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THE ROLE OF INSTANTONS IN QUANTUM CHROMODYNAMICS II HADRONIC STRUCTURE

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HADRONIC STRUCTURE

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Abstract

The typical instanton dimension $\rho_c \simeq 0.3$ fermi, discussed in the first part of this work [1], shows up in hadronic structure in the form of "constituent quark" substructure of ordinary hadrons, having about the same dimensions. The role of this parameter in the method of QCD sum rules is also discussed, in particular summation of the power OPE corrections as well as the calculation of "exponential" ones is made. The latter effects is shown to dominate in examples of pion and scalar gluonium, for which reasonable values of parameters are shown to follow from relevant sum rules.

1. Introduction

This is the second part of our work devoted to discussion of the instanton-induced effects in QCD. In the first one [1] we have shown that some empirical facts concerning the physical QCD vacuum can be explained in the simple model in which it is considered as some 4-dimensional "liquid", which is dilute enough so that it is meaningful to say that it is made of separate instantons. The central point of this consideration was that such instantons have dimensions essentially smaller than assumed by some previous works: the so called critical radius is about $\rho_c \simeq 1/600$ Mev. This quantity provides new scale of effects in QCD, rather different from the confinement length $R_{conf} \simeq 1/200$ Mev, at which the coupling becomes really strong.

In the present paper these ideas are applied to hadronic structure. In this case the empirical facts also suggest the existence of the second scale in form of certain substructure inside the ordinary hadrons, with the dimensions of the order of ρ_c. These facts are collected in the section 2 in brief form, and they definitely indicate the existence of some quasiparticles called "constituent quarks" or "valons" as the very important ingredient of the hadronic structure. In section 3 we summurize the present status of the theoretical ideas about hadronic structure. The popular MIT bag model [12] was qualitatively connected [13, 14] with the suppression of vacuum fluctuations inside hadrons, resulting in the bag constant or the "vacuum pressure". Although physically sound, this interpretation is in conflict with the fact [14] that the empirical bag constant is much smaller than the total vacuum energy density.

We also do not see the place for the first order transition found in [13] , see [1] . Also the new value for ρ_c suggests much smaller "cavity" as a result of the instanton suppression by quarks.

All these difficultes are naturally resolved in the following picture of the hadronic structure. The two components of the physical vacuum, the fluctuations with scales ρ_c and R_{conf}, are both suppressed by quarks. As a result, two types of "cavities" are formed with related dimensions and energy scales, identified with valons and hadrons respectively.

This discussion, although interesting by its potential applications, is made at qualitative level only and no more specific models are attempted in the present work. Instead, we come to such much more strict theoretical method as the so called QCD sum rules suggested and successfully applied by Shifman, Vainshtein and Zakharov [2] (and references therein). This method is especially important because it bridges the gap between the hadronic and vacuum structure in most direct and transparent way.

Let us remind also its applications to heavy quarkoniums [2,3], vector and axial currents made of ordinary light quarks [2] , ordinary baryons [4] (see also [5]), mesons [5,6] and baryons [5] with one heavy quark etc., which all have produced very reasonable results on the basis of the account of several first terms of the operator product expansion (OPE) for the correlators of relevant currents.

At the same time, in * channels with zero spin(both for currents made of quark and gluon fields) such calculations have produced wrong results, see [18] . This shows that better control over higher corrections as well as of exponential ones, not given by perturbative OPE at all, is needed in order to understand why this happens.

Based on the model of vacuum structure considered in [1] we have attempted in some cases to sum up the OPE series as well as to estimate the magnitude of the exponential terms. After the introductory section 4, we come to the discussion of the B-type mesons made of one very heavy ($m_Q \to \infty$) and one very light ($m_q \to 0$) quarks in section 5. From the methodical point of view it is the most simple problem with nontrivial dynamics, in some sense the "hydrogen atom" of the world of hadrons. We have calculated the sum of the OPE series in the one instanton approximation and have shown that with this result our knowledge of the current correlator have increased to essentially larger interval. Roughly speaking, we came from the scale ρ_c to R_{conf}, where the approximation used becomes inapplicable because of many-instanton effects.

The section 6 is devoted to ordinary hadrons, by which we mean those made of light u,d,s quarks with the exception of spin-zero particles. In this case the summation in the one-instanton approximation can also be done, as well as the estimates for the exponential term. However, the conclusion here is that they are small due to some theoretical reasons and therefore the success of the original analysis [2,4,5] is explained. We also find some arguments in favor of valons, which help to understand why such calculations, ignoring strong coupling and confinement problems, can still predict accurate masses of ordinary hadrons.

The next two sections are connected with two exceptional cases mentioned above: that of the pion and scalar gluonium.

Their particular physical nature has been discussed in multiple theoretical papers, and the main empirical and theoretical observations known so far are discussed in recent paper by Novikov et al [18]. Just to remind several main facts we mention that the pion, the lightest hadron, is in fact surprisingly heavy, connected with some parameter of the order of 2 Gev (30). The η' meson is very heavy by itself, which is known as U(1) problem raised by Weinberg, presumably due to mixing with still heavier gluoniums. In the latter case the low energy theorems [18] and other considerations point toward the conclusion that the asymptotical freedom is settled in gluonic channels at Q^2 as large as 10-15 Gev^2. Nothing of the kind is present in the domain of ordinary hadrons.

The explanation of these effects, suggested in [18], is connected with the instanton-induced "exponential" effects, which are enhanced in these cases by some large factors. Their origin is nontrivial. For gluonic currents the "classical" parameter $1/\alpha_s(\rho)$ was suggested in [18], which implies that the fluctuations considered are sufficiently short-range. For pion case (as compared to, say, ρ- meson one) the parameter is $(M_{eff}(\rho_c)\rho_c)^{-2} \simeq 10$, which in turn can be traced to $(R_{conf}/\rho_c)^2$.

Estimating these effects quantitatively with our parameters of the vacuum structure we have found reasonable physical predictions for the pionic coupling to pseudoscalar current (or, in other terms, $m_u + m_d$), the mass and the coupling of the scalar gluonium.

The work is summarized and some open questions are briefly mentioned in section 9.

2. Hadronic structure: empirical facts

The understanding of hadronic structure has begun with the phenomenological $SU(3)_{flavour}$ symmetry leading to widely known statement: "hadrons are made of quarks". Further development of nonrelativistic (and semirelativistic) models of hadronic structure has shown that they explain qualitatively the spectrum of hadrons and some their characteristics like magnetic moments. Moreover, some results are in quantitative agreement with experiment and presumably these models reflect the reality of strong interactions.

At the same time it is not clear how these models can be justified in the QCD framework. In its Lagrangian one finds nearly massless quarks and massless gluons and it is misterious how the valence quarks can be separated as meaningful objects from the common cloud of gluonic and quark fields. Still we know from experiment that it happens somehow and the quasiparticle with quantum numbers of valence quarks exist, while the excitation of the "cloud" (in form of exotic hadrons) are absent.

In order to distiguish quarks as objects of field theory and such quasiparticle the latter are called "constituent" quarks and the former "current" quarks. In order to make this terminology shorter we use new name, recently proposed for constituent quark - "valon", and use the word "quark" only in its usual field theory meaning.

The differences between quark and valons are many. The former are nearly massless (we mean u,d,s quarks here) and pointlike, while valons have mass of the order of 300 Mev and nonzero dimentions, which we briefly discuss now.

It was noted in [7] that valons are approximately additive in total hadronic cross sections, in particular this can explain the ratio of NN and πN cross sections $\sigma(NN)/\sigma(\pi N)\simeq 3/2$. If so, the valon-valon cross section is only about 1/9 σ_{NN}, as for black disk with radius 0.3 fermi. Last years these ideas of additive valons were used for collisions with heavy nuclei in the works [8] (see also review [9]) and they seem to explain existing data well .

