Radiative Decays of Vector Mesons in Broken SU(3) Models*

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We have studied the radiative decays of the vector mesons in two SU(3)-breaking schemes. In our models we find it hard to reconcile the newly measured radiative widths of $\rho \to \pi\gamma$, $K^{0*} \to K^0\gamma$, $\varphi \to \pi\gamma$, and $\varphi \to \eta\gamma$ with the older measurements and upper bounds on other radiative rates. In particular we have difficulty in understanding the narrow radiative width of ρ and the upper bound on $K^{+*} \to K^+\gamma$.

Until very recently the radiative decays of vector mesons ($V \to P + \gamma$) were well understood in terms of the quark model picture.[1] More recently a strong-anomaly calculation of the hadronic PVV vertex together with vector-meson dominance (VMD) has been used by Torgerson[2] to predict the radiative decays. The best fit was not very much different from those of the quark model picture. Indeed the nonet symmetry with ideal nonet ω-φ mixing angle would yield a ratio $\Gamma(\omega^0 \to \pi^0\gamma)/\Gamma(\rho^- \to \pi^-\gamma)$ close to 9. This feature would also persist in a VMD scheme of the kind of Gell-Mann, Sharp, and Wagner[3] (see also Dashen and Sharp[4]). The recent measurements on the decay rates of $\rho^- \to \pi^-\gamma$ [5] and $K^{0*} \to K^0\gamma$ [6] have changed this situation. The ratio $\Gamma(\omega \to \pi\gamma)/\Gamma(\rho^- \to \pi^-\gamma)$ is now about a factor of 3 larger than the canonical quark-model value or the nonet-symmetry value with ideal nonet ω-φ mixing angle. More recently new numbers have been obtained for $\varphi \to \eta\gamma$ and $\varphi \to \pi\gamma$ at Orsay in an e^+e^- experiment.[7] Again the decay rate for $\varphi \to \eta\gamma$ is well below the old rate[8] and the rate for $\varphi \to \pi\gamma$ is well within the old bound.[8] If the $\omega \to \pi\gamma$ rate remains unaltered one obviously has difficulty understanding these decays in a nonet-symmetry scheme.

Recently Boal, Graham, and Moffat[9] have tried to understand the new rates (the new Orsay rates on $\varphi \to \pi\gamma$ and $\varphi \to \eta\gamma$[7] were not then available) in a nonet-symmetry scheme (one parameter) and in an SU(3)-symmetry scheme (three parameters) and found that not all the rates could be satisfactorily understood.

In this note we have looked at some models of SU(3) breaking in the effective $PV\gamma$ interaction to see if the new measurements can be understood in terms of SU(3) violations. We are aware of only one calculation done in the past[10] which incorporates SU(3) breaking in the radiative vector-meson decays. This work was done well before the presently known decay rates were available. Consequently it does not make a detailed prediction of the decay rates. We present in the following two models and their results in an abbreviated form. The details will be submitted for publication elsewhere.

Model I: The "ABCD model."—Consider the process

$$V_m \to P_i + V_n, \tag{1}$$

where m and i are symmetry indices running from 0 to 8 and n is the SU(3) index of the photon, $n = (3, 8)$.

To put it briefly this model is such that the decay rate is given by

$$\Gamma = \frac{(M_m^2 - M_i^2)^3}{M_m^3}\Big[A d_{\min} + \tfrac{1}{2}B(d_{8ik}d_{kmn} - d_{8nk}d_{kmi} - d_{8mk}d_{kni}) + (C + \tfrac{1}{6}B)(\delta_{8m}\delta_{ni} + \delta_{8n}\delta_{mi}) + (D + \tfrac{1}{6}B)\delta_{mn}\delta_{8i}\Big], \tag{2}$$

where the symmetry indices run from 0 to 8. The above can be derived by a generalization of a work by Muraskin and Glashow[11] to a nonet symmetry,

$$V = \frac{1}{\sqrt{2}}\sum_{i=0}^{\infty}\lambda_i V_i, \quad P = \frac{1}{\sqrt{2}}\sum_{i=0}^{\infty}\lambda_i P_i,$$

and introducing SU(3) breaking via a λ_8 spurion. C conjugation and nonet symmetry limit the number of parameters to four. The particular combination of A, B, C, and D implies that if the symmetry indices are restricted to the values 1 to 8 the decay rate is given by $[(i,m,n)=1 \text{ to } 8]$

$$\Gamma = \frac{(M_m^{\,2}-M_i^{\,2})^3}{M_m^{\,3}}[Ad_{min}+Bd_{8ik}d_{kmn}+C(\delta_{8m}\delta_{ni}+\delta_{8n}\delta_{mi})+D\delta_{mn}\delta_{8i}]^2. \tag{3}$$

