DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 76/18
April 1976

SU(4) Breaking of Meson Coupling Constants and Decays of the J/ψ

by

A. Kazi, G. Kramer
II. Institut für Theoretische Physik der Universität Hamburg

D. H. Schiller
Gesamthochschule Siegen, Fachbereich 7 (Physik)

2 HAMBURG 52 · NOTKESTIEG 1

To be sure that your preprints are promptly included in the
HIGH ENERGY PHYSICS INDEX ,
send them to the following address (if possible by air mail) :

DESY
Bibliothek
2 Hamburg 52
Notkestieg 1
Germany

SU(4) Breaking of Meson Coupling Constants and Decays of the J/ψ.

by

A. Kazi, G. Kramer

II. Institut für Theoretische Physik der Universität, Hamburg

D.H. Schiller

Gesamthochschule Siegen, Fachbereich 7 (Physik)

Abstract

We consider vector-pseudoscalar-pseudoscalar and vector-vector-pseudoscalar coupling constants in broken SU(4). With these coupling constants various two-body decays of J/ψ are calculated with particular emphasis on the radiative decays.

1. Introduction

In two previous papers [1)2)] we studied the decay properties of meson multiplets in broken SU(4) assuming full symmetry of the three-body couplings with breaking of SU(4) only in the masses and wave functions.

We found, that, if the usual vector mesons (ρ, K^*, ω, ϕ) together with the J/ψ (3.1) are placed into a 1 + 15 representation of SU(4), the three I = 0 vector mesons ω, ϕ and J/ψ came out as almost pure ideally mixed states $\omega_\sigma = (u\bar{u} + d\bar{d})/\sqrt{2}$, $\omega_S = s\bar{s}$ and $\omega_C = c\bar{c}$. The same SU(4) symmetry breaking, applied to the pseudoscalar mesons, gave η (0.548), η'(0.958) and ψ_p (2.75) strongly mixed in the basis η_σ, η_S and η_C [1)]. This had the consequence that the radiative decay widths for $J/\psi \to \eta\gamma, \eta'\gamma$ were rather large, inconsistent with the experimentally known total width of the J/ψ. In ref. 2 we were able to reduce this discrepancy by assuming a different symmetry mixing between the 1 and 15 representation for the pseudoscalar mesons than for the vector mesons. A still remaining problem in this approach was the too large width for the decay $J/\psi \to \psi_p\gamma$. This problem does not depend significantly on the mixing of the vector and pseudoscalar mesons. It is a challenge for any framework based on SU(4) symmetry if the recent reported particle with mass around 2.8 GeV is indeed the ψ_p [3)]. One possibility to solve this problem is to give up the full SU(4) symmetry of the three-body couplings. Breaking of coupling constants has been studied earlier in connection with SU(3) symmetry [4)]. There it turned out that these breaking effects are small, of the order of 10 %. Since SU(4) symmetry must be rather badly broken, as one can see already from the mass spectrum, it is all the more necessary to study the SU(4) breaking also of the coupling constants. A first step in this direction has been done by Aubrecht and Razmi [5)]. These authors studied only a few radiative decays and did not fully take into account the effects of mixing of the wave functions.

2. Breaking of V→PP and V→VP Couplings.

Following Aubrecht and Razmi [5] we write the hamiltonian as a sum of scalar densities u_0, u_8 and u_{15}:

$$\mathcal{H} = a_0 u_0 + a_8 u_8 + a_{15} u_{15} \tag{2.1}$$

with coefficients a_0, a_8 and a_{15}. Here u_0 is invariant under SU(4) and u_8 and u_{15} break the symmetry according to the 8th and 15th component of the regular representation of SU(4).

(a) V→PP

On the basis of eq. (2.1) the VPP interaction has the following form [5]:

$$\mathcal{H}(VPP) = \sum_{a,b,c,d=0}^{15} \left(G_0 f_{abc} + G_8 d_{8ad} f_{dbc} + G_{15} d_{15ad} f_{dbc} \right) \left(P^a \overleftrightarrow{\partial}^{\mu} P^b \right) V^c_{\mu} , \tag{2.2}$$

where the f_{abc} are the SU(4) structure constants (with $f_{oab} = 0$) and the d_{abc} are the symmetric coefficients (with $d_{oab} = \delta_{ab}/\sqrt{2}$) . In the symmetry limit $G_8 = G_{15} = 0$. The relations between the coupling constants $G(V,P_1,P_2) = \langle V | P_1, P_2 \rangle$ of the physical particles V, P_1 and P_2 , which can occur in strong decays $V \to P_1 \; P_2$ or $P_1 \to V \; P_2$, and the parameters G_0, G_8 and G_{15} are:

$$\begin{aligned}
G(\rho^0, \pi^-, \pi^+) &= 2(X - 4Y) , \\
G(K^{*+}, K^+, \pi^0) &= X - Y , \\
G(V, K^-, K^+) &= \left(\alpha_\sigma^{(V)} - \sqrt{2}\,\alpha_s^{(V)}\right)(X + 2Y) , \\
G(K^{*+}, K^+, P) &= \alpha_\sigma^{(P)}(X - Y) - \alpha_s^{(P)}\sqrt{2}\,(X + 5Y) , \\
G(D^{*+}, D^+, \pi^0) &= X - 3Y + Z ,
\end{aligned} \tag{2.3}$$

with $V = (\omega, \phi, J/\psi)$ and $P = (\eta, \eta', \psi_P)$. The Lorentz structure multiplying $G(V, P_1, P_2)$ is $V_\mu (P_1 \overleftrightarrow{\partial}^{\mu} P_2)$. In eqs. (2.3),