Another source of information is connected with various hard processes like Drell-Yan pairs, large p_t hadrons etc. In order to explain their distribution over the transverse momentum the so called "intrinsic" transverse momentum of partons was introduced. It happens that it is rather large, of the order of 1 Gev, and not of the order of 1/R where R are hadronic dimensions of the order of 1 fermi. The assumption that partons are in fact confined in some smaller objects can explain the observed large intrinsic transverse momentum.

Last but not least point is the scaling violation in deep-inelastic lepton-hadron scattering. In contrast with those mentioned above here one can use powerful theoretical methods and do not rely on model-dependent considerations. Recently the method of operator expansion was applied to Q^{-2} corrections [10,11], which are expressed in terms of certain well defined operators averaged over the nucleon state. The four-fermion operators seem to be dominant and in principle their average values can be extracted directly from data. The present experimental data are rather uncertain, but still it is seen that estimates ignoring valons [10,11] lead to effect with the wrong sign and magnitude. The account for valons [10] may im-

prove the situation. This field of research is now rapidly developing and it is probable that soon enough we would know more about the properties of valons.

All these considerations lead to conclusion that valon is several times smaller than hadron itself. If so, the approximate additivity of valons in hadronic structure and interactions is understood. Still the question on the physical nature of valons remains open.

3. QCD and hadronic structure: the qualitative picture

At present most of the applications of QCD are connected with hard processes, and in the field of hadronic spectroscopy one uses now only some QCD-inspired models. However there exist indirect ways of estimation of hadronic properties, in particular the so called QCD sum rules to be discussed below. Still we would like to start with brief discussion of the qualitative picture of hadronic structure as we understand it now.

One of the most popular QCD-inspired models is the so called MIT bag model [12] , which includes the effect of confinement in very simple way. It is assumed in this model that in volume occupied by coloured objects some additional positive energy density B_{bag} is present. In other terms, the bag is under constant "vacuum pressure" B_{bag} , balanced by the pressure of constituents from the inside region. Due to its attractive simplicity, this model has been used for many calculations, sometimes phenomenologically successful.

The physical explanation of the origin of B_{bag} was suggested in the works [13,14], where it was connected with some suppression of vacuum fluctuations inside hadrons.

Note first, that physical vacuum has lower energy than the perturbative (or "empty") vacuum. This statement is evident for instantons, because tunneling between classical vacua surely makes the energy lower. More strict argument is based on the relation [15] , connecting the trace of the stress tensor with the gluon condensate

$$\varepsilon_{vac} = \frac{1}{4} T_{\mu\mu} = -\frac{11 N_c - 2 N_f}{3 \cdot 2^7 \pi^2} \langle 0 | (g G^a_{\mu\nu})^2 | 0 \rangle \simeq$$

$$\simeq -4 \cdot 10^{-3}\, GeV^4 \simeq -0.5 Gev/fm^3 \qquad (1)$$

If so, suppression of such fluctuation leads to positive (as compared to physical vacuum) energy density.

In the case of complete suppression one evidently has the following prediction for the bag constant:

$$B_{Bag} = | \varepsilon_{vac} | \qquad (2)$$

Such picture has been suggested by Callan, Dashen and Gross [13] on the basis of their studies of instantons in external field. We have already noted in [1] that in our picture there is no place for first order transition found in this work, for the vacuum permeability is not so large.

Here we note another difficulty of such model, noted already in the author work [14] : the relation (2) is badly violated and in reality one has

$$B_{Bag} \lesssim \frac{1}{10} | \varepsilon_{vac} | \qquad (3)$$

which was interpreted as partial or very inhomogeneous suppression of vacuum fluctuations. This fact shows that although the whole physical picture is sound, something important is missing.

The bag model has also another important defect, stressed by Callan, Dashen and Gross [13]. It is the explicit violation of chiral symmetry on the bag boundary. It is very simple to see this: the massless quark reflected by scalar mirror changes its chirality. The proposal of CDG [13] to cure this defect was the consideration of pions outside the bag in such a way that the axial current becomes conserved at the boundary of the bag. Such model was also considered in paper [16] , where it was shown that in such case pions create so large "pressure" on the bag that it compresses into the "little bag", the proposed name for this model. We consider this phenomenon as one more inconsistency of the bag model.

In this work we propose new picture of the hadronic structure, which is based on the same physical ideas but provides also the explanation of these difficulties. Its central point is that both types of vacuum fluctuations are suppressed by quarks. We mean here short-range instanton-type fluctuations with radius $\rho_c \simeq 1/600$ Mev and long-range collective ones with typical scale of the instanton separation R≈1/200 Mev.

As a result, two types of "cavites" in vacuum are formed, identified with valons and hadrons, respectively.

The correspondence of their dimensions is streightforward:

$$\rho_c \simeq R_{valon} \qquad R \simeq R_{hadron} \qquad (4)$$

and it is in agreement with phenomenology.

The energy densities in these "cavities" are different too. see Fig.1. Only inside valons it is strongly affected, so since they occupy only small fraction of the volume of hadrons the small number in (3) becomes natural. It also shows, that the energy associated with long-range fluctuations is comparably small. In such picture pions are coupled not to hadronic surface, but mainly to valons, representing new version of the "little bag", in some sense.

The relative weakness of the confinement forces compared to that inside valons also explains why "strings" slowly break by two-valon production, resulting in relatively nerrow resonances with large spin.

Of course, this attractive picture should be supported by more strict analysis. Some of its aspects are discussed below in the framework of QCD sum rules. The suppression of instantons by quarks in the quark gas will be discussed in the third paper of this series.

Let us also emphasize one important difference between our point of view and that of Callan, Dashen and Gross. It was very important for them, that their "dilute phase" inside hadrons is close to "empty" vacuum. Even the title of their work shows that they hoped to separate the problems of hadronic and vacuum structure.

On the contrary, we stress that it is essentially the same problem. The properties of hadrons and valons are just the reflection of the parameters, intrinsic to physical vacuum. So, the applications of the macroscopic language common to the bag model (say, "vacuum pressure") can be only qualitative, at best.

The most clear demonstration of the close relation between these two problems is provided by the method of QCD sum rules, to which we now proceed.

4. QCD sum rules: the introduction

This method was suggested and applied to several important hadronic channels by Shifman, Vainshtein and Zakharov, see [2] and references therein. It is based on two main ideas.

(i) The short distance behaviour of the two-current correlator

$$K(q) = i\int \langle 0|T(j(x)\, j(0))|0\rangle e^{iqx}\, dx \qquad (5)$$

can be calculated by OPE, including the vacuum averages of the nontrivial operators.

(ii) Standard dispersion relations can be used to connect the results with properties of physical states with relevent quantum numbers.

Although both ingredients have been known previously, only these authors were able to show that their combination is very practical method, connecting vacuum and hadronic structure.

The QCD sum rules were first applied to charmonium [2] where the gluon condensate was first introduced. The sum rules including its effect turn out to be very successful from the phenomenological point of veiw, see also later works [3]. Then the vector and axial currents made of light quarks were discussed [2], and this time the quark condensate entered.

These studies were then generalized to baryons [4] (see also [5]). The studies of mesons [5,6] and baryons [5] containing one heavy quark Q=c,b... were also done recently. In all these cases very reasonable results are obtained, and other applications of the method are now in progress.

Sometimes the author come across the sceptical opinion that QCD have produced no quantitative predictions so far. In order to argue against it, let us give here a couple of examples provided by works mentioned above.

