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The width of ψ (3105)

by

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We extend a weakly broken nonet symmetry of the vector mesons to SU(4) so as to include a new $c\bar{c}$ state ψ. From the masses we determine the mixing among ϕ, ω, ψ and thereby estimate $\Gamma(\psi \to \text{hadrons}) \approx 60$ keV. We discuss the significance of this for the case of a symmetry as badly broken as SU(4) must be if the new meson at 3.1 GeV is $c\bar{c}$.

A narrow resonance has been seen at $m_{e^+e^-} = 3.1$ GeV in $p + Be \to e^+e^- + X$ (1) and in $e^+e^- \to e^+e^-$, $\mu^+\mu^-$, hadrons (2),(3),(4). Preliminary reports indicate a total width $\Gamma \simeq 100$ keV and $\Gamma_{e^+e^-} \approx 6$ keV (5). There have been attempts to identify this with the $c\bar{c}$ ground state vector meson in the SU(4) (charm) scheme (6),(7),(8). The widths are then a problem. Using SU(4) for the photon-meson couplings f^{-1} would lead to $\Gamma_{e^+e^-} \approx 26$ keV. SU(4) for mf^{-1} would lead to a more reasonable leptonic width, and is needed for duality considerations in $e^+e^- \to$ hadrons anyway (6),(9).

So long as $\psi \approx c\bar{c}$, the hadronic decay below the charm threshold takes place by mixing of $c\bar{c}$ to normal quark pairs, or of ψ to ω, ϕ if one restricts oneself to the ground state vector mesons. We discuss $\Gamma_{\text{had.}}$ in this context; while we can offer no final clarifications, we believe that suppression of the hadronic width of the ψ can be made plausible /1/.

We extend Okubo's nonet Ansatz (10) to SU(4) by writing the vector meson matrix in lowest order as

$$V = \begin{pmatrix} \frac{\omega+\rho}{\sqrt{2}} & \rho^+ & K^{*+} & \bar{D}^{*0} \\ \rho^- & \frac{\omega-\rho}{\sqrt{2}} & K^{*0} & D^{*-} \\ K^{*-} & \bar{K}^{*0} & \phi & F^{*-} \\ D^{*0} & D^{*+} & F^{*+} & \psi \end{pmatrix} \qquad (1)$$

Meson masses as well as the small deviation from this 16-plet symmetry are obtained from the mass Lagrangian

$$\frac{1}{4}\, tr\left(\{\mathcal{M}^2, V\}\, V\right) + \frac{1}{2} m_3^2 \left(tr\, V\right)^2 ; \quad \mathcal{M}^2 = m_0^2 \underset{\sim}{1} + m_1^2 \underset{\sim}{Y} + m_2^2 \underset{\sim}{C} \tag{2}$$

where $\underset{\sim}{Y}$ and $\underset{\sim}{C}$ are matrices whose 3-3 and 4-4 elements are unity; the others are zero. Then m_3^2 is a mixing parameter for which we shall assume $m_3^2 \ll m_0^2, m_1^2, m_2^2$. Diagonalizing the mass matrix we obtain ($m_\rho = \rho$, etc) a small mixing between ϕ, ω, and ψ [2]:

$$\delta\theta_{\omega\phi} \approx \frac{\sqrt{2}\, m_3^2}{m_1^2}, \quad \delta\theta_{\omega\psi} \approx \frac{\sqrt{2}\, m_3^2}{m_2^2}, \quad \delta\theta_{\phi\psi} \approx \frac{m_3^2}{m_2^2 - m_1^2}$$

Numerically, $\delta\theta_{\omega\phi} \approx 0.7 \times 10^{-1}$, $\delta\theta_{\omega\psi} \approx 0.3 \times 10^{-2}$ and $\delta\theta_{\phi\psi} \approx 0.2 \times 10^{-2}$. The first mixing angle is in good agreement with $\Gamma(\phi \to \rho\pi) \approx 0.88$ MeV[12]. Estimation of $\Gamma(\psi \to \text{hadrons})$ requires further assumptions. We take the following:

(i) From universality of the vector meson couplings, we expect hadronic couplings $g_{\psi AB}$ proportional to f_ψ, the (inverse) coupling of the ψ to the photon. We assume that this proportionality holds even when the symmetry is broken.

(ii) We assume that when the symmetry is broken, mf_ψ^{-1} retains its symmetry value (we have already remarked on this).

We also take the phase space proportional to the mass of the decaying particle[3]. Then

$$\Gamma(\psi \to \omega \to had.) \approx \left(\frac{m_\psi}{m_\phi}\right)^3 \left(\frac{\delta\theta_{\omega\psi}}{\delta\theta_{\omega\phi}}\right)^2 \Gamma(\phi \to \omega \to had.) \simeq 42\,\text{keV} \tag{3}$$

$$\Gamma(\psi \to \phi \to had.) \approx \left(\frac{m_\psi}{m_\phi}\right)^3 \left(\frac{\delta\theta_{\phi\psi}}{\delta\theta_{\omega\phi}}\right)^2 \Gamma(\phi \to \omega \to had) \simeq 21\,\text{keV}$$

