particle has normal electromagnetic couplings, but is very weakly coupled to hadrons ($\Gamma'/\Gamma_\rho \sim 10^{-4}$).

A family of unit-spin particles with just these characteristics had been anticipated in a new unified theory of electromagnetic and weak interactions,[2] one that was designed to account for the empirical absence of $\Delta Y = 1$ neutral currents by abandoning the Cabibbo rotation that creates the theoretical problem. It was replaced by a mixing between two types of unit-spin mesons that is produced by the SU(3) symmetry-breaking interaction, combined with the hypothesis that the second, primed, set is only weakly coupled to the familiar low-lying hadrons. That hypothesis has now received impressive support from the new experimental discovery.

This interpretation of the new particle also enables one to go further and to assign a substantial fraction of the observed hadronic decay rate, Γ_h', to the effect of electromagnetic mixing with the "normal" spin-1 mesons. A short calculation, based on the couplings introduced in Ref. 2, which could be characterized as a generalized vector-dominance model, leads to the result that the branching ratio between hadronic and e^+e^- decay is

$$\Gamma_h'/\Gamma_e'|_{\text{e.m.}} = R(m'),$$

where $R(m')$ is the nonresonant branching ratio between hadronic and $\mu^+\mu^-$ production in e^+e^- collisions at the center-of-mass energy $m' = 3.1$ GeV. The experimental values that have been found for the latter are in the interval 3–4, which is less than, but not of a different order of magnitude than the decay branching ratio. Since neither the experiments nor the theoretical model have a definitive status, this rough coincidence raises, but does not settle, the interesting question of whether all of the hadronic decay can be attributed to electromagnetic mixing.[3]

Another consequence of this interpretation is the anticipated existence of other such long-lived particles, constituting all the counterparts of ρ^0, ω, and φ. Perhaps these have already been seen in the Brookhaven National Laboratory experiments.

Note added.—The public announcement by the Stanford Linear Accelerator group of a second very sharp resonance at 3.7 GeV lends additional support to this interpretation, and diminishes the appeal of any alternative interpretation that does not provide a natural setting for more than one such particle.

*Work supported in part by the National Science Foundation.

[1]All the numbers cited are inferred from J.-E. Augustin *et al.*, Phys. Rev. Lett. 33, 1406 (1974).

[2]J. Schwinger, Phys. Rev. D 8, 960 (1973).

[3]Nothing in the original conception excludes a residual hadronic coupling. But, even then, there is the possibility that such coupling could be an indirect consequence of electromagnetic interaction.

Possible Explanation of the New Resonance in e^+e^- Annihilation*

S. Borchardt, V. S. Mathur, and S. Okubo
University of Rochester, Rochester, New York 14623
(Received 18 November 1974)

We propose that the recently discovered resonance in e^+e^- annihilation is a member of the $15\oplus1$ dimensional representation of the SU(4) group. This hypothesis is consistent with the various experimental features reported for the resonance. In addition, we make a prediction for the masses of the charmed vector mesons belonging to the same representation.

Very recently a new type of resonance which couples to the hadrons and the leptons has been discovered[1] both at Stanford Linear Accelerator Center (SLAC) and at Brookhaven National Laboratory. Denoting this structure as $\psi(3105)$, SLAC has quoted the mass and width of this resonance as

$$M_\psi = 3.105 \pm 0.003 \text{ GeV},$$
$$\Gamma_\psi \leq 1.3 \text{ MeV}. \tag{1}$$

In this note, we discuss the theoretical interpretation of this structure. For simplicity, we assume the spin of ψ to be 1. Writing the effective interaction of ψ with the electron-positron pair as

$$H' = ig\bar{e}\gamma_\mu(a+b\gamma_5)e\psi_\mu,\quad |a|^2+|b|^2=1, \tag{2}$$

the total production cross section of ψ, integrated over the width of ψ, is computed to be

$$\int ds\,\sigma(e\bar{e}\to\psi)=\pi g^2. \tag{3}$$

From the experimentally measured cross section, we estimate[2]

$$g^2=2.4\times10^{-5}. \tag{4}$$

Next using this value, we compute the partial decay width for $\psi\to e\bar{e}$ to be

$$\Gamma(\psi\to e\bar{e})=(g^2/12\pi)M_\psi\approx2.0\text{ keV}. \tag{5}$$

Experimentally, from the figures in Ref. 1, we roughly estimate $\Gamma(\psi\to e\bar{e})/\Gamma(\psi\to\text{all})\approx\frac{1}{25}$, so that we expect

