PHYSICAL REVIEW LETTERS

VOLUME 36 | 26 JANUARY 1976 | NUMBER 4

Meson Decay Rates*

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(Received 12 November 1975)

The new decay rates of mesons which have been published within the last year are examined to determine their consistency with SU(3) symmetry, vector dominance, and the quark model. It is shown that despite an apparent overall trend of the new data to disagree with certain quark-model predictions by a factor of 3 or so, the consistency of the data with usual ideas of low-energy phenomenology is impressive. It would appear that the new data do not constitute a crisis for the "old" physics.

Within the past year much new data on meson-decay rates have been published,[1-5] most of it on radiative decays (see Table I). In turn, most of the new measurements of radiative decays have been obtained from high-energy scattering experiments using the Primakoff effect[6] to isolate the Coulomb exchange. An outstanding feature of almost all of the new data is the fact that the new measured partial widths are consistently a factor of 2 or 3 smaller than quark-model predictions. Since theories of the new ψ particles have most trouble usually in explaining the small radiative widths it becomes important for us to know whether there is a crisis for theory in explaining the radiative decays of the "old" physics.

One immediate (and quite likely) possibility is that the extraction of a radiative-decay width by means of a Primakoff effect is more sensitive to the details of strong-interaction effects than has so far been suspected. Although this might explain the shift in an individual result it is unlikely to explain the general trend. In this paper I shall take the new experimental values as given and examine whether the new numbers do, in fact, constitute a crisis for SU(3), the quark model, or low-energy phenomenology in general.

Since I shall only deal with 0^- and 1^- mesons which, in the quark model, have the quarks bound in a relative S state, there is considerable overlap between the quark-model description and the vector-dominance approach based on SU(3).[7] For the majority of the paper I shall use the latter description and reserve the SU(6) approach to remove the arbitrariness of two parameters.

In all attempts to extract symetry predictions from cross sections or decay rates a number of ambiguities present themselves. In extracting the leptonic-decay constants from the colliding-beam data finite-width effects can be important. In using the ω-φ and η-η' mixing angles, should the angles obtained from the mass formulas be used or should they remain parameters to be

TABLE I. Partial widths.

Decay	Width (kev)	Ref.
$\pi^0 \to \gamma\gamma$	$(7.92 \pm 0.42) \times 10^{-3}$	2
$\eta \to \gamma\gamma$	0.324 ± 0.046	1
$\rho^- \to \pi^-\gamma$	35 ± 10	3
$K^{*0} \to K^0\gamma$	75 ± 35	4
$\varphi \to \eta\gamma$	65 ± 15	5
$\varphi \to \pi\gamma$	5.9 ± 2.1	5

fitted from the partial widths?[8] How does one isolate the symmetry predictions from the phase-space and angular-momentum-barrier factors?

The prescription I shall adopt here is the following. The couplings of the ρ, ω, and φ to the photon are defined to be[9] $em_\rho^2/2\gamma_\rho$, $em_\omega^2\sin\theta_V/2\sqrt{3}\gamma_Y$, and $em_\varphi^2\cos\theta_V/2\sqrt{3}\gamma_Y$, respectively, where θ_V is the vector-meson mixing angle. SU(3) symmetry is taken to imply $\gamma_Y^2/4\pi\approx\gamma_\rho^2/4\pi=0.53\pm0.10$ from the $\rho\to e^+e^-$ data. Since this value of γ_Y gives an angle $\theta_V\sim 36°$ from $\omega\to e^+e^-$, I shall adopt the "ideal" mixing angle of $\tan^{-1}(1/\sqrt{2})$ throughout. For the pseudoscalars the η-η' mixing angle θ_P is taken to be $-10°$ as given by the quadratic mass formula. SU(3) symmetry is to be applied also to the dimensionless coupling constants[10] for the decays $V\to P\gamma$ and all decay rates will be taken relative to that for $\pi^0\to\gamma\gamma$ since this decay rate has remained relatively stable under the new measurements. Also, it is the smallest of the decay rates considered here so that dividing it by the other decay rates should give a reasonbly stable method of comparison. Expressing results in such ratios should also minimize the effects of ignoring finite-width corrections. However, there is clearly a minimum of 20% error (coming from $\gamma_\rho^2/4\pi$) which will be taken as an estimate of the error of the theory.

