

# Are the $\psi$ and $\psi'$ mesons orbital excitations of $\omega$ and $\phi$ ?

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On the basis of the  $SU(6) \times O(3)$  quark model, the vector mesons  $\psi(3105)$  and  $\psi'(3695)$  are interpreted as orbital excitations of  $\omega$  and  $\phi$ . New mesons  $\tilde{\rho}(3100)$  ( $\Gamma_{\tilde{\rho}} < \Gamma_{\rho}$ ) and  $K(3400)$ , ( $\Gamma_{\tilde{K}} < \Gamma_{K^*}$ ) are predicted; they are members of the  $SU(3)$  nonet with  $J^{PC} = 1^{--}$  and  $L = 2$ .

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The recent discovery of the vector particles  $\psi(3105)$  and  $\psi'(3695)$ <sup>[1]</sup> has increased the interest in a search for symmetries higher than  $SU(3)$ . Several models were proposed to explain the nature of  $\psi$  and  $\psi'$ .<sup>[2]</sup> In particular, in the  $SU(4)$  model with the new additive quantum number ("charm"), the  $\psi$  meson is regarded as connected with the state of charmed quark and antiquark.<sup>[3]</sup>

In this article we attempt to explain the existence of  $\psi$  and  $\psi'$  mesons without involving a fourth quark. Namely, within the framework of the  $SU(6)$  quark model with orbital excitation, we consider the case when  $\psi$  and  $\psi'$  are members of the  $SU(3)$  nonet with  $J^{PC} = 1^{--}$  and  $L = 2$ , i. e., they are terms of the (35, 5) multiplet relative to the  $SU(6) \times O(3)$  group.

The existence of the  $\rho(1600)$  meson, which usually is ascribed to the  $1^{--}$  nonet with  $L = 2$ , can serve as an obstacle to such a distribution of the  $\psi$  and  $\psi'$ . However, the  $\rho(1600)$  meson, together with the not yet firmly

established  $\psi'(1250)$  meson, is a suitable candidate for  $\rho(770)$  radially excited states if account is taken of the masses and widths of the excited states of the vector mesons, obtained in certain quarks and dual resonance models.<sup>[4]</sup> For example, in the Veneziano model  $m_{\rho}^2 = (2n + 1)m_{\rho}^2$ , i. e.,  $m_{\rho 1} \approx 1.27$  GeV and  $m_{\rho 2} \approx 1.61$  GeV.

Let us estimate the possible masses and widths of the members of the vector nonet  $L = 2$ , starting from the assumption that  $\psi$  and  $\psi'$  are orbital excitations of  $\omega$  and  $\phi$ .

Taking into account the  $SU(6) \times O(3)$  symmetry, one should expect the mixing for the particles with  $I = Y = 0$  and  $J^{PC} = 1^{--}$ ,  $2^{--}$ ,  $3^{--}$  to be close to ideal, whereas  $2^{+-}$  mesons with  $Y = I = 0$  will be almost pure states of the singlet and octet. In this case the masses of the members  $1^{--}$  of the nonet satisfy the Okubo formulas.<sup>[5]</sup>

We shall use the symbol  $\rho$  for the mesons with  $I = 1$ , and  $\tilde{K}$  for those with  $I = 1/2$ .

The Okubo formulas yield for the  $\tilde{\rho}$  and  $\tilde{K}$  masses the values  $m_{\tilde{\rho}} \approx m_{\tilde{\psi}} \approx 3105$  MeV and  $m_{\tilde{K}} = [(1/2)(m_{\tilde{\psi}}^2 + m_{\tilde{\rho}}^2)]^{1/2} \approx 3400$  MeV. Thus, the peak  $\sim 3105$  MeV in the  $e^+e^-$  channel can be explained in two ways: either  $\tilde{\rho}^0$  and  $\psi$  are very close in mass and make a common contribution to the  $e^+e^-$  cross section, a contribution seen as a single resonance, or else<sup>1)</sup>  $m_{\tilde{\rho}^0} - m_{\tilde{\psi}} \approx 15$  MeV, but a mixed state of  $\tilde{\rho}^0$  and  $\psi$  of the type  $5^{-1/2}(2\tilde{\rho}^0 - \tilde{\psi})$  is observed in the  $e^+e^-$  channel and is connected with the photon, while the other state of the type  $5^{-1/2}(\tilde{\rho}^0 + 2\tilde{\psi})$  is suppressed in the  $e^+e^-$  channel.

