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Pionic and Radiative Decay Widths of Charmed Hadrons

in

a Badly Broken SU(4) Symmetry

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On the basis of current algebras and duality a general rule is proposed to introduce large breaking of a higher symmetry into decay rates. The rule is applied to charmed meson decays. We also derive an upper bound on the $D^{0*} \to D^0 + \pi^0$ decay rate which is used to set an lower bound on its Q value.

The electron-positron annihilation experiment has revealed evidences for charmed mesons (1) and the high energy γBe collision has indicated existence of charmed hadrons. (2) In the standard picture of quantum chromodynamics, there exists an SU(4) symmetry among flavors which is badly broken by large mass differences of quarks. Because of the very large symmetry breaking, relating decay coupling constants of charmed hadrons with those of light hadrons is not meaningful unless a prescription is given as to how the breaking interaction is to be taken into account. One approach to this problem is to calculate each decay coupling constant explicitly in the potential model of quark bound states. We present here another approach that refers far less to specific details of strong interactions. It is based on the SU(2) charge algebra at equal times and Regge asymptotic behaviors.

Following the standard method, we can derive the Adler-Weisberger (A-W, hereafter) relation for a charmed hadron target. To be concrete, we choose the D^0 meson of $J^P = 0^-$ here. The relation is written as

$$1 = \frac{2f_\pi^2}{\pi}\int_{\nu_0}^{\infty} \frac{d\nu}{\nu}\left\{\sigma_0^+(\nu) - \sigma_0^-(\nu)\right\} , \qquad (1)$$

where $\sqrt{2} f_\pi = m_\pi$, $\sigma_0^\pm$ are the $\pi^\pm D$ total cross sections with the massless pion, and $2m_D\nu + m_D^2 + m_\pi^2$ is the center-of-mass energy squared, s. The integral in the right-hand side of (1) should converge like $\int^\infty d\nu\, \nu^{-1.5}$ according to the Regge asymptotic behavior with $\alpha_\rho(0) \simeq 0.5$. If the integral is saturated with nonexotic resonances, Equation (1) becomes

$$1 = f_\pi^2 \sum_n \left\{ 4\pi (2J_n+1)/|p_{on}|^3 \right\} (p_{on}/p_n)^{2J_n+1}\, \Gamma_n \quad , \qquad (2)$$

where p_n is the momentum of the D^0 in the decay into $D^0\pi^+$ of the n th resonance of spin J_n and decay width Γ_n , and p_{on} is the decay momentum of the D^0 in the case of the pion being massless.

To predict an SU(4) breaking effect for each individual coupling, we have to supplement (2) with duality of strong interaction dynamics. The leading Regge terms have been successfully extrapolated in the sense of finite-energy sum rule down to the thresholds of all of the hadron-hadron scattering amplitudes so far analyzed. The rate of convergenece in ν or in s of the integral in (1) is the same as that for $\pi\pi$ or $K\pi$ scattering, since the convergence is determined in common by the ρ Regge trajectory. We therefore introduce a crucial dynamical assumption on strong interactions on which most of the following results depend on. <u>The ρ Regge exchange amplitude can be extrapolated to the low energy region of the πD scattering to describe all of the direct channel D resonances in the sense of finite-energy sum rule</u>. Then, it leads us to a similarity relation between πD and $\pi\pi$(or $K\pi$) amplitudes of I = 1 in t channel. Furthermore, the similarity relation becomes a simple proportionality relation if resonances populate in the same density (in s) in the two channels. For instance, relative importance of the lowest resonance to the rest in (2) is the same as that in $\pi\pi$(or $K\pi$) scattering. If we saturate the A-W relation of $\pi\pi$ scattering only with the ρ meson in s channel, we get $g^2_{\rho\pi\pi} = m_\rho^2/f_\pi^2$ for the $\rho\pi\pi$