The ρ-meson coupling to photon was found in [2] to be

$$\frac{g_\rho^2}{4\pi} \simeq \frac{2\pi}{e} \simeq 2.3 \qquad (\text{exp. } 2.36 \pm 0.18) \qquad (6)$$

and the ratio of the isobar mass to that of nucleon is [5]

$$\frac{m_\Delta}{m_N} \simeq 5^{1/6} = 1.31\ldots \qquad (\text{exp. } 1.31) \qquad (7)$$

Of course, both expressions are approximate, but it is important that corrections can be calculated in the systematic way.

However, some important questions of this method remain open so far. Let us formulate them in parralel with two main points mentioned above:

(i) Only first several terms of power OPE series are calculated so far. Better understanding is needed of further terms and of the behaviour of their sum. There also exist effects not included into power OPE series, the exponential corrections, which also may be important. Such progress is possible if better understanding of vacuum structure is reached.

(ii) Even with the known correlator it is nontrivial to understand what information about hadronic states is present in it. For example, one should be able to say at what distances the correlator should be known in order to determine the mass of the lowest state. For this we evidently need better understanding of the hadronic structure.

The importance of these questions is seen from the fact, that the sum rules including first power corrections, highly successful in cases mentioned above, are wrong in other cases, for the so called exceptional currents. The first example of such kind was the pseudoscalar current made of light quarks [2] in which the properties of the pion can not be understood on the same level as in the axial current case. In further works by Novikov, Shifman, Vainshtein and Zakharov [17] devoted to gluonic channels other examples are given, and their present understanding is summarized in recent work "Are all hadrons alike ?" [18]. It is suggested in this work that for spin-zero currents some larger corrections to correlators exist, presumably connected with instantons and not given by the ordinary OPE series.

In the present paper we make an attempt to put these consideration on more quantitative level, but using some model for the vacuum structure suggested in [1], which was shown to reproduce the average value of several operators known so far. So, in this model at least first power corrections are garanteed. Two types of calculations are made below, aiming to increase the knowledge of the current correlators. The first is the summation of the OPE series by the calculation of some time-dependent correlator of fields in section 5. The second, connected with the problem of the exceptional currents mentioned above, are connected with "exponential" corrections of the instanton nature. The word "exponential" is conditional and correspond to the one-instanton level of the calculation. What comes out after the averaging over the instantons (or in other, more general approach) is difficult to say and the more strict way to indentify such effects is to observe that they are absent in the perturbative calculation of the OPE coefficients.

In contrast with [18], we emphasize not the difference between hadrons and currents used, but the similarity of the physical nature of all corrections, power and "exponential" ones. Although they really produce rather different mass scales, they all are connected with size-ρ_c instantons.

5. Hadrons containing heavy quark

Our discussion of the QCD sum rules do not follow the historical order, and we start with mesons of the type $\bar{Q}q$, where Q represent heavy (c,b,...) and q light (u,d,s) quarks. Some states of this type are known as D,F,B... mesons, but the experimental information is still rather limited here. However, the theoretical analysis of this case can be done in more simple in transparent way than in other cases.

The reason is that one can put the large mass m_Q to be arbitrary large, and small mass m_q completely negligible. So, the heavy quark becomes just a static center, making the problem similar to that of hydrogen atom. Still it is highly nontrivial one, for the light quark interacts not only with the static field of the center but also with fluctuations in the physical vacuum. Nevetheless, it is much simpler than the case of ordinary mesons.

We do not start with heavy quarkonia $\bar{Q}Q$, although make some remarks on them at the end of this section. In the limit of very large m_Q this problem becomes trivial and it reduces to that of positronium. First corrections are known now [2,3]. It is however likely that further corrections are needed for charmonium, and this is an interesting open question.

The consideration of QCD sum rules starts with the choice of the relevant current. In the limit $m_Q \to \infty$ the pseudoscalar and vector mesons are degenerate [5], also the corresponding sum rules are identical. The pseudoscalar current is simpler

$$j = i \bar{Q} \gamma_5 q \qquad (8)$$

Because infinitely heavy quark does not propagate, the correlator should be taken in the same space point, but at different time moments

$$K(t) = \langle 0 | T (j(t) j(0)) | 0 \rangle \qquad (9)$$

The Fourier transform $K(\omega)$ obeys ordinary dispersion relations:

$$Re\, K(\omega) = \frac{1}{\pi} \int \frac{Im\, K(\omega')}{\omega - \omega'} d\omega' \qquad (10)$$

The spectral density $Im\, K(\omega)$ contains the information on physical states with corresponding quantum numbers. The most interesting state is the lowest one, the B-type meson.

It was suggested in [2] that in order to increase sensivity to lowest states it is convenient to perform the Borel improvement of the sum rules. The corresponding operation is defined as follows

$$f(\tau) \equiv \hat{B} f(\omega) = \lim_{\left\{\begin{array}{l}\omega, n \to \infty \\ \tau = n/\omega = const\end{array}\right\}} \frac{\omega^n}{(n-1)!} \left(-\frac{d}{d\omega}\right)^n f(\omega) \qquad (11)$$

In particular, one has

$$\hat{B} \frac{1}{\omega + \omega'} = \tau \exp(-\omega' \tau) \qquad (12)$$

and so the power weight is changed to exponentional one, which converges much better.

In the nonrelativistic case considered the Borel transform is just the original correlator (9) taken at imaginary (Euclidean) time $\tau = it$ multiplied by τ:

$$\hat{B} K(\omega) = \tau K(\tau) = \frac{\tau}{\pi} \int d\omega\, Im\, K(\omega) \exp(-\tau\omega) \qquad (13)$$

Now, we want to calculate this correlator directly. At small enough time t the asimptotic freedom tells us that quarks propagate freely. It means that $K(\tau)$ can be found from (13) where the simple perturbative spectral density

$$Im\, K^{pert}(\omega) = \frac{3}{2\pi} \omega^2 \qquad (14)$$

is substituted, corresponding to direct production of the $\bar{Q}q$ pair by the current. Of course, the same result is given by the direct calculation of the loop diagram shown at Fig.2a.

The next step is the calculation of the nonperturbative corrections, caused by vacuum fluctuations. In order to select the main effect the following observation of SVZ [2] is useful: loop diagram are always connected with small geometrical factors like $1/16\pi^2$ and therefore largest corrections are connected with Born diagrams without loops. It means in our case that light quarks should be absorbed by physical vacuum, see the diagram Fig.2b. If the OPE is postponed, the whole series of relevant corrections is included in the following quantity

$$\varphi(\tau) = \langle 0 | \bar{\Psi}(\tau, 0)\, P\exp\left(i\int_0^{\tau} \hat{A}_0\, dt\right) \Psi(0,0) | 0 \rangle \qquad (15)$$

where the integral is taken over the straight line in Euclidean time. Evidently, it is gauge invariant quantity, and the exponent can be droped in $A_0^a = 0$ gauge.

The OPE series calculated in the work [5] is the expansion of $\varphi(\tau)$ in powers of τ, and it looks as follows:

$$\varphi(\tau) = \langle \bar{\Psi}\Psi \rangle - \frac{\tau^2}{32} \langle \bar{\Psi} (ig\,\sigma_{\mu\nu} G^a_{\mu\nu} t^a) \Psi \rangle - \frac{\tau^3 g^2}{1152} \langle (\bar{\Psi}\gamma_\mu t^a \Psi)^2 \rangle + \ldots \qquad (16)$$

Other power corrections are strongly suppressed and the sum rule can be written as

$$K^{pert}(\tau) - \frac{\tau}{2}\varphi(\tau) \simeq \frac{\tau}{\pi}\int_0^{\infty} \mathrm{Im}\, K(\omega)\, e^{-\tau\omega}\, d\omega \qquad (17)$$

Using the estimates of vacuum averages and the spectral density in the form

$$\mathrm{Im}\, K(\omega) = \frac{\pi}{2} f_B^2 M_Q\, \delta(\omega - E_z) + \theta(\omega - E_c)\, \mathrm{Im}\, K^{pert}(\omega) \qquad (18)$$

the parameters f_B, E_z, E_c were fitted for $\tau < 1/400$ Mev with the result

$$E_z = 0.4 \pm 0.1 \text{ Gev}, \quad E_c = 0.9 \pm 0.1 \text{ Gev}, \quad f_B = 0.25\, \frac{\text{Gev}^{3/2}}{\sqrt{M_B}} \qquad (19)$$

These parameters are very reasonable. The mass value for B meson is then $m_b + E_z \simeq 5200$ Mev, known to be right. The value of the decay constant f_B can in principle be measured, but it is rather difficult in practice. However, most of works including potential models [19], corrected MIT bag [20] etc. give very close results. The larger value found in sum rule analysis [6] is probably due to improper consideration of the continuum contribution (the second term in (18)). The value of E_c is closely related with f_B by the duality relation. So, one may conclude that the real values are not far from those given in (19), so the true correlator is approximately known.