whence $\Gamma(\psi \to \text{hadrons}) \approx 60$ keV. Evidently, we expect $\approx 1/3$ of the decay events to contain a $K\bar{K}$ pair. The input assumptions obviously degrade the output to an order of magnitude estimate; we claim no more for it.[4] The peculiar nature of broken SU(4) has as a consequence that while the result for $\Gamma(\phi \to \rho\pi)$ should be reasonably good because of the mixing is between nearby states, our results for Γ_ψ may be questioned: mixing to states nearby in mass cannot a priori be neglected in comparison to $\psi - \omega$ and $\psi - \phi$ mixing. As justification for our order of magnitude estimate we only remark: (i) Mixing of the ground state $c\bar{c}$ with heavy charmed quarks to a $q\bar{q}$ state of light quarks may be small. Following the parton model, we may expect the wave function of the $q\bar{q}$ final state to resemble a plane wave (free particles) at short distances. The overlap of this wave function with that of the initial state may be expected to be small if the $c\bar{c}$ state has a radius comparable to that of the other vector mesons. This is because a (free) parton wave function should have many oscillations inside the range of the $c\bar{c}$ wave function. This leads to small mixing, though the effect is hard to quantify without a specific model. (ii) In the relativistic quark model, the vector meson states nearby in mass to the ψ have (radial) wave functions nearly orthogonal to that of the ψ for a potential of the same range as that of $c\bar{c}$ states. The mixing could be then as we have discussed-between ψ and ω, ϕ [5].

It appears to us interesting and instructive to note that the allowed hadronic decays of certain states like the ψ can be suppressed not because the symmetry breaking is small, but because it is large. In our case, $\delta\theta_{\omega\psi}, \delta\theta_{\phi\psi} \to 0$ as $m^2_\psi \to \infty$.

Footnotes

/1/ After this was written, we became aware of a dissimilar attempt to explain Γ_ψ ; Ref. (7).

/2/ Here, $\delta\theta = \theta - \theta_0$, $\theta_0 = \tan^{-1} 1/2$ being the ideal mixing angle. Besides this, we have $m_1^2 \approx \phi^2 - \rho^2$; $m_2^2 \approx \psi^2 - \rho^2$ and $m_3^2 \approx 1/2(\omega^2 - \rho^2) \approx \phi^2 + \rho^2 - 2\overset{*}{K}{}^2$, for first order in m_3^2 . Eliminating m_3^2 entirely,

$$(\omega^2-\rho^2)(\phi^2-\rho^2)(\psi^2-\rho^2) = 2(\overset{*}{K}{}^2-\rho^2)(\overset{*}{D}{}^2-\rho^2)(\rho^2+\omega^2+\phi^2+\psi^2-2\overset{*}{K}{}^2-2\overset{*}{D}{}^2)$$

$$(\omega^2+\phi^2-2\rho^2)(\psi^2-\rho^2) + (\omega^2-\rho^2)(\phi^2-\rho^2) = 4(\overset{*}{K}{}^2-\rho^2)(\overset{*}{D}{}^2-\rho^2)$$
$$+\frac{3}{2}(\overset{*}{K}{}^2+\overset{*}{D}{}^2-2\rho^2)(\rho^2+\omega^2+\phi^2+\psi^2-2\overset{*}{K}{}^2-2\overset{*}{D}{}^2)+\frac{5}{8}(\phi^2+\omega^2+\rho^2+\psi^2-2\overset{*}{K}{}^2-2\overset{*}{D}{}^2)^2$$

follows, analogous to Schwinger mass formula(11),

/3/ This might hold if we take the total decay amplitude proportional to a (dimmensionless) coupling $g_{\psi A\bar{B}}$; then $\Gamma_{tot} \propto \sum_{had.} | g_{\psi \to hadrons} |^2 m_\psi$.

/4/ If we take this determination of the mixing angle seriously, independent of the extra assumptions needed to get Γ_ψ, then the very small mixing may lead to a suppression of hadronic ψ-production even greater than would be expected from the suppression of Γ_ψ compared to a "normal" hadronic width.

/5/ This remark is due to M. Krammer, who has also considered the more realistic case of potentials of unequal radii for $c\bar{c}$ and $q\bar{q}$(= $c\bar{c}$) states. (private communication)

References

(1) J.J. Aubert et al., Phys. Rev. Letters 33, 1404 (1974).

(2) J.-E. Augustin et al., Phys. Rev. Letters 33, 1406 (1974).

(3) C. Bacci et al., Phys. Rev. Letters 33, 1408 (1974)

(4) DASP and PLUTO Collaborations (to be published)

(5) J.D. Jackson, Lawrence Radiation Laboratory Physics Notes (unpublished)

(6) S. Kitakado, S. Orito and T.F.Walsh, DESY Preprint (1974).

(7) T. Appelquist and H.D. Politzer, Harvard Preprint (1974);
A. De Rujula and S.L. Glashow, Harvard Preprint (1974).

(8) CERN Theory Division Collaboration
H. Harari, "Psi-chology" (SLAC preprint, 1974)
C. Callan et al, Princeton Preprint, 1974

(9) D.Schildknecht and F. Steiner, DESY preprint (1974)

(10) S. Okubo, Phys. Letters 5, 165 (1963).

(11) J. Schwinger, Phys. Rev. Lett. 12,237 (1964)

(12) Particle Data Group Booklet