coupling constant, which is twice as large as the experimental value. (Compare it with the KSRF relation, $g^2_{\rho\pi\pi} = \frac{1}{2} m_\rho^2/f_\pi^2$.) In other words, the A-W relation is saturated up to 50 % by the s channel ρ meson. The proportionality between πD and $\pi\pi$ implies that if we saturate (2) with the D^{+*} meson state ($J^P = 1^-$), we would obtain the $D^{+*}D^0\pi^-$ coupling constant twice as large as the experimental value. The $D^{0*} \to D^0 + \pi^0$ decay rate is determined in this way, including the nonsaturating factor of $\frac{1}{2}$,

$$\Gamma(D^{+*} \to D^0 + \pi^+) = \frac{1}{2} \times \frac{p^3}{12\pi f_\pi^2} \quad , \qquad (3)$$

where p is the decay momentum in the rest frame of D^{+*}. Notice that a dimensional quantity f_π enters the decay rate explicitly. This formula would not result if one relates the dimensionless couplings of $\rho\pi\pi$ and $D^*D\pi$ by the SU(4) symmetry.

Let us include higher mesons in our argument. The higher resons should saturate the balance of the actual D^{+*} contribution. As has been pointed out above, there should be a simple proportionality relation between each corresponding pair of resonance contributions in πD and $\pi\pi$/$K\pi$, provided that the density of resonances is the same in the center-of-mass squared. The last condition is fulfilled, for instance, if mass formulas hold for a corresponding pair of mesons, $D'(J^P)$ and $K'(J^P)$, in mass squared as $m^2(D') - m^2(D) = m^2(K') - m^2(K)$. It has been known that such formulas hold well in SU(3) multiplets, and so let us assume them for charmed mesons for a while. (Note that $m^2(D^*(1^-)) - m^2(D(0^-)) \simeq m^2(\rho) - m^2(\pi)$, experimentally.) The proportionality relation can then be written in the form of

$$\frac{\Gamma(D'(J^P) \to D + \pi)}{\Gamma(K'(J^P) \to K + \pi)} = \left(\frac{p_D}{p_K}\right)^{2J+1} \times \left(\frac{p_{oK}}{p_{oD}}\right)^{2J-2} \qquad (4)$$

where p_D and p_K are decay momenta of D and K in the rest frames of D' and K', respectively, and p_{oD} and p_{oK} are the decay momenta with massless pions. Within SU(3) multiplets, this rule can not be tested decisively against others because of experimental ambiguities. For instance, (4) predicts from $\Gamma(K^*) = 49.8$ MeV that the ρ meson width $\Gamma(\rho)$ should be 129 MeV, while the SU(3) symmetric values for the dimensionless couplings lead us to $\Gamma(\rho) = 173$ MeV.

The present method is less powerful in radiative decays as the electromagnetic current consists of isovector and isoscalar parts. For the isoscalar current, equal-time algebras provide us with no convergent sum rule which we can use for our purpose. We can derive, however, interesting results for the isovector part from the Cabibbo-Radicati (C-R, hereafter) sum rule. [3] Following the standard procedure, we obtain the C-R sum rule for the D^o meson in the resonance approxiamtion as

$$-F_v'(0) = \sum_n \frac{4\pi(2J_n+1)\,m_n^3}{(m_n^2 - m_D^2)^3} \times 2\,\Gamma_n \quad , \qquad (5)$$

where Γ_n is the "decay rate" of the n th resonance into D^o + isovector photon, $F_v'(0)$ is the first derivative in q^2 of the isovector electromagnetic form factor $F_v(q^2)$ of the D^o meson, and exotic mesons are assumed to be absent, as before. Note that the isovector photon can couple only with the u and d quarks. The electromagnetic charge radius in the left-hand side of (5) is therefore determined by the light quark distribution inside of the physical D^o meson. With the Okubo-Zweig-Iizuka rule taken into account, we can write the complete form factor $F(q^2)$ in the form of

