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SCALAR GLUONIUM AND PSEUDOSCALAR GOLDSTONE MESONS

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The existence of bound states of gluons[1], called gluonia or glueballs, is a clear prediction of QCD, but predictions of the properties of the glueballs are less clear[2]. Some theoretical calculations seem to approach the definite values for gluonium masses[2-4], however decay properties of the glueballs are not so known.

The scalar gluonium is probably the lightest one with the mass around 1 GeV[2-4]. So, the number of its hadronic decay modes is limited. It decays dominantly to the pair of lighter pseudoscalar mesons. This suggests, that in order to understand the decay properties of the scalar glueball, it is required to have a model describing interactions between this gluonium and pseudoscalar mesons.

Recently, such effective Lagrangian models have been suggested[5-8]. These phenomenological Lagrangians satisfy some important low energy theorems[4,9] of broken chiral symmetry and scale invariance, and the scalar glueball is assumed to dominate the anomalous trace of the energy-momentum tensor of QCD[10]*. This approach can be based on the linear[5] as well as the nonlinear[7,8] realization of chiral symmetry, and it seems that dimensionally correct treatment of the anomalous trace of the energy-momentum tensor leads to the conclusion[5,8] that the heavy (with mass >1 GeV) scalar glueball has probably a large width independently of the realization used.

In this talk we shall show this result more explicitly by reviewing the effective Lagrangian models[7,8] based on the nonlinear realization of chiral symmetry. We shall briefly discuss relevance of such models to the present scalar glueball candidates g_s (1240)[7,13,14] and G (1590)[14-16].

To do this, we shall assume[5,6] that in low energy, pure gluodynamics (with no quarks) is described by a single scalar gluonium field $\sigma(x)$ with dimension $d_\sigma = 1$[7,8]. The connection

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*In fact, effective Lagrangians for broken chiral and scale invariance were developed more than 10 years ago[11] before the quark model and QCD were generally accepted. At that time, the existence of the wide scalar particle connected with broken scale invariance was also deduced[11,12], however, before QCD, no one had thought about glueballs. Now, when an effective Lagrangian treatment of the trace anomaly is available[5,6], one can interpret this particle as gluonium[7,8].

with the trace anomaly of the energy-momentum tensor of QCD[10]

$$(\theta^{\mu}_{\mu})_{an} \equiv -H = \frac{\beta(g)}{2g} F^{(a)}_{\mu\nu} F^{(a)\mu\nu} , \qquad (1)$$

($F^{(a)}_{\mu\nu}$'s, a = 1,2,...,8, and $\beta(g)$ being gluon-field strength tensors and the renormalization-group function, respectively) is proven to be[5-8]

$$H(x) = \frac{m_\sigma^4}{16H_0} [\sigma(x)]^4 , \qquad (2)$$

in order for the σ-glueball to dominate the scalar gluonic current H(x) and to satisfy low-energy theorems of refs.[4,9]. Here m_σ is a mass of the σ-particle, $H_0 = \langle 0|H|0\rangle$, and a physical interpolating field $\tilde{\sigma}(x)$ of the σ-particle is defined as follows[6-8,11]

$$\sigma(x) = \sigma_0 \exp\left(\frac{\tilde{\sigma}(x)}{\sigma_0}\right), \qquad (3)$$

where $\sigma_0 = \langle 0|\sigma|0\rangle$.

Low-energy physics of pure gluodynamics is then described by the effective Lagrangian[5-8]

$$\mathcal{L}_G = \frac{1}{2} (\partial_\mu \sigma)^2 - \frac{m_\sigma^4}{16H_0} \sigma^4 \ln \frac{\sigma}{\Lambda} , \qquad (4)$$

where Λ is a constant of integration of mass dimension and is fixed by the relation

$$4 \ln \frac{\sigma_0}{\Lambda} = -1 \qquad (5)$$

in order to eliminate the linear term in $\tilde{\sigma}$ from the Lagrangian. It is clear that the logarithmic potential breaks scale invariance and leads to the trace anomaly (2), thus representing quantum effects of pure gluodynamics. This means that, unlike the pion, scalar gluonium is not expected to have a mass $\ll 1$ GeV.

Since we are interested mainly in decay properties of the scalar glueball to pseudoscalar pairs, Lagrangian (4) has to be enlarged so as to incorporate light pseudoscalar mesons (i.e., light quarks). This has been done in refs.[7-8] starting from the conventional[11] current-algebra Lagrangian

$$\mathcal{L}_Q = \frac{1}{4} \mathrm{Tr}[(\partial_\mu U)(\partial^\mu U^+)] , \qquad (6)$$

where U(x) is parametrized as the unitary matrix

$$U(x) = f_\pi \exp\left(i \sum_{j=1}^{8} \frac{\lambda_j \phi_j(x)}{f_\pi}\right). \qquad (7)$$

Here the pion decay constant $f_\pi = 93$ MeV, the ϕ_i's are fields of the pseudoscalar Goldstone mesons and the Gell-Mann λ matrices are normalized to $\mathrm{Tr}(\lambda_i \lambda_j) = 2\delta_{ij}$. In chiral symmetry limit, the complete effective Lagrangian, including the pseudoscalar Goldstone meson and the σ-gluonium fields, has been found in[7,8] and can be compactly presented as follows

$$\mathcal{L}_{QG} = \frac{1}{2}(\partial_\mu \sigma)^2 + \frac{1}{4}\left(\frac{\sigma(x)}{\sigma_0}\right)^N \mathrm{Tr}[(\partial_\mu U)(\partial^\mu U^+)] - \frac{m_\sigma^4}{16H_0}\sigma^4 \ln\frac{\sigma}{\Lambda}, \qquad (8)$$

where the condition (5) is satisfied, and $N = 0$[7] or $N = 2$[8]. This Lagrangian fulfils low-energy theorems of refs.[4,9] and leads[7] to the following trace of the "improved"[17] energy-momentum tensor

$$\theta_\mu^\mu = \frac{N-2}{4}\left(\frac{\sigma(x)}{\sigma_0}\right)^N \mathrm{Tr}[(\partial_\mu U)(\partial^\mu U^+)] - \frac{m_\sigma^4}{16H_0}\sigma^4. \qquad (9)$$

