On possible role of scalar glueball-quarkonia mixing in the f(0)(1370,1500,1710) resonances produced in charmonia decays

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Preliminaries

Motivations: (1)The new data, (2)New challenges

1.The UKQCD Collab.: new **unquenched** LQCD-calculation of the $J^{PC} = 0^{++}$ glueball

$$M_G{}^{unquen} = 1795(60) vs M_G{}^{quen} = 1730(50)$$

(E. Gregory *et al.*,JHEP, 2010 (1012),170.)

2. After 40 years of EXP- and TH- work the knowledge on the 0^{++} -mesons has been considerably improved but till now no proof of the existence of the 0^{++} -glueball and determination of its mass. The identification of the supernumerous state in the nonet is difficult if broad objects like the $f_0(1370)$ are involved with small 2-body decay branching ratios

(W. Ochs, "Spectroscopy with glueballs and the role of $f_0(1370)$",

Preliminaries

The existence of glueballs is a consequence of the self-interaction of gluons in QCD. Their continued nonobservation would be more serious than a mere embarrassment for QCD, while an unambiguous signal of their observation would constituent a remarkable success for the theory.
Efforts applied: **1312 cit.** in SPIRES for the titles including "glueball"
For amusement: Prog.Theor Phys. 61 **(1979)** 352 "Comment on the **Boxiton** (Glueball) States in the Lattice Gauge Theory",..." ..the existence of the boxiton states is not proved."

Preliminaries

Theoretically, it is generally accepted that the lowest mass glueball is the scalar 0^{++} -state. The scalar meson states above (below) 1 GeV, listed by PDG are:

$f_0(1370), f_0(1500), f_0(1720), K_0^*(1430), a_0(1450);$

$f_0(500)/\sigma, f_0(980), K_0^*(800)/\kappa, a_0(980).$

The inspection of the mixing within the 3 isoscalar f_0's and on the base of **different** TH- models has lead to **numerous** mixing schemes giving the glueball mass, mainly, either around 1500 MeV or around 1700 MeV.

Schematically, these approaches may be defined as follows:

TH-model parameters $\Longrightarrow$ Data

Our approach will, in fact, be "antiparallel":

Data $\Longrightarrow$ Model parameters $\Longrightarrow$ Mixing angles, etc.

Preliminaries

So we concentrate on the mass region $1.3 \div 1.7$ GeV occupied by the spin-zero 0^{++} mesons. In this group of mesons there are three isoscalar mesons with similar masses which, in the presence of the nearly lying isotriplet and isodublet ones, suggest on the overpopulated nonet where a possible glueball is hidden within structures of the three isoscalar states. Whether this idea is right or wrong one should to deduce from the solution of the formulated problem as well as from the relations between branching ratios of the resonance decays. With this in mind, we present results of a simple approach enabling to discuss an acute problem of the existence and properties of glueballs with quantum numbers $I^G J^{PC} = 0^+0^{++}$.

Underlying relations

We define the 3×3 mass-matrix $\hat{V(i)}$ as acting on the basis vectors N, S, G to transform them into one of three vectors of the physical meson states, $f_0(i)$

$$(f_0(i)) = \hat{V(i)} \cdot \begin{pmatrix} N \\ S \\ G \end{pmatrix} \qquad (1)$$

where in simple case

$$N = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d}), \qquad S = s\bar{s},$$

and G is the glueball.

Underlying relations

We consider the mass-matrices $\hat{V(i)}$ taking into account explicitly the different appearance of the two types of gluon effects in mixing states of the differing flavor. In a certain sense, we follow the way proposed in old works by Isgur to connect the strong "non-ideality" of the $SU(3)$-singlet-octet mixing angle in the lowest pseudoscalar and scalar meson nonet with the overwhelmingly strong, as compared with the respective term in the vector or tensor meson nonets, annihilation term in the mass-matrix, inducing the non-diagonal $q\bar{q} \leftrightarrow s\bar{s}$ transitions.

Mass formulas.