If so, one may invert the arguments and try to compare various approximations with this "true" behaviour. At Fig.3 the curve corresponding to (18, 19) is given, as well as the curves marked 0,1,2 corresponding to loop diagram, first and two first terms in OPE, respectively. The parameters of vacuum average values are those found in [1] and they somehow deviate from those used in [5]. It is seen, that the region where these corrections makes the agreement better exists but is rather limited.

It is tempting to try direct estimates of the quantity $\varphi(\tau)$ without expansion in power series. For instanton zero modes the corresponding estimate looks as follows

$$\varphi(\tau) \equiv \langle \bar\psi\psi \rangle \cdot f(\tau/\rho_c)$$

$$f(x) = \frac{8}{\pi} \int \frac{\cos\left(\int_0^x A_0^{(instanton)} dt\right)}{[(1+z^2+t^2)(1+z^2+(t+x)^2)]^{3/2}} z^2 dz\, dt \qquad (20)$$

The corresponding curve is also shown at Fig.3. It is seen that the sum of these corrections look much smaller than one may guess on the basis of first few terms. Moreover, the agreement is reasonable up to τ of the order of 1 fermi=5 Gev^{-1}, while the original fit based on first terms was made for $\tau \lesssim 0.5$ fm.

The interesting phenomenon is the turn in the correlator at $\tau \simeq 0.9$ fm and then decrease with smaller slope. In terms of physical spectrum it is caused by the gap between the first resonance and "continuum" contribution. Another interpretation directly in terms of the correlator is as follows: this turn means that one came from one instanton to the neighbouring one. The corresponding value of τ is just the same as instanton separation $3\rho_c$, see [1]. Evidently, that in this point the calculations based on the account of one instanton becomes inapplicable, as it is also seen at Fig.3. The estimates for correlator at τ larger than 1 fm need the serious knowlege of vacuum structure at such scale, not available so far. Still it is interesting to see that the correlation increases when one comes to next instanton, as it should be.

Summarizing this discussion one may say, that power OPE serie converge very inhomogeneously. Our estimates of their sum with one-instanton approximation produce not so large effect but increase the knowledge of the correlator up to $\tau \lesssim 1$ fm. Two scales of vacuum ρ_c, R_{conf} are reflected in different E_0, E_c.

Now, some remarks concerning heavy quarkoniums are in order. It is known [3] that already Υ family is strongly connected with perturbative Coulomb effects, which are not interesting for us now. Therefore, we should consider only charmonium case, very well studied experimentally. Note here, that for vector currents not only levels and their properties, but continuum is measured as well. So, the empirical basis for similar analysis exists.

Theoretical progress may be reached on two different levels. The first one is the calculation of further OPE terms after the now famous correction due to gluon condensate [2]. We remind in this connection that the average values for further operators as given by our model of the vacuum are rather large [1]

$$\langle g^3 f^{abc} G^a_{\alpha\beta} G^b_{\beta\gamma} G^c_{\gamma\alpha} \rangle \simeq 0.4 \text{ Gev}^6 \qquad (21)$$

$$\langle (g G^a_{\mu\nu})^4 \rangle \simeq 1.8 \text{ Gev}^8$$

However, the corresponding OPE coefficients are so far unknown.

The second, more ambitious approach is the calculation of the loop diagram in the instanton field, which sum up the whole series of corrections in our picture of the vacuum.

When the present work was completed we were informed by Yu.Pinelis that the problem of heavy quarkonium in the instanton field is studied by him now.

6. Ordinary hadrons

By ordinary hadrons we mean those consisting of light u,d,s quarks. More definitely, we consider QCD sum rules related with the correlators of vector currents, relevant to ρ, ω, φ mesons, and also mention the baryonic currents, connected with Δ, N .

Our aim is similar to that of the preceeding section, namely the understanding of higher power corrections and also the exponential ones, not given by OPE. Our main tool, as before, is the one-instanton approximation. We also discuss some indications in favor of real existence of valons as important ingredients of ordinary hadrons.

Let us start with the vector current with ρ-meson quantum numbers

$$j^{(\rho)}_\mu = \frac{1}{2}(\bar u \gamma_\mu u - \bar d \gamma_\mu d) \qquad (22)$$

Its correlator was calculated in the classical paper [2] with the following power corrections $(Q^2 = -q^2)$

$$i\int dx\, e^{iqx} \langle 0|T\{j^{(\rho)}_\mu(x)\, j^{(\rho)}_\nu(0)\}|0\rangle = (q_\mu q_\nu - q^2 g_{\mu\nu})\Pi^{(\rho)}(q^2) \qquad (23)$$

$$\Pi^{(\rho)}(Q^2) = -\frac{1}{8\pi^2}\left(1+\frac{\alpha_s}{\pi}+\dots\right)\ln\frac{Q^2}{\mu^2} + \frac{\langle m\bar\psi\psi\rangle}{Q^4} + \frac{\langle (gG^a_{\mu\nu})^2\rangle}{96\pi^2 Q^4} - \frac{\pi\alpha_s}{Q^6}\cdot$$
$$\cdot\left[(\bar u\gamma_\mu\gamma_5 t^a u - \bar d\gamma_\mu\gamma_5 t^a d)^2/2 - (\bar u\gamma_\mu t^a u + \bar d\gamma_\mu t^a d)\Big(\sum_{u,d,s}\bar q\gamma_\mu t^a q\Big)/9\right] + \dots$$

The phenomenological success of related sum rules was great: both the mass and the coupling (6) of the ρ-meson were found correctly.

The subject of our discussion is further corrections. Note

here, that this current is unique because direct experimental measurements of the correlator exist for

$$\mathrm{Im}\,\Pi^{(\rho)}(Q^2) = \frac{\sigma(e^+e^- \to \text{hadrons}, I=1)}{12\pi\,\sigma(e^+e^- \to \mu^+\mu^-)} \qquad (24)$$

and, unlike the example of the preceeding section, all predictions can be checked directly.

The calculations of the correlator for vector currents in the instanton field were performed in the works [21] . Some errors were present in them and the true result was first found in [22], which looks as follows

$$\Pi^{(\rho)}(Q^2) = -\frac{1}{8\pi^2}\ln(Q^2/\mu^2) + \qquad (25)$$
$$+ \sum_{(\text{inst}+\text{antiinst})}\int dn(\rho)\left[\frac{2}{3Q^4} - \frac{2\rho^2}{Q^2}\int_0^1 dx\, K_2\!\left(\frac{2Q\rho}{\sqrt{1-x^2}}\right)\right] + \dots$$

Making the averaging over the instantons with the account of relations

$$\langle 0|(gG^a_{\mu\nu})^2|0\rangle = 32\pi^2 \sum_{(\text{inst}+\text{anti})}\int dn(\rho) \qquad (26)$$
$$\langle 0|m\bar\psi\psi|0\rangle = -\sum\int dn(\rho)$$

one can see that Q^{-4} corrections in (23) and (25) are identical. But were are other power correctons?

