Decays of heavy quarkonia which violate the *OZI* rule

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It is shown that the decay widths for the decay of $\psi(3770)$ and $\Upsilon(10580)$ to $\pi^+\pi^-, K\overline{K}, \omega\pi^0, \omega\eta, \omega\eta', \rho\pi, \rho\eta, \rho\eta', K^*\overline{K}^*, K^*\overline{K}$ + cc and $\rho^+\rho^-$ are relatively large. Their sum is an order of magnitude greater than the three-gluon width if $\psi(3770)$ and $\Upsilon(10580)$ are $Q\overline{Q}$ states. These results can be used to determine the isospin of these states.

1. Some time ago, we pointed out the important role played by the direct decays $\phi\to\pi^+\pi^-, \omega\pi^0, \eta\pi^+\pi^-$ (Refs. 1 and 2), and possibly $\phi\to\rho\pi$ (Ref. 3), where "direct" means not due to $\phi\omega$ mixing. In the present letter we show that the partial widths of direct *OZI*-violating decays of heavy quarkonia,

$$\psi(3770),\ \Upsilon(10580)\to\pi^+\pi^-,\ K\bar{K},\ \omega\pi^0,\ \omega\eta,\ \omega\eta', \tag{1}$$

$$\rho\pi,\ \rho\eta,\ \rho\eta',\ K^*\bar{K}+\bar{K}^*K,\ \rho^+\rho^-,\ K^*\bar{K}^*,$$

are comparatively large. The sum of these widths for each of the specified quarkonia is an order of magnitude greater than the three-gluon width [if $\psi(3770)$ and $\Upsilon(4S)\equiv\Upsilon(10580)$ are $Q\overline{Q}$ states].

Direct decays which violate the *OZI* rule are described by nonplanar quark diagrams (Fig. 1). From the standpoint of the dispersion-relation approach, these decays are determined by the intermediate states $D\overline{D}, D^*\overline{D}, D^*\overline{D}^*...(B\overline{B}, B^*\overline{B}, B^*\overline{B}^*...)$, whose contributions must be canceled in order to satisfy the *OZI* rule. These expectations are supported by a study of the *OZI*-violating decays[4] $J/\psi\to\omega\pi^0, \omega\eta, \omega\eta', \rho\eta, \rho\eta', \phi\eta, \phi\eta', K^*\overline{K}+\overline{K}^*K$,[4] whose partial widths are much smaller than the three-gluon width. The decay $\Upsilon(1S)\to\rho^0\pi^0$ is also suppressed.[5]

If the first intermediate states $D\overline{D}$ ($B\overline{B}$) become real, we might expect to see a large imaginary part of an *OZI*-violating decay $\mathrm{Img}(\psi(3770)\to D\overline{D}\to\text{hadrons})$ [or $\mathrm{Img}(\Upsilon(4S)\to B\overline{B}\to\text{hadrons})$]. If the energies are such that several channels are open, we would expect their contributions to cancel out.

2. The imaginary parts of the coupling constants for decays (1) are given by the diagrams in Fig. 2. Here are the corresponding expressions, in which we are using $m_{\psi(3770)}\approx 2m_D$ and ignoring the difference between the masses of the pseudoscalar and vector mesons D, D^* (B, B^*) (expressions not based on these approximations are given in Ref. 6):

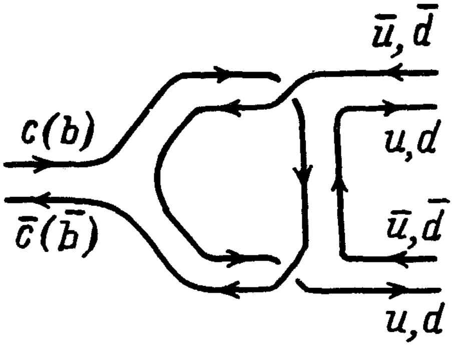

FIG. 1.

