observed effect is due to neutral currents, the distributions in inelasticity $y = E_{\text{had}}/E_\nu$ depend on the type of coupling to the weak current.[8] For example, the familiar $V-A$ neutrino interaction has constant dN/dy, but a scalar or pseudoscalar coupling would produce a distribution $dN/dy \propto y^2$, while a $V+A$ coupling would produce $dN/dy \propto (1-y)^2$. These different distributions reflect themselves in the E_{had} distributions. The $E_{\text{had}} > 6$-GeV cut in the data gives detection efficiencies differing by almost a factor of 2 depending on which coupling is assumed. More detailed knowledge of the distribution in hadron energy will be necessary to determine the coupling mechanism and also to determine accurately the magnitudes of the ratios to ordinary charged currents.

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[5] Events which had charged particles leaving the detector through the downstream end are not included. The available fiducial volume for a particle of penetration P varies with P, becoming small when P approaches the length of the detector. The data have been corrected for this purely geometrical effect so that the resulting distribution is that of an infinitely long detector.

[6] B. C. Barish *et al.*, in Proceedings of the Seventeenth International Conference on High Energy Physics, London, 1–10 July 1974 (to be published).

[7] In particular, deviations from this form have been reported for $x \leq 0.1$ [B. Aubert *et al.*, Phys. Rev. Lett. 33, 984 (1974)]. Such an effect would alter the curve primarily in the region of small θ_μ and large P, not in the small-P region.

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SU(4) Explanation of the Narrow Resonances in e^+e^- Annihilation*

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The narrow resonances at $M_\psi = 3.105$ GeV and $M_{\psi'} = 3.695$ GeV are assigned, together with the familiar SU(3) nonet of vector mesons, as members of the $\underline{1} \oplus \underline{15}$ representation of SU(4). This leads to a solution consistent with the observed particle spectrum and accounts for the narrow widths of the ψ and ψ'. The masses of the charmed vector and pseudoscalar mesons are predicted.

A narrow resonance, ψ, at a mass of 3.105 GeV with a width $\Gamma_\psi \leq 1.3$ MeV was reported recently by the Stanford Linear Accelerator Center,[1] Brookhaven National Laboratory,[2] and Frascati[3] groups. A second narrow resonance, ψ', with a mass of 3.695 GeV has also been observed by the Stanford Linear Accelerator Center group.[4]

The narrowness of these resonances suggests that new selection rules are operating and that we have to consider higher symmetry groups such as SU(4) and SU(8).[5] In the following, we shall investigate the consequences of assigning the ψ and ψ' to the $\underline{1} \oplus \underline{15}$ representation of SU(4).

To accommodate the ψ and ψ' in SU(4), we assume that there exists a new semistrong interaction[6] which breaks hypercharge and the new quantum number $W = \frac{1}{3}X - \frac{1}{4}N$ such that the total charge and isospin in the extended Gell-Mann–Nishijima formula[7]

$$Q = I_3 + \tfrac{1}{2}Y + \tfrac{1}{3}X - \tfrac{1}{4}N \tag{1}$$

are conserved. This interaction allows the single production of charmed particles as well as their decay into noncharmed ($W=0$) particles. We suppose that the ψ' is almost pure $|c\bar{c}\rangle$, while the ψ is almost entirely $|s\bar{c}\rangle + |c\bar{s}\rangle$. The new semistrong interaction causes mixing between these latter states and those with $Y=0$ and $I=0$ (i.e., the ω, φ, and ψ'), thus allowing the physical ψ to couple to a virtual photon in e^+e^- annihilation. The present framework provides a natural explanation of the photon decay modes of the ψ[3] and the observed small decay[8] $\psi'\to\psi+2\pi$.

In order to explore these ideas more fully, we will employ a simple effective-Lagrangian model to describe the vector- and pseudoscalar-meson mass spectra. The point of this exercise is not to obtain detailed predictions or fits to data; rather, it is to demonstrate the consistency of our scheme with the present experimental situation. The simplest *effective* Hamiltonian with the desired properties is given by

$$H_{\mathrm{int}}=T_8+aT_{15}+bT_{13}', \tag{2}$$

where T_8 and T_{15} are the 8 and 15 components of one $\underline{15}$ representation of SU(4) and T_{13}' is the 13 component of a *different* $\underline{15}$ representation. The 13 component T_{13} of the same representation as T_8 and T_{15} can of course be rotated away to lowest order.[9] T_{15} separates the SU(4) multiplets, while T_8 splits the masses within the SU(3) submultiplets and mixes the particles of the same hypercharge and charm (e.g., ω, φ mixing). The T_{13}' mixes particles of equal isospin but different hypercharge and X subject to the condition

$$\Delta Y=-\tfrac{2}{3}\Delta X. \tag{3}$$

For the fractionally charged quark model of SU(4) described in Ref. 7, T_{13}' conserves charge.[10]

