Remarks on $\theta(1640)$.

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Summary. — We point out the possibility that $\theta(1640)$ is identified with the $f_1$ which has been suggested by Rosner and discuss the effects of $\theta(1640)$ on the reaction $\gamma\gamma \rightarrow \rho^0\rho^0$ near threshold.

Recently $\pi(1440)$ and $\theta(1640)$ with $J^{PC} = 0^{++}$ and $2^{++}$, respectively, have been observed in the radiative decays $\phi \rightarrow \gamma X$. Since the process $\phi \rightarrow \gamma X$ is a glueball favoured channel, they are the likely candidates for glueballs. However, there seem to be some problems with the identification of the $\theta(1640)$ as a glueball. The most serious point is the nonobservation $^1$ of a $\pi\pi$ decay mode of the $\theta(1640)$, in spite of the prediction $B(\theta \rightarrow \pi\pi) \approx 3B(\theta \rightarrow \eta\eta)$ derived from the postulated unitary singlet nature of the $\theta(1640)$.

Some authors $^{2,3}$ have said that a state with which $\theta(1640)$ might be identified is $(1/\sqrt{2})(u\bar{u} + d\bar{d})s\bar{s}$, because this state has no kinematically allowed fall-apart modes and cannot decay into $\pi\pi$. Then, $\theta \rightarrow \eta\eta$ and $\theta \rightarrow KK$ would be the important two-body decay modes. Although the present data $^{1,2}$ seem to favour the interpretation of the exotic state $^4$ for the $\theta(1640)$, in spite of the prediction $B(\theta \rightarrow \pi\pi) \approx 3B(\theta \rightarrow \eta\eta)$ derived from the postulated unitary singlet nature of the $\theta(1640)$, it is of course necessary to examine whether or not there is another interpretation for it. We wish to study this problem.

In a previous paper $^5$ we have suggested a model in which the $\pi(1440)$ can be identified with either the $H_1$ or the $H_2$ defined by

\begin{align}
(1) & \quad H_1 = \frac{[\eta'(1440) + G(1440)]}{\sqrt{2}} \\
(2) & \quad H_2 = \frac{[-\eta'(1440) + G(1440)]}{\sqrt{2}},
\end{align}

where one of them, \( \psi(1440) \), decays mainly via the intermediate \( \delta \pi \) state and the other via the intermediate \( \tau \pi \) state and \( G(1440) \) and \( \psi'(1440) \) are a glueball with \( J^{PC} = 0^{+} \) and a member of the radially excited pseudoscalar nonet, respectively (6). In ref. (5), we have shown that the data for \( \psi \rightarrow \gamma X \), particularly a strong \( (K \bar{K} \pi) \) signal and a weak \( (\pi \pi \pi) \) signal, can be explained well by the mixing model.

We try now to describe \( \psi(1640) \) along the same line with our approach (6) to the \( \psi(1440) \). For this purpose we pay attention to the mixing model for the gg and \( q\bar{q} \) states which has been introduced by Rosner (7). In his model, \( f(1270) \) is described by an admixture of \( q\bar{q} \) and gg components:

\[
|f\rangle = \cos \theta |qq\rangle + \sin \theta |gg\rangle ,
\]

and its orthogonal partner \( f^\perp \) is given by

\[
|f^\perp\rangle = -\sin \theta |qq\rangle + \cos \theta |gg\rangle .
\]

Under the assumption that \( f^\perp \) decouples from \( \pi \pi \), he has given the decay widths not only of the \( f \) but also of the \( f^\perp \) to a pair of \( 0^{-} \) mesons and has predicted that the mass of \( f^\perp \) lies in the region \((1.45 \div 1.87) \) GeV (7), that is \( M(f^\perp) = (1.66 \pm 0.21) \) GeV. This is almost the same as the mass of \( \psi(1640) \). Moreover, the lack of a \( \pi \pi \) decay mode is one of the most remarkable results for the experiments \( \psi \rightarrow \gamma \psi \).

On the basis of the fact that \( f^\perp \) seems to have properties similar to those of \( \psi(1640) \), we wish to suggest the following interpretation for \( \psi(1640) \): it is \( f^\perp \) rather than a glueball itself that corresponds to \( \psi(1640) \). Adopting this interpretation, in what follows we study and discuss the properties of \( \psi(1640) \).

Rosner (7) has predicted that

\[
\Gamma(f^\perp \rightarrow \eta \eta) \approx \frac{1}{4} \Gamma(f^\perp \rightarrow K \bar{K}) \simeq (0.5 \div 1.5) \text{MeV}
\]

and

\[
4 \leq \Gamma(f^\perp) \leq 40 \text{ MeV} .
\]

This is considerably small compared with the experimental value (1)

\[
\Gamma(\psi(1640)) = 220^{+100}_{-70} \text{ MeV} .
\]

In the estimation of \( \Gamma(f^\perp) \), he has regarded \( f^\perp \rightarrow 4\pi \) as the main decay mode. As is stated later, however, it is the decay process \( f^\perp \rightarrow \rho \rho(\omega \omega) \) that has a large effect on \( \Gamma(f^\perp) \). Probably the difference between the values of (6) and (7) mainly comes from the width \( \Gamma(f^\perp \rightarrow \rho \rho(\omega \omega)) \).

If the \( \psi(1640) \) is identified with the state \((1/\sqrt{2})(uu+dd)s\bar{s}\), on the other hand, the exotic state is below threshold for all kinematically allowed fall-apart modes and its decay width will be pretty narrow. It is impossible to explain the observed width (cf. eq. (7)) of \( \psi(1640) \) by the scheme.

In radiative decays of \( \psi \), \( f \) and \( f^\perp \) can be produced through the glueball (or \( |gg\rangle \) state), and it follows from eqs. (3) and (4) that the production ratio \( R \) of the former to

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