The entries in Table II are then easily obtained using the usual vector-dominance and SU(3) arguments[7,9] and depend on the parameters $\gamma_{\rho\pi\pi}^2/4\pi$ and the ratio $g_{\varphi\rho\pi}/g_{\omega\rho\pi}$. The former is obtained from the decay widths for $\rho\to\pi\pi$ while the latter is taken from the ratio of the decays $\varphi\to\pi\gamma$ and $\omega\to\pi\gamma$. This latter ratio is small (~ 0.05) and plays an important role mainly for the ratio $\Gamma(\varphi\to\pi\gamma)/\Gamma(\pi\to\gamma\gamma)$. Because of the (minimum) 20% uncertainty, Table II implies that agreement with the data is reasonably good.

Table III gives a comparison of theory and experiment for decays involving the η, η' system. In deriving these results I have used vector dominance, SU(3), and the quark model to remove two additional parameters. That is, the dimensionless $\pi\to\gamma\gamma$ coupling constant is given by

$$f_{\pi\gamma\gamma}\approx e(f_{\pi\rho\gamma}/2\gamma_\rho+f_{\pi\omega_8\gamma}/2\sqrt{3}\gamma_Y), \tag{1}$$

$$\approx ef_{\rho\pi\gamma}/\gamma_\rho, \tag{2}$$

when use is made of the relations $\gamma_Y\approx\gamma_\rho$ and the SU(3) conditions

$$\sqrt{3}f_{\pi\rho\gamma}=f_{\pi\omega_8\gamma}=f_{\eta_8\rho\gamma}=-\sqrt{3}f_{\eta_8\omega_8\gamma}, \tag{3}$$

where ω_8, η_8 refer to the octet components of the ω-φ and η-η' systems, respectively. The corresponding singlet parts are denoted by ω_1 and η_1. The quark-model magnetic dipole transition matrix elements allow further restrictions to be made, viz.,

$$\sqrt{3}f_{\eta_1\omega_8\gamma}=f_{\eta_1\rho\gamma}=\sqrt{2}f_{\eta_8\rho\gamma}, \tag{4}$$

and

$$f_{\omega_1\pi\gamma}=\sqrt{6}f_{\rho\pi\gamma}. \tag{5}$$

Use of Eqs. (4) and (5) is not consistent with the previous results in Table II since the same assumptions would give zero for the decay $\varphi\to\pi\gamma$. Nevertheless, the relative smallness of this decay experimentally and the fact that a small change in the mixing angle θ_V from the ideal value would allow a nonzero $\varphi\to\pi\gamma$ decay mean that

TABLE II. Vector-meson decays. The entries denote the ratio $\Gamma(\pi\to\gamma\gamma)/\Gamma_i$ for the ith entry. The width formulas are $\Gamma(\pi\to 2\gamma)=m_\pi|f_{\pi\gamma\gamma}|^2/64\pi$, $\Gamma(V\to P\gamma)=(m_V^2-m_P^2)^3|f_{VP\gamma}|^2/96\pi m_V^3 m_\pi^2$, and $\Gamma(V\to PP')=\frac{1}{3}(\gamma_{VPP'}^2/4\pi)m_V^{-5}[(m_V^2-m_P^2-m_{P'}^2)^2-4m_P^2m_{P'}^2]^{3/2}$. The first five entries use $\gamma_\rho^2/4\pi=0.53\pm0.1$; the width for $\rho\to\pi\pi$ is used to enable the remaining entries to be calculated. The value $\gamma_{\rho\pi\pi}^2/4\pi=0.72\pm0.05$ is used.

