# ON THE NATURE OF THE θ (1670) STATE

By J. Turnau

Institute of Nuclear Physics, Cracow*

(Received May 9, 1983)

It is shown that the quarkonium-gluonium mixture model of θ (1670) state fails in many points. On the other hand, the mixing of the $s\bar{s}$ state with the $u\bar{u}s\bar{s}$ member of $\underline{36}$-plet is shown to yield the decay properties of f′ (1515) and θ (1670) consistent with the experimental observations.

PACS numbers: 13.25.+m

The recent review [1] on the theoretical and experimental status of the θ(1670) state observed in the radiative decay of $J/\psi$ [2, 3] summarizes the situation as follows:

*i*) The hypothesis that θ (1670) does not exist but is an interference effect between the $2^{++}$ radial excitation and the ground state [4] fails badly on the basis of the measurement of the upper limit for the $\pi\pi$ decay mode.

*ii*) The hypothesis that θ (1670) is a $u\bar{u}s\bar{s}$ state is consistent with the data, unless a connection between the $\varrho\varrho$ structure observed in Mark II data [3] and θ is firmly established.

*iii*) The hypothesis that θ (1670) is a gluonium-quarkonium mixture [5, 6] is consistent with the data.

Hypothesis (*iii*) emerged as an attempt to explain the nonobservability of the $\pi\pi$ decay mode of θ (1670). In the f-f′-θ mixing model f′ and θ decouple from the $\pi\pi$ channel by accidental cancellation of the contributions from nonstrange quarks and gluonium, both present in the wave function. Although particular realization of the mixing model proposed in Ref. [6] fails badly in description of the $f' \to \gamma\gamma$ width [7] it can be (most probably) saved by some symmetry breaking.

In this letter we would like to point out that there are other difficulties in any model built along the lines of Ref. [5] or [6]. Let us take Rosner's [6] prescription for f′ and θ wave functions and calculate from SU (3) their decay width in the $K\bar{K}$ and $\bar{K}K^*+K\bar{K}^*$ channels. This can be done without any new parameters, due to the selection rule forbidding the $2^{++}$ SU (3) singlet state (i.e. gluonium) to decay into $\bar{K}K^*+K\bar{K}^*$. We get

$$\Gamma(f' \to K\bar{K}) \approx 30 \text{ MeV},$$

* Address: Instytut Fizyki Jądrowej, Kawiory 26a, 30-055 Kraków, Poland.

$$\Gamma(\mathrm{f}' \to \mathrm{K}\bar{\mathrm{K}}^* + \bar{\mathrm{K}}\mathrm{K}^*) \approx 10 \text{ MeV},$$

$$\Gamma(\theta \to \mathrm{K}\bar{\mathrm{K}}) \approx 11 \text{ MeV},$$

$$\Gamma(\theta \to \mathrm{K}\bar{\mathrm{K}}^* + \bar{\mathrm{K}}\mathrm{K}^*) \approx 28 \text{ MeV}. \tag{1}$$

These values disagree with the results of three recent studies:

1) It is hard to understand why we do not observe θ (1670) together with ι (1440) in the $K\bar{K}\pi$ channel of the radiative $J/\psi$ decay.

2) Recent results [8] of partial wave analysis in $K\bar{K}\pi$ system produced in the reaction $K^-p \to K\bar{K}\pi\Lambda$ at 4.2 GeV/$c$ show that there is no $2^{++}$ wave signal in the 1.2–2.0 GeV mass range. If we consider cross sections for production of f′, E, D′ (1526) [8] estimated in the same experiment, namely

$$\sigma(\mathrm{K}^-\mathrm{p} \to \mathrm{E}(\to \mathrm{K}\bar{\mathrm{K}}\pi)\Lambda) = 4.8 \pm 1.5\ \mu\mathrm{b}$$

$$\sigma(\mathrm{K}^-\mathrm{p} \to \mathrm{D}'(\to \mathrm{K}\bar{\mathrm{K}}\pi)\Lambda) = 18.3 \pm 2\ \mu\mathrm{b}$$

$$\sigma(\mathrm{K}^-\mathrm{p} \to \mathrm{f}'(\to \mathrm{K}\bar{\mathrm{K}})\Lambda) = 19 \pm 3\ \mu\mathrm{b}$$

the SU (3) results (1) imply the presence of the θ (1670) signal at the level of 18 μb, i.e. the same as D′ (1526) signal and f′ (1515) signal at the level of 6 μb, i.e. of the order of E (1420) signal, clearly seen in the data.

