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Search for the glueball identification of $\theta(1640)$

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We examine the argument that $\theta(1640)$ is the tensor glueball. The difficulty of the identification of $\theta(1640)$ as a flavor-singlet state is shown by analyzing the decay mode of $\theta(1640)$. The search for decay events of $J/\psi \rightarrow \omega\theta$ is urged to decide whether $\theta(1640)$ is a tensor glueball or a quarkonium. If $\theta(1640)$ is a glueball, the $\omega\theta$ final state is suppressed in the decay of J/ψ. On the other hand, if θ is a radially excited state of the f meson, $\omega\theta$ is observed copiously as well as $\gamma\theta$.

Within the framework of QCD it has been believed that the glueballs should exist.[1] The discovered new mesons $\iota(1440)$ and $\theta(1640)$ (Ref. 2) are candidates for glueballs. In our previous papers,[3] we have investigated the pseudoscalar glueball by analyzing the meson decays and the two-photon decay. It was remarked that the decay mode and width of $\iota(1440)$ were consistent with that of the pseudoscalar glueball.

In this Brief Report, the possibility of $\theta(1640)$ being a tensor glueball is studied and an experimental test is proposed. First, we point out the difficulty of the identification $\theta(1640)$ as a tensor glueball by studying the decay modes of this meson. If $\theta(1640)$ is a tensor glueball and is an SU(3)-flavor-singlet state, flavor symmetry predicts the decay modes of the glueball as discussed by Lipkin.[4] According to this symmetry, the ratio of the decay amplitudes of an SU(3)-flavor-singlet state into two pseudoscalar mesons is

$$A(\underline{1}\rightarrow\pi^0\pi^0):A(\underline{1}\rightarrow\pi^+\pi^-):A(\underline{1}\rightarrow K^+K^-):(\underline{1}\rightarrow\eta\eta) = 1:\sqrt{2}:\sqrt{2}:1 \quad . \tag{1}$$

We take the decay width to be of the form

$$\Gamma \propto |A(\underline{1}\rightarrow 0^{-+}0^{-+})|^2 q^5 \exp(-q^2/8\beta^2) \quad , \tag{2}$$

where q is the momentum of a 0^{-+} meson in the center-of-mass system, and the form factor has the typical cutoff, $\beta^2=0.15\ \text{GeV}^2$ (Ref. 5). Then, the ratio of the decay widths is

$$\Gamma(\pi^0\pi^0):\Gamma(\pi^+\pi^-):\Gamma(K^+K^-):\Gamma(\eta\eta) = 3.3:6.5:2.7:1 \quad . \tag{3}$$

If the SU(3)-breaking effect is taken into account, the values of $\Gamma(K^+K^-)$ and $\Gamma(\eta\eta)$ may be reduced slightly. Since the experimental value of the decay width[2] is $\Gamma = 200^{+100}_{-70}$ MeV and the decay into $\pi^0\pi^0$ is not seen, $B(\theta\rightarrow\pi^0\pi^0) < B(\theta\rightarrow\eta\eta)$, the predicted ratio of (3) is inconsistent with the experimental one for the present. Thus, it is not favored that $\theta(1640)$ is a flavor-singlet state.

Let us consider the case that $\theta(1640)$ is a quarkonium. If $\theta(1640)$ is a radially excited state of the $f(1270)$ meson (f_R), the ratio of the decay widths is[5]

$$\Gamma(\pi^0\pi^0):\Gamma(\pi^+\pi^-):\Gamma(K^+K^-):\Gamma(\eta\eta) = 13:26:2.7:1 \quad . \tag{4}$$

This result is also inconsistent with the experimental one. In the case that $\theta(1640)$ is a radially excited state of the $f'(1515)$ meson (f'_R), the ratio is obtained as[5]

$$\Gamma(\pi\pi):\Gamma(K^+K^-):\Gamma(\eta\eta) = 0:2.7:1 \quad . \tag{5}$$

This ratio favors that $\theta(1640)$ is an $s\bar{s}$ radially excited state; however, the mass difference between $\theta(1640)$ and $f'(1515)$ is too small to identify $\theta(1640)$ with f'_R. Thus, the experimental and theoretical stiuation is not clear with respect to $\theta(1640)$. Further studies are needed to clarify the true character of $\theta(1640)$.

