The Quark-diagram Classification of Charm Decays

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