$\alpha_i^{(V)}$ and $\alpha_i^{(P)}$ are the coefficients in the wave functions of the vector and pseudoscalar mesons as defined in ref. 1. The X, Y and Z are related to G_0, G_8 and G_{15} by

$$X = G_0 - G_{15}/\sqrt{6} \quad , \quad Y = G_8/4\sqrt{3} \quad , \quad Z = 4\,G_{15}/\sqrt{3} \quad . \tag{2.4}$$

The coupling constants in eqs. (2.3) occur in the width formulas as

$$\begin{aligned} \Gamma(V \to P_1 P_2) &= \frac{G^2(V, P_1, P_2)\; p_{P_1}^3}{6\pi\, m_V^2} \quad , \\ \Gamma(P_1 \to V P_2) &= \frac{G^2(V, P_1, P_2)\; p_V^3}{2\pi\, m_V^2} \quad . \end{aligned} \tag{2.5}$$

Eqs. (2.3) tell us that X and Y can be determined from the experimentally known decay rates for $\rho \to \pi\pi$ and $K^* \to K\pi$. With this information the decays $\phi \to K\bar{K}$, $J/\psi \to K\bar{K}$ and $\psi_p \to K^* \bar{K}$ can be calculated. The parameter Z and therefore the coupling constants G_0 and G_{15} separately can be determined only from the decay of the charmed meson D^*, $D^* \to D\pi$, in case the mass difference between D^* and D is as large as calculated [2]. The relations (2.3) agree with those of ref. 5, if G_8 is put equal to zero.

(b) $V \to VP$

The coupling of two vector mesons and one pseudoscalar meson is more involved because now in the symmetry limit also the singlet field couples. As in ref. 1 we shall make the "ideal mixing assumption" for the VVP couplings in the SU(4) symmetry limit. This is equivalent to assuming the continuity of quark lines and describes, for example, the deviation of $\Gamma(\phi \to \rho\pi)$ and $\Gamma(J/\psi \to \rho\pi)$ from zero by the deviation from ideal mixing of the wave functions of ϕ and J/ψ, respectively. Then the VVP interaction including symmetry breaking terms is:

$$H(VVP) = \sum_{a,b,c,d=0}^{15} \left(g_0\, d_{abc} + g_8\, d_{8ad}\, d_{dbc} + g_{15}\, d_{15ad}\, d_{dbc} \right) \epsilon^{\kappa\lambda\mu\nu}\, P^a \partial_\kappa V_\lambda^b\, \partial_\mu V_\nu^c . \tag{2.6}$$

In the symmetry limit $g_8 = g_{15} = 0$. Similar to eq. (2.4) we introduce

$$x = g_0 + g_{15}/\sqrt{6} \ , \quad y = g_8/2\sqrt{3} \ , \quad z = g_{15}/\sqrt{6} \ . \tag{2.7}$$

Then the coupling constants $G(V_1, V_2, P) = \langle V_1 | V_2, P \rangle$, which can occur in strong decays $V_1 \to V_2 P$ or $P \to V_1 V_2$, are related to x, y and z by:

$$\begin{aligned}
G(V,\rho^+,\pi^-) &= G(V,\rho^0,\pi^0) = \alpha_\sigma^{(V)}\, 2\,(x+2y)\ ,\\
G(\rho^+,\rho^-,P) &= G(\rho^0,\rho^0,P) = \alpha_\sigma^{(P)}\, 2\,(x+2y)\ ,\\
G(V_1,V_2,P) &= \Big[\alpha_\sigma^{(V_1)}\alpha_\sigma^{(V_2)}\alpha_\sigma^{(P)}(x+2y) + \alpha_s^{(V_1)}\alpha_s^{(V_2)}\alpha_s^{(P)}\sqrt{2}\,(x-4y)\\
&\qquad + \alpha_c^{(V_1)}\alpha_c^{(V_2)}\alpha_c^{(P)}\sqrt{2}\,(x-4z)\Big]\, b_{V_1V_2}\ ,\\
G(K^{*+},K^{*+},P) &= G(K^{*0},K^{*0},P) = \alpha_\sigma^{(P)}(x+2y) + \alpha_s^{(P)}\sqrt{2}\,(x-4y)\ ,\\
G(K^{*+},\rho^0,K^+) &= -G(K^{*0},\rho^0,K^0) = x-y\ ,\\
G(K^{*+},V,K^+) &= G(K^{*0},V,K^0) = (\alpha_\sigma^{(V)}+\sqrt{2}\,\alpha_s^{(V)})(x-y)\ ,\\
G(D^{*+},\rho^0,D^+) &= -G(D^{*0},\rho^0,D^0) = -(x+y-2z)\ ,\\
G(D^{*+},V,D^+) &= G(D^{*0},V,D^0) = (\alpha_\sigma^{(V)}+\sqrt{2}\,\alpha_c^{(V)})(x+y-2z)\ ,\\
G(F^{*+},V,F^+) &= (\alpha_s^{(V)}+\alpha_c^{(V)})\sqrt{2}\,(x-2y-2z)\ ,
\end{aligned} \tag{2.8}$$

with $V, V_1, V_2 = \omega, \phi, J/\psi$, $P = \eta, \eta', \eta_P$ and $b_{V_1V_2} = 1 + \delta_{V_1V_2}$.

