Multiquark configurations in nuclei

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(Submitted 4 June 1984; resubmitted 13 September 1984)
Pis'ma Zh. Eksp. Teor. Fiz. **40**, No. 8, 359–362 (25 October 1984)

A scattering by colorless multiquark formations in nuclei can explain the observation that the ratio of the structure functions of different nuclei is not unity. In the model proposed here a nucleus may contain a superfast quark, which could carry the entire momentum of the nucleus in the extreme case.

Recent studies have led to the conclusion that models of nuclei as systems of quasi-independent, nonrelativistic nucleons are incomplete and that both a relativistic description of the motion of the nucleons themselves and an examination of the quark degrees of freedom in nuclei are necessary. Of foremost interest here are the prediction[1] and discovery[2] of a cumulative production of particles in hadron-nucleus and nucleus-nucleus collisions and of a power-law decay of the elastic form factors of light nuclei at large momentum transfers,[3] in agreement with the predictions of the quark counting rules.[4] The significant differences in the behavior of the quark distribution functions of nuclei with different atomic numbers and the nontrivial A dependence of

 0021-3640/84/201165-05$01.00

the cross sections of the cumulative processes demonstrate the different manifestations of the quark degrees of freedom in these nuclei.[5] This conclusion is also suggested by the results of recent experiments on deep inelastic lepton-nucleus scattering (the EMC effect[6]; see also some of the theoretical attempts to explain this effect[7]). These results are apparently general in nature[8] and stem from the possibility that multiquark configurations (multiquark bags) will form in nuclei.

Let us examine the deep inelastic scattering of charged leptons by a nucleus A. We assume that in addition to the nucleons in the nucleus, there is a certain probability for the formation of quark bags with six, nine, etc., quarks[9,10] and there is a certain probability for leptons to interact with the quarks of any of these bags. The structure function of the nucleus can then be written

$$F_2(x) = \sum_{k=1}^{A} N(A,K) F_2^K(x), \tag{1}$$

where F_2^K is the structure function of a nucleus A containing a $3K$-quark bag and A–K nucleons. The coefficients $N(A,K)$ are the effective numbers of $3K$-quark bags in nucleus A and can be parametrized as a Bernoulli distribution,

$$N(A,K) = \frac{A!}{K!(A-K)!} p(A)^{K-1}[1-p(A)]^{A-K}. \tag{2}$$

We assume that the parameter $p(A)$ is determined by the ratio of the volume of the quark bag to the volume of the nucleus[11]: $p(A) = r_K^3/(R_0 A^{1/3})^3 \approx 0.187 A^{-1}$. Here we have set the bag radius r_K approximately equal to the radius of a nucleon, $r_K \approx 0.8$ fm, and $R_0 \approx 1.4$ fm.

A calculation of the structure functions F_2^K in the deep inelastic limit for quark distribution functions $f^K(x)$, defined in accordance with

$$F_2^K(x) = \langle e_q^2 \rangle x f^K(x) \tag{3}$$

($\langle e_q^2 \rangle$ is the expectation value of the square of the charge of the quarks), leads to the expression[12]

$$f^K(x) = \frac{3K}{A} I_K(x_A) / \int_0^1 dx_A I_K(x_A); \quad K = 1, 2, \ldots, \quad A-1, \tag{4}$$
$$f^A(x) = 3(3A-1)(1-x_A)^{3A-2},$$

where

$$I_K(x_A) = \int_{x_A}^1 dZ_K \frac{(1-Z_K)^{A-K-1}}{1 + \frac{\beta_K}{\alpha_A}(1-Z_K)} \left(1 - \frac{x_A}{Z_K}\right)^{3K-2}$$

The variable $x_A = Q^2/2M_A \nu$ changes the interval $0 < x_A < 1$ and is related to the Bjorken variable x by $x_A = x/A$. Obviously, $0 < x < A$.

The distribution functions $f^K(x)$ are consistent with the possible existence in the nucleus of a superfast quark, which in the extreme case carry the entire momentum of nucleus A. In a more detailed paper we will report the results of calculations of the structure functions of multiquark formations with allowance for the quantum-chromodynamic corrections to the quark counting rules.

The parameters α_A and β_K determine the momentum distributions of the nucleons in the nucleus and of the quarks in the bag, respectively, in the case of the following parametrization of the relativistic wave functions[13] of the nucleus, ϕ_A, and of the quark bag, ϕ_{3K}:

$$\phi_A([x_i;\ \mathbf{p}_{i,\perp}]) \sim \exp\left\{-\alpha_A \sum_{i=1}^{A} [(\mathbf{p}_{i,\perp}^2 + M_i^2)/x_i]\right\},$$

$$\phi_{3K}([z_j;\ \mathbf{k}_{j,\perp}]) \sim \exp\left\{-\beta_K \sum_{j=1}^{3K} [(\mathbf{k}_{j,\perp}^2 + m_j^2)/z_j]\right\}.$$

