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NUCLEAR STRUCTURE FUNCTIONS IN THE BOUNDARY REGION OF THE SINGLE-PARTICLE KINEMATICS

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A theoretical analysis of nuclear structure functions in the region $x \sim 1$ is given. It is shown that the contributions of pure nucleons and multiquark components of the nuclear wave function in this region are comparable and the binding effects and Q^2-evolution lead to softening of the nuclear quark distributions. Numerical predictions for the carbon structure function in the cumulative region were made.

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

Ядерные структурные функции в граничной области однонуклонной кинематики

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Дан теоретический анализ ядерных структурных функций в области $x \sim 1$. Показано, что вклады в структурную функцию чисто нуклонных и многокварковых компонент ядерной волновой функции в этой области сравнимы, а эффекты связанности нуклонов и Q^2-эволюции подводят к смягчению кварковых распределений в ядре. Выполнены предсказательные расчеты для структурной функции углерода в кумулятивной области.

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1. Recently, it has become commonly accepted that the EMC-data [1] in a medium range of x are explained by the nuclear binding effects, as prescribed by the standard nuclear shell model and its excitations [2]. The traditional Fermi motion of the on-shell nucleons (with a more hard impulse distribution) leads to another, qualitatively different, behaviour of the theoretical ratio F_{2A}/F_{2N} compared with the experiment. Clearly, the same situation should arise also in the boundary region $x \sim 1$, where pure nucleon components tend to zero, and the contribution of the Fermi motion and multiquark configurations are comparable. The detailed investigations of the role of multiquark configurations (high impulse components) in the cumulative hA-reactions with a relatively small momentum transfer ($Q^2 \lesssim 10 \lesssim \lesssim \text{GeV}^2/c^2$) are given in [3]. In the deep-inelastic μA-scattering the

momentum transfer is essentially greater ($Q^2 \sim 100\text{-}300\ \mathrm{GeV}^2/c^2$) and the multiquark distribution behaviour in the region $x \sim 1$ may differ. A qualitative analysis of Q^2-dependence of the nuclear structure functions for $x > 1$ without taking the Fermi motion into account was given in ref.[4]. As far as in the boundary region $x \sim 1$ the Fermi motion effects are essential, the investigation of the total contribution of the multiquark components of the nuclear wave function and of the Fermi motion of the binding nucleons is of interest for getting quantitative evaluations. Also, this problem is actual because of the increase in the scaling violation in the structure function of free nucleons for $x > 1$.

2. The nuclear structure function $F_{2A}(x, Q^2)$ at fixed Q^2 may be written in terms of the binding nucleons and six-quark components as:

$$F_{2A}(x) = (1-P_6) \int dy\, d^4k\, F_{2N}\left(\frac{x}{y}\right) S(k)\, \delta\left(y - \frac{kq}{pq}\right) + P_6 * F_2^{6q}\left(\frac{x}{2}\right), \qquad (1)$$

where, $x = -q^2/2pq$, $-q^2 = Q^2$, $S(k)$ is the nucleon spectral function, including all the binding effects, F_2^{6q} is the six-quark structure function (in the region $0.8 \leq x \leq 1.2$ the main contribution comes from six-quark configurations), P_6 is the corresponding probability.

In the standard nuclear shell model the spectral function $S(k)$ is just a single particle impulse distribution. However, to explain the EMC-effect it is necessary to take into account in the spectral function more complicated collective nuclear excitations, as is shown in ref.[2]. For this purpose it is convenient to use the spectral function $S(k)$ from the Antonov, — Nikolaev — Petkov model[8] which describes the main characteristics of a nucleus, energy and impulse distributions. In this case the impulse distribution coincides with the theoretical values obtained by other authors[8] in their microscopical calculations.

The nucleon structure function $F_{2N}(x, Q^2)$ in (1) should be determined from the conditions of good description of the lepton scattering data on hydrogen and deuteron at the fixed Q^2-value. Unfortunately, the BCDMS-collaboration data in the region $Q^2 \sim 100\text{-}300\ \mathrm{GeV}^2/c^2$ alone are insufficient for a reliable parametrisation of the true nucleon structure function. Therefore, we use the parametrisation which satisfactorily describes the data of both the EMC and CDHS-collaborations[8] at $Q^2 \sim 15\text{-}25\ \mathrm{GeV}^2/c^2$. Note that the parameters of the F_2^{6q}-structure function are determined also at enough small Q^2. In this way, we can compute the nuclear structure function $F_{2A}(x, Q_0^2)$, where $Q_0^2 \sim 15\ \mathrm{GeV}^2/c^2$. For the comparison with the BCDMS-data ($Q^2 \sim 100\text{-}300\ \mathrm{GeV}^2/c^2$) we need to solve the Lipatov —

Antarelli — Parisi equations [9] with the initial conditions, determined by (1) at $Q_0^2 \sim 15$ GeV$^2/c^2$. However, due to the choice of the initial conditions, there are uncertainties. First, the comparison of the EMC and BCDMS-collaboration nuclear data shows that there is a small systematic discrepancy between the results, which seems to exist also for the nucleon data and must necessarily influence the corresponding solutions of differential equations. Second, the multiquark distribution parameters in $F_2^{6q}(x)$, such as the six-quark configuration probability, the impulse distribution slopes and others are determined from the hadron-nucleus reactions. These uncertainties are due to the inclusion of second nuclear effects, for instance, rescattering of hadrons in the initial and final states, nuclear absorption, etc.