$$\mathrm{Im}g_{\pi\pi} \equiv \mathrm{Im}g(\psi(3770) \to D\bar{D} \to \pi^+\pi^-) \simeq -4g^2_{D^*D\pi^0} r_{\mp} \,, \tag{2}$$

$$\Gamma(\psi(3770) \to \pi^+\pi^-) = \frac{|g_{\pi\pi}|^2}{6\pi m^2_{\psi(3770)}} q^3_\pi \,,$$

$$\mathrm{Im}g_{\omega\pi} \equiv \mathrm{Im}g(\psi(3770) \to D\bar{D} \to \omega\pi^0) \simeq 4g_{D^*D\omega} g_{D^*D\pi^0} r_{\mp} \,, \tag{3}$$

$$\Gamma(\psi(3770) \to \omega\pi^0) = |g_{\omega\pi}|^2 q^3_\omega / 12\pi.$$

The other VP states are found from (3) in accordance with the quark model, with an $\eta\eta'$ mixing angle $\theta_p = -18^0$:

$$\mathrm{Im}g_1(\psi(3770) \to \rho^+\rho^-) \simeq -\frac{1}{2} g^2_{D^*D\rho} m^2_{\psi(3770)} r_{\mp},$$

$$\mathrm{Im}g_2(\psi(3770) \to \rho^+\rho^-) \simeq -4g^2_{\rho DD} r_{\mp}, \tag{4}$$

$$\mathrm{Im}G(\psi(3770) \to \rho^+\rho^-) \simeq g^2_{D^*D\rho} r_{\mp},$$

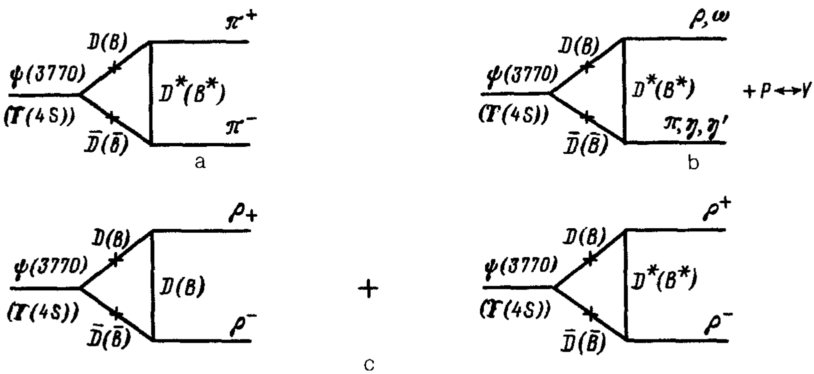

FIG. 2.

where g_1, g_2, and G are linear combinations of the invariant amplitudes of the decay $\psi(3770)\to\rho^+\rho^-$, which appear in the width expression

$$\Gamma(\psi(3770)\to\rho^+\rho^-)=\frac{q_\rho^3}{24\pi m^2_{\psi(3770)}}\left\{3|g_1|^2+8|g_2|^2\frac{m^2_{\psi(3770)}}{m_\rho^2}+\right\}$$

$$\times\left\{|G|^2q_\rho^4+\left[g_1\left(g_2\frac{m_{\psi(3770)}}{m_\rho}+Gq_\rho^2\right)^*+2Gq_\rho^2g_2^*\frac{m_{\psi(3770)}}{m_\rho}+\mathrm{cc}\right]\right\}. \tag{5}$$

In expressions (2)–(4),

$$r_\mp=\frac{g_{\psi(3770)DD}}{6\pi m^3_{\psi(3770)}}(q^3_{D^+}\mp q^3_{D^0}). \tag{6}$$

The upper (lower) sign corresponds to an isospin $I=0$ ($I=1$) of the $\psi(3770)$ meson. For the final states $K\bar{K}$, $K^*\bar{K}+\bar{K}^*K$, $K^*\bar{K}^*$, only the single charge combination $D\bar{D}$ contributes, so we need to replace $r_\mp$ by $(1/2)r_+$. Expressions for the case of $\Upsilon(4S)$ can be found through the obvious change in notation.