The squared-mass matrix for the $\underline{1}\oplus\underline{15}$ representation of the vector mesons V_i $(i=0, 1, \ldots, 15)$ can be written as

$$\begin{aligned}
&(M^2)_{ij}=\overline{M}^2\delta_{ij}+A(d_{i8j}+ad_{i15j})+bA'd_{i13j},\\
&(M^2)_{0i}=B(\delta_{8i}+a\delta_{15i})+bB'\delta_{13i},\\
&(M^2)_{00}=\overline{M}_0^{\,2}.
\end{aligned} \tag{4}$$

$\overline{M}^2$ and $\overline{M}_0^{\,2}$ are the SU(4)-invariant squared masses of the regular representation $\underline{15}$ and the singlet representation, respectively, and A, A', B, and B' are the reduced matrix elements. To obtain a solution for the parameters of the mass matrix, and for the physical eigenstates, in terms of the known masses of the ρ, K^*, ω, φ, ψ, and ψ' we shall make several simplifying assumptions. We take $A/B=A'/B'$, a relationship which is suggested by SU(8) symmetry. In addition, as a rough guess, we set $A'=A$. A numerical analysis then leads to a solution

$$\begin{aligned}
&\overline{M}^2=5.0\ \mathrm{GeV}^2,\quad A=A'=-0.23\ \mathrm{GeV}^2,\\
&a=46.0,\quad \overline{M}_0^{\,2}=3.0\ \mathrm{GeV}^2,\\
&B=B'=-0.12\ \mathrm{GeV}^2,\quad b=0.05.
\end{aligned} \tag{5}$$

The physical eigenstates ω, φ, ψ, and ψ' are given by

$$\begin{aligned}
&\omega=0.509V_8+0.338V_{15}+0.792V_0,\\
&\varphi=0.861V_8-0.001V_{13}-0.197V_{15}-0.469V_0,\\
&\psi=0.001V_8+0.999V_{13}-0.001V_{15},\\
&\psi'=-0.003V_8+0.001V_{13}+0.920V_{15}-0.391V_0.
\end{aligned} \tag{6}$$

Instead of the usual SU(3) mixing angle θ there will now be three angles. We see from Eq. (6) that the quark contents of ψ and ψ' are predominantly $|s\bar{c}\rangle+|c\bar{s}\rangle$ and $|c\bar{c}\rangle$, respectively. It follows that decays such as $\psi\to K+\overline{K}$, etc., will be essentially forbidden and hence Γ_ψ will be very small,[11] in agreement with the experimental data.[1-3] It is also observed from (5) that the size of the T_{13}' breaking is very small compared with the breaking caused by T_{15} and T_8, so that the conservation of the quark spins[5] J_s and J_c is still true, to a good approximation, suppressing decays like $\psi'\to K^*+\overline{K}$.

Since ψ' is not completely pure $|c\bar{c}\rangle$ and ψ is not pure $|s\bar{c}\rangle+|c\bar{s}\rangle$ the observed decay $\psi'\to\psi\pi\pi$ can take place.[12]

The values of the parameters in (5) predict the mass for the charmed-vector-meson isodoublet ξ^* to be

$$M_{\xi^*}=3.04\ \mathrm{GeV}. \tag{7}$$

The pseudoscalar mesons are also assigned[13] to the $\underline{1}\oplus\underline{15}$ representations of SU(4). Then, using the same values of a and b in the mass matrix for the pseudoscalar mesons, we predict

$$\begin{aligned}
&M_{\xi_P}=3.08\ \mathrm{GeV},\\
&M_{\psi_P}3.11\ \mathrm{GeV},\\
&M_{\psi_P'}=4.07\ \mathrm{GeV}.
\end{aligned} \tag{8}$$

The remaining parameters of the pseudoscalar mass matrix are $A=A'=-0.25\ \mathrm{GeV}^2$, $B=B'=-0.12\ \mathrm{GeV}^2$, $\overline{M}^2=4.85\ \mathrm{GeV}^2$, and $\overline{M}_0^{\,2}=3.15\ \mathrm{GeV}^2$. It is interesting to note that these vary by less than 8% from those in the vector-meson case. In particular, $\overline{M}^2$ varies by less than 3% in agreement with what one might expect from SU(8) considerations.

