Radiative decays of vector mesons

C. P. Singh and P. K. Chatley
Department of Physics, Panjab University, Chandigarh-160014, India
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The effect of meson masses on the transition moments for $V \to P\gamma$ decays is investigated. We find that this additional symmetry-breaking assumption fits the experimental data well, except for the decay $\psi \to \eta_c \gamma$.

It is well known that the simple additive quark model[1] does not explain accurately the experimentally known values of magnetic moments of $\frac{1}{2}^+$ baryons and radiative decay widths of 1^- mesons. De Rŭjula, Georgi, and Glashow[2] (DGG) and Lipkin[3] successfully predicted the magnetic moment $\mu(\Lambda)$ by incorporating the symmetry-breaking effects due to the difference in quark masses, but did not succeed in reproducing $\mu(\Sigma^+)$, $\mu(\Xi^0)$, and $\mu(\Xi^-)$. Also, using the same quark-mass-ratio parameters,[4] the radiative decay widths of vector mesons cannot be fitted. Several authors[5] have attempted to resolve these discrepancies by considering additional symmetry violations which may arise due to strong-interaction effects.[6] In particular, Teese and Settles[5] have demonstrated that magnetic moments are hadron-mass dependent. Employing a mass-correction term $(m_P/m_B)^{1/2}$, they have obtained a reasonably good fit. Recently,[7] by using a different value for the quark-mass-ratio parameter y $(=m_u/m_s)$, and then applying the mass correction, the gap between theory and experiment has further been lessened.

The purpose of this paper is to investigate the meson-mass dependence of the transition moments for $V \to P\gamma$ processes. As before,[4,7] we use the principle of quark additivity and assume that the quark magnetic moments are proportional to their charge-to-mass ratio. For the quark-mass-ratio parameter y, we have[7]

$$y=\frac{m_u}{m_s}=\frac{m_\Delta - m_\omega}{m_\Omega - m_\phi}=0.69\,. \tag{1}$$

Analogously, we can write

$$z=\frac{m_u}{m_c}=\frac{m_\Delta - m_\omega}{m_{\Omega^*_{ccc}} - m_\psi}=0.23\,, \tag{2}$$

where for $m_{\Omega^*_{ccc}}$ we are guided by the theoretical prediction of Ref. 8. Using Eqs. (1) and (2), we determine the transition moments in the units of proton magnetic moment for various $1^- \to 0^- \gamma$ decays by evaluating the matrix elements

$$\mu_0=\left\langle P\left|\sum_q \mu_q \sigma_z^q\right|V\right\rangle , \tag{3}$$

where

$$\mu_q=\frac{\hbar e_q}{2m_q c}\,. \tag{4}$$

For the processes $\phi \to \pi\gamma$ and $\phi \to \eta\gamma$, we use

$$|\eta\rangle=\cos\theta_P\,|s\bar{s}\rangle-\frac{\sin\theta_P}{\sqrt{2}}\,|u\bar{u}+d\bar{d}\rangle \tag{5}$$

and

$$|\phi\rangle=\cos\theta_V\,|s\bar{s}\rangle+\frac{\sin\theta_V}{\sqrt{2}}\,|u\bar{u}+d\bar{d}\rangle\,, \tag{6}$$

where $\theta_P=45^\circ$ and $\theta_V=5^\circ$, as has been suggested by the quadratic mass formula for mesons.[9]

To investigate the mass dependence of the transition moments, we examine two mass-correction terms: (a) $(m_P/m_V)^{1/2}$ and (b) $(E_P/m_V)^{1/2}$, so that the transition moments can now be expressed as

$$\text{(a)}\quad \mu=(m_P/m_V)^{1/2}\mu_0 \tag{7}$$

and

$$\text{(b)}\quad \mu=(E_P/m_V)^{1/2}\mu_0\,, \tag{8}$$

where m_P and E_P are the mass and the energy of the emitted pseudoscalar meson, respectively, and m_V is the mass of the decaying vector meson. The radiative decay widths are then calculated using the expression[1]

$$\Gamma(V \to P\gamma)=\frac{\langle\mu\rangle^2 k^3}{3\pi}\,, \tag{9}$$

where k is the photon momentum in the rest frame of the decaying vector meson and is given by $(m_V{}^2-m_P{}^2)/2m_V$. Our results, along with the experimental data, are displayed in Table I.