We remind, that the celebrated Gell-Mann–Okubo (GMO) formula

$$3m_{f_8}^2 = 4m_{K_0^*}^2 - m_{a_0}^2$$

is following as the mass sum rule after exclusion of parameters introduced into the general mass term of phenomenological meson lagrangian

$$M^2 \cdot Tr(V_8 V_8) - \mu^2 \cdot Tr(V_8 V_8 \lambda_8).$$

Okubo proposed to replace $V_8 \to V_9$ in the GMO mass operator and drop the term proportional to $Tr(V_9)$. The well-known "ideal mixing " mass relations

$$m^2(\rho) = m^2(\omega),\ 2m^2(K^*) - m^2(\rho) = m^2(\phi)$$

fulfilled for the vector and reasonably well for tensor nonet, but

Mass formulas

We indicate also the hierarchy of meson masses, following from effective lagrangian GMO

$$m^2(s\bar{s}) \geq m^2(q\bar{s}) \geq m^2(q\bar{q}).$$

The idea to relate the apparently specific situation for the pseudoscalar meson sector with additional strong annihilation mechanism transforming the quark field combinations into each other was put forward phenomenologically by Isgur, and interpreted now as mediated by short-range fluctuations in the quark-gluon vacuum.

We follow this idea in the further generalized form via the introducing the "bare" scalar or pseudoscalar glueball mass and non-diagonal glueball-quarkonium transition-mass into the meson

Mass formulas.

Hence, in the $N = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d}), S = s\bar{s}$ basis our symmetric mass-matrix acquires the following form

$$\hat{M}^2 = \begin{pmatrix} M_N^2 + 2A_Q & \sqrt{2}A_G & \sqrt{2}A_Q \\ \sqrt{2}A_G & M_G^2 & A_G \\ \sqrt{2}A_Q & A_G & M_S^2 + A_Q \end{pmatrix}$$

After reducing it to the diagonal form we should get the matrix of the eigenvalues $\hat{M}^2{}_{ph}$:

$$\hat{M}^2{}_{ph} = \begin{pmatrix} M_{f_0}^2(1) & 0 & 0 \\ 0 & M_{f_0}^2(2) & 0 \\ 0 & 0 & M_{f_0}^2(3) \end{pmatrix}$$

The isoscalar "sub-multiplets" in scalar sector

We start the treating of mass relations with the higher-mass, scalar 0^{++}-sector:

$$M_{a_0} = 1474 \pm 19, M_{K^*{}_0} = 1425 \pm 50$$

$$M_{f_0}(1) = 1370 \pm 50, M_{f_0}(2) = 1505 \pm 6,$$

$$M_{f_0}(3) = 1724 \pm 7$$

where all values are in MeV.
We define the "bare" mass values M_N and M_S devoid of the strong annihilation contributions via

$$M_N = M_{a_0}, {M_S}^2 = 2{M_{K^*{}_0}}^2 - {M_{a_0}}^2$$

The isoscalar "sub-multiplets" in scalar sector

A short digression: the second relation is alike of the S-wave vector quarkonia, but we would like to note the opposite mass hierarchy sequence

$$M^2(s\bar{s}) \leq M^2(q\bar{s}) \leq M^2(q\bar{q})$$

which follows if one changes the sign of the parameter μ^2 in the GMO mass operator and serves as demonstration of the significant flavor dependence in the spin-dependent (the spin-orbit, etc.) mass terms of the P-wave scalar mesons and specific mixing effect of the states belonging to already mentioned different (*i.e.* higher-mass and lower-mass)scalar multiplets. We accept the viewpoint that light scalars make a full SU(3) flavor nonet. Their mass spectrum, with the peculiar inversion of the κ and f_0 or a_0

The isoscalar "sub-multiplets" in scalar sector

The most natural explanation for such complete multiplet with inverted mass spectrum is that these mesons are diquark–antidiquark bound states. Diquark–antidiquark bound states (tetraquarks, for short) naturally reproduce the SU(3) nonet structure with the correct mass ordering, as indicated by the explicit quark composition:

$\sigma^{[0]} = [ud][\bar{u}\bar{d}]$

$\kappa = [su][\bar{u}\bar{d}]; \ [sd][\bar{u}\bar{d}]$ (+ conjugate doublet)

$f_0^{[0]} = \frac{[su][\bar{s}\bar{u}]+[sd][\bar{s}\bar{d}]}{\sqrt{2}}$

$a_0 = [su][\bar{s}\bar{d}]; \ \frac{[su][\bar{s}\bar{u}]-[sd][\bar{s}\bar{d}]}{\sqrt{2}}; \ [sd][\bar{s}\bar{u}]$

The isoscalar "sub-multiplets" in scalar sector

The intermediate gluon-matter originated terms A_Q and A_G and the gluon mass M_G are unknown variables which have to be found by solution of the system of **three equations** representing the equalities of **three invariants** of the diagonalizing process: the trace, the determinant and the sum of main minors of the matrices under consideration.

