$\theta(1690)$ — ISN'T IT A GLUEBALL?

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An alternative mixing pattern of 2^{++} mesons f, f′, θ leads to the conclusion that θ(1690) can be understood as a particle containing about 90% of glueball state.

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The θ(1690) meson is regarded as one of the most prominent candidates for glueball state (see e.g. [1, 2]). Unfortunately, tests for identification of glueball state are not conclusive. The θ state satisfies some of them but not the others. For example, it is produced in the gluon rich process $J/\psi \to \gamma\theta$, but its total width is about 130 MeV [2], i.e. typical of quarkonium.

A possible way to prove the gluonic nature of the θ is an analysis of its influence on the f and f′ states. The mixings of f, f′, θ states have been discussed by many authors [3–8].

The exhaustive phenomenological analysis of f, f′, θ couplings has been carried out by Rosner and Tuan [7] under assumption that these are mixed states of quarkonium $\left(\text{non-strange } |N\rangle = \left|\frac{1}{\sqrt{2}}(u\bar{u}+d\bar{d})\right\rangle \text{ and strange } |S\rangle = |s\bar{s}\rangle\right)$ and glueball ($|G\rangle$). The approximate contents of quarkonia and glueball in f, f′, θ are given in the Table III of Ref. [7]. The self-evident properties of these mixings are:

(*i*) the states f, f′, θ are dominated by N, S, G respectively; in particular, f′ is almost pure S state;

(*ii*) the admixture of G is higher in f than in f′; similarly, the admixture of N is higher in θ than in f′. So, this is the case where the mixing of the states with the nearest masses does not dominate.

Such kind of mixing cannot be explained in the model of flavour independent mixing [9, 10]. In this model, the mixing of the states with the nearest masses does dominate [4, 7]. For example [7], the f′ (θ) state consists in ~60% of the S (G) state and in ~35% of the G (S) state. As a result of this:

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(*i*) the two-photon decay of f′ is nearly totally suppressed;

(*ii*) the suppression of the decay $f' \to \pi\pi$ follows as (rather accidental) interference effect between the N and G states.

These failures of the model, especially the first one, are sometimes regarded as an argument against the gluonic nature of θ [11, 12].

In the present letter we would like to pay attention to the Exotic Commutator Method (ECM) of breaking a flavour symmetry [13]. ECM seems to be an appropriate pattern for f, f′, θ mixing. An application of ECM to meson decouplet [14] (SU(3) quarkonium nonet + SU(3) singlet being glueball, as we assume below) leads to the following properties of the mixing isosinglets:

(*i*) two of the three physical isosinglets have the masses almost equal to the ones expected for the ideal mixing. In this respect, the admixture of an extra singlet weakly disturbes the ideality. But only in this respect, because

(*ii*) these two isosinglets can have quite different structure (quarkonium and glueball content) than that of the two isosinglets from the ideally mixed nonet. This feature of the three mixing states is quite natural since the mixing matrix is the rotation matrix of the three vectors in the space. The mixing matrix depends on one parameter.

Within this framework we can easily:

a. Adjust the mass of θ to the masses of other members of decouplet. Indeed, putting $A_2 = (1.311\ \text{GeV})^2$, $K^{**} = (1.432\ \text{GeV})^2$, $f = (1.281\ \text{GeV})^2$, $\theta = (1.725\ \text{GeV})^2$ we get from Eq. (7) of Ref. [14] $f' = (1.522\ \text{GeV})^2$. θ increases when A_2, K^{**}, f, f′ tend to their mean experimental values [15].

b. Obtain the quarkonium-glueball content of f, f′, θ very similar to that from the phenomenological analysis [7]. Indeed, using Eqs. (10) and (12) of Ref. [14] and choosing $\cos\vartheta_2 = 0.94$; $\sin\vartheta_2 < 0$; $\cos\vartheta_1 > 0$; $\sin\vartheta_1 < 0$; $\cos\vartheta_3 > 0$; $\sin\vartheta_3 > 0$ we get three physical states in the form:

$$x|N\rangle + y|S\rangle + z|G\rangle,$$

where the numbers x, y, z are given in the Table.