Decay	Theory	Experiment	Ref.
$\rho^-\to\pi^-\gamma$	1.34×10^{-4}	$(2.26\pm0.78)\times10^{-4}$	3
$\omega\to\pi\gamma$	1.2×10^{-5}	$(0.91\pm0.14)\times10^{-5}$	11
$\varphi\to\pi\gamma$	1.8×10^{-3}	$(1.34\pm0.55)\times10^{-3}$	5
$K^{*0}\to K^0\gamma$	0.6×10^{-4}	$(1.06\pm0.55)\times10^{-4}$	4
$K^{*+}\to K^+\gamma$	2.4×10^{-4}	$>9.9\times10^{-5}$	11
$\rho\to\pi\pi$	5.28×10^{-8}	$(5.28\pm0.65)\times10^{-8}$	11
$\varphi\to K\bar{K}$	2.34×10^{-6}	$(2.32\pm0.40)\times10^{-6}$	11
$K^*\to K\pi$	1.8×10^{-7}	$(1.59\pm0.12)\times10^{-7}$	11
$\omega\to3\pi$	1.52×10^{-6}	$(0.90\pm0.10)\times10^{-6}$	11

TABLE III. Meson decays involving the η-η' system. Entries denote ratio as in Table II.

Decay	Theory	Experiment	Ref.
$\eta\to2\gamma$	0.0223	0.0244 ± 0.005	1
$\varphi\to\eta\gamma$	0.7×10^{-4}	$(1.2\pm0.4)\times10^{-4}$	5
$\eta'\to2\gamma$	1.34×10^{-3}	$>0.4\times10^{-3}$	11
$\rho\to\eta\gamma$	2.2×10^{-4}		
$\eta'\to\rho\gamma$	1.1×10^{-4}	$>0.3\times10^{-4}$	11
$\eta'\to\omega\gamma$	1.2×10^{-3}	$>10^{-4}$	11
$\omega\to\eta\gamma$	1.74×10^{-3}	$>1.5\times10^{-4}$	11
$\varphi\to\eta'\gamma$	1.8×10^{-2}		11

use of Eqs. (4) and (5) will not cause much of an error. With this proviso all of the entries in Table III involve no new parameters. Tables II and III taken together give an extremely consistent picture based on the vector-dominance and SU(3) models particularly when it is remembered that theory columns should have errors of the order of 10–20% and do not explicitly take finite-width corrections into account.

In the analysis presented here the errors assigned to theory are only those arising from the coupling-constant determinations and do not include estimates of errors incurred by using vector dominance. The naive quark model predicts absolute values for radiative decays. To the extent that relative values of decays are considered it can be put into correspondence with the vector-dominance approach, the latter method allowing a reasonable estimate of error to be made. It is clear from the tables that most of the data will have to be known much more accurately than it is at present before a meaningful test is to be made. As an example, the $\rho^- \to \pi^- \gamma$ width of either[3] 35 ± 10 keV or a factor of 2 larger[12] can reasonably be accounted for by the result in Table II.

I should like to thank D. Ryan for an informative discussion on the experimental analysis of the Primakoff effect.

*Research supported in part by the National Research Council of Canada.

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Study of the Isospin Properties of Single-Pion Production by Neutrinos*

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Results are presented on the three single-pion production reactions $\nu p \to \mu^- p \pi^+$, $\nu n \to \mu^- n \pi^+$, and $\nu n \to \mu^- p \pi^0$. Measurements were made from threshold to a neutrino energy of 1.5 GeV using the Argonne National Laboratory 12-ft bubble chamber filled with hydrogen and deuterium and exposed to a broad-band neutrino beam. In addition to a resonant isopin $T = \frac{3}{2}$ πN amplitude, we find a large $T = \frac{1}{2}$ amplitude as predicted by Adler.

Single-pion production is one of the simplest reactions between neutrinos and hadrons. Within the framework of $V-A$ theory, detailed calculations have been made by Adler[1] for the production of low-mass π-nucleon systems in the charged-current reactions

$$\nu p \to \mu^- p \pi^+, \tag{1a}$$

$$\nu d \to \mu^- p \pi^+ (n_s), \tag{1b}$$

$$\nu d \to \mu^- n \pi^+ (p_s), \tag{2}$$