We note that several of the ratios between coupling constants are unchanged to first order in the SU(4) symmetry breaking and a few even to first order in the SU(3) and SU(4) symmetry breaking.

The coupling constants in eqs. (2.8) appear in the width formulas as:

$$\begin{aligned}
\Gamma(V_1 \to V_2 P) &= \frac{1}{12\pi}\, G^2(V_1,V_2,P)\, p_{V_2}^3\ ,\\
\Gamma(P \to V_1 V_2) &= \frac{s}{4\pi}\, G^2(V_1,V_2,P)\, p_{V_1}^3\ .
\end{aligned} \tag{2.9}$$

The statistical weight factors are : $s = 1 - \frac{1}{2}\delta_{V_1V_2}$.

(c) $V \to P\gamma$

With the VVP coupling constants in eqs. (2.8) we can also calculate the radiative decays $V \to P\gamma$ and $P \to 2\gamma$ by applying the VDM approximation to the photon. If the direct coupling between the photon and a vector meson V is written as $e m_V^2/f_V$, the matrix element for the decay $V \to P\gamma$ is:

$$G(V,P,\gamma) = e \sum_{V'=\rho^0,\omega,\phi,J/\psi} G(V,V',P)\, f_{V'}^{-1} . \tag{2.10}$$

In eq. (2.10) we resticted the sum over the vector mesons V' to the members of the lowest lying SU(4) multiplet. The influence of this assumption on our results will be discussed later.

From the known leptonic decay widths[6] $\Gamma(\rho^0 \to e^+e^-) = 6.45\ \mathrm{KeV}$, $\Gamma(\omega \to e^+e^-) = 0.76\ \mathrm{KeV}$, $\Gamma(\phi \to e^+e^-) = 1.34\ \mathrm{KeV}$ and $\Gamma(J/\psi \to e^+e^-) = 4.8\ \mathrm{KeV}$, and from the width formula $\Gamma(V \to e^+e^-) = 4\pi\alpha^2 m_V / 3 f_V^2$ we have

$$f_\rho^{-1} : f_\omega^{-1} : f_\phi^{-1} : f_\psi^{-1} = 1 : 0.34 : -0.40 : 0.43 \tag{2.11}$$

and $f_\rho^{-2} = 0.0376$. The signs in (2.11) are chosen according to the Glashow - Iliopoulos - Maiani assignment of the quark charges [7].

Combining the relations (2.10) and (2.8) the matrix elements for $V \to P\gamma$ can be expressed by the wave functions $\alpha_i^{(V)}$ and $\alpha_i^{(P)}$ and the constants x, y and z. The results are:

$$G(\rho^0,\pi^0,\gamma) = e \sum_{V'} \alpha_\sigma^{(V')} f_{V'}^{-1}\, 2(x+2y) ,$$

$$G(\rho^0,P,\gamma) = e\, \alpha_\sigma^{(P)} f_\rho^{-1}\, 2(x+2y) ,$$

$$G(V,\pi^0,\gamma) = e\, \alpha_\sigma^{(V)} f_\rho^{-1}\, 2(x+2y) ,$$

$$G(V,P,\gamma) = e\Big\{ \alpha_\sigma^{(V)}\alpha_\sigma^{(P)} \sum_{V'} b_{VV'}\, \alpha_\sigma^{(V')} f_{V'}^{-1} (x+2y)$$
$$+ \alpha_s^{(V)}\alpha_s^{(P)} \sum_{V'} b_{VV'}\, \alpha_s^{(V')} f_{V'}^{-1} \sqrt{2}\,(x-4y)$$
$$+ \alpha_c^{(V)}\alpha_c^{(P)} \sum_{V'} b_{VV'}\, \alpha_c^{(V')} f_{V'}^{-1} \sqrt{2}\,(x-4z)\Big\}, \tag{2.12}$$

$$G\begin{pmatrix} K^{*+}, K^{+}, \gamma \\ K^{*0}, K^{0}, \gamma \end{pmatrix} = e\Big[\pm f_\rho^{-1} + \sum_{V'} \left(\alpha_\sigma^{(V')} + \sqrt{2}\,\alpha_s^{(V')}\right) f_{V'}^{-1} \Big](x-y),$$

$$G\begin{pmatrix} D^{*+}, D^{+}, \gamma \\ D^{*0}, D^{0}, \gamma \end{pmatrix} = e\Big[\mp f_\rho^{-1} + \sum_{V'} \left(\alpha_\sigma^{(V')} + \sqrt{2}\,\alpha_c^{(V')}\right) f_{V'}^{-1} \Big](x+y-2z),$$

$$G\left(F^{*+}, F^{+}, \gamma\right) = e \sum_{V'} \left(\alpha_s^{(V')} + \alpha_c^{(V')}\right) f_{V'}^{-1} \sqrt{2}\,(x-2y-2z).$$

In eqs. (2.12) the sum over V' runs over ω, ϕ and J/ψ only and $V = \omega, \phi, J/\psi$, $P = \eta, \eta', \psi_P$, $b_{VV'} = 1 + \delta_{VV'}$.