The answer to this question was given in the paper by Dubovikov and Smilga [22] : further power terms contain only operators which vanish in the selfdual (or antiselfdual) fields. Some examples, in which the explicit calculations are done are discussed in the work [23] .

The discussion above reveals the following defect of such naive calculations in the instanton field: effects proportional to effective (M_{eff}) and mechanical (m) masses are mixed, in particular those due to $(gG^a_{\mu\nu})^2$ and $(m\bar{\psi}\psi)$. So, before the applications are attempted one should first separate them, e.g. by going to very small distances where only m can contribute. Separating in this calculation the contributions of distances of the order of 1/Q and ρ , one can then obtain instead of (25) the power term like

$$\frac{1}{Q^4}\sum_{inst+anti}\int dn(\rho)\left(\frac{1}{3}-\frac{m}{M_{eff}}\right) \qquad (27)$$

Evidently, in real vacuum the second term is small.

This consideration suggests the extension of the Dubovikov-Smilga theorem: further power terms are absent for effects proportional to M_{eff} and m <u>separately</u>, not in sum. For example, due to this the coefficients of the operators $(m\bar{\psi}g\sigma_{\mu\nu}G^a_{\mu\nu}t^a\psi)$ and $(f^{abc}G^a_{\alpha\beta}G^b_{\beta\gamma}G^c_{\gamma\alpha})$ in the OPE should be zero separately.*)

This absence of further power corrections in the instanton field has real, not academic significance if our picture for the vacuum is accepted. It suggests that they are of the order of $(1/QR_{conf})^n$ rather than $(1/Q\rho_c)^n$ for $n > 4$.

The next is the exponential term in (25), containing the strong cut-off over large ρ . Can one calculate it without assumptions concerning the "instanton liquid"? Unfortunately (see [18]), it can be done only for too large Q to be used in applications.

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*) For the first operator it was checked by the direct calculation in [2] . The prove of this statement contained in [22] is wrong, for there two operator contributions are erroneously identified with two (gauge dependent!) diagrams.

As a result, <u>the exponential term should be considered at the same level as power ones</u>, namely one has to use some picture for the vacuum, e.g. that suggested in this work. In this and two next section we attempt such calculation, and the results are very reasonable.

The resulting contribution of this term into $\Pi^{(S)}(Q)$ is then

$$\Pi^{(exp)}(Q^2) = +\frac{4}{\pi^2}\frac{(\pi^2 n_c \rho_c^4)}{(Q\rho_c)^2}\int_0^1 dx\, K_2\left(\frac{2Q\rho_c}{\sqrt{1-x^2}}\right) \qquad (28)$$

where $n_c = 8\cdot 10^{-4}\,Gev^4$ and ρ_c =1/600 Mev, see [1] .

Note the small packing fraction $f = \pi^2 n_c \rho_c^4 \simeq 1/20$ entering this relation: it is just the probability to happen so that our currents are inside the instanton. We see that at $Q^2 \simeq m_\rho^2$ this term is small relative to the first one in (25), so it also can not affect the original SVZ analysis [2] .

Now we come to the four-fermion operator in (23), not considered so far. Of course, the Dubovikov-Smilga theorem has nothing to do with it for it is of next order in α_s and, in some sense, it is the radiational correction. However, it is enhanced because, unlike the leading loop diagram, it does not contain small geometrical factor about $1/16\pi^2$. Evidently further corrections (say 6-quark ones) do not posess further enhancement factors and are therefore small.

There exists the series of power corrections to this four-fermion operator, containing some powers of the gauge field. Encouraged by the example considered in the preceeding section we think that this series can approximately be summed up by the one-instanton approximation and that the result is not very different from the leading term at $Q \sim \rho_c^{-1}$ and is decreasing at larger Q . Since even the leading term is only about 20% at $Q^2 \simeq m_g^2$, these corrections also can hardly effect the sum rules as analysed in [2].

Summarising this discussion we may say, that Dubovikov-Smilga theorem plus the vacuum made of instantons ensure the smallness of corrections connected with gluonic operators. The diluteness of the instanton liquid also cause the smallness of the exponential corrections. As a result, the enhanced radiative correction of four-fermion type becomes the dominant correction. All this seems to explain the success of the analysis made in [2] .

Let us make also some remarks concerning the baryonic currents. Here the Dubovikov-Smilga theorem can also be applied and we have only corrections of the types

$$1 + C_1/Q^4 + C_2/Q^6 + O(\exp(Q)) \qquad (29)$$

in the selfdual (or antiselfdual) field, but no other power terms.

Again, these corrections are not important because the four-fermion corrections are enhanced now by the square of the geometrical factors $16\pi^2$, for now two loops are absent. It is evident that this phenomenon becomes more prominant if some case with larger number of the constituents is discussed.

It is instructive to understand the physical meaning of this fact: the main effect is not the interaction between quarks, but of quarks directly with vacuum. Moreover, as suggested in [2] (and discussed in [1] for our model for vacuum) the average values of relevant multi-fermion operators are approximately factorized into the product of quark condensates. It means that such <u>interaction with vacuum is approximately independent</u>.

These observation we consider as some evidence in favor of valon picture of ordinary hadrons, which suggests that they are made of approximately additive (=weakly interacting) valons, being the result of the independent interaction of the quarks with physical vacuum. Of course, the interaction of valons is crucial for construction of hadrons as bound states (the confinement effects), but it can be of little importance as far as the calculation of hadronic masses are concerned.

This consideration provides a key to another question, in fact the most striking one for anybody who works with the sum rule method. It can be understood that some correlators can be calculated for distances $\lesssim 0.3$ fermi, where the coupling constant is still reasonably small and problems connected with confinement physics can be avoided. But the fact that rather accurate values for hadronic masses can be obtained from this correlator looks completely misterious: we know that the dimensions of these particles are essentially larger, of the order of R_{conf}, and at such scale the coupling is strong.

We suggest the following answer: <u>the valons are formed already at such distances, and their mass is the main ingredient in that of ordinary hadrons</u>. Therefore, the success of the method is the direct consequence of existence of two scales in QCD.

7. The pion

In the classical paper [2] it was shown, that the although the account of first power corrections to the correlator of pseudoscalar currents give unreasonable results, the properties of the pion can also be studied in the correlator of axial current making use of the Goldstone nature of this particle.

In their later work [18] they have stressed that various empirical and theoretical observations exist, which show that the pseudoscalar channel is essentially different from the vector and axial ones, and larger mass scale is present here. So, we start with breif summary of these observations.

The pion is well known because it is the lightest hadron. Now we would like to argue, that in some sense it is surprisingly heavy.

In the chiral limit of exactly massless quark the pion is the massless Goldstone mode. So its mass is the effect of the nonzero quark masses, explicitely violating the chiral symmetry, and m_π^2 is proportional to m_q. Let us divide by this quantity in order to have some quantity being nonzero in the chiral limit. The result is

$$\frac{m_\pi^2}{m_u + m_d} \simeq 1.8 \text{ Gev} \qquad (30)$$

which is unusually large number. [24]

Recently the second resonance was discovered in the pion channel with the mass 1342±20 Mev, so the gap between these states is about 1.2 Gev, or also unusually large.

Another empirical fact, discussed in [25,18], is that in pseudoscalar channel η meson is nearly pure SU(3) octet, while

in vector and tensor channels the mixing between strange and nonstrange states is much smaller.

It was suggested that instantons are somehow connected with these facts. Indeed, definite chiral properties of the fermion zero modes make it possible to contribute directly in the pseudoscalar channel, but not vector or tensor one. However, this observation remained only qualitative and even the numerical parameter, relevant to this consideration, was not specified.