The first term in Eq. (2), depending on A, will generate the usual nonet-symmetry results, i.e., $\Gamma(\omega\to\pi\gamma)/\Gamma(\rho^-\to\pi^-\gamma)\approx 9$ and $\Gamma(\varphi\to\pi\gamma)=0$ with ideal nonet ω-φ mixing angle. The latter decay is now allowed via the parameters B and C. D contributes to $\varphi\to\eta\gamma$ only. The decays we used to fit the four parameters A, B, C, and D are the first five listed in Table I. The solutions in Table I were obtained by doing minimum-χ^2 fits to the square roots of the rates. Only the best fits have been reproduced. Solution 1 was obtained by doing a minimum-χ^2 to all the five rates using $+(\text{expt. rate})^{1/2}$ for all the rates except $\varphi\to\pi\gamma$ for which $-(\text{expt. rate})^{1/2}$ was used. Solution 2 was obtained by doing a minimum-χ^2 to all the five rates using $+(\text{expt. rate})^{1/2}$ for all the five rates. Parentheses in the table indicate the rates so fitted. Solution 3 was obtained by *determining* the four parameters by using four rates (including $\varphi\to\eta\gamma$). Figures underlined indicate the rates that were used. The first figure represents the case where $-(\text{expt. rate})^{1/2}$ was used for $\varphi\to\pi\gamma$ and the second figure the case with $+(\text{expt. rate})^{1/2}$ for $\varphi\to\pi\gamma$. We have used the ideal nonet mixing angle ($\sin\theta_v=1/\sqrt{3}$) for ω-φ mixing and a mixing angle of $\theta_p=-10^\circ$ for η-X^0. The fits with $\theta_p=+10^\circ$ were not much different.

Model II: The "KDF model."—In this model the parametrization of the SU(3) breaking is obtained via the baryon-loop model of Rockmore and collaborators.[13] If one assumes that the $V\to P\gamma$ decay proceeds via a baryon-antibaryon loop with an SU(3) octet of baryons and if one assumes degenerate baryon masses in the loop together with SU(3)-symmetric VBB and PBB coupling, one simply gets the SU(3)-symmetric term which can be generalized to the nonet symmetry. The SU(3) symmetry can be broken by having nondegenerate baryon masses in the loop. Thus if the baryon masses are given by

$$M_{ij}=m_0\delta_{ij}+\delta M_F(-if_{8ij})+\delta M_D d_{8ij}, \tag{4}$$

the three parameters in Eq. (4) can in principle be determined by fitting the baryon mass spectrum as was done in Ref. 13. One can now evaluate the baryon loop with the mass-splitting spurion insertions in one baryon propagator at a time (see Ref. 13 for details). The final expression then involves a symmetric term which depends on the VBB and PBB coupling constants and the d/f ratios and, in principle, is determined.

TABLE I. The *ABCD* model. See text for explanation. All rates in keV.

Decay Mode	Solution 1	Solution 2	Solution 3	Exp.
$\phi\to\pi\gamma$	(6.9)	(4.5)	<u>5.9</u>, <u>5.9</u>	5.9±2.1 [7]
$\rho^-\to\pi^-\gamma$	(73.1)	(98.4)	76.5, 104	35±10 [5]
$K^{0*}\to K^0\gamma$	(75.1)	(75.2)	<u>75.0</u>, <u>75.0</u>	75±35 [6]
$\omega\to\pi\gamma$	(846)	(833)	<u>870</u>, <u>870</u>	870±80 [8]
$\phi\to\eta\gamma$	(65.0)	(65.0)	<u>65.0</u>, <u>65.0</u>	65±15 [7]
$\rho\to\eta\gamma$	10.7	10.2	9.4, 9.7	<160 [12]
$K^{+*}\to K^+\gamma$	177	133	183, 142	< 80 [8]
$\omega\to\eta\gamma$	0.24	2.5	0.27, 2.7	< 50 [8]
$\phi\to X^0\gamma$	0.03	0.11	0.03, 0.10	-
$X^0\to\rho\gamma$	148	124	152, 129	<270 [8]
$X^0\to\omega\gamma$	10.9	13.0	11.4, 13.8	< 80 [8]

The SU(3)-breaking terms are proportional to $\delta M_F/M$ and $\delta M_D/M$ where M is an average mass used in the adiabatic approximation to the baryon-loop integrals. One could now take two attitudes. One, take the model literally in which case there are no free parameters. The result of such an attitude is not expected to differ markedly from the quark model (or nonet symmetry) *up to a scale factor* since the symmetry breaking is small.[13] On the other hand, one could take only the symmetry-breaking *structure* seriously and fit the parameters (three in this case) to the data. The solutions obtained this way are listed as solutions 1, 2, and 3 in Table II. These solutions will be further identified later.

As the structure of the amplitude is rather involved we refer the reader to Ref. 13 for the SU(3) case where the indices run from 1 to 8. We have generalized the $PV\gamma$ case to include the singlet and *imposed* nonet symmetry on the unbroken term. We have also included the mass breaking to first order. We have three parameters in the amplitude, two of which break the SU(3) symmetry. The decay rate can eventually be cast in the form (the details will be published elsewhere)

$$\Gamma = (kK + dD + fF)^2, \tag{5}$$

where k, d, and f depend on the masses (through phase space), the d/f ratios, and the matrices d_{min}, f_{min}. K is the symmetric term, $D = K(\delta M)_D/M$, and $F = K(\delta M)_F/M$. The results of the fit are shown in Table II. Only the best fits have been reproduced. Solution 1 was obtained by fitting the three parameters to five rates (those in parentheses) by minimizing χ^2 to the square roots of the rates. Solution 2 was obtained by fitting the three parameters using four rates (those in parentheses) by minimizing χ^2. Solution 3 was obtained by *determining* the three parameters by using three rates (those underlined).