$$\Gamma(\psi\to\text{all})\approx50\text{ keV}. \tag{6}$$

We propose that ψ is a member of the $15\oplus1$ dimensional representation V_α ($\alpha=0, 1, \ldots, 15$) of SU(4). This representation for the vector mesons (1^-) will contain the usual nonet ($\rho, K^*, \omega, \varphi$), an SU(3) charm-carrying triplet (C_u, C_d, C_s) consisting of the $I=\frac{1}{2}$ vector mesons C_u and C_d and an $I=0$ strangeness-carrying meson C_s, a corresponding charge conjugate SU(3) triplet ($\bar{C}_u, \bar{C}_d, \bar{C}_s$), and the uncharmed meson ψ. Note that ω, φ, and ψ are identified with the physical states resulting from a mixing between the V_0, V_8, and V_{15} members of the representation. We claim that the various experimental features reported for ψ are consistent with this hypothesis. In addition, we predict the masses of the charmed mesons.

First, we would like to point out that this hypothesis can explain the value of g in Eq. (4) obtained from experimental results. We shall assume that parity is conserved in the interaction (2); later we shall discuss possible ways of testing this assumption. Assuming (as for ρ, ω, and φ) that ψ is coupled to the $e\bar{e}$ system through a virtual photon exchange, we obtain from Eq. (3)

$$g^2=(4\pi\alpha)^2G_\psi^2/M_\psi^4, \tag{7}$$

where α is the fine structure constant and G_ψ is the effective coupling between ψ and the photon. Now G_ψ can be estimated from the following considerations. Assuming that the electromagnetic current has, besides the usual structure $V_\mu^3+(1/\sqrt{3})V_\mu^8$, an extra contribution xV_μ^{15} in the SU(4) theory, where[3] $x\approx1$, we may use Weinberg's first spectral function sum rule to estimate G_ψ, if we neglect the mixing problem. Using the *Ansatz* of pole dominance for spectral functions, we estimate

$$G_\psi^2/M_\psi^2\approx G_\rho^2/M_\rho^2. \tag{8}$$

With the experimental value for G_ρ or using the Kawarabayashi-Suzuki-Riazuddin-Fayyazuddin relation[4] $G_\rho^2/M_\rho^2=f_\pi^2$, where f_π is the π-decay constant (numerically $f_\pi\approx m_\pi$, the pion mass), we obtain from Eqs. (7) and (8)

$$g^2\approx1.7\times10^{-5} \tag{9}$$

which is close to the result of Eq. (4).

We now turn to the intriguing question why the width of ψ should be as small as the result quoted in Eq. (1) or obtained in Eq. (6). Essentially this arises from considerations of ω, φ, ψ mixing which lead to the result that ψ has predominantly a $\bar{\mathcal{P}}'\mathcal{P}'$ quark structure ($\mathcal{P}'$ is the fourth charm-carrying quark) with very small admixtures of $(\bar{\mathcal{P}}\mathcal{P}+\bar{\mathfrak{N}}\mathfrak{N})$ and $\bar{\lambda}\lambda$. This is not unexpected and the situation here is analogous to the usual ω, φ mixing theory, where φ has predominantly a $\bar{\lambda}\lambda$ quark structure. Physically this implies that the decay of ψ into ordinary hadrons is highly suppressed. Furthermore, if the charmed-particle masses are ≥1.5 GeV, decays like $\psi\to C\bar{C}$ would be energetically forbidden. In order to obtain the mass formulas for broken SU(4), we assume in direct generalization of the SU(3) theory, that the mass splitting arises from an interaction

$$H_{\text{int}}=T_8+\alpha T_{15} \tag{10}$$

where T_8 and T_{15} belong to the same 15-plet of SU(4). Note that T_{15} breaks SU(4) to the level of SU(3), and T_8 breaks SU(3) down to SU(2) in the usual manner.

The matrix elements of the squared mass matrix for the $15\oplus1$ representation of vector mesons V_α can then be written as

$$(M^2)_{ij}=\bar{M}^2\delta_{ij}+D(d_{i8j}+\alpha d_{i15j}),\quad (M^2)_{0i}=A(\delta_{8i}+\alpha\delta_{15i}),\quad (M^2)_{00}=\bar{M}_0^2, \tag{11}$$

where $i,j=1, \ldots, 15$, $\bar{M}^2$ and $\bar{M}_0^2$ are the SU(4) invariant squared masses of the 15-plet and singlet, respectively, and D and A are the reduced matrix elements. The matrix (11) contains the off-diagonal matrix elements $(M^2)_{8,15}$, $(M^2)_{0,8}$, $(M^2)_{0,15}$. Diagonalizing the matrix in this sector, we can determine the five unknown parameters in (11) by using the known masses of ρ, K^*, ω, φ, and ψ. Numerically we obtain the values[5]

$$\overline{M}^2 = 2.8\ \text{GeV}^2, \quad D = -0.23\ \text{GeV}^2, \quad \alpha = 21.6,$$
$$\overline{M}_0^{\,2} = 3.5\ \text{GeV}^2, \quad A = -0.19\ \text{GeV}^2. \tag{12}$$