We see that for $N \neq 2$, the Lagrangian (8) gives a dimension $N+2 \neq 4$ contribution to the effective trace anomaly, eq.(9). The special case $N=0$[7] represents the situation when zero-mass pseudoscalar particles decouple from the glueball. Then possible coupling of the scalar gluonium to pseudoscalar mesons can be only due to the chiral-symmetry-breaking quark-mass term in QCD Lagrangian implying small width of the scalar glueball and large SU(3) breaking in its decay. This model was shown[7] to be in reasonable agreement with the gluonium assignment for the $g_s(1240)$ state[13,14]. Unfortunately, the case $N \neq 2$ is not consistent with QCD trace anomaly (1) of dimension 4[8].

To be consistent with eq.(1), one needs[8] $N=2$ in eqs.(8) and (9). The model with $N=2$ was treated in[8] (see also[12]) and was found to give a large width for heavy scalar glueball to decay into two pions. Unlike the previous case ($N=0$), the case when $N=2$ represents the situation with strong couplings between scalar gluonium and the members of the pseudoscalar meson octet. Due to the presence of the quark-mass term, these couplings are only weakly corrected and remain almost SU(3) invariant[8]. On the basis of existing data[18] we doubt that scalar gluonium of the model with $N=2$ could exist with mass smaller than 1 GeV, and therefore we believe that this glueball has a mass larger than 1 GeV and is probably too wide to be recognized as a well-defined resonance. Nevertheless, it is interesting to note that the model estimate of the width $\Gamma(\sigma \to \pi\pi)$[8] is qualitatively consistent with the estimated width of the $\epsilon(1300)$ meson[18].

We must keep in mind that results we have reviewed here are based on the assumption of a single scalar glueball dominance of the anomalous trace of the energy-momentum tensor of QCD and this dominance can be questionable for heavy and wide resonance. Moreover, on the basis of large N_c-calculation it has been argued[4] that the following relations[4]

$$i \int dx \langle 0 | T(H(x) H(0)) | 0 \rangle = 4H_0,$$
$$i \int dx \langle 0 | T(H(x) m_q \bar{q} q(0)) | 0 \rangle = 3 \langle 0 | m_q \bar{q} q | 0 \rangle \qquad (10)$$

($q(x)$ being the field of the light quark of the mass m_q) cannot be simultaneously saturated by a single meson. To saturate eqs.(10) in the limit $N_c \to \infty$, one needs two distinct scalar resonances: one of quarkonium and the other of gluonium nature[4].

So, assuming that also in the real world the trace anomaly is dominated by two scalar resonances, σ and χ (with dimensions $d_\sigma = d_\chi = 1$), then $\mathcal{L}_Q$ (eq.(6)) in eq.(8) can be multiplied by combination $(\chi(x))^{2-N}(\sigma(x))^N$ instead of $(\sigma(x))^N$. In this way, the consistency with eq.(1) is obtained for any N. This opens room for speculations that we could have one of the particles reasonably narrow to assign it to one of the recently discovered states $g_s(1240)$[13,14] or $G(1590)$[14,15], while the other particle should still remain broad. However, without any knowledge of dynamics (and mixing) between σ and χ particles our speculations can be only academic.

In conclusion we should note that the basic result of this talk on the existence of at least one heavy and wide resonance (glueball), strongly coupled to the anomalous trace of the energy-momentum tensor, seems to be supported also by QCD sum rule approach[19] as well as by the effective Lagrangian approach based on linear realization of chiral symmetry[5] with consistent inclusion of scalar quarkonium states and their eventual mixing with gluonium.

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Ланик Й. E2-85-260
Скалярный глюоний и псевдоскалярные
голдстоуновские мезоны

Представляется короткий обзор недавно предложенных эффективных лагранжевских моделей на основе нелинейной реализации киральной симметрии для связей между низколежащим скалярным глюонием и псевдоскалярными голдстоуновскими мезонами. Эти феноменологические лагранжианы удовлетворяют низкоэнергетическим теоремам нарушенной киральной и масштабной симметрий и ,таким образом, автоматически приводят к ненулевому следу тензора энергии-импульса. Предполагая согласие этого феноменологического следа с аномальным следом тензора энергии-импульса КХД и, что один низколежащий скалярный глюоний доминирует этот след, мы приходим к заключению, что такой глюбол, вероятно, очень широкий и его трудно понимать как хорошо определенный резонанс. Это и может быть источником трудностей в его обнаружении.

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Lánik J. E2-85-260
Scalar Gluonium and Pseudoscalar Goldstone Mesons

Recently suggested effective Lagrangian models for couplings between the lowest-lying scalar gluonium and pseudoscalar Goldstone mesons, based on the nonlinear realization of chiral symmetry, are reviewed. These phenomenological Lagrangians satisfy low-energy theorems of broken chiral symmetry and scale invariance, and in such a way, they automatically lead to the non-zero anomalous trace of the energy-momentum tensor. Demanding consistency of this phenomenological trace anomaly with the anomalous trace of the energy-momentum tensor of QCD, and furthermore, assuming that the anomaly is dominated by a single lowest-lying scalar gluonium, we conclude that such a glueball is probably too broad to be recognized as a well-defined resonance. Thus, this can be the source of troubles in the search for the lowest-lying scalar glueball.

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

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