dQ^2\,dx}=\frac{4\pi\alpha^2}{Q^4}\cdot\frac{F(x,Q^2)}{x}, \qquad (1)$$

where $F(x,Q^2)\equiv F_2^p(x,Q^2)$ is the proton structure function, that can be found from the Lipatov-Altarelli-Parisi evolution equations [3]. To solve the equations, it is necessary to define the initial condition - $F(x,Q_0^2)$ at some reference point $Q^2=Q_0^2$. For a large value of the scaling variable x ($x>0.3$) $F_2(x,Q_0^2)$ can be written as:

$$F_2^p(x,Q_0^2)=\frac{4}{9}xu(x,Q_0^2)+\frac{1}{9}xd(x,Q_0^2).$$

$$F_2^n(x, Q_0^2) = \frac{1}{9}\, xu(x, Q_0^2) + \frac{4}{9}\, xd(x, Q_0^2) \qquad (2)$$

and the distributions for u- and d-quarks are parametrized, for example, as follows:

$$f_i(x, Q_0^2) = c_i\, x^{\alpha_i}(1-x)^{\gamma_i}\ ; \quad i = u, d;\ f_u = xu,\ f_d = xd. \qquad (3)$$

The parameters c_i, α_i, γ_i are found from comparison with experimental data at the reference point $Q^2 = Q_0^2$. The main qualitative features of the Q^2-dependence of the nucleon structure function can be found by an approximate analytical solution of the evolution equations [4], which becomes exact in the limit $x \to 1$:

$$f_i(x, Q^2) = f_i(x, Q_0^2) \cdot \delta(x, Q^2), \qquad (4)$$

$$\delta(x, Q^2) = (r/r_0)^{0.11}\,[(1-x)/(1+\gamma_i)]^P, \qquad (5)$$

where

$$r_0 = \ln(Q_0^2/\Lambda^2), \quad r = \ln(Q^2/\Lambda^2), \quad P = 0.64\ln(r/r_0),$$

γ_i is the parameter in eq. (3), Λ is the scale parameter of QCD. Note that relation (4) agrees with the numerical solution of the evolution equations within an accuracy of more than 10% for $x > 0.3$ [5]. So, it can be used not only for qualitative but also for quantitative estimations.

3. Passing to the events with $1 \le x < 2$, we suppose that in this kinematic range the incident muon is deep-inelastic scattered by the two-nucleon 6-quark system of mass $M_f \simeq 2M$. The structure function of the 6-quark system depends on the scale variable $x' = Q^2/2M_f\nu = x/2$. Assuming the quark distributions for u- and d-quarks in the 6-quark system to be the same $u_f(x, Q^2) = d_f(x, Q^2)$ we can write the expression for the cross section of deep inelastic μA scattering:

$$\frac{1}{A} \cdot \frac{d^2\sigma}{dQ^2 dx} = \frac{4\pi\alpha^2}{Q^4} \cdot \frac{F_2^A(x, Q^2)}{x}, \qquad (6)$$

$$F_2^A(x, Q^2) = \frac{5}{18}\left(1 - \frac{2(A-1)}{A} P_2\right)\left(xu(x, Q^2) + xd(x, Q^2)\right) + \frac{5}{18} \cdot \frac{2(A-1)}{A} P_2 \cdot \left[\frac{x}{2} u_f\left(\frac{x}{2}, Q^2\right)\right], \qquad (7)$$

where P_2 is the probability of the 6-quark admixture in the NN-pair of 2-nucleons (deuteron) and A is the atomic weight of the target nucleus.

The first term of eq. (7) is the structure function of the nucleons and gives the main contribution in the region of $0 \le x < 1$. The second term of eq. (7) is the structure function of a 6-quark system in nuclei. It contributes in the range of scaling variables: $x < 2$. Eq. (7) does not take into account the Fermi motion of nucleons in the nucleus which contributes to the cross section about 10-15% for $x = 0.8$-0.9 and practically disappears for $x \ge 1.15$.