$$\left.\begin{aligned} F(q^2) &= F_v(q^2) + F_s(q^2)\ , \\ F_v(q^2) &= -\tfrac{1}{2}\,(1 - q^2/m_\rho^2)^{-1}\ , \\ F_s(q^2) &= (2/3)(1 - q^2/m_\varphi^2)^{-1} - (1/6)(1 - q^2/m_\omega^2)^{-1}, \end{aligned}\right\} \qquad (6)$$

for the D^o meson in the simple pole approximation. We thus have $F_v'(0) = -\frac{1}{2} m_\rho^{-2}$. By substituting this in (5), we compare (5) with the C-R sum rule, for instance, for the kaon in the same approximation,

$$\tfrac{1}{2}\, m_\rho^{-2} = \sum_n \frac{4\pi(2J_n+1)\,m_n^3}{(m_n^2 - m_K^2)^3} \times 2\,\Gamma_n \quad . \qquad (7)$$

Again under the assumption that the density of resonances be the same for charmed meson sector and strange meson sector, radiative decay rates into the isovector photon are subjected to the SU(4) correction as follows:

$$\frac{\Gamma(D'(J^P) \to D + \gamma_v)}{\Gamma(K'(J^P) \to K + \gamma_v)} = \left(\frac{p_D}{p_K}\right)^3 \qquad (8)$$

for an arbitrary spin J. When the decay is through an M1 or E1 transition, this correction factor is in agreement with what the static quark model predicts. Note that M1 and E1 transition matrix elements of γ_v are inversely proportional to the light quark mass for $m_c \gg m_u$.

The comparison with the static quark model suggests that the radiative decay rate for the emission of a photon from a light quark, partly isovector and partly isoscalar, may be given by

$$\frac{\Gamma(D'^o(J^P) \to D^o + \gamma_q)}{\Gamma(K'^+(J^P) \to K^+ + \gamma_q)} \simeq \left(\frac{p_D}{p_K}\right)^3 , \qquad (9)$$

where γ_q denotes the photon emitted from a light quark.

Let us apply our rule to the D^{0*} decays. One interesting features of the charmed meson mass spectroscopy is that the $D^{0*} \to D^0 + \pi^0$ decay is barely allowed with a Q value not much larger than a few MeV. The radiative decay $D^{0*} \to D^0 + \gamma$ may well compete with the pionic decay. Experimentally,

$$m(D^{0*}) + m(D^0) = 3869 \pm 6.4 \text{ MeV}, \tag{10}$$

but the mass difference has not been determined sufficiently accurately. The radiative branching ratio $B_\gamma = \Gamma(D^{0*} \to D^0 + \gamma)/[\Gamma(D^{0*} \to D^0 + \gamma) + \Gamma(D^{0*} \to D^0 + \pi^0)]$ has been given to be $(40 \pm 5)\%$ in the preliminary report [1]. If one retains only the photon emission from the light quark, the radiative D^{0*} decay is related to the $\omega \to \pi^0\gamma$ decay through (9) as

$$\Gamma(D^{0*} \to D^0 + \gamma) = \frac{4}{9}(q_D/q_\pi)^3\,\Gamma(\omega \to \pi^0 + \gamma), \tag{11}$$

where q_D and q_π are the decay momenta. With the charmed quark contribution included according to the static quark model, (11) is modified as

$$\Gamma(D^{0*} \to D^0 + \gamma) = \frac{4}{9}(q_D/q_\pi)^3\,(1 + \mu_c/\mu_u)^2\,\Gamma(\omega \to \pi^0 + \gamma), \tag{12}$$

where μ_c and μ_u are the total magnetic moments of the c and u quarks, respectively. The pionic decay is calculated from (4) as

$$\Gamma(D^{0*} \to D^0 + \pi^0) = (p_D/p_K)^3\,\Gamma(K^{0*} \to K^0 + \pi^0), \tag{13}$$