From Rosner's expressions for widths [7] we get:

a. $$\frac{\Gamma(f \to \gamma\gamma)}{\Gamma(A_2 \to \gamma\gamma)} = 2.62 \times \text{(phase-space correction)},$$

$$\frac{\Gamma(f' \to \gamma\gamma)}{\Gamma(A_2 \to \gamma\gamma)} = 0.124 \times \text{(phase-space correction)},$$

$$\frac{\Gamma(\theta \to \gamma\gamma)}{\Gamma(A_2 \to \gamma\gamma)} = 0.257 \times \text{(phase-space correction)}.$$

The decay $f' \to \gamma\gamma$ is allowed and its width is in agreement with [16] $\Gamma(f' \to \gamma\gamma)B(f' \to K\bar{K}) = (0.11 \pm 0.06)$ keV.

TABLE

Normalized eigenvectors of f, f′, θ states

	x	y	z
f	0.9532	0.0633	0.2957
f′	−0.0711	0.9973	0.0157
θ	−0.2940	−0.0360	0.9551

b. Using the experimental values [2]

$$B(J/\psi \to \gamma\theta)B(\theta \to K\bar{K}) = (9.6 \pm 3)10^{-4},$$

$$B(J/\psi \to \gamma\theta)B(\theta \to \pi\pi) = (2.4 \pm 0.9)10^{-4}$$

we can determine the parameter r [7]. Then, putting 115 to the place of 112 [7], we find: $\Gamma(f \to \pi\pi) = 130.6$ MeV, $\Gamma(f' \to \pi\pi) = 1.0$ MeV, $\Gamma(\theta \to \pi\pi) = 1.9$ MeV, $\Gamma(f \to K\bar{K}) = 7.0$ MeV, $\Gamma(f' \to K\bar{K}) = 39.4$ MeV, $\Gamma(\theta \to K\bar{K}) = 7.6$ MeV.
The decay $f' \to \pi\pi$ is suppressed as a result of almost pure S nature of the f′ state.

The overall agreement of these results with experimental data follows from the phenomenological analysis [7]. Therefore, we restrict ourselves to few remarks.

1. PDG [15] quotes the world average $\dfrac{\Gamma(f \to K\bar{K})}{\Gamma(f \to \pi\pi)} = 0.034 \pm 0.0027$. We get 0.054, and this value cannot be significantly changed. However in the number of experiments [15] the values about 0.05 were obtained.

2. It follows from our results, that $\Gamma(\theta \to \pi\pi) + \Gamma(\theta \to K\bar{K}) + \Gamma(\theta \to \eta\eta) \simeq 10$ MeV. Moreover, the decays into $\bar{K}K^* + K\bar{K}^*$ and $\eta\eta'$ are forbidden [17] (the octet content of θ is 2%). This can look surprising compared with $\Gamma^{exp}(\theta) = 130$ MeV. However, part of the θ signal may come from the state 0^{++} G(1590) [18] and this could reduce $\Gamma(\theta)$ (see also [11]). On the other hand other decay modes like $\varrho\varrho$, $\omega\omega$, $K\bar{K}\pi\pi$, $\pi\pi\pi\pi$ can contribute to $\Gamma(\theta)$ [6].

3. According to common belief our results would be modified at least due to

a. flavour independent mixing

b. mixing with higher-lying multiplet.

The latter is expected to shift down the mass of θ, implicitly shifting the masses of particles from nonet towards their mean experimental values. Therefore agreement of our results with experimental data does not need to be excellent, even if formulae for widths were exact.

4. Our results correspond to the results of early version of Rosner's analysis; it can be noticed that our ϑ_2 plays the role of Rosner's ϑ [3].

We conclude, that according to available experimental data θ(1690) can be understood as 90% glueball.

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