From the table, we find that the mass correction (b) to the transition moments gives an overall better fit for the decay widths, while the mass correction (a) yields lower values for the processes where a pion is emitted. This may be because pions are comparatively lighter and so relativistic effects may play a role $(E_\pi \gg m_\pi)$. It is noticed that both (a) and (b) give almost similar results for the decays where heavier mesons are emitted $(E_P \simeq m_P)$. There seems to be a strong disagreement for the decay $\psi \to \eta_c\gamma$; it may be attributed to the additional contribution from the gluon annihilation[2] which cannot be ignored for

TABLE I. Radiative decay widths (in keV) for $1^- \to 0^-$ transitions. $x = m_u/m_d = 1$.

Process	Matrix elements	Transition moments in nm with mass corrections (a)	(b)	Radiative decay widths (theoretical) (a)	(b)	Experimental values
$\rho \to \pi\gamma$	$\frac{1}{3}(x-2)$	−0.39	−0.67	22.2	66.3	67 ± 7 (Ref. 11)
$\omega \to \pi^0\gamma$	$-\frac{1}{3}(x+2)$	−1.17	−2.00	205.8	602.1	789 ± 92 (Ref. 12)
$\phi \to \pi^0\gamma$	$-\frac{0.08}{3}(x+2)^a$	−0.08	−0.16	2.34	8.9	6.5 ± 1.9 (Ref. 13)
$\rho \to \eta\gamma$	$\frac{1}{3\sqrt{2}}(2+x)$	1.61	1.64	51.8	54.2	52 ± 13.7 (Ref. 14)
$\omega \to \eta\gamma$	$\frac{1}{3\sqrt{2}}(2-x)$	0.56	0.58	6.82	7.32	$3.2^{+2.6}_{-1.9}$ (Ref. 14)
$\phi \to \eta\gamma$	$\frac{1}{3\sqrt{2}}[1.98y - 0.08(2-x)]^a$	0.62	0.67	49.8	58.9	65 ± 15 (Ref. 13,14)
$K^{*+} \to K^+\gamma$	$\frac{1}{3}(y-2)$	−0.92	−0.99	69.2	79.2	< 80 60 ± 15 (Ref. 15)
$K^{*0} \to K^0\gamma$	$\frac{1}{3}(y+x)$	1.16	1.26	108.8	127.3	75 ± 35 (Ref. 16)
$D_c^{*+} \to D_c^+\gamma$	$\frac{1}{3}(x-2z)$	−0.48	−0.48	1.59	1.59	
$D_c^{*0} \to D_c^0\gamma$	$-\frac{2}{3}(1+z)$	−2.21	−2.21	35.2	35.2	
$F_c^{*+} \to F_c^+\gamma$	$\frac{1}{3}(y-2z)$	−0.21	−0.21	0.12	0.12	
$\psi \to \eta_c\gamma$	$\frac{2}{\sqrt{3}}z$	0.72	0.72	23.6	23.6	1.2

[a]The factor 0.08 in ϕ decays occurs because of the mixing. Also see the text.

the processes having no net flavor.

It is known that the calculation of the matrix elements for the $1^- \to 0^-$ transitions involves the evaluation of a spatial-overlap integral Ω^2 of the initial and final wave functions. In earlier calculations,[1,4] the value of Ω^2 was taken to be unity. However, Isgur[10] pointed out that due to strong-interaction effects, it should always be <1. He used the value $\Omega^2 = 0.6$ and took it to be flavor independent (i.e., the same for all the $V \to P\gamma$ decays). However, such effects may not be the same for all the decays. With this aspect in view, we introduce the mass dependences of the type $(m_P/m_V)^{1/2}$ and $(E_P/m_V)^{1/2}$ (which are also <1). This ansatz of replacing the overlap integral by such mass-correction terms, though *ad hoc*, yields comparatively a much better overall fit, except for the decay $\psi \to \eta_c\gamma$.

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