There is no absorption in the intermediate state in Fig. 2, since the energies are in the threshold region. A plausible incorporation of absorption in the final state leads to a factor of 1/2 in the expression for each of the amplitudes.[6]

At this point, it is difficult to say just what the size of the form factor $F=\exp[-R^2(t+m^2_{D^*(B^*)})]$ should be in the amplitudes for the reactions $D\bar{D}(B\bar{B})\to PP$, VP, VV (Fig. 2). We would naturally choose it with a radius R deter-

TABLE I.

Mode	$\psi(3770)$	$\Upsilon(4S)$
$\pi^+\pi^-$	$2\cdot10^{-6}(7\cdot10^{-5})$	$8\cdot10^{-8}(6\cdot10^{-6})$
$K\bar{K}$	$2\cdot10^{-5}$	$2\cdot10^{-6}$
$\omega\pi^0$	$2\cdot10^{-5}(7\cdot10^{-4})$	$5\cdot10^{-6}(4\cdot10^{-4})$
$\omega\eta$	$3\cdot10^{-4}(1\cdot10^{-5})$	$3\cdot10^{-4}(4\cdot10^{-6})$
$\omega\eta'$	$1\cdot10^{-4}(7\cdot10^{-6})$	$2\cdot10^{-4}(2\cdot10^{-6})$
$\rho\pi'$	$2\cdot10^{-3}(7\cdot10^{-5})$	$1\cdot10^{-3}(2\cdot10^{-5})$
$\rho\eta$	$1\cdot10^{-5}(3\cdot10^{-4})$	$4\cdot10^{-6}(3\cdot10^{-4})$
$\rho\eta'$	$7\cdot10^{-6}(1\cdot10^{-4})$	$2\cdot10^{-6}(2\cdot10^{-4})$
$K^*\bar{K}$+cc	$3\cdot10^{-4}$	$4\cdot10^{-4}$
$\rho^+\rho^-$	$3\cdot10^{-5}(1\cdot10^{-3})$	$1\cdot10^{-4}(8\cdot10^{-3})$
$K^*\bar{K}^*$	$7\cdot10^{-4}$	$3\cdot10^{-3}$
$3g$	$2\cdot10^{-4}$	$4\cdot10^{-4}$
	$\Sigma=4\cdot10^{-3}(3\cdot10^{-3})$	$\Sigma=5\cdot10^{-3}(13\cdot10^{-3})$

Numbers not in parentheses correspond to the isospin of the decaying $I=0$ state which occurs in the $Q\bar{Q}$ model (numbers which are in parentheses correspond to the $I=1$ state, which is possible in the case of the $D\bar{D}$ or the $B\bar{B}$ molecule).

mined by the position of the nearest two-particle state. For near-threshold energies we would then have $F \simeq 1/e = 1/2.718...$.

Our results are shown in Table I. We used a quark model in order to find the unknown coupling constants: $g_{D^*D\pi^0} \simeq g_{K^*K\pi^0}$, etc. The masses of the B mesons were taken from Ref. 7. By virtue of (6), the dependence of the calculated widths on the masses of the B mesons is very strong.

We would like to call attention to the mode $\Upsilon(4S) \to \rho^+\rho^-$. Even in the case of $(b\bar{b})$ quarkonium, this mode would have a respectable probability, comparable to the three-gluon probability. In the case of a $\Upsilon(4S) = B\bar{B}$ molecule with $I = 1$, on the other hand, the intensity of the $\rho^+\rho^-$ decay of $\Upsilon(4S)$ would be particularly large and could be used for an experimental test of the hypothesis of the $B\bar{B}$ molecule.

3. A comparison of our predictions with future experiments at B and C factories would provide information primarily on the form factors for exchange with bare charm and beauty. It might also be possible to test the naive quark model for mesons with bare charm and beauty. Finally, it might be possible to determine the isospins of $\psi(3770)$ and $\Upsilon(10580)$.

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