These distributions can be related to the radii of the nucleus and of the $3K$-quark bag. It can be seen from (4) that the structure functions depend on the parameter ratio

$$\beta_K/\alpha_A = (A/3K)(r_K^2/R_A^2) = (r_K^2/3R_0^2)(A^{1/3}/K).$$

Figure 1 shows experimental data[14] on the ratio of cross sections σ_A/σ_D for the deep inelastic scattering of several nuclei, along with theoretical curves for the ratio $R = F_2(A)/F_2(D)$, which correspond to calculations from Eqs. (1)–(4) [each of the functions $F_2(A)$ is divided by the corresponding atomic weight]. A more careful comparison of these quantities would generally require allowance for the contribution of the struc-

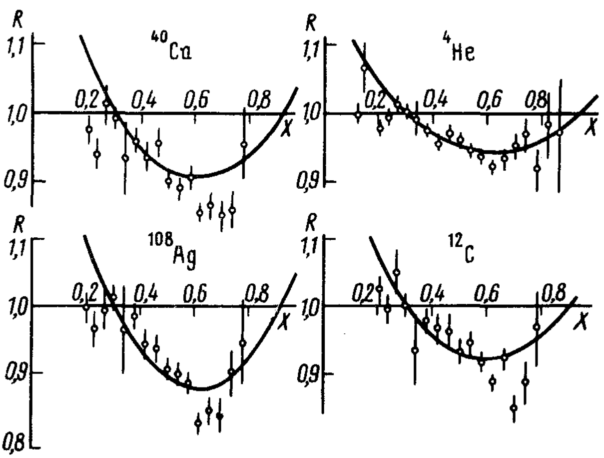

FIG. 1. Ratios of the structure functions of the nuclei ^{4}He, ^{12}C, ^{40}Ca, and ^{108}Ag to the structure function of the deuteron. The experimental data are from Ref. 14.

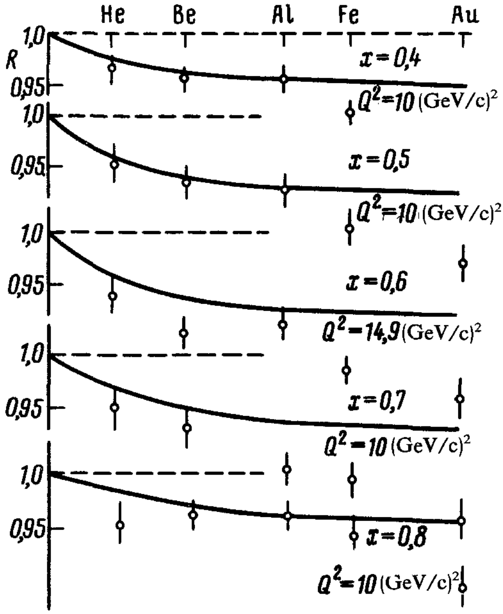

FIG. 2. The A dependence of the ratio $R = F_2(A)/F_2(D)$ for various values of x.

ture function F_1 to the cross section. Figure 2 shows the A dependences of these ratios for various values of x.

It is interesting to note the analogy mentioned in Ref. 8 between the x behavior of the ratio of the cross sections for the production of cumulative pions at various nuclei and the ratio of the structure functions for the deep inelastic scattering by the same nuclei. By using data on the cumulative production, we can study the region $x > 1$, which is presently inaccessible to deep inelastic scattering experiments. We calculated the ratios $F_2(\mathrm{Fe})/F_2(\mathrm{D})$, $F_2(\mathrm{Fe})/F_2(\mathrm{He})$, and $F_2(\mathrm{Fe})/F_2(\mathrm{Al})$ over the entire range of the kinematic variable x $(0 < x < A)$. The curves in Fig. 3 show the results of these calcula-

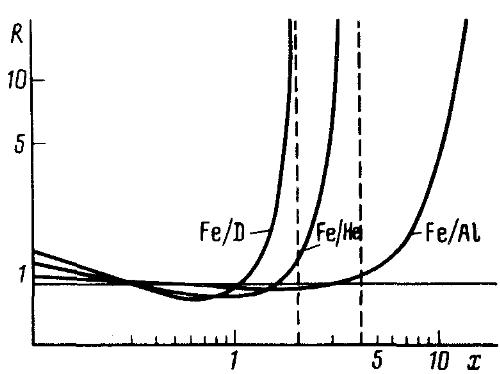

FIG. 3. Ratios of the structure functions of various nuclei over the entire range of the variable x $(0 < x < A)$.

tions in full logarithmic scale. At $x > 1$ the predictions of the various models differ in nature.

We are deeply indebted to A. M. Baldin and A. N. Tavkhelidze for their stimulating interest in these topics and for useful discussions. We also thank P. N. Bogolyubov, S. B. Gerasimov, T. I. Kopaleĭshvili, V. A. Matveev, L. A. Slepchenko, and F. G. Tkebuchava for interest in this study and for some extremely useful discussions.

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Translated by Dave Parsons
Edited by S. J. Amoretty