For the partial decay widths $V \to P\gamma$ and $P \to V\gamma$ we have:

$$\Gamma(V \to P\gamma) = \frac{1}{12\pi}\, G^2(V,P,\gamma)\, p_\gamma^3 ,$$
$$\Gamma(P \to V\gamma) = \frac{1}{4\pi}\, G^2(V,P,\gamma)\, p_\gamma^3 . \tag{2.13}$$

(d) $P \to 2\gamma$

In an analogous way the coupling constants for $P \to 2\gamma$ are calculated by applying VDM to both photons. The result is:

$$G(\pi^0,\gamma,\gamma) = e^2 \sum_V \alpha_\sigma^{(V)} f_V^{-1} f_\rho^{-1}\, 4(x+2y),$$
$$G(P,\gamma,\gamma) = e^2 \Big[\alpha_\sigma^{(P)} (1 + A_\sigma)\, 2(x+2y) + \alpha_s^{(P)} A_s\, 2\sqrt{2}\,(x-4y)$$
$$+ \alpha_c^{(P)} A_c\, 2\sqrt{2}\,(x-4z)\Big], \tag{2.14}$$

with

$$A_\sigma = \frac{1}{2} \sum_{V,V'} b_{VV'}\, \alpha_\sigma^{(V)} \alpha_\sigma^{(V')} f_V^{-1} f_{V'}^{-1} \tag{2.15}$$

and similar expressions for A_s and A_c. Here $P = \eta, \eta', \psi_P$ and the sums in (2.14) and (2.15) go over ω, ϕ and J/ψ . The $b_{VV'}$ have been defined above.

The width formula is

$$\Gamma(P \to 2\gamma) = \frac{1}{8\pi} \, G^2(P,\gamma,\gamma)\, p_\gamma^3 \tag{2.16}$$

3. Results.

We start with the strong decays. For the VPP coupling we can determine X and Y from the decay rates for $\rho \to \pi\pi$ and $K^* \to K\pi$ and can predict $\phi \to K\bar{K}$, $J/\psi \to K\bar{K}$ and $\psi_P \to K^*\bar{K}$. These decays do not depend on the parameter Z which occurs only in decays allowed by the Zweig rule in connection with charmed quarks. The parameter Z can be determined only from the decays $D^* \to D\pi$, which are unknown. Therefore we calculated $D^* \to D\pi$ with two assumptions: (i) Z = 0 and (ii) Z = 10 Y. Our results are given in table 1. The value for the choice (ii) is given in parenthesis.

Actually two solutions for Y/X are possible. In table 1 we have chosen the solution which produces the signs for $G(\rho^0, \pi^-, \pi^+)$ and $G(K^{*+}, K^+, \pi^0)$ in accordance with the symmetry limit Y = 0. The wave functions for ϕ, J/ψ and ψ_P and the masses of D^* and D have been chosen as determined in ref.2. We see that the SU(3) breaking parameter is rather small consistent with older calculations [4]. The $\phi \to K^+K^-$ decay width increased due to the SU(3) breaking of the coupling constant and is still consistent with the experimental value as it was without coupling constant breaking. [1)2)] For $\psi_P \to K^{*+}K^-$ we obtain an appreciable decay width, which is around 1 MeV. This result depends very much on the wave function of the ψ_P, which has been taken from our previous work [2].