Theoretical estimation of the probability of the 6-quark admixture predicts a P_2 value in an interval of $(2-7)\cdot 10^{-2}$ [6,7]. The same values come from the data on nuclear reactions at large momentum transfers [2,8]. We choose the quark distribution in the form:

$$xu_f(x, Q_0^2) = c_f\, x^{\alpha_f}(1-x)^{\gamma_f}. \qquad (8)$$

The parameters in (8) cannot be found now from the comparison with experimental data because they are absent there. So, they should be determined from some general considerations. For this aim we use the quark counting rules [9], which connect the exponent γ with the number of valence quarks n:

$$\gamma = 2n - 3. \qquad (9)$$

The preasymptotic effect leads to a certain decrease of γ. So, if one takes the proton structure function from the analysis of experimental data for $Q^2 = 3$-9 $(\mathrm{GeV}/c)^2$, then $\gamma_{eff} \simeq 2.3 \div 2.5$, i.e., $\gamma_{eff} = \delta \cdot \gamma$, where $\delta \simeq 0.8$. The experimental data for the electron-deuteron elastic scattering show that the asymptotic behaviour for the six-quark system sets up later than that for the proton [11], namely, the preasymptotic behaviour of the proton form factor at $Q^2 = 3 \div 9$ $(\mathrm{GeV}/c)^2$ corresponds to the same behaviour of the six-quark form factor at $Q^2 = 25 \div 30$ $(\mathrm{GeV}/c)^2$. So, we choose $\gamma_f = 7$ at $Q^2 = Q_0^2 = 27.5$ $(\mathrm{GeV}/c)^2$.

The scaling violation effect is expressed by formulas (4) and (5). Let us point out here that due to increasing γ in eq. (5) this effect is a little bit greater for the six-quark system than for the nucleon. But we should mentioned also that the dependence of the six-quark structure function on $x/2$ (not on x) brings about a sensitive decreasing of the Q^2-dependence of the nuclear structure function at $x \sim 1$.

4. In our calculations the parameters in eq. (3) and (8) were chosen as follows:

$$\alpha_u = \alpha_d = \alpha_f = 0.5;\ c_u = 2.1,\ c_d = 1.44;\ \gamma_u = 3,\ \gamma_d = 4;\ \Lambda^2 = 0.1\,(\mathrm{GeV}/c)^2.$$

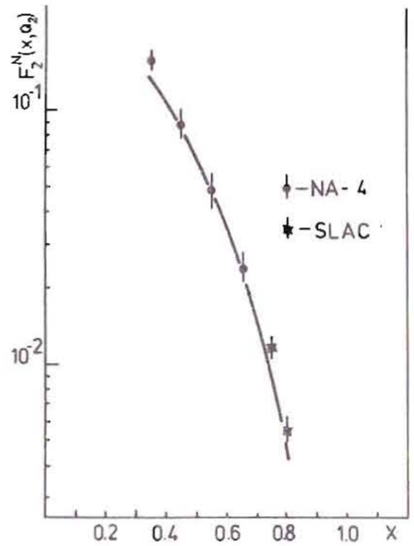

Fig.1. The nucleon structure function (Q_0^2= 27.5 (GeV/c)^2). The data (✱)[13] were continued to the reference point Q_0^2.

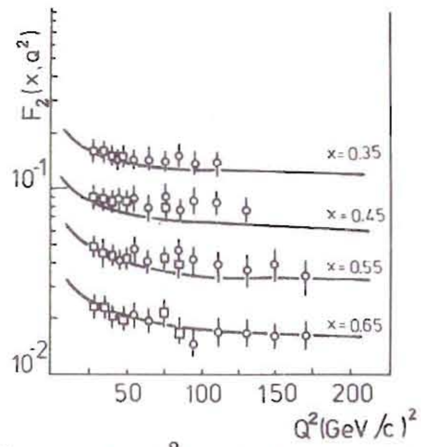

Fig.2. The Q^2-dependence of the nucleon structure function.

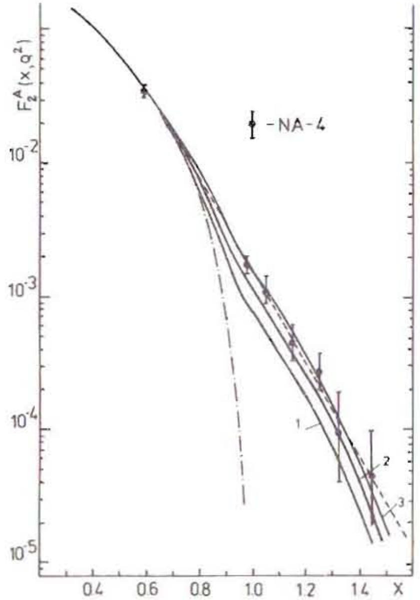

Fig.3. The ^{12}C-structure function at Q^2= 30 (GeV/c)^2. The lines correspond to: 1 - P_2= 0.05, 2 - P_2=0.07, 3 - P_2=0.10, dash-dotted - P_2=0. The dashed line is the experimental data fit taken from paper [13].