Recently, Cohen, Isgur, and Lipkin[5] pointed out that large interference terms between the ground and radially excited quarkonia can arise in the radiative decay of J/ψ. They showed that a broad $\eta\eta$ signal is automatically expected due to this interference in the 1500–1800-MeV region, and then proposed the measurement of the K^+K^- spectrum. In this Brief Report, we propose another experimental test in order to decide whether $\theta(1640)$ is a glueball or a quarkonium.

As shown in Fig. 1, $\theta(1640)$ is produced in the radiative decay of J/ψ. If $\theta(1640)$ is a glueball, the decay $J/\psi\rightarrow\omega\theta$ is caused by the electromagnetic interaction as shown in Fig. 2(a) or by higher-order effects of QCD [e.g., Fig. 2(b)]. The contribution of Fig. 2(a) can be estimated in the vector-meson-

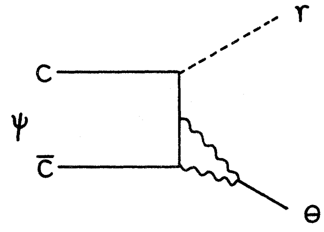

FIG. 1. The decay process of $\psi \rightarrow \gamma\theta$. A wavy and a dotted line denote a gluon and a photon, respectively.

dominance model. The transition amplitude of decay $J/\psi \rightarrow \omega\theta$ is given by

$$\langle \omega\theta | J/\psi \rangle = (e/f_\omega) \langle \gamma\theta | J/\psi \rangle \ , \tag{6}$$

where $f_\omega{}^2/4\pi = 14.8 \pm 2.8$.[6] Taking into account the S-wave phase space, we obtain the result

$$\Gamma(J/\psi \rightarrow \omega\theta) \simeq 4 \times 10^{-4} \Gamma(J/\psi \rightarrow \gamma\theta) \ .$$

On the other hand, the gluon-counting rule[7] suggests roughly the order of the contribution in Fig. 2(b) to be

$$\frac{\Gamma(J/\psi \rightarrow \omega\theta)}{\Gamma(J/\psi \rightarrow \gamma\theta)} \sim \frac{\alpha_s{}^8}{e_c{}^2 \alpha \alpha_s{}^2} \sim 10^{-2} \ , \tag{7}$$

where e_c is the charge of the charm quark and $\alpha_s = 0.2$ is taken. This ratio is possibly further suppressed by one order, because the coupling constant of $3g \rightarrow \omega$ as shown in Fig. 2(b) is proportional to $|\Psi_\omega(0)|^2/m_\omega{}^3$, where $\Psi_\omega(0)$ is the value of the wave function of the ω meson at the origin. Thus, if $\theta(1640)$ is a glueball, the decay into $\omega\theta$ comes from higher-order processes of QCD mainly, and then the value of $\Gamma(J/\psi \rightarrow \omega\theta)$ is suppressed as compared with $\Gamma(J/\psi \rightarrow \gamma\theta)$.

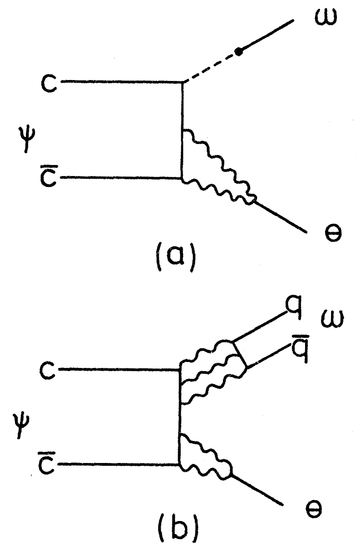

FIG. 2. The decay processes of $\psi \rightarrow \omega\theta$ in the case of θ = a glueball, caused by (a) the electromagnetic interaction and (b) the higher-order effect of QCD. The notations are same as in Fig. 1.