The situation is similar for the strong vertex VVP. We could determine x and y from the two decays $\phi \to \rho\pi$ and $J/\psi \to K^*K$. But z remains undetermined since we have no information about $J/\psi \to \omega\eta$, $\omega\eta'$, etc. To use the decay rate of $J/\psi \to K^*K$ for a determination of y/x is not appropriate since the experimental value for $J/\psi \to K^*K$ must be corrected for the contribution of $J/\psi \to \gamma \to K^*K$, which is unknown, to obtain the contribution of the direct decay [8]. Therefore we have chosen the following procedure. We fix the ratios y/x and z/x as determined from the radiative decays to be discussed later. Then x is determined from $\Gamma(\phi \to \rho\pi)$ = 663.6 KeV. We obtain $G(\phi,\rho,\pi)$ = 1.147 GeV^{-1} which leads to x = 8.32 GeV^{-1}. With this we calculated the strong two-body decays of ϕ, J/ψ and ψ_p as given in table 2. Of course the determination of z/x may still depend on effects of electromagnetic interference, which are unknown. But up to now the radiative decays are the only ones which can be used for determining x, y and z separately. For example, x and y can be obtained from $\omega \to \pi^0\gamma$ and $K^{*0} \to K^0\gamma$. Then z follows from $\phi \to \eta\gamma$ or $J/\psi \to \eta\gamma$. The latter is more suitable since in this decay the parameter z enters in a more dominant way than in $\phi \to \eta\gamma$ (see eq. (2.12)). Using for the wave functions the results from ref. 2 and as input the decay rates of $\omega \to \pi^0\gamma$ $K^{*0} \to K^0\gamma$ and $J/\psi \to \eta\gamma$ the various other radiative decays $V \to P\gamma$ and $P \to 2\gamma$ come out as collected in table 3. The input data in table 3 are underlined. For $K^{*0} \to K^0\gamma$ we assumed the largest value consistent with the experimental error. We see, that, because of the reduction of $J/\psi \to \eta\gamma$ compared to our old calculation [2], which is due to $z \neq 0$, now $J/\psi \to \psi_p\gamma$ is reduced by roughly one order of magnitude. Clearly this reduction is correlated with the input for $J/\psi \to \eta\gamma$. With $\Gamma(J/\psi \to \eta\gamma)$= 64 eV we would obtain $\Gamma(J/\psi \to \psi_p\gamma)$ = 19 KeV. These values for $J/\psi \to \psi_p\gamma$ are presumably still too large. But we have to remind us that our result for z depends very much on the wave function of the η. Furthermore $\Gamma(J/\psi \to \psi_p\gamma)$ decreases with increasing mass of the ψ_p . If m_{ψ_p} is increased from the value 2.75 GeV, the value we assumed in ref. 2, to m_{ψ_p}= 2.85 GeV, the width $\Gamma(J/\psi \to \psi_p\gamma)$ decreases roughly by a factor 2.5. The better way, of course, would be to determine z from $J/\psi \to \psi_p\gamma$ and adjust the wave functions of η and η' to the decay rates of $J/\psi \to \eta\gamma$ and $J/\psi \to \eta'\gamma$. Clearly also $\psi_p \to 2\gamma$ is reduced compared to our old calculation [2]. Therefore this decay could be used also for a determination of z, when this partial decay rate is known. In table 3 we also report the radiative decay rates of D^{*+}, D^{*o} and F^{*}, which also depend on z. Of course, the results for these decays depend very sensitively on the masses of the charmed mesons. We notice that the radiate decay rates of D^{*+}, D^{*o} and F^{*+} differ appreciably. For the decays of the D^{*+} and F^{*+} the various contributions (ρ, ω and J/ψ in the case of D^{*+}, and ϕ and J/ψ in the case of F^{*+}) cancel almost exactly, whereas in the decay of the D^{*o} the ρ, ω and J/ψ contribution add up.

All other results in table 3 are tests of coupling constant breaking in SU(3) and are reported since several experimental data have just become available recently. Thus the experimental value for $\phi \to \eta\gamma$ has changed from 123 KeV to 65 KeV. The old value was consistent with our prediction without coupling constant breaking [2]. The symmetry breaking with $y > 0$ reduces $\phi \to \eta\gamma$, but already too much with y determined from $K^{*o} \to K^{o}\gamma$, which was assumed at the upper end of the experimental limit, otherwise y/x would have been even larger (for y = 0 the theoretical value for $\Gamma(K^{*o} \to K^{o}\gamma)$ is 192 KeV). We see that in our framework of coupling constant breaking the rates of $K^{*o} \to K^{o}\gamma$ and $\phi \to \eta\gamma$ cannot be made completely consistent. A similar problem is the relation between $\rho^{o} \to \pi^{o}\gamma$ and $\omega \to \pi^{o}\gamma$. The formulas (2.12) show that the ratio of $\Gamma(\rho^{o} \to \pi^{o}\gamma)$ and $\Gamma(\omega \to \pi^{o}\gamma)$ is independent of x and y and is always near 1/9 as in the theory with SU(3) symmetric couplings and ideal mixing for the ω wave function. The experimental value of $\rho^{o} \to \pi^{o}\gamma$ is at least a factor 2 smaller than our prediction. Possible ways to resolve this discrepancy and to improve also $\phi \to \eta\gamma$ have been discussed recently by several authors [9]. Our result for $\eta \to 2\gamma$ is also not too satisfactory. But if, instead of normalizing to $\omega \to \pi^{o}\gamma$, we normalize to $\pi^{o} \to 2\gamma$, the result for $\eta \to 2\gamma$ is: $\Gamma(\eta \to 2\gamma) = (642 \pm 76)$ eV, to be

compared with the experimental value (374 ± 69) eV.
We notice that the SU(3) breaking in VVP is much larger than in VPP, roughly given by y/x = 0.097 in VVP and by Y/X = 0.019 in VPP. The three coupling parameters for VVP, as obtained from the analysis of the radiative decays, are g_0 = 4.76 GeV^{-1}, g_8 = 1.85 GeV^{-1} and g_{15} = 1.90 GeV^{-1}. So in the VVP coupling SU(3) and SU(4) breaking have roughly the same strength, contrary to ref. 5, where $g_{15} \gg g_8$ was assumed.