The isoscalar "sub-multiplets" in scalar sector

Successively excluding unknown variables A_Q and A_G in favor of M_G, we solve numerically the last equation by varying remaining unknown M_G under constraint ${A_G}^2 \geq 0$. There are no solutions for M_G for $A_G \geq 0$ and one for $A_G \simeq 0$. We have to accept as physically acceptable the value of the decoupled physical glueball mass

$$M_G(ph) \simeq 1730\ MeV \text{ vis-a-vis } M_{f_0}(3) = 1720 \pm 7\ MeV$$

The state vectors of the $f_0(1506)$ and $f_0(1370)$ are obtained by the diagonalizing the rest 2×2 matrix:

$$|f_0(1506) >= 0.868|N > +(-)0.496|S >$$

$$|f_0(1370) >= -(+)0.496|N > +0.868|S >$$

The choice of signs remains to be done on the physics ground

Isoscalar f_0 -resonance production and decays in processes including the lowest mass charmonia

The sensitive check of our results can also provide the radiative and hadronic decays of the J/Psi-resonance. In the radiative transitions, it is natural to accept the dominance of diagrams of the annihilation. of bound $c\bar{c}$)-quarks to photon and the pair of intermediate gluon followed by the hadronization process.

Isoscalar f_0 -resonance production and decays in processes including the lowest mass charmonia

Under these assumptions, we turn to several processes with participation of the vector $\phi(1.02)$- and $\omega(.783)$-mesons that serving to be very good flavor "filters" for the state vectors of scalars participating in a particular reaction. The matrix elements of the process $(J/\Psi \to V + f_0(1720))$ include a series of virtual transitions $J/\Psi \to 3g \to V + gg \to V + f_0(1720)$ that are proportional to the well-known SU(3)-singlet component of the ω- and ϕ- meson and to the form-factors of the $3gV$-vertex.

Isoscalar f_0 -resonance production and decays in processes including the lowest mass charmonia

As the intermediate gluons are "hard" vector quanta we replace approximately the ratios of the full ω- and $\phi-$ form-factors by the respective ratios of their radial "functions-at-zero-distance", entering into the ratios of the widths of $V \to e^- e^+$ - decays. Thus,

$$R_{\omega\phi}(f_0(1720) = \frac{|\vec{k}_{\omega f_0(1720)}|}{|\vec{k}_{\phi f_0(1720)}|} \cdot (tan\theta_V)^{-2} \cdot \frac{R^2_\omega(0)}{R^2{}_\phi(0)} \simeq 1.0(1.33 \pm .34)$$

Isoscalar f_0 -resonance production and decays in processes including the lowest mass charmonia

The $SU(3)$-octet dominance of the $f_0(1370)$ filters as well octet parts of the vector meson states and we obtain

$$R_{\omega\phi}(f_0(1370)) = \frac{|\vec{k}_{\omega f_0(1370)}|}{|\vec{k}_{\phi f_0(1370)}|} \cdot (tan\theta_V)^2 \leq .72$$

Isoscalar f_0 -resonance production and decays in processes including the lowest mass charmonia

The color-averaged, gluon-exchange contributions operating in transitions $c\bar{c} \to gg \to gg|_{bound}$ are proportional to the 3-gluon couplings and are at least 3/(4/3) times larger than in the corresponding $c\bar{c} \to gg \to q\bar{q}|_{bound}$ -transitions. Furthermore, the factor of the "wave-function-at-zero" squared which is natural in the transition of the gluon-gluon S-wave state, has further advantage over the derivative of "wave-function-at-zero" squared connected with the transition matrix element of two-quark P-wave state.

A model for $f_0(q\bar{q})$-resonances radiative production and decays

Hence the ratio $BR(J/\Psi \to \gamma + f_0(1506)) = (1.01 \pm .32) \cdot 10^{-4}$ is markedly smaller than
$BR(J/\Psi \to \gamma + f_0(1720) \to \gamma K\bar{K}) = (8.5^{+1.2}{}_{-.9}) \cdot 10^{-4}$ (PDG12)
and especially than the ratio
$BR(J/\Psi \to \gamma + f_0(1720) \to \gamma \bar{K}K)/BR(f_0(1710) \to K\bar{K}) \geq (8.5 \pm 1.2) \cdot 10^{-4}$

"Gone with the Wind"? (Problem and role of the $f_0(1370)$ for previous parts of this talk)

Like in many schemes with $1.5 \div 1.7$ GeV glueball, the crucial element of our numerical results is the existence of f_0(1370. The PDG review propose the rather wide ranges for mass and width: $M = 1200 \div 1500$ MeV and $\Gamma = 200 \div 500$ MeV. The available data of **many decay modes of** $f_0(1370)$ **quoted as "seen" do not present a convincing direct signal**,neither a peak above low background nor a clear resonance effect **such as were observed from the nearby** $f_0(1500)$ (**W.Ochs,hep-ph/1001.4486, hep-ph/1304.7634**)
We want, nevertheless, to draw attention to some interesting facts appearing from experiments if we are accepting the existence of this controversial state.