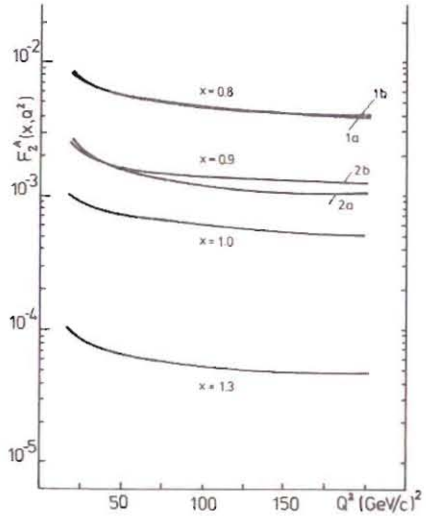

Fig.4. The Q^2-dependence of the ^{12}C-structure function. The lines correspond to: 1a,2a - P_2=0; 1b,2b,3,4 - P_2=0.07.

The parameter c_f was fixed by the condition: $\langle x\rangle^p_{u+d} = \langle x\rangle^f_{u+d}$ which means that the momenta of the u- and d-quarks in the nucleon and in the six-quark system are equal.

Figures 1,2 show the result of calculation and comparison with the experiment [12] of the nucleon structure function: $F_2^N = \frac{1}{2}(F_2^p + F_2^n)$. Figure 3 shows calculations of the nucleons structure function. Different curves correspond to different value of P_2 taken as parameters. The dashed line is the experimental data fit taken from paper [14]. The dash-dotted line is the nucleon contribution (P_2= 0). This figure shows the qualitative agreement between theoretical calculations and experimental data. The contribution of the six-quark configuration to the region of $x > 1$ is rather large and can be investigated experimentally.

Figure 4 shows the Q^2-dependence of nuclear structure functions. Curves 1a and 2a were calculated with P_2=0 (without the 6-quark admixture). Curves 1b, 2b, 3,4 were calculated with P_2 = 0.07. The curves 1a,b and 2a,b were normalized at point $Q^2 = Q_0^2$. The figure shows that the Q^2-dependence becomes stronger at $x \sim 1$ without 6-quark admixture. This means that the determination of the scale parameter of QCD from the muon-nucleus data at $x \sim 1$ without a six-quark-state admixture gives rise to a smaller value of Λ.

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Титов А.И. E2-83-72

Многокварковые состояния
в глубоконеупругом рассеянии мюонов ядрами

Дан теоретический анализ глубоконеупругого рассеяния мюонов ядрами в области, кинематически запрещенной для рассеяния на свободных нуклонах. Расчеты проведены в предположении, что основной вклад в сечение при значениях бьеркеновской масштабной переменной $1 \leq x < 2$ дает глубоконеупругое рассеяние мюонов шестикварковыми конфигурациями в ядрах. Показано, что примесь шестикварковой компоненты в ядре $/2\text{-}7/ \cdot 10^{-2}$ приводит к значению ядерной структурной функции $10^{-4} - 10^{-5}$ при $x \approx 1{,}4$. Показана важность учета шестикварковых состояний при извлечении масштабного параметра квантовой хромодинамики из мюон-ядерных данных при $x \sim 1$.

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Titov A.I. E2-83-72

Multiquark States in Deep-Inelastic
Muon-Nucleus Scattering

Deep-inelastic muon-nucleus scattering in the region of the Bjorken-scaling variable $x > 1$ is analysed. It is shown that the main contribution to the nuclear structure function in that region comes from scattering of muons by six-quark configurations inside the nuclei. The six-quark state probability of an order of 2-7 per cent gives the value for the nuclear structure function about $10^{-4} - 10^{-5}$ at $x \approx 1.4$, i.e., can be studied experimentally. The role of the six-quark states is revealed in the determination of the scale parameter of QCD from the muon-nucleus data at $x \sim 1$.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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