The strong VVP decays and the radiative decays were normalized separately, the former with $\phi \to \rho\pi$, the latter with $\omega \to \pi^0\gamma$. On the other hand the VDM relates the VVP couplings to the VPγ couplings. From $\Gamma(\phi \to \rho\pi)$ = 0.66 MeV the vector dominance model, based on the lowest multiplet of vector mesons, predicts $\Gamma(\omega \to \pi^0\gamma)$ = 1965 KeV, which is larger than the experimental value, roughly by a factor of 2. This discrepancy is well known and is usually attributed to the fact, that higher vector mesons and continuum contributions are neglected in the VDM relations used above. The couplings of these higher vector mesons (ρ', ρ'', ω', ϕ' etc.) should be of such a nature, that they make the VPγ couplings and the P$\gamma\gamma$ couplings agree with experiment. Precise predictions are difficult since the experimental information on these higher vector mesons is very poor. That in such a scheme the relation between the $\omega\rho\pi$ or $\phi\rho\pi$ coupling and the $\omega\pi\gamma$ coupling can be understood qualitatively has been shown by Bramon and Greco [10]. It is clear that then also the ψ'(3.7) and all higher excitations in the cc channel must be taken into account. These contributions may influence also the analysis of $J/\psi \to \eta\gamma$, $J/\psi \to \eta'\gamma$ and $J/\psi \to \psi_p\gamma$. Estimates of the ψ' contribution in $J/\psi \to \eta\gamma$ may be found in ref. 11. Because of the almost complete cancellation of the ρ, ω, ϕ and J/ψ contributions the radiative decays of D^{*+} and F^{*+} must depend sensitively on these higher vector meson intermediate states.

We emphazise that our analysis depends very much on the wave functions , in particular on those of η, η' and ψ_p which have been taken from our earlier work [2]. There the wave functions of the pseudoscalar mesons were fitted to the ratio of $\Gamma(J/\psi \to \eta'\gamma)$ to $\Gamma(J/\psi \to \eta\gamma)$ with a value around 5, the published experimental limits are 4 ± 2.5 [3] and less than 5 [3]. As we can see from table 3 this ratio does not change through the breaking of coupling constants.

Another problem might be the large hadronic decay rate of the ψ_p. If we add all channels given in table 1 and 2 we predict $\Gamma(\psi_p \to \text{hadrons}) > 17$ MeV. Then the branching ratio $\Gamma(\psi_p \to 2\gamma)/\Gamma(\psi_p \to \text{hadrons}) \lesssim 1.0 \; 10^{-4}$. Experimentally $\left[\Gamma(J/\psi \to \psi_p\gamma)/\Gamma(J/\psi \to \text{all})\right] / \left[\Gamma(\psi_p \to 2\gamma)/\Gamma(\psi_p \to \text{all})\right] \simeq 1.5 \cdot 10^{-4}$. This result is consistent with the large hadronic rate of the ψ_p only if the rate for $\Gamma(J/\psi \to \psi_p\gamma)$ would be an appreciable fraction of the total J/ψ width, as predicted in table 3. Of course these strong decays of the ψ_p depend also very much on the ψ_p wave function. Less strong decays of the ψ_p as predicted here would indicate an even smaller admixture of non-charmed quarks in the wave function of the ψ_p.

To test the influence of the pseudoscalar wave functions on our results we have recalculated these wave functions using different input assumptions. Instead of $m_{\psi_p} = 2.75$ GeV we used $m_{\psi_p} = 2.85$ GeV as input and assumed

$|\alpha_c^{(\eta')}| \simeq |\alpha_c^{(\eta)}|$ instead of $|\alpha_c^{(\eta')}| \simeq 2.5\,|\alpha_c^{(\eta)}|$ as in ref. 2.

This latter assumption has the effect that we shall obtain $\Gamma(J/\psi \to \eta'\gamma) \simeq \Gamma(J/\psi \to \eta\gamma)$. The wave functions calculated with these assumptions are displayed in table 4, together with the results for the decays, based on these wave functions. Here we list only those decays which changed appreciably compared to the results presented in table 1,2 and 3. Concerning normalization of the various decays the same input was used. The breaking parameter z, as deduced from the radiative decays, is now $z = 0.841$ GeV^{-1}, x and y are as in table 3. The results in table 4 show that the input concerning the ratio