In paper [25] the consideration was made at one-instanton level, at which there is no chiral symmetry breaking and the relevant parameter was $m_q \rho$, where m_q is the quark mass. In [18] it was correctly argued that in the physical chirally asymmetric vacuum the quark mass is not important at all and some effective mass (see e.g. [1]) takes its place. So, on general grounds no small parameter separating "direct" and "indirect" instantons is seen.

It is very nontrivial ingredient of our picture of QCD vacuum that in it such parameter is in fact present:

$$M_{eff}(\rho_c) \cdot \rho_c \simeq 1/3 \qquad (31)$$

As explained in [1] , it reflects the fact that the effective mass and quark condensate appears due to collective interaction of instantons and antiinstantons, so it is connected with interinstanton separation rather than their dimensions ρ_c . This very parameter is relevant to the pion problem.

This statement becomes evident if one compares the contribution of the instantons into the correlator of currents

$$j^{(\pi)} = \frac{i}{2}(\bar{u}\gamma_5 u - \bar{d}\gamma_5 d) \qquad (32)$$

which is equal to

$$\Pi^{(exp)} = Q^2 \int \left(\frac{K_1(Q\rho)}{M_{eff}(\rho)\rho}\right)^2 \rho^4 dn(\rho) \qquad (33)$$

with the corresponding exponential term in the sum rules for vector mesons discussed above. Numerically, this contribution becomes nearly one order of magnitude larger and now it can not be neglected as compared to power terms. This explains why their account without direct instantons give unreasonable results.

As far as in our picture of "instanton liquid" all parameters are fixed, one may attempt to calculate the pion contribution from the sum rules. Writing the spectral density as

$$Im\,\Pi^{(\pi)}(s) = \frac{\pi}{2} f_\pi^2 \frac{m_\pi^4}{(m_u+m_d)^2}\delta(s-m_\pi^2) + \theta(s-S_0)\, Im\,\Pi^{(Pert)}(s) \qquad (34)$$

we have fitted the Borel-improved sum rules in the form

$$\frac{3}{16\pi^2}\int_0^{S_0} e^{-S/M^2} s\,ds + \frac{1}{2}\frac{\sqrt{\pi}\, n_c}{(M_{eff}(\rho_c)\rho_c)^2}(M\rho_c)^3 \exp(-M^2\rho_c^2) = \qquad (35)$$

$$= \frac{1}{2}\frac{f_\pi^2 m_\pi^4}{(m_u+m_d)^2}\exp(-m_\pi^2/M^2) \qquad (M\rho_c \gg 1)$$

for $M > 2$ Gev and have found the following values of the parameters

$$\left.\frac{f_\pi m_\pi^2}{(m_u+m_d)}\right|_{\mu=2Gev} = 0.27 \pm 0.03\ Gev^2 \qquad S_0 = 2.5 \pm 0.3\ Gev^2 \quad (36)$$

The pion mass was found to be much smaller than S_0, but of course there is no sufficient accuracy to determine it directly.

These results are reasonable from the phenomenological point of veiw. The first number implies $(m_u + m_d)_{\mu\simeq 2Gev} \simeq 9$ Mev, not so far from other estimates. As for the S_0 value, it is slightly higher than the position of the second resonance for $m_{\pi'}^2 \simeq 1.7$ Gev^2. Such situation is typical, as noted in [5] it happens also for other channels where the second resonance is known: Δ', N' and ρ'-meson.

Summarizing this section we may say, that instantons with the parameters suggested in [1] are sufficient to produce larger scale of masses in the pseudoscalar channel without any additional assumptions.

8. Scalar gluonium

The pion case is an example that more strong interaction with vacuum fluctuations leads to larger mass scale. Since the main fields in vacuum are the gluon ones, it is natural to look for similar effects in the gluonic channels. This problem was discussed in the works [17,26] for scalar gluoniums, where the OPE expansion for the correlator of the current

$$j^{(G)} = \alpha_s (G_{\mu\nu}^a)^2 \qquad (37)$$

was found to be

$$\Pi^{(6)}(Q) = -\frac{2Q^4}{\pi^2}\alpha_s^2 \ln\frac{Q^2}{\mu^2} + \frac{\alpha_s\langle (gG^a_{\mu\nu})^2\rangle}{\pi} + \tag{38}$$

$$+ \frac{\alpha_s}{\pi Q^2}\langle g^3 f^{abc} G^a_{\alpha\beta} G^b_{\beta\gamma} G^c_{\gamma\alpha}\rangle - \frac{\alpha_s}{2\pi Q^4}\langle (g^2 f^{abc} G^a_{\mu\nu} G^b_{\alpha\beta})^2\rangle +$$

$$+ \frac{7\alpha_s}{\pi Q^4}\langle (g^2 f^{abc} G^a_{\mu\alpha} G^b_{\alpha\nu})^2\rangle + \ldots$$

It is seen that no large scale larger than, say, 1 Gev can be present here.

The important point of the work [17] is that it can not be the true result, for it is in contradiction with the low energy theorem derived in this work

$$\Pi^{(6)}(0) = \frac{24}{11N_c - 2N_f}\langle 0|(gG^a_{\mu\nu})^2|0\rangle \tag{39}$$

With this information one may write down "improved" sum rules

$$\Pi^{(6)}(Q^2) = \Pi^{(6)}(0) - \frac{Q^2}{\pi}\int\frac{\mathrm{Im}\,\Pi^{(6)}(s)\,ds}{s(s+Q^2)} \tag{40}$$

and it becomes evident that $\Pi(0)$ is much larger than other power terms so that the (Borel transforemed) sum rules as given in [17] are

$$\frac{1}{\pi}\int \mathrm{Im}\,\Pi^{(6)}(s)\,e^{-s/M^2}\,ds/s = \frac{2M^4}{\pi^2}\alpha_s^2(M) + \Pi^{(6)}(0) + \frac{\alpha_s}{\pi}\langle (gG^a_{\mu\nu})^2\rangle + \ldots \tag{41}$$

This sum rule fitted literally gives ridiculous value for the mass of the lowest state, about 20 Mev. It is evident, that something important is missing.

Again, direct interaction with instantons are suggested in [18]. The parameter which makes their effect larger is in this case the "classical" parameter $1/\alpha_s^2(\rho_c)$. It is not a problem to calculate the relevant effect for one instanton, but, as emphasized in [18], one can not average over the instantons without additional assumptions.

Again, we may try to do this with our parameters of the "instanton liquid". Then the following contribution should be added to sum rule (41) $(M\rho_c \gg 1)$:

$$\Pi^{(exp)} = 32\pi^{3/2} n_c (M\rho_c)^5 \exp(-M^2\rho_c^2) \tag{42}$$

Note that the improved sume rule becomes similar to that for pion.

The standard fit with the spectral density

$$\mathrm{Im}\,\Pi(s) = \pi|\langle 0|\alpha_s G^2|\sigma\rangle|^2 \delta(s - m_\sigma^2) + \theta(s - s_0)\,\mathrm{Im}\,\Pi^{pert}(s) \tag{43}$$

was made with the results:

$$m_\sigma = 1.4 \pm 0.2 \text{ Gev}; \quad s_0 = 11.5 \pm 0.5 \text{ Gev}^2$$
$$\langle 0|\alpha_s G^2|\sigma\rangle \simeq 1.4 \pm 0.4 \text{ Gev}^3 \tag{44}$$

It is very gratifying to see that the mass of the scalar gluonium is reasonable. Moreover, it is close to that suggested by Shifman [26] on the bases of other considerations.

Experimentally, there exists the resonance $\varepsilon(1300)$ with corresponding quantum numbers, and it can be that it is the state revieled by our sum rules.