Definite mass relations should exist between the members of the (35, 5) plet. What kind of interactions between quarks can lead to so large masses of the  $1^{--}$  mesons? Within the framework of the composite model of the mesons,<sup>6)</sup> in the general case, we have

$$H_{q\bar{q}} = H_S + H_{SS} + H_{SL} + H_T + H_U,$$

where  $H_A$  denotes the contributions made to the Hamiltonian  $H_{q\bar{q}}$  by the scalar, spin-spin, spin-orbit, tensor forces and by the forces responsible for the  $SU(3)$  splitting, respectively. We assume, as is customary, that the term  $2^{--}$  of the nonet with  $I=1$  is the  $F_1(1540)$  meson, whose spin and parity have not been firmly established. Then, taking into account the masses of the  $g(1680)$  meson with  $J^{PC} = 3^{--}$  and  $A_3(1640)$  meson with  $J^{PC} = 2^{--}$ , we arrive at the conclusion that for the multiplet with  $L=1$  an important role should be played by the tensor force between two quarks. The ratio of the spin-spin, spin-orbit, and tensor forces, say for the  $2^{--}$  nonet, will be  $H_{SS} : H_{SL} : H_T \approx 1.4 : 1 : 2.7$ . If the principal role is played by the spin-spin and spin-orbit interaction, then the member  $2^{--}$  of the nonet with  $I=1$  should have a mass  $\sim 2500$  MeV.

We present certain decay channels for  $\tilde{\rho}$ ,  $\psi$ ,  $\psi'$ ,  $\tilde{K}$ :  $\rho \rightarrow (\rho f'(1514), B(1235) \text{ and } \eta \text{ or } \eta')$ ;  $\psi, \psi' \rightarrow (3\pi, 5\pi, K\bar{K})$ ; and  $\tilde{K} \rightarrow (K\pi, K^*A_2, K\pi\pi)$ . These channels point to a possible difficulty of observing  $\tilde{\rho}$  with the aid of the decay products. For example, this will be the case if the dominant decay is  $\tilde{\rho} \rightarrow B\eta$ , since  $B \rightarrow \omega\pi$  and  $\eta \rightarrow 2\gamma, 3\pi^0$ .

One should expect a decrease of the hadron width  $\Gamma_h$

of the members  $1^{--}$  of the nonet with  $L=2$  in comparison with  $\Gamma_h$  of the members of the main nonet. Actually  $\Gamma_h \sim [(kR)^L / (2L+1)!!]^2$ , where  $k$  is the average momentum of the decay and  $R$  is the "radius of the meson".<sup>17)</sup> For example, at  $k \sim 1$  GeV/c and  $R \sim 0.2F$ , i.e.,  $kR \sim 1$ , the widths decrease rapidly with increasing  $L$ . From this point of view, the experimentally verifiable inequality  $\Gamma_{\psi'} > \Gamma_{\psi}$  and the existence of the decay  $\psi' \rightarrow \psi 2\pi$  indicates either that the Zweig rule does not hold for states with  $L=2$ , or that the ideal mixing between  $\psi$  and  $\psi'$  is violated.

Thus, the observed properties of  $\psi$  and  $\psi'$  can be explained within the framework of the quark model. The search for real mesons corresponding to  $\tilde{\rho}(3105)(\Gamma_{\tilde{\rho}} < \Gamma_{\rho})$  and  $\tilde{K}(3400)(\Gamma_{\tilde{K}} < \Gamma_{K^*})$  would be important for the explanation of the symmetry that is satisfied by  $\psi$  and  $\psi'$  mesons.

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