$\Gamma(J/\psi \to \eta'\gamma)/\Gamma(J/\psi \to \eta\gamma)$ has strong influence on the admixture of non-charmed quarks in the ψ_p. For this ratio near one the coefficient $\alpha_\sigma^{(\psi_p)}$ goes through zero. Therefore we obtained very small rates for $\psi_p \to \rho^+\rho^-, 2\omega$, in particular $\Gamma(\psi_p \to 2\rho^0) \simeq \Gamma(\psi_p \to 2\gamma)$. Since $\alpha_s^{(\psi_p)}$ is of the order of 10^{-2}, the ψ_p is still coupled to strange quarks and the rates for $\psi_p \to K^{*+}K^-, K^{*+}K^{*-}$ and 2ϕ are relatively large. Of course with small changes of the input parameters the mixing parameter $\alpha_\sigma^{(\psi_p)} = 0$ and then the ψ_p could decay only into final states with strange quarks. With the numbers in table 4 the hadronic width of the ψ_p is still larger than 6 MeV, whereas from $[\Gamma(J/\psi \to \psi_p\gamma)/\Gamma(J/\psi \to all)]/[\Gamma(\psi_p \to 2\gamma)/\Gamma(\psi_p \to all)] \simeq 1.5 \cdot 10^{-4}$ we obtain $\Gamma(\psi_p \to all) = 1.4$ MeV if we use our prediction for $\Gamma(J/\psi \to \psi_p\gamma)$ and $\Gamma(\psi_p \to 2\gamma)$ from table 4. Therefore the predicted rates for $\psi_p \to K^{*+}K^-, K^{*+}K^{*-}, 2\phi$ are still too large. So far we can see, it seems to be difficult to reduce $\alpha_s^{(\psi_p)}$ without increasing $\alpha_\sigma^{(\psi_p)}$.

References:

1) A. Kazi, G. Kramer and D.H. Schiller, Acta Physica Austriaca (to be published) and Desy Report 75/11 (1975) References about similar work are given there. See also R. Vergara-Caffarelli, Physics Letters 55B (1975) 481

2) A. Kazi, G. Kramer and D.H. Schiller, Nuovo Cimento Letters 15 (1976) 120 and Desy Report 75/38 (1975)

3) J. Heintze, Desy Report 75/34 (1975)
B. Wiik, Desy Report 75/37 (1975)

4) M. Muraskin and S.L. Glashow, Phys. Rev. 132 (1963) 482;
B. Diu, H. Rubinstein and J.L. Basdevant, Nuovo Cimento 35(1965) 460;
M. Gourdin, Unitary Symmetries (North Holland Publishing Comp. , Amsterdam, 1967)

5) G. J. Aubrecht II and M.S.K. Razmi, Phys. Rev. D 12 (1975) 2120

6) Particle Data Group, Phys. Letters 50 B (1974) 1 and Rev. Mod. Phys. 47 (1975) 535

7) S.L. Glashow, J. Iliopoulos and L. Maiani, Phys. Rev. D2 (1970) 1285

8) S. Rudaz, Preprint, Cornell University, CLNS - 324

9) B.J. Edwards and A.N. Kamal, Phys. Rev. Letters 36 (1976) 241 and the literature given there; G. Grunberg and F.M. Renard, Preprint, University of Montpellier, PM/76/02.

10) A. Bramon and M. Greco, Nuovo Cimento 14A (1973) 323

11) L. Clavelli and S. Nussinov, Preprint, University of Maryland, No. 76-013

12) B. Gobbi, J.L. Rosen, H.A. Scott, S.L. Shaprio, L.Strawczynski and C.M. Meltzer
Phys. Rev. Letters 33 (1974) 1450,
C. Bemporad, Proceedings of the Conference on Lepton and Photon Interactions at High Energies, Stanford Linear Accelerator Center, Stanford, California 21-27 August, 1975,
G. Cosme et al., Preprint, University Paris-Sud, Orsay, L.A.L. 1279 (Aug. 1975);
W.C. Carithers , P. Mühleman, D. Underwood and D.G. Ryan, Phys. Rev. Letters 35 (1975) 349,

M.E. Nordberg Jr., J. Abramson, D. Andrews, J. Harvey, F. Lobkowicz, E. May, C. Nelson, M. Singer and E.H. Thorndike, Phys. Letters 51 B (1974) 106.

Table Captions:

Table 1: Strong decays $V \to PP$ for various vector mesons. The row labelled (1) gives the predictions, (2) are the experimental data. Input values are underlined, X and Y are parameters in the coupling.

Table 2: The same as table 1 for strong decays $V \to VP$ and $P \to VV$. The parameters x, y and z describe the VVP coupling with SU(3) and SU(4) breaking.

Table 3: The same as table 2 for radiative decays $V \to P\gamma$, $P \to V\gamma$ and $P \to 2\gamma$.

Table 4: New wave functions for η, η' and ψ_p and strong and radiative decays predicted with these wave functions. Otherwise the same assumptions as in table 1,2,3.