However, if $\theta(1640)$ is a radially excited state of $f(1270)$ or $f'(1515)$, it is expected that the events of $\omega\theta$ or $\phi\theta$ are produced copiously in the decay of J/ψ as shown in Fig. 3, as well as events of ωf and $\phi f'$.[8]

In order to estimate the decay width, we need a reliable model. The two-meson decay of J/ψ has been successfully explained using a mixing model by Freund and Nambu,[9] and by Robson.[10] For example, the decay $\psi \rightarrow \rho\pi$ proceeds as $J/\psi \rightarrow$ glueball $\rightarrow \omega \rightarrow \rho\pi$ is this model. As the coupling $g_{\omega\rho\pi}$ is known, only the value of the J/ψ-ω mixing is an unknown parameter.

Now, let us consider the decay $J/\psi \rightarrow \omega f$ and ωf_R. In this case, these decays proceed as $J/\psi \rightarrow$ glueball $\rightarrow \omega \rightarrow \omega f$ and ωf_R. The ratio

$$\Gamma(J/\psi \rightarrow \omega f_R)/\Gamma(J/\psi \rightarrow \omega f)$$

is independent of the value of J/ψ-ω mixing. Since we estimate only the ratio, we do not need the detailed dynamical assumption of J/ψ-ω mixing as do Freund and Nambu.[9] On the other hand, as the couplings $g_{\omega\omega f}$ and $g_{\omega\omega f_R}$ are unknown parameters, we must estimate the ratio $g_{\omega\omega f_R}/g_{\omega\omega f}$ using some model. Therefore, we use the quark-pair-creation model proposed by Yaouanc *et al.*[11] Since this model has been explained by many authors,[11-13] we comment only the degree of success briefly. The predictions by this model seem to fit the experimental decay width satisfactorily within a factor 2,[13] even if the decays are relativistic (such as $f \rightarrow \pi\pi$). Especially, this model nicely explains the small branching ratio of ρ'(2s state) $\rightarrow \pi\pi$ due to the node of a 2S wave function.[14]

To check the reliability of our estimate, we calculate first of all the ratio $\Gamma(J/\psi \rightarrow \rho\pi)/\Gamma(J/\psi \rightarrow \rho A_2)$, which is known experimentally as 0.70 ± 0.38.[15] Including phase space, the result is

$$\frac{\Gamma(J/\psi \rightarrow \rho A_2)}{\Gamma(J/\psi \rightarrow \rho\pi)} = \left| \frac{g_{\omega\rho A_2}}{g_{\omega\rho\pi}} \right|^2 \frac{E_\rho E_{A_2} K_{A_2}}{E_\rho E_\pi K_\pi} \ , \tag{8}$$

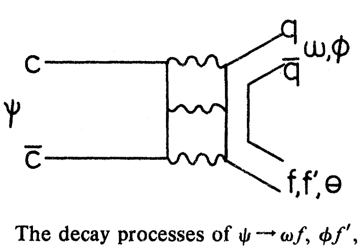

FIG. 3. The decay processes of $\psi \rightarrow \omega f$, $\phi f'$, $\omega\theta$, and $\phi\theta$ in the case of θ being a quarkonium. The notations are same as in Fig. 1.

