Vector Meson Dominance and the $\psi(3105)$ and $\psi(3700)$ Mesons.

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If one makes $SU'_6 \otimes SU''_3$ -type considerations on 1^- vector mesons, one can fit better the ψ phenomenology without introducing an awkward SU_3 breaking, $SU'_6 \otimes SU''_3$ being the extension of SU_6 to Han-Nambu's $SU'_3 \otimes SU''_3$ scheme. Consider the Han-Nambu scheme (or the SUB scheme) and *no* SU''_3 breaking. SU''_3 nonsinglet hadrons can decay into ordinary hadrons only through electromagnetic (or weak) interactions. The electromagnetic interaction being invariant under U'' -spin in the Han-Nambu model, the eigenstates of the Hamiltonian (for a given component of SU'_3) will be degenerate. $8''_{\pi^+}$ and $8''_{\pi^0}$; $8''_{K^+}$, $8''_{K^0}$ and $8''(U''=1, U''_3=0)$ will have exactly the same mass. $8''(U''=0)$ (that we will call 8_γ) is an isolated eigenstate. The U'' -spin doublet, singlet and triplet state mass differences are second-order electromagnetic, that is about $(1 \div 10)$ MeV. The same reasoning, after substitution of I'' -spin for U'' -spin, applies to the SUB model.

Only the SU''_3 nonsinglet states transforming like 8_γ under SU''_3 can be produced singly in e^+e^- annihilations or photoproduction experiments. One would then expect only $(\omega, 8_\gamma)$ and $(\varphi, 8_\gamma)$ states to be produced isolatedly in e^+e^- annihilation and through the SU'_3 -singlet components of ω and φ . ω and φ stand for the $(1/\sqrt{2})(\bar{p}p + \bar{n}n)$ and $\bar{\lambda}\lambda$ quark-antiquark states. One gets then instead of relation (6)

$$(10) \quad g\{(\omega, 8_\gamma) - \gamma\} = \sqrt{2}g\{(\varphi, 8_\gamma) - \gamma\}.$$

One could therefore tentatively interpret $\psi(3105)$ and $\psi(3695)$ to be the $(\omega, 8_\gamma)$ and $(\varphi, 8_\gamma)$ states. If one takes into account (2) and (10), $\sigma(e^+e^- \rightarrow \psi(3695)) = 0.42 \sigma(e^+e^- \rightarrow \psi(3105))$ for $(\omega, 8_\gamma) = \psi(3105)$ and $(\varphi, 8_\gamma) = \psi(3695)$ and for the opposite assignment $\sigma(e^+e^- \rightarrow \psi(3695)) = 1.67 \sigma(e^+e^- \rightarrow \psi(3105))$. Both $(\omega, 8_\gamma)$ and $(\varphi, 8_\gamma)$ can decay electromagnetically into $\bar{e}e$, $\bar{\mu}\mu$, $\gamma\gamma$, $\gamma\gamma'$, $\gamma\bar{K}K$, but only $(\omega, 8_\gamma)$ by Zweig's rule can decay into $\gamma + 2n\pi$ ($T=0$). Furthermore, all the channels

$$(a) \quad \psi(3695) \rightarrow \psi(3105) + \eta,$$

$$(b) \quad \psi(3695) \rightarrow \psi(3105) + 2\pi \ (T=0),$$

$$(c) \quad \psi(3695) \rightarrow \psi(3105) + 4\pi \ (T=0),$$

allowed by isospin and charge conjugation invariance, violate Zweig's rule. Channel (b) has an S -wave final state and a Q -value of 300 MeV, we expect it to be the dominant channel, larger than second-order electromagnetic decays and with a partial width of the order of 1 MeV.

The new resonance at 4.1 GeV ⁽¹⁰⁾ could be interpreted as a Regge or radial recurrence of $\psi(3105)$. $\psi(4100) \rightarrow \psi(3695) + 2\pi$ is forbidden by Zweig's rule, but $\psi(4100) \rightarrow \psi(3105) + \eta$ is allowed by this rule and should lead to a partial width of about 100 MeV. If $\psi(3105)$ and $\psi(4100)$ are $(\varphi, 8_\gamma)$, this would be its only large- Q -value decay mode into $\psi(3105)$; if they were $(\omega, 8_\gamma)$, also $\psi(4100) \rightarrow \psi(3105) + 2n\pi$ ($T=0$) would be allowed and give a partial width of about 100 MeV.

Where are the other members of the $(8+1, 8) 1^-$ multiplet? In particular $(\rho, 8_\gamma)$ and $(K^*, 8_\gamma)$. There are some difficulties with mass formulae; in naive quark models one expects $m(\varphi, 8_\gamma) - m(\omega, 8_\gamma) = m(\varphi) - m(\omega)$ and this is not verified. But in general from SU'_3 breaking and $(\omega, 8_\gamma)$ and $(\varphi, 8_\gamma)$ being $(1/\sqrt{2})(\bar{p}p + \bar{n}n)$ and $\bar{\lambda}\lambda$ one gets

$$(11) \quad m\{(\omega, 8_\gamma)\} + 2m\{(\varphi, 8_\gamma)\} + m\{(\rho, 8_\gamma)\} = 4m\{(K^*, 8_\gamma)\}.$$