3. We solve the Lipatov — Altarelli — Parisi equations in the leading order approximation with the QCD scale parameter $\Lambda \sim (0.21-0.23)$ GeV$^2/c^2$. The nucleon and six-quark structure functions at point Q^2 are taken from ref. [5]:

$$F_{2N}(x, Q_0) = 5/18\sqrt{x}(1-x)^3\,(2{,}25 + 1{,}55(1-x)),$$
$$F_2^{6q}(x, Q_0) = 5/18\ \sqrt{x}(1-x)^7 + 2/3 * 0.23(1-x)^{11}. \qquad (2)$$

The results of Q^2-evolution of the carbon structure function for different values of x including both the corrections of the binding nucleons and six-quark admixtures are shown in fig.1. The shaded

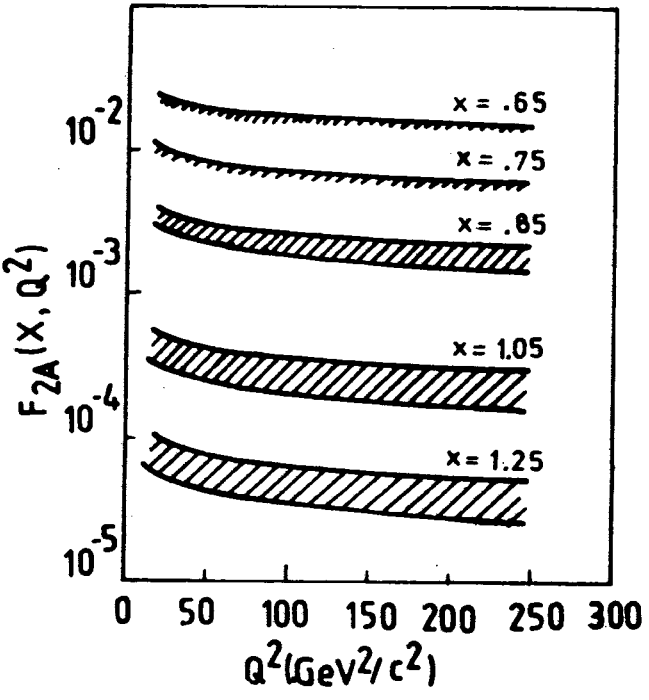

Fig.1. Q^2-evolution of the carbon structure function including both the corrections of the binding nucleons and six-quark admixtures at various x. About the shaded region see the text.

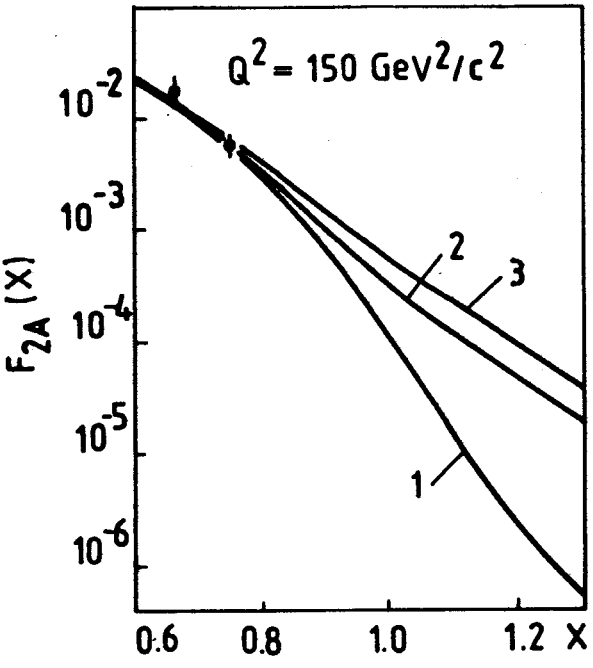

Fig.2. Various contributions to the carbon structure function at $Q^2 = 150\ GeV^2/c^2$ versus x. Curve 1 refers to results with only nucleonic contribution (including the binding effects). Curves 2,3 refer to the results, including 6q-admixtures with $P_6 = 5\%$ and $P_6 = 10\%$, respectively. The experimental points are from ref.[4].

region reflects the uncertainties in the initial conditions we have told above. We change the six-quark configuration probability P_6 in carbon in the limits from 5% up to 10%. The numerical results of the carbon structure function at $Q^2 = 150\ GeV^2/c^2$ in the boundary region of x are shown in fig.2. From both figures one can see that the Fermi motion of the binding nucleons satisfactorily explains the experimental data in the noncumulative region of x. The contribution of the six-quark component is comparable with the Fermi motion at single particle kinematical limit and becomes dominant when x further increases. As compared to the cumulative hA-reactions, the Q^2-evolution and inclusion of the off-mass nucleons lead to the softening of high impulse components in nuclei. This result is to be taken into account, when one compares different experimental data on structure functions from different processes — lepton-nucleus (high Q^2) or hadron-nucleus scattering (medium and low Q^2).

We should like to note one more circumstance. We have solved the evolution equations in the leading order. In the last time one computes the high-twist corrections. It turns out that the contributions from the higher twists are inverse proportional to Q^2 and increase with x. In our case these corrections are not essential. Indeed, in the boundary region of $x \approx 0.9$—1.2 the main contributions come from six-quark components (see fig.2) and for them a scale variable x is twice smaller than the nucleon one, i.e. $x_{eff} \sim 0.45$—0.60 and at these x higher twists are small irrespective of Q^2.

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