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[7] J. W. Moffat, Phys. Rev. $\underline{140}$, B1681 (1965). The quantum numbers Q, I_3, Y, and X of the four quarks are $u(\frac{2}{3},\frac{1}{2},\frac{1}{3},\frac{1}{4})$, $d(-\frac{1}{3},-\frac{1}{2},\frac{1}{3},\frac{1}{4})$, $s(-\frac{1}{3},0,-\frac{2}{3},\frac{1}{4})$, and $c(-\frac{1}{3},0,0,-\frac{3}{4})$; N equals $\frac{1}{3}$ for all four quarks. Note that the usual quarks u, d, and s have "charm," $W=0$, and c has $W=-\frac{1}{3}$.

[8] G. Goldhaber, private communication.

[9] S. Coleman and S. Glashow, Phys. Rev. $\underline{134}$, B671 (1964).

[10] It should be pointed out that, if another narrow resonance were to be discovered in e^+e^- annihilation experiments, it could be accommodated in the present framework by the addition of a T_{11} interaction to Eq. (2). Such a contribution would mix ξ^{*0} with ω, φ, ψ, ψ', and ρ^0. With the quark quantum-number assignments of S. L. Glashow, J. Iliopoulos, and L. Maiani [Phys. Rev. D $\underline{2}$, 1285 (1970)] we have checked that ψ and ψ' can be accommodated by replacing T_{13}' by T_9' in Eq. (2). A third narrow e^+e^- resonance could not be fitted into the $\underline{1}\oplus\underline{15}$ representations in the latter scheme. See D. Boal *et al.*, to be published.

[11] This, of course, depends on the masses of the charmed mesons being large enough so that the decay of ψ into one of them (plus, say, a kaon) is energetically forbidden. The charmed-meson masses in our simple model have this property.

[12] In fact, if one takes the effective Lagrangian for $V'\rightarrow V+2\pi$ to be $gV_\mu'V_\mu\vec{\pi}\cdot\vec{\pi}$ and uses the decay $\rho'\rightarrow\rho+2\pi$ to estimate the size of g, one finds $\Gamma(\psi'\rightarrow\psi\pi\pi)\sim 0.02(g^2/4\pi)b^2$ MeV $\gtrsim 20$ keV [b is the strength parameter in Eq. (2)].

[13] This is based on the SU(8) decomposition, $\underline{8}\otimes\underline{8}^*=\underline{1}\oplus\underline{63}$. The $\underline{63}$ contains the $\underline{1}\oplus\underline{15}$ SU(4) representations of vector mesons and a $\underline{15}$ representation of pseudoscalar mesons. (See Ref. 7 for details.)

Polarized-Photon Asymmetries in K^+ Photoproduction at 16 GeV*

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Using a 16-GeV linearly polarized photon beam, we have measured asymmetries in the process $\gamma N\rightarrow K^+(\Lambda+\Sigma)$ from hydrogen and deuterium, for square of four-momentum transfer, t, between -0.01 and -0.8 (GeV/c)^2. The data show that for $-t\gtrsim 0.1$ (GeV/c)^2, the cross sections for $\gamma p\rightarrow K^+\Lambda$, $\gamma p\rightarrow K^+\Sigma^0$, and $\gamma n\rightarrow K^+\Sigma^-$ are strongly dominated by natural-parity exchange, as is the case in single-pion photoproduction.

It is generally assumed that pseudoscalar-meson photoproduction at high energies and small momentum transfers proceeds through t-channel exchange mechanisms. The use of a linearly polarized photon beam allows separation of these exchanges into natural- and unnatural-parity sequences, since, to leading order in t/s, $d\sigma_\perp/dt$ ($d\sigma_\parallel/dt$), the cross section for photons polarized perpendicular (parallel) to the reaction plane, is dominated by natural- (unnatural-) parity exchange.[1] Thus the polarized-photon asymmetry

$$\Sigma\equiv\frac{d\sigma_\perp/dt-d\sigma_\parallel/dt}{d\sigma_\perp/dt+d\sigma_\parallel/dt}$$

is a measure of the relative importance of the two parity sequences.

Prior to this experiment, measurements of the differential cross sections for the reactions[2,3] $\gamma p\rightarrow K^+\Lambda$, $\gamma p\rightarrow K^+\Sigma^0$, and $\gamma n\rightarrow K^+\Sigma^-$ and the recoil Λ polarization in $\gamma p\rightarrow K^+\Lambda$ have been reported.[4] We present here the first measurements of the polarized-photon asymmetry in these reactions.

The polarized-photon beam used was produced through the selective absorption, by coherent pair production, of one linear polarization state from an unpolarized 16.05-GeV bremsstrahlung beam. This beam, which has been described in detail elsewhere,[5] had an energy spectrum near