3) The ratio $\Gamma(\theta \to K\bar{K})/\Gamma(f' \to K\bar{K}) \approx 1/3$ predicted in Ref. [6] seems to be in contradiction with the very high statistics data on the reaction $Kp \to K^+K^-\Lambda$ [9] where a very clean f′ signal without any interference effects in the θ (1670) region is seen.

The mixing model proposed in Refs [5, 6] may be challenged on the more general grounds. Firstly, the suppression of the $f' \to \pi\pi$ width due to accidental cancellation looks fairly suspicious. Our belief that f′ is a pure $s\bar{s}$ state is based on ample evidence for suppression of the Okubo-Iizuka-Zweig (OIZ) forbidden transitions [10] involving f′ (like $\psi \to \omega f'$, $p\bar{p} \to \pi^+\pi^- f'$ or $t$-channel $f' \to N\bar{N}$). Secondly, if we believe that the physical $2^{++}$ gluonium ground state is the first particle on the pomeron trajectory, its octet content should be small.

How then about the hypothesis (*ii*), i.e. f′ being an almost pure $s\bar{s}$ state and θ (1670) corresponding to a $u\bar{u}s\bar{s}$ state? It appears that SU (3) relations for the ideally mixed $2^{++}$ nonet also contradict the results of Ref. [8]. Using present data we get

$$\Gamma(\mathrm{f}' \to \mathrm{K}\bar{\mathrm{K}}) = 34 \pm 4 \text{ MeV},$$

$$\Gamma(\mathrm{f}' \to \bar{\mathrm{K}}\mathrm{K}^* + \mathrm{K}\bar{\mathrm{K}}^*) = 12 \pm 1 \text{ MeV}, \tag{2}$$

the result close to that of mixing model [1], already discarded by us. To obtain this result, we follow the observation made in Ref. [11] that the true parameters of f′ should be determined from the reaction $K^-p \to K\bar{K}\Lambda$ only. This yields $m(f') = 1524 \pm 2$ MeV, $\Gamma(f') = 76 \pm 6$ MeV. Note that the results of Samios et al. [12] for widths (2) differ from ours considerably. They overestimate $\Gamma(f' \to K\bar{K}) \approx 58$ MeV due to the SU(3) fit with $K^*(1430) \to K\pi$, incorrectly measured at the time. The width $\Gamma(f' \to K\bar{K}^* + \bar{K}K^*)$ is very sensitive to the f′ mass estimated to be considerably lower at that time (1513 MeV), which yielded $\Gamma(f' \to K\bar{K}^* + \bar{K}K^*) \approx 8$ MeV.

To get a reasonable explanation of the data on production and decay of f′ and θ we have to mix the pure $s\bar{s}$ state with another one which (a) behaves like $s\bar{s}$ state as far as OIZ rule is concerned, (b) its decay properties differ from that of $s\bar{s}$ state in such a way that, by mixing, $f' \to K\bar{K}$ can be enhanced while $f' \to K\bar{K}^* + \bar{K}K^*$, $\theta \to K\bar{K}$ and $\theta \to K\bar{K}^* + \bar{K}K^*$ are suppressed. Just to get an idea if anything like that might work we tried, $\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}$ $s\bar{s}$ member of the nonet ($\underline{3} \otimes \bar{\underline{3}}$) and the $\underline{36}$-plet ($\underline{6} \otimes \bar{\underline{6}}$) [13]. For the 36-plet member we construct the following model

$$|f'\rangle = \cos\vartheta|s\bar{s}\rangle + \sin\vartheta|\underline{36}\rangle$$

$$|\theta\rangle = -\sin\vartheta|s\bar{s}\rangle + \cos\vartheta|\underline{36}\rangle.$$