Note that in [17] it was suggested to check the coupling of the gluonium σ in the decay $\psi \to \gamma + \sigma$. If the c quark be infinitely heavy, such decay is the point-like sourse of gluons and the following relation holds

$$\frac{\Gamma(\psi \to \gamma + \sigma)}{\Gamma(\psi \to \gamma + \eta')} = \frac{9}{64} \left| \frac{\langle 0 | \alpha_s G^2 | \sigma \rangle}{\langle 0 | \alpha_s G\tilde{G} | \eta' \rangle} \right|^2 \tag{41}$$

which with our numbers imply $\Gamma(\psi \to \gamma + \sigma) \simeq 200 \div 400$ ev. However, the accuracy of such estimate is not clear.

We do not consider in this section multiple questions conserning mixing between scalar gluonic and quark states. We only comment that in pseudoscalar channels it has been shown in [18] that η' meson, considered usually as the quark state, is in fact very important in the correlator of gluonic currents as well and therefore can be named gluonium with equally good reasons. It may be that similar phenomena happen in the scalar channel. We hope to consider all such questions in separate publications.

Another comment is connected with the tensor gluonium. As shown in [18], there are no direct instantons in this case and its mass is connected with power OPE corrections. However, this channel is exceptional in other way [23]: the arising corrections vanish in the selfdual field. Therefore, in our picture of the vacuum we assume this channel to have essentially smaller mass scale. This can also be checked by the decays $\psi \to \gamma +$ hadrons in which hadrons are in 2^+ state.

9. Summary and discussion

The central conclusion of the present paper is that the new scale in QCD suggested in [1], the critical instanton radius $\rho_c \simeq 1/600$ Mev, is very important for hadronic structure as well. Multiple empirical observations together with some theoretical arguments discussed above point toward the existence of some substructure inside the ordinary hadrons with dimensions of the order of ρ_c in form of quasiparticle with quark quantum number called valon.

The qualitative arguments of works [13,14] that the quark suppress instantons have led to the picture of some "cavity" in physical vacuum, in which the nonperturbative fluctuations are somehow moderated and some positive energy is therefore connected with it. Now we argue that such cavity is more naturally identified with the valon and not with hadrons themselves, as suggested previously [13,14]. It is still possible that similar picture holds for hadrons as well, but connected not with instantons but with some more long-wave collective fluctuations, relevant to confinement.

We have also shown that some indications to valons can also be found in the framework of the QCD sum rule method, which suggests that the main effect for ordinary hadrons like ρ meson and baryons Δ, N is the direct and approximately independent interaction of constituents with the quark condensate. Moreover, the fact that this method works without account for strong coupling and confinement can be explained only if the existence of the second scale ρ_c in QCD is recognized, which is the dominant one for these sum rules and hadronic masses.

However, hadronic structure is more complicated than the simple model of additive valons. This was noticed in the application of "exceptional" currents with zero spin. In this case the asymptotic freedom is violated at essentially smaller distances due to direct interaction of such currents with instanton-type fluctuations in vacuum. The corresponding effect is not seen if one calculates the OPE coefficients perturbatively.

Roughly speaking it means, that the component of the hadronic wave function in which constituents are close enough is quite different for ordinary hadrons (say, ρ meson) and "exceptional" ones (say, π meson). In the former case the main interaction is with the quark condensate, being rather homogeneous in space, so in first approximation the interaction between valons is small even if they are at distances comparable to their dimensions. In the latter case the situation is different: the intersions. In the latter case the situation is different: the interaction with instanton is very strong and it is connected with rather large energy. As a result, such "flucton" configurations (occuring rather rarely in all hadrons because their dimension essentially exceeds that of the instantons) can still be very essential for determination of some parameters of such "exceptional" hadrons, including their masses. For example, the pion coupling to pseudoscalar current is in some sense large, while that to axial current is "normal", for it does not probe the relevant "flucton" configuration.

Interesting that for scalar and pseudoscalar gluoniums their masses are detrmined entirely by such "fluctons", but at the same time their masses are in some sense small compared to typical energies at which the asymptotic freedom breakes down. This observation supports their interpretation as "quark" states, mixed a little with gluonic world and obtaining their mass due to it. If so, their gluonic component is only virtual, as six-quark state of the deuteron, producing some core-type short-range interaction. The question can be asked whether the "true" gluonium states exist in these channels. The answer depends on whether some barrier can separate them from lower-energy quark states, and we see no place for such barrier in the instanton-induced mechanism of the mixing. Of course, higher spin gluoniums may have such barrier, e.g. due to centrifugal forces.

Interesting, that the sum rule method is even more adequate for discussion of the properties of such "fluctons" than of "normal" state of hadrons, in which their constituents are rather distant and interact with different instantons, producing approximately separate valons. And indeed, we have found the quantitative description of these phenomena in our picture of QCD vacuum without any new parameters and assumptions.

Returning to ordinary valon-type configurations, we may say that our consideration of B-type mesons shed some light to it. We have summed up the OPE series, correcting the interaction with quark condensate, and, roughly speaking, were able to come from the $\tau \lesssim \rho_c$ region to $\tau \lesssim R_{conf}$. It is tempting to make similar analysis for ordinary mesons, where the direct experimental data are present.

The so far unexplored region is the studies of multi-instanton effects at distances of the order of R_{conf}. Obviously, the sum rule method also can provide rich empirical basis for it.

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Figure captions

1. Qualitative picture of the structure of ordinary baryons, consisting of three valons with the dimensions about 1/3 of that of the baryon itself. The lower part of the picture is the hypothetical energy distribution along the diameter shown at upper picture by the dashed line. The energy density is slightly different from that in physical vacuum, with the exception of valon regions, where it is strongly affected by quarks.

2. The diagrams giving the perturbative (a) and nonperturbative (b) corrections to sum rules for B-type mesons.

3. The correlator of currents $K(\tau)$ versus τ, the Euclidean time. The solid curve marked "exp" is due to imaginary part of the correlator as given by formulae (18,19). The curves marked 0,1,2 correspond to calculations containing the perturbative loop, and 1 or 2 first power OPE corrections, respectively. The curve marked "sum" is the sum of the OPE series estimated in one-instanton approximation. The related function $f(x)$ (20) is plotted in the upper incertion of the same Figure.