where

$$\left|\frac{g_{\omega\rho A_2}}{g_{\omega\rho\pi}}\right|^2=\frac{5}{81}R^2\frac{{K_{A_2}}^4}{{K_\pi}^2}\exp\left[-\frac{R^2}{6}({K_{A_2}}^2-{K_\pi}^2)\right] , \tag{9}$$

here E and K are the energy and momentum, respectively, in the c.m. system, and R^2 is a parameter corresponding to the extension of the meson. We have used nonrelativistic Gaussian wave function[16] for simplicity. By a input of $R^2=8\ \mathrm{GeV}^{-2}$ as usual,[11] we get

$$\Gamma(J/\psi\to\rho A_2)/\Gamma(J/\psi\to\rho\pi)=0.88 . \tag{10}$$

This value fits the experimental value[15] 0.70 ±0.38 satisfactorily. Thus, the estimate of $g_{\omega\omega f_R}/g_{\omega\omega f}$ is also expected to be reliable.

Using a $2P$ nonrelativistic wave function as follows,[16]

$$\Psi(K)=-i\left(\frac{4}{15}\right)^{1/2}\frac{1}{\pi^{1/4}}R^{5/2}\left(\frac{5}{2}-\frac{K^2R^2}{4}\right)\times KY_1^m(\hat{K})e^{-K^2R^2/8} , \tag{11}$$

we obtain

$$\left|\frac{g_{\omega\omega f_R}}{g_{\omega\omega f}}\right|^2=\frac{729}{160}\frac{{K_{f_R}}^4(-\frac{16}{81}+\frac{2}{243}R^2{K_{f_R}}^2)^2}{{K_f}^4}\times\exp\left[-\frac{({K_{f_R}}^2-{K_f}^2)}{6}R^2\right] . \tag{12}$$

Putting $R^2=8\ \mathrm{GeV}^{-2}$ ($10\ \mathrm{GeV}^{-2}$), we predict (including phase space)

$$\Gamma(J/\psi\to\omega f_R)/\Gamma(J/\psi\to\omega f)\simeq 0.056\ (0.050) . \tag{13}$$

This ratio is suppressed somewhat due to the node of the $2P$ wave function and phase space. Using experimental values $B(J/\psi\to\omega f)=(23\pm8)\times10^{-4}$,[15] we get $B(J/\psi\to\omega f_R)\simeq1.3\times10^{-4}$. This value is not so small comparing with the observed value[2]

$$B(J/\psi\to\gamma\theta)\times B(\theta\to\eta\eta)\simeq5\times10^{-4} .$$

Let us consider the other case that $\theta(1640)$ is a radially excited state of the $f'(1515)$ meson. In this case, $\phi\theta$ is produced instead of $\omega\theta$ in the decay of J/ψ. The decay proceeds as $J/\psi\to\text{glueball}\to\phi\to\phi f_R'$. The result is obtained using $R^2=8\ \mathrm{GeV}^{-2}$ as

$$\Gamma(J/\psi\to\phi f_R')/\Gamma(J/\psi\to\phi f)=0.077 . \tag{14}$$

By input of the experimental value[17]

$$B(J/\psi\to\phi f')\times B(f'\to K\bar{K})=(3.4\pm1.3)\times10^{-4} ,$$

we predict $B(J/\psi\to\phi f_R')\simeq0.26\times10^{-4}$, where $B(f'\to K\bar{K})=1$ is assumed. Since this value is small compared to $B(J/\psi\to\gamma\theta)\times B(\theta\to\eta\eta)\simeq5\times10^{-4}$, it may be difficult to distinguish f_R' from a glueball. But it is not likely that $\theta(1640)$ is a radially excited state of $f'(1515)$, from consideration of its mass as discussed above.

In summary, we conclude that the search for the event $\omega\theta$ in the decay of J/ψ is very useful to decide whether $\theta(1640)$ is a glueball or a radially excited quarkonium. If $\theta(1640)$ is a tensor glueball, the production of $\omega\theta$ is suppressed by 2 or 3 orders compared to the $\gamma\theta$ event, but if θ is a radially excited state, $\omega\theta$ will be observed copiously as well as $\gamma\theta$. We expect that this experimental information will be available in the near future.

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