We assume $\langle K\bar{K}|s\bar{s}\rangle = \langle K\bar{K}|\underline{36}\rangle = \langle K\bar{K}^*|\underline{36}\rangle$, the SU(3) relations for ss state, and the $|\underline{36}\rangle$ recouplings to flavour decay channels as given by [13]. We set the $|s\bar{s}\rangle - |\underline{36}\rangle$ mixing angle $\vartheta = 30°$ and obtain

$$\Gamma(f' \to K\bar{K}) = 74 \text{ MeV}$$

$$\Gamma(f' \to K\bar{K}^* + \bar{K}K^*) = 13 \text{ MeV}$$

$$\Gamma(\theta \to K\bar{K}) = 10 \text{ MeV}$$

$$\Gamma(\theta \to K\bar{K}^* + \bar{K}K^*) = 3 \text{ MeV}$$

$$\Gamma(f' \to \eta\eta) = 13 \text{ MeV}$$

$$\Gamma(\theta \to \eta\eta) = 1 \text{ MeV}.$$

Similar construction with the nonet ($\underline{3} \otimes \bar{\underline{3}}$) will not work due to the opposite sign of the recoupling coefficient to ηη, resulting in

$$\Gamma(\theta \to \eta\eta)/\Gamma(\theta \to K\bar{K}) > 1.$$

The ratio $\Gamma(f' \to K\bar{K}^* + \bar{K}K^*)/\Gamma(f' \to K\bar{K}) \approx 1/6$ obtained in the above model is marginally acceptable in view of the data on the reaction $K^-p \to K\bar{K}\pi\Lambda$ [8]. Our model predicts also small widths $\Gamma(\theta \to K\bar{K})$ and $\Gamma(\theta \to K\bar{K}^* + \bar{K}K^*)$ as required by the data, but the total decay width of f′ is too large (≈ 100 MeV). Sure enough, we could do much better playing with model free parameters and/or introducing a $|\underline{9}\rangle - |\underline{36}\rangle$ mixing. However we feel that there is no point in playing such a game at present level of the available experimental information. When one member of the $\underline{36}$-plet family is introduced, immediately arises a question — where are the others? We have no good answer to it. We can offer only a suggestion that the existence of the $qq\bar{q}\bar{q}$ state might depend on its possibility to mix with the $q\bar{q}$ state.

We are aware that the introduction of the $\underline{36}$-plet into the game creates probably more problems than it solves, but solutions of the θ(1670) puzzle should be sought out also in this direction. Much better experimental data for f′ and θ decay modes are necessary before any kind of mixing model can be reasonably confirmed.

The author would like to thank Drs J. Kwieciński and K. Rybicki for discussion.

REFERENCES

[1] E. D. Bloom, SLAC-PUB-2976 (1982) preprint.
[2] C. Edwards et al., *Phys. Rev. Lett.* **49**, 259 (1982).
[3] Mark II preliminary results (see Ref. [1]).
[4] I. Cohen, et al., *Phys. Rev. Lett*, **48**, 1074 (1982).
[5] H. J. Schnitzer, Brandeis University Preprint (1981).
[6] J. L. Rosner et al., UH-511-477-82 preprint.
[7] M. Althoff et al., (TASSO Collaboration), DESY 82-071 preprint.
[8] Ph. Gavillet et al., CERN/EP 82-98 preprint.
[9] T. Armstrong et al., *Phys. Lett.* **110B**, 77 (1982).
[10] S. Okubo, *Progr. Theor. Phys. Suppl.* **63**, 1 (1978).
[11] V. Chabaud et al., CERN/EP 82-117 preprint.
[12] N. P. Samios, *Rev. Mod. Phys.* **46**, 49 (1974).
[13] R. J. Jaffe, *Phys. Rev.* **D15**, 267 (1977).