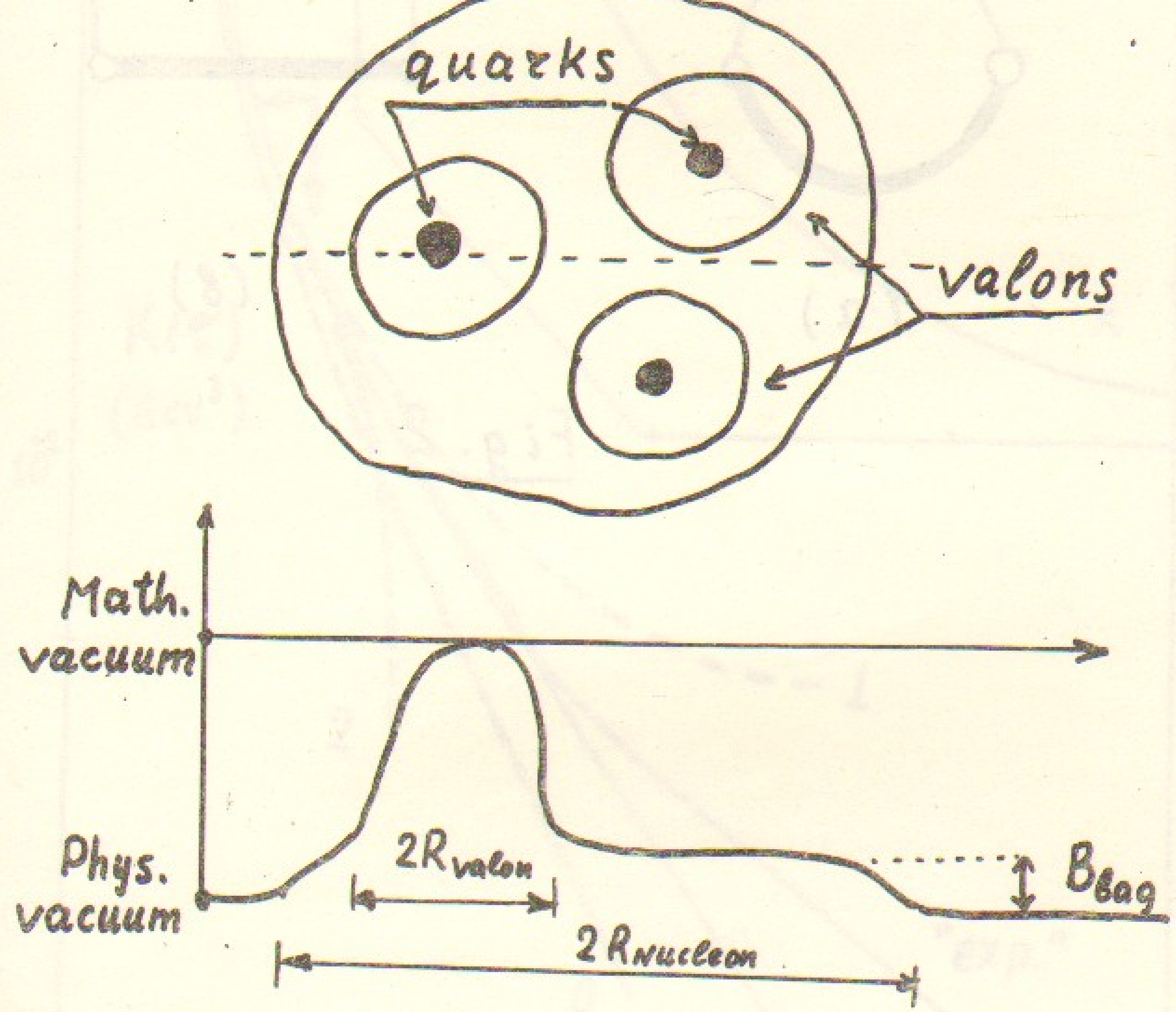

Fig. 1

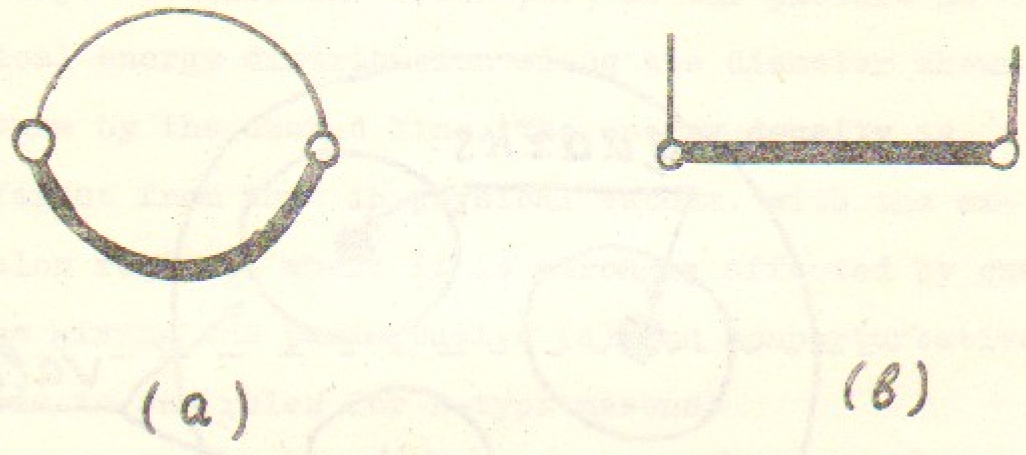

Fig. 2

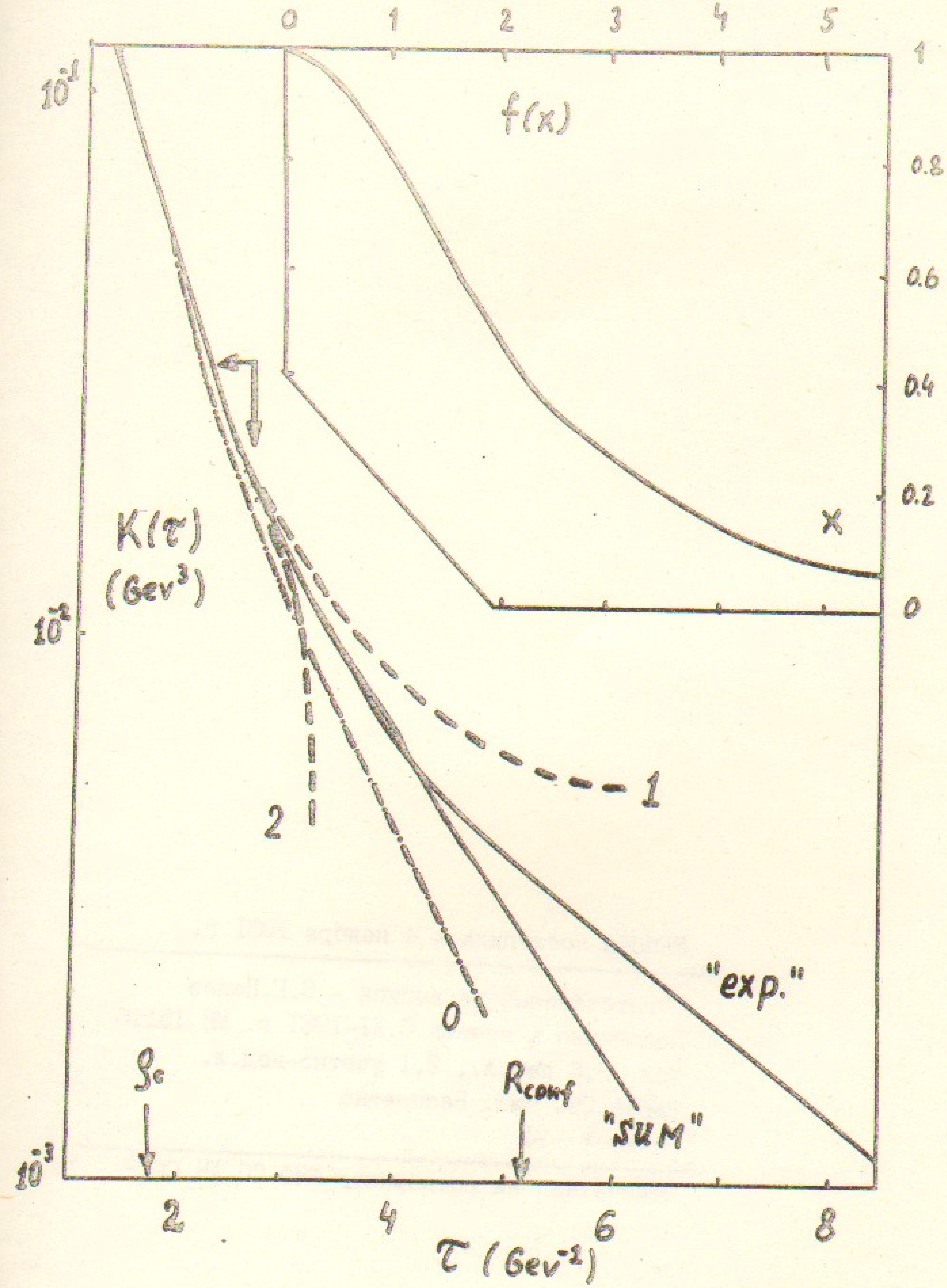

Fig. 3