Furthermore, the physical states φ, ω, and ψ are to a very good approximation given by the simple relations

$$\varphi = \cos\theta\, V_8 - \sin\theta\, \tfrac{1}{2}(\sqrt{3}\, V_0 + V_{15}),$$
$$\omega = \sin\theta\, V_8 + \cos\theta\, \tfrac{1}{2}(\sqrt{3}\, V_0 + V_{15}), \tag{13}$$
$$\psi = \tfrac{1}{2}(V_0 - \sqrt{3}\, V_{15}),$$

where θ is the usual ω, φ mixing angle in the SU(3) theory. Note in particular that in terms of quark content $\psi \approx |\overline{\mathcal{P}}'\mathcal{P}'\rangle$. Our numerical analysis in fact shows that the admixture of quark structures $(\overline{\mathcal{P}}\mathcal{P} + \overline{\mathcal{N}}\mathcal{N})$ and $\overline{\lambda}\lambda$ in the state ψ is less than 5%. As an illustration we find that the width for $\psi \to K\overline{K}$ is about 8 keV. We point out however that this width is very sensitive to the mass of the ρ. For example, if we reduce the mass of the ρ by 2% the calculated width is reduced by a factor 0.03 to about 0.23 keV.

The numerical values in (12) predict the following masses for charmed vector mesons

$$M(C_u) = M(C_d) = 2.19\ \text{GeV}$$
$$M(C_s) = 2.22\ \text{GeV}. \tag{14}$$

Using the same value for α in the mass formulas for pseudoscalar mesons, we find almost the same masses for the corresponding charmed pseudoscalar mesons. These charmed particles could decay weakly into the usual hadrons and leptons, and for short enough lifetime could have escaped detection.[6] If we believe in the Glashow-Iliopoulos-Maiani construction[7] for the weak charged currents, it should be noted that for the emitted hadrons, the Cabibbo angle favors decay modes where at least one strange particle is produced, so one would expect predominantly the $K\pi$, $K\overline{K}$, or $K\pi\pi$, etc., as final particle states.

It is interesting to note that if we define

$$G = g^2/M_\psi^{\,2}$$

then using the estimate (4), we see that G is numerically also close to the usual Fermi constant G_F of weak interactions.[8] The identification of ψ with the intermediate vector-boson mediating weak interactions, at a mass value given by (1), would contradict the mass constraint imposed by the currently popular unified gauge theory models of weak and electromagnetic interactions.[9] Experimentally, the question can be settled in principle by investigating whether parity is conserved or not in the two- and three-body decays of ψ, in much the same fashion as was done for the θ and τ modes of decay of the kaon.

Details of this paper with further developments of our hypothesis will be published later. We would like to thank Professor T. Ferbel and Dr. D. Weingarten for stimulating discussions.

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*Work supported in part by the U. S. Atomic Energy Commission.

[1]J.-E. Augustin *et al.*, Phys. Rev. Lett. 33, 1406 (1974); J. J. Aubert *et al.*, Phys. Rev. Lett. 33, 1404 (1974).

[2]We have fitted the experimental peak in Ref. 1 with a Breit-Wigner form in estimating the integral in (3).

[3]The structure of the electromagnetic current depends on the charge assignment of the quarks. A more precise determination of G_ψ for different structures of the current will be discussed elsewhere.

[4]K. Kawarabayashi and M. Suzuki, Phys. Rev. Lett. 16, 255 (1966); Riazuddin and Fayyazuddin, Phys. Rev. 144, 1071 (1967).

[5]There are other possible solutions which we do not discuss here.

[6]A new particle reported by K. Niu, E. Mikumo, and Y. Maeda, Prog. Theor. Phys. 46, 1644 (1971), in a cosmic-ray event at a mass ≈ 1.8 GeV and lifetime $\approx 2.2\times 10^{-14}$ sec may possibly be one of these charmed mesons.

[7]S. L. Glashow, J. Iliopoulos, and L. Maiani, Phys. Rev. D 2, 1285 (1972).

[8]We are indebted to Dr. D. Weingarten for this remark.

[9]S. Weinberg, Phys. Rev. Lett. 19, 1264 (1967), and 27, 1688 (1972); A. Salam in *Proceedings of the Eighth Nobel Symposium on Elementary Particle Theory, Relativistic Groups, and Analyticity, Stockholm, Sweden, 1968*, edited by N. Svartholm (Almquist and Wiksell, Stockholm, 1968), p. 367.