"Gone with the Wind"? (Problem and role of the $f_0(1370)$ for previous parts of this talk)

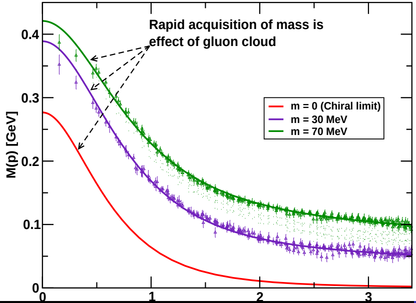
M. Ablikim, et al.(BES Collaboration),"Partial Wave Analysis of $\chi_{c0} \to \pi^+\pi^-K^+K^-$", Phys.Rev., **D 72** 2005, 092002.
A partial wave analysis of $\chi_{c0} \to \pi^+\pi^-K^+K^-$ in $\psi(2S) \to \gamma\chi_{c0}$ decay is presented. From the fit, significant contributions to χ_{c0} decays from the channels $f_0(980)f_0(980)$, $f_0(980)f_0(2200)$, $f_0(1370)f_0(1710)$, $K^*(892)^0\bar{K}^*(892)^0$, $K_0^*(1430)\bar{K}_0^*(1430)$, $K_0^*(1430)\bar{K}_2^*(1430) + c.c.$, and $K_1(1270)K$ are found. Values obtained for the masses and widths of the resonances $f_0(1710)$, $f_0(2200)$, $f_0(1370)$, and $K_0^*(1430)$ are presented.

"Gone with the Wind"? (Problem and role of the $f_0(1370)$ for previous parts of this talk)

$Br(\chi_{c0} \to f_0(1370) f_0(1710)) \cdot 10^4 = 7.12 \pm 1.85 \pm 3.28(1.68); (6.5\sigma)$.
$Br(\chi_{c0} \to f_0(1500) f_0(1710)) \cdot 10^4 \leq 0.7$ (PDG)
$Br(J\Psi \to \gamma f_0(1710) \to \gamma K\bar{K}) \cdot 10^4 = 8.5 \pm 1.2(0.8)$.
$Br(J\Psi \to \gamma f_0(1500)) \cdot 10^4 = 1.01 \pm 0.32$
$Br(J\Psi \to \gamma f_0(1370)) =$ (?!) - eagerly wanted to be measured!
There is seemingly strong **mismatch** between the **flavour** $SU(3)$-symmetry and **chiral** symmetry at sufficiently high internal virtual momenta as in the decays of heavy hadrons into the states composed of light quarks. In particular, the idea of the suppression of the scalar coupling to (almost) massless $u(d)$- quarks was advanced in the paper **M.Chanowitz** "Chiral suppression of scalar glueball decay", Phys.Rev.Lett. **95**, 2005, 172001.

"Gone with the Wind"? (Problem and role of the $f_0(1370)$ for previous parts of this talk)

The unquenched LQCD suggests the running mass of light quarks tending to the "constituent" masses relevant to low-energy hadron phenomenology.



"Gone with the Wind"? (Problem and role of the $f_0(1370)$ for previous parts of this talk)

M.A.Ivanov, Lecture at this School and references.
S.G. "Meson structure constants in a model of the quark diagrams", JINR E2-11693, 1978, Yad.Fiz. **29**, 1979, 513.

"Gone with the Wind"? (Problem and role of the $f_0(1370)$ for previous parts of this talk)

J.Schwinger, (1964)

$$(\eta' - \pi)(\eta - \pi) - (4/3)(\eta' + \eta - 2K) = 0$$

$$(f_0' - a_0)(f_0 - a_0) - (4/3)(f_0' + f_0 - 2K_0) = 0$$

Outlook

(•) BES 3: Improved statistics on $J/Psi \to \gamma + \pi\pi, K\bar{K}, \eta\eta$ is expected.
(•) PANDA;J-PARK: $p\bar{p} \to lightresonances$, J/Psi,
(•) LHC : heavy hadron weak decays $\to X$ + meson resonances; leading resonances in gluon jets (**W.Ochs**)
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