Table 1: X = 3.261 , Y = 0.0625

Decay	(1)	(2)
$\rho^0 \to \pi^+\pi^-$	150.4 MeV	(150.4 ± 2.9) MeV [6)]
$K^{*+} \to K^+\pi^0$	16.6 MeV	(16.6 ± 0.3) MeV [6)]
$\phi \to K^+K^-$	2.21 MeV	(1.96 ± 0.20) MeV [6)]
$J/\psi \to K^+K^-$	0.84 eV	< 14 eV [6)]
$\psi_P \to K^{*+}K^-$	0.991 MeV	—
$D^* \to D^+\pi^0$	0.966 MeV (1.39 MeV)	—

Table 2: $x = 8.32\ \mathrm{GeV}^{-1}$, $y = 0.805\ \mathrm{GeV}^{-1}$, $z = 1.17\ \mathrm{GeV}^{-1}$

Decay	(1)	(2)
$\phi \to \rho^+\pi^-$	221 KeV	(221 ± 6) KeV [6]
$J/\psi \to \rho^+\pi^-$	328 eV	(299 ± 120) eV [6]
$J/\psi \to K^{*+}K^-$	74.2 eV	(107 ± 33) eV [6]
$J/\psi \to \omega\eta$	38.2 eV	-
$J/\psi \to \omega\eta'$	26.3 eV	-
$J/\psi \to \phi\eta$	0.474 eV	-
$J/\psi \to \phi\eta'$	1.33 eV	-
$\psi_P \to \rho^+\rho^-$	1.91 MeV	-
$\psi_P \to K^{*+}K^{*-}$	2.66 MeV	-
$\psi_P \to 2\omega$	0.93 MeV	-
$\psi_P \to 2\phi$	1.47 MeV	-
$\psi_P \to \omega\phi$	589 eV	-

Table 3: $x = 5.53\ \mathrm{GeV}^{-1}$, $y = 0.535\ \mathrm{GeV}^{-1}$, $z = 0.775\ \mathrm{GeV}^{-1}$.

Decay	(1)	(2)
$\omega \to \pi^0\gamma$	870 KeV	(870 ± 86) KeV [6]
$\omega \to \eta\gamma$	6.51 KeV	$<$ 50 KeV [6]
$\eta' \to \omega\gamma$	10.7 KeV	$<$ 80 KeV [6]
$\rho^0 \to \pi^0\gamma$	83.4 KeV	(35 ± 10) KeV [12]
$\rho^0 \to \eta\gamma$	55.4 KeV	$<$ 160 KeV [12]
$\eta' \to \rho^0\gamma$	113 KeV	$<$ 269 KeV [6]
$\phi \to \pi^0\gamma$	6.69 KeV	(5.9 ± 2.1) KeV [12]
$\phi \to \eta\gamma$	34.2 KeV	(65 ± 15) KeV [12]
$\phi \to \eta'\gamma$	145 eV	-
$K^{*0} \to K^0\gamma$	110 KeV	(75 ± 35) KeV [12]
$K^{*+} \to K^+\gamma$	36 KeV	$<$ 80 KeV [6]
$J/\psi \to \pi^0\gamma$	0.61 eV	$<$ 350 eV [3]
$J/\psi \to \eta\gamma$	94.0 eV	(94 ± 30) eV [3]
$J/\psi \to \eta'\gamma$	512 eV	$\lesssim$ 450 eV [3]
$J/\psi \to \psi_p\gamma$	27.8 KeV	-
$\psi_p \to \rho^0\gamma$	3.99 KeV	-
$\psi_p \to \omega\gamma$	487 eV	-
$\psi_p \to \phi\gamma$	1.52 KeV	-
$D^{*+} \to D^+\gamma$	158 eV	-
$D^{*0} \to D^0\gamma$	107 KeV	-
$F^{*+} \to F^+\gamma$	4.86 eV	-
$\pi^0 \to 2\gamma$	10.2 eV	(7.71 ± 0.89) eV [6]
$\eta \to 2\gamma$	0.849 KeV	(0.374 ± 0.069) KeV [6]
$\eta' \to 2\gamma$	6.74 KeV	$<$ 22 KeV [6]
$\psi_p \to 2\gamma$	1.65 KeV	-

Table 4 :

$m_\pi = 0.13803$, $m_K = 0.4957$, $m_\eta = 0.5488$, $m_{\eta'} = 0.9576$, $m_{\psi_p} = 2.85$

$\alpha_p = 19.2856$, $\beta_p = 2.534$, $m_D = 2.053$, $m_F = 2.108$

	α_σ	α_s	α_c
η'	0.70035	0.71376	0.00726
η	0.7138	-0.70032	-0.00668
ψ_p	-0.00032	-0.00986	0.99995

Decay	Width
$\psi_p \to K^{*+}K^-$	889 KeV
$D^{*+} \to D^+\pi^0$	293 KeV (421 KeV)
$\psi_p \to \rho^+\rho^-$	5.51 KeV
$\psi_p \to K^{*+}K^{*-}$	597 KeV
$\psi_p \to 2\omega$	3.07 KeV
$\psi_p \to 2\phi$	790 KeV
$\psi_p \to \omega\phi$	1.63 KeV
$J/\psi \to \eta\gamma$	94.0 eV
$J/\psi \to \eta'\gamma$	93.5 eV
$J/\psi \to \psi_p\gamma$	8.33 KeV
$\psi_p \to \rho^0\gamma$	11.1 eV
$\psi_p \to \omega\gamma$	4.57 eV
$\psi_p \to \phi\gamma$	771 eV
$D^{*+} \to D^+\gamma$	69.4 eV
$D^{*0} \to D^0\gamma$	47.0 KeV
$F^{*+} \to F^+\gamma$	2.06 eV
$\psi_p \to 2\gamma$	1.71 KeV