Leaving the Q value for $D^{0*} \to D^0 + \pi^0$ as a free parameter, we obtain from (12) and (13) with $\mu_c/\mu_u = 0.2$

$$B_\gamma = 1/[1 + (Q/4.06 \text{ MeV})^{\frac{3}{2}}]. \tag{14}$$

By equating this to the preliminary experimental value 0.40, we deduce

Q = 5.3 MeV. It is interesting to note that (2) sets an upper bound on $\Gamma(D^{+*} \to D^0 + \pi^+)$ as

$$\Gamma(D^{+*} \to D^0 + \pi^+) < \frac{p^3}{12\pi f_\pi^2}. \tag{15}$$

This is a consequence of the current algebra and absence of exotic charmed mesons with no further dynamical assumption at all. It leads us to

$$B_\gamma > 1/[1 + (Q/2.71 \text{ MeV})^{\frac{3}{2}}], \tag{16}$$

which in turn requires $Q > 3.4$ MeV for $B_\gamma = 0.40$. If one relates $D^{0*} \to D^0 + \gamma$ and $\omega \to \pi^0 + \gamma$ by the static quark model and uses the SU(4) symmetric values for the dimensionless $D^{0*}D^0\pi^0$ and $\rho\pi\pi$ couplings, the denominator of Q in (14), 4.06 MeV, would be multiplied by $[m(D^{*0})/m(K^*)]^{4/3} = 2.97$.

We have so far been assuming that the mass difference formulas hold in squared mass so that the density of resonances is the same in channels of different quantum numbers. This would not be the case for baryons. If it happens that the mass formulas hold in some power of mass different from square, our prescription should be modified accordingly. Let assume that the mass formulas work best in m^λ. Then, the formula (4) should be replaced by

$$\frac{\Gamma(D'(J^P) \to D+\pi)}{\Gamma(K'(J^P) \to K+\pi)} = \left(\frac{p_D}{p_K}\right)^{2J+1}\left(\frac{p_{0K}}{p_{0D}}\right)^{2J-2}\left(\frac{m(D')}{m(K')}\right)^{2-\lambda}\left\{\frac{m^2(D')-m^2(D)}{m^2(K')-m^2(K)}\right\}^{\alpha_\rho(0)-2} \tag{17}$$

and the radiative decay formula (8) should also to modified in the same way. This modification applies to the lowest resonance with $J^P = 1^-$, too.

However, this does not affect the ratio $\Gamma(D^{0*} \to D^0 + \gamma)/\Gamma(D^{0*} \to D^0 + \pi^0)$ as calculated in (14) and (16), since the modifying factors in (17) cancel themselves. In fact, independently of the charmed mass spectrum, the formula for ratios

$$\frac{\Gamma(D'^{0}(J^P) \to D^0 + \pi^0)}{\Gamma(K'^{0}(J^P) \to K^0 + \pi^0)} = \left(\frac{p_D}{p_K}\right)^{2J+1} \cdot \left(\frac{p_{oK}}{p_{oD}}\right)^{2J-2} \cdot \left(\frac{q_K}{q_D}\right)^{3} \cdot \frac{\Gamma(D'^{0}(J^P) \to D^0 + \gamma_v)}{\Gamma(K'^{+}(J^P) \to K^+ + \gamma_v)} \quad (18)$$

holds valid. For the decays of baryons, J should be replaced by orbital angular momentum ℓ in the right-hand side of (18).

References

1. G. Goldhaber et al., Phys. Rev. Lett. 37 (1976) 255; I. Peruzzi et al., Phys. Rev. Lett. 37 (1976) 569; G. Goldhaber, talk at SLAC Summer Conference on Particle Physics, August, 1976 and LBL Report LBL-5534.
2. B. Knapp et al., Phys. Rev. Lett. 37(1976) 882.
3. N. Cabibbo and L. A. Radicati, Phys. Lett. 19 (1966) 697.

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