We shall assume $(\omega, 8_\gamma) = \psi(3105)$ and $(\varphi, 8_\gamma) = \psi(3695)$ in the following discussion. If $\psi(3105)$ is to be narrow, the decay mode $(\omega, 8_\gamma) \rightarrow (\rho, 8_\gamma) + \pi$, allowed by Zweig's rule, has to be energetically forbidden, therefore $m\{(\rho, 8_\gamma)\} > 2.95$ GeV and from (11) $m\{(K^*, 8_\gamma)\} > 3.35$ GeV. Thus, also $\psi(3695) \rightarrow (K^*, 8_\gamma) + \bar{K}$, allowed by Zweig's rule, is forbidden energetically and consistent with a narrow $\psi(3695)$. On the other hand, if $m\{(\rho, 8_\gamma)\} < 3.55$ GeV,

$$\psi(3695) \rightarrow (\rho, 8_\gamma) + \pi$$

forbidden by Zweig's rule could be competitive with channel (b). If $m\{(K^*, 8_\gamma)\} < 3.6$ GeV, $\psi(4100) \rightarrow (K^*, 8_\gamma) + \bar{K}$ could be an important decay channel.

A remark on vector-meson dominance. When there is only one vector meson $(\omega, 8_\gamma)$, if its coupling to the photon is small, its coupling to the quarks must necessarily be large. On the contrary, in a generalized vector-meson dominance scheme $\psi(3105)$ coupling to quarks could be small and consequently also small its radiative-decay rate. Furthermore, in the present scheme, neutral channels (not just $\eta\gamma$, $\eta'\gamma$ etc.) could be present and give a substantial decay of $\psi(3105)$ into neutrals, leading to a larger than 100 keV width for $\psi(3105)$.

There are many other states in this scheme, corresponding to the other components of the SU'_3 octet, but they would not be produced singly in e^+e^- annihilations or photo-production; they would be produced in pairs of SU'_3 -octet particles. In the present scheme they would have (up to electromagnetic-mass differences) the same masses as the corresponding 8_γ -component of the SU'_3 octet.

Where is the $(8, 8)$ multiplet of pseudoscalars that with the preceding $(8+1, 8)$ vector mesons completes the $(35, 8)$ representation of $SU'_6 \times SU'_3$? Stability of $\psi(3105)$

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decay against the strong modes

$$\psi(3105) \rightarrow (\eta, 8_\gamma) + 3\pi \quad (T = 0),$$

$$\psi(3105) \rightarrow (\pi, 8_\gamma) + 2\pi \quad (T = 1),$$

$$\psi(3105) \rightarrow (K, 8_\gamma) + \bar{K}$$

requires $m\{(\eta, 8)\} > 2.7 \text{ GeV}$, $m\{(\pi, 8)\} > 2.8 \text{ GeV}$ and $m\{(K, 8)\} > 2.6 \text{ GeV}$. Stability of $\psi(3695)$ for decay into channels

$$\psi(3695) \rightarrow (\eta, 8_\gamma) + \varphi,$$

$$\psi(3695) \rightarrow (\pi, 8_\gamma) + K\bar{K} \quad (T = 1),$$

$$\psi(3695) \rightarrow (K, 8_\gamma) + \bar{K},$$

allowed by Zweig's rule, requires $m\{(\eta, 8_\gamma)\} > 2.7 \text{ GeV}$, $m\{(\pi, 8_\gamma)\} > 2.7 \text{ GeV}$ and $m\{(K, 8_\gamma)\} > 3.2 \text{ GeV}$. Thus, together they give $m\{(\eta, 8)\} > 2.7 \text{ GeV}$, $m\{(\pi, 8)\} > 2.8 \text{ GeV}$ and $m\{(K, 8)\} > 3.2 \text{ GeV}$. A $(1, 8)$ multiplet of pseudoscalars, degenerate in mass if no large mixing with the above $(8, 8)$ multiplet of pseudoscalars occurs, would have mass larger than 2.7 GeV . Heavy pseudoscalars decaying weakly would be a good search ground for hypothetical heavy neutral leptons.

What would happen if SU_3'' were broken like SU_3' by an interaction transforming like the eighth component of an octet of SU_3'' , $(1, 8_\eta)$? In the SUB model only $(\varphi, 8_\eta)$, $(\omega, 8_\eta)$ and $(\rho^0, 8_\eta)$ would couple to the photon and all would decay into SU_3'' -singlet hadrons to first order in SU_3'' breaking. An undesirable situation. Consider next the Han-Nambu model. The 8_γ components would split up into 8_{π^0} and 8_η components and also $(\rho^0, 8_\eta)$ would couple to the photon. How could one place these five states $(\omega, 8_{\pi^0})$, $(\varphi, 8_{\pi^0})$, $(\omega, 8_\eta)$, $(\varphi, 8_\eta)$ and $(\rho^0, 8_\eta)$? A solution could be to have $\psi(3105) = (\omega, 8_{\pi^0})$, $\psi(3695) = (\varphi, 8_{\pi^0})$, $(\omega, 8_\eta)$ and $(\rho^0, 8_\eta)$ near 4.1 GeV and predict with a $1/m^2$ mass formula $(\varphi, 8_\eta)$ to lie at 5.9 GeV . One would then need SU_3'' -octet pseudoscalars low enough to allow strong-decay modes for the 4.1 GeV resonances. Unless one finds further resonances of the ψ family, SU_3'' breaking does not seem necessary.