To conclude, we found that in the *ABCD* model the minimum-χ^2 program tended to yield the $\rho^- \to \pi^-\gamma$ rate around 75 keV when $-$(expt. rate)$^{1/2}$ was used for $\varphi \to \pi\gamma$. The $K^{+*} \to K^+\gamma$ rate was then pushed beyond the upper bound.[8] The solution with $+$(expt. rate)$^{1/2}$ for $\varphi \to \pi\gamma$ tended to produce the ρ^- rate around 100 keV and the K^{+*} rate somewhat lower but still outside the upper bound. If we assume that the ρ^- rate is 80 ± 10 keV (a possible value[5]) we get an excellent χ^2 (0.10 compared to 10 for solution 1 of Table I with one degree of freedom). All solutions of the *ABCD* model show large SU(3) violations as evidenced by the ratio of K^{0*} rate to K^{+*} rate which ought to be 4 if SU(3) were a good symmetry. We remark that Brown, Munczek, and Singer[10] had also predicted a value of 75 keV for the ρ^- rate and it is possible in their model to generate large SU(3) violations of the kind we have.

In the *KDF* model the $\rho^- \to \pi^-\gamma$ rate also tended

TABLE II. The *KDF* model. See text for explanation. All rates in keV.

Decay Model	Solution 1	Solution 2	Solution 3	Exp.
$\phi \to \pi\gamma$	(7.1)	(6.1)	<u>5.9</u>	5.9 ± 2.1 [7]
$\rho^- \to \pi^-\gamma$	(80.8)	107	28.3	35 ± 10 [5]
$K^{0*} \to K^0\gamma$	(205)	(270)	<u>75.0</u>	75 ± 35 [6]
$\omega \to \pi\gamma$	(796)	(836)	342	870 ± 80 [8]
$\phi \to \eta\gamma$	(125)	(91.3)	<u>65.0</u>	65 ± 15 [7]
$\rho \to \eta\gamma$	76.5	127	24.3	<160 [12]
$K^{+*} \to K^+\gamma$	53.0	84.7	16.2	< 80 [8]
$\omega \to \eta\gamma$	6.8	11.4	1.95	< 50 [8]
$\phi \to X^0\gamma$	0.66	0.73	0.26	-
$X^0 \to \rho\gamma$	112	135	43.8	<270 [8]
$X^0 \to \omega\gamma$	10.0	17.4	2.7	< 80 [8]

to come out around 80 keV when all five rates were used in the minimum-χ^2 program. The ratio of K^{0*} to K^{+*} rate was also roughly 4. This last feature did not change appreciably in solutions 2 and 3 of Table II where four and three decay rates were used, respectively, to fit the parameters. In solution 3 the ρ radiative width agrees with the experiment and K^{+*} width is well within the experimental bound. The ω radiative width comes out to be less than half the experimental width but is consistent with the value of $\Gamma(\omega\to\pi\gamma)/\Gamma(\rho\to\pi\gamma)$ obtained in solutions 1 and 2.

We feel that it would be very desirable to repeat the $\rho^-\to\pi^-\gamma$ measurement and, if possible, to measure this rate in an e^+e^- experiment. The measurement of K^{+*} rate is very important to provide a check of SU(3) violations by comparing it with the K^{0*}.

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Photoneutron Polarization Studies of the Giant $M1$ Resonance in ^{208}Pb†

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The photoneutron polarization from states near threshold was measured, for the first time, for the reaction ^{208}Pb$(\gamma,n_0)^{207}$Pb throughout the neutron energy range 500 to 1000 keV. Spin and parity assignments were made for these states. The giant $M1$ resonance in ^{208}Pb was found to be less fragmented than previously thought. The data suggest that there is some "missing" $M1$ strength in ^{208}Pb.

Although there has been nearly a decade of speculation[1] concerning the existence of a giant $M1$ resonance, data on the characteristics of the collective $M1$ strength in nuclei have remained sparse and inconclusive. In general, the $M1$ strength in photonuclear reactions should be enhanced at those energies corresponding to spin-flip transitions of nucleons between the filled and empty members of spin-orbit partners. An ideal nucleus for observation of such a collective $M1$ effect is ^{208}Pb. Theoretical calculations of the strength of the $M1$ resonance in ^{208}Pb have taken two distinct forms. Vergados[2] and Lee and Pittel[3] have followed the precedent of Arima and Horie[4] by employing the concept of configuration mixing and a free-nucleon $M1$ operator to the calculation of the $M1$ ground-state radiation width, whereas Ring and Speth[5] chose to renormalize the $M1$ operator in a phenomenological way in order to account for configuration mixing and mesonic effects.[6] The discrepancies between the results of the two theories are large. The ground-