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Scalar-meson contributions to the radiative decays of vector mesons

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We study the contributions made by the $\delta(980)$ scalar meson to radiative decays of vector mesons. Using results from previous studies of pseudoscalar-meson decays, we calculate the widths of the three-body decays $\rho, \omega, \phi \to \eta\pi\gamma$ and $\phi \to K\bar{K}\gamma$.

In two previous papers,[1,2] we investigated the role which scalar mesons play in the radiative decays of pseudoscalar mesons. We found that the $\delta(980)$ resonance, the only well-established scalar meson, plays an important role in the dynamics of several radiative decays of the K and η mesons.

In the present paper we investigate the contribution which the δ scalar meson makes to the radiative decays of vector mesons. Since the $\delta(980)$ couples predominantly to $\eta\pi$ and $K\bar{K}$, we focus our attention on the three-body radiative decays

$$\begin{aligned} &\rho \to \eta\pi\gamma\,, \\ &\omega \to \eta\pi\gamma\,, \\ &\phi \to \eta\pi\gamma\,, \\ &\phi \to K\bar{K}\gamma\,. \end{aligned} \tag{1}$$

In our model we assume that processes (1) are dominated by a δ intermediate state which virtually decays either into $\eta\pi$ or $K\bar{K}$. In Fig. 1 we exhibit the Feynman diagrams contributing to these processes. As is evident from the diagrams, we invoke vector dominance in describing the coupling of the photon to the vector-meson–scalar-meson system.

In evaluating the decay widths from the diagrams in Fig. 1, various coupling constants must be determined. The δ-η-π coupling instant $g_{\delta\eta\pi}$ is obtained from the observed decay width for $\delta \to \eta\pi$ which we take to be 55 ± 5 MeV.[3] The resulting value for the coupling is[4,5]

$$g_{\delta\eta\pi} = 2.1 \pm 0.1 \text{ GeV}\,. \tag{2}$$

The δ-K-$\bar{K}$ coupling can be estimated from the SU(3) prediction

$$g_{\delta K\bar{K}} = (\tfrac{3}{2})^{1/2} g_{\delta\eta\pi}\,. \tag{3}$$

Since the photons are real, we shall use the vector-meson–photon couplings obtained from photoproduction rather than from e^+e^- colliding beams.[6] The values are[7]

$$\frac{\gamma_\rho^2}{4\pi} = 0.61\,, \quad \frac{\gamma_\omega^2}{4\pi} = 7.6\,, \quad \frac{\gamma_\phi^2}{4\pi} = 5.9 \tag{4}$$

where the vector-meson–photon coupling is given by $em_V^2/2\gamma_V$. Finally, the coupling constants $g_{\rho\omega\delta}$, and $g_{\rho\phi\delta}$, associated with the ρ-ω-δ and ρ-ϕ-δ strong vertices, are determined[1] by fitting the δ model to the radiative decay $\eta \to \pi^0\gamma\gamma$. One obtains

$$g_{\rho\omega\delta} = 180 \pm 40 \text{ GeV}^{-1}\,. \tag{5}$$

The value of $g_{\rho\phi\delta}/g_{\rho\omega\delta}$ is assumed[1] to be equal to the ratio $g_{\rho\phi\pi}/g_{\rho\omega\pi} = 0.073$. This ratio is obtained from vector dominance and the ratio of the experimentally observed decay widths for $\phi \to \pi\gamma$ and $\rho \to \pi\gamma$.[8] The uncertainties in our subsequent results will be due mainly to the large uncertainty in (5) which can be traced to a 35% uncertainty in the width of the decay $\eta \to \pi^0\gamma\gamma$.[1]

Using the coupling constants given by Eqs. (2)–(5), the decay widths for processes (1) are calcu-

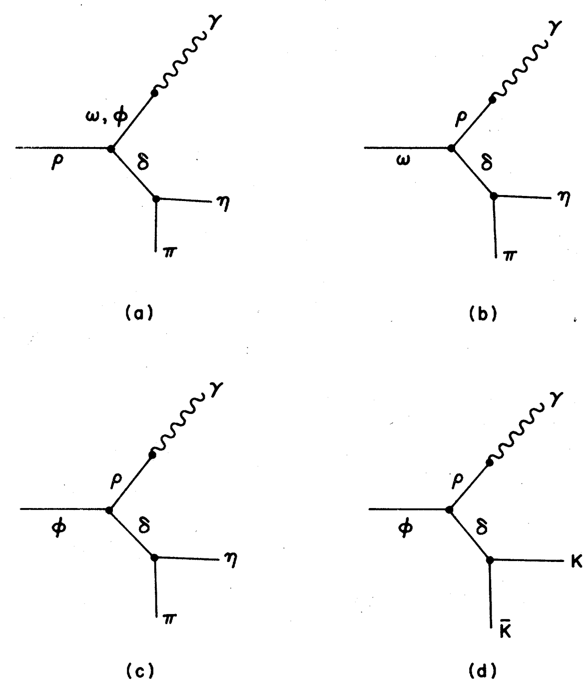

FIG. 1. Diagrams for the radiative vector-meson decays (a) $\rho \to \eta\pi\gamma$, (b) $\omega \to \eta\pi\gamma$, (c) $\phi \to \eta\pi\gamma$, and (d) $\phi \to K\bar{K}\gamma$ in the δ-meson model.

lated to be

$$\Gamma(\rho\to\eta\pi\gamma)=0.10\pm0.05 \text{ keV}, \tag{6a}$$

$$\Gamma(\omega\to\eta\pi\gamma)=1.8\pm0.9 \text{ keV}, \tag{6b}$$

$$\Gamma(\phi\to\eta\pi\gamma)=(0.82\pm0.44)\text{–}(0.41\pm0.22) \text{ keV}, \tag{6c}$$

$$\Gamma(\phi\to K^+K^-\gamma)=22\pm12 \text{ eV}, \tag{6d}$$

$$\Gamma(\phi\to K^0K^0\gamma)=3.3\pm1.8 \text{ eV}. \tag{6e}$$

In the case of $\phi\to\eta\pi\gamma$ we have used the narrow-width approximation[9]

$$\Gamma(\phi\to\eta\pi\gamma)=\Gamma(\phi\to\delta\gamma)B(\delta\to\eta\pi), \tag{7}$$

where $B(\delta\to\eta\pi)$ is the branching ratio of $\delta\to\eta\pi$ to $\delta\to$all. There is some uncertainty on the value for the full width of the δ partly due to the possibility that the $K\bar{K}$ channel is strongly coupled to the δ. In addition, vector dominance predicts[10] that some of the radiative decays of the δ give sizable contributions to the full width Γ_δ. As a result, the range of values for $\Gamma(\phi\to\eta\pi\gamma)$ appearing in (6c) is obtained by having the full δ width lie within the range 55 MeV $\leq\Gamma_\delta\leq$ 110 MeV.

Although there is no reported data on the radiative processes (1) to compare with the predictions (6), there is one relevant experimental upper limit,[11]

$$\Gamma(\omega\to\eta+\text{neutrals})<150 \text{ keV}. \tag{8}$$

Using (8) as an approximate[12] upper limit for $\Gamma(\omega\to\eta\pi^0\gamma)$ we see that the predicted value (6b) is about 2 orders of magnitude below this limit.

Finally, we compare the scalar-model predictions (6) with the corresponding predictions based on vector dominance. For instance, in the vector-dominance picture, the decay $\omega\to\eta\pi\gamma$ proceeds by $\omega\to\eta\omega\to\eta\pi\gamma$. In order to estimate the decay width, we first compare this process to $\eta\to\omega\omega\to\pi\gamma\gamma$. We find

$$\Gamma(\omega\to\eta\pi\gamma)/\Gamma(\eta\to\pi\gamma\gamma)\simeq\left(\frac{\gamma_\omega{}^2}{\pi\gamma}\right)\Phi, \tag{9}$$

where $\Phi=5.6\times10^{-2}$ represents a phase-space correction. A recent vector-dominance-model calculation[1] for $\eta\to\pi\gamma\gamma$ gives $\Gamma(\eta\to\pi\gamma\gamma)=0.06$ eV and, therefore, we expect vector dominance to yield a width $\Gamma(\omega\to\eta\pi\gamma)\simeq0.014$ keV which is about 2 orders of magnitude smaller than our prediction based on the δ model. Similar conclusions can be made for the three-body radiative decays of the ρ and ϕ mesons.

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[1] G. K. Greenhut and G. W. Intemann, Phys. Rev. D 16, 776 (1977).

[2] G. W. Intemann and G. K. Greenhut, Phys. Rev. D 18, 224 (1978).

[3] J. B. Gay *et al.*, Phys. Lett. 63B, 220 (1976).

[4] We use a value of 981 ± 6 MeV for the mass of the δ as obtained in Ref. 3.

[5] We are ignoring the possibility discussed by S. Flatté [Phys. Lett. 63B, 224 (1976)] that the observed $\delta\to\eta\pi$ width may be considerably reduced from its actual value because of the existence of the $\delta\to K\bar{K}$ channel and the combined effects of unitarity and analyticity. However, Flatté obtains a minimum χ^2 fit to the data in Ref. 3 for a value of $\Gamma(\delta\to\eta\pi)$ close to the experimentally reported value for a ratio of the δ-K-$\bar{K}$ to δ-n-π couplings in approximate agreement with the prediction of SU(3).

[6] E. H. Thorndike, in ***Experimental Meson Spectroscopy, 1977***, proceedings of the Fifth International Conference, Boston, edited by E. von Goeler and R. Weinstein (Northeastern Univ., Boston, 1978).

[7] A. Silverman, in *Proceedings of the 1975 International Symposium on Lepton and Photon Interactions at High Energies, Stanford, California*, edited by W. T. Kirk (SLAC, Stanford, 1976), p. 335.

[8] In Ref. 6, it is shown that in the recent photoproduction data of D. E. Andrews *et al.* (to be published) there is evidence that the relative phase between the amplitudes for $\rho\to\pi\gamma$ and $\phi\to\pi\gamma$ is ~180°. It this relative phase occurs in the ρ-ϕ-π and ρ-ω-π couplings in the vector dominance expressions for these amplitudes, then the sign of $g_{\rho\phi\delta}/g_{\rho\omega\delta}$ must be changed and we obtain $g_{\rho\omega\delta}=220\pm50$ GeV^{-1}. This has the effect of increasing all our calculated three-body vector-meson radiative decay widths by a factor of ~1.5.

[9] We expect this approximation to be accurate to within about 10%, which is comparable to the overall accuracy of the calculation.

[10] G. K. Greenhut and G. W. Intemann, Phys. Rev. D 18, 231 (1978).

[11] S. Flatté *et al.*, Phys. Rev. 145, 1050 (1966).

[12] The only C-conserving two-body decay which can be included in the upper limit for $\Gamma(\omega\to\eta+\text{neutrals})$ is $\omega\to\eta\gamma$. Experimentally, $\Gamma(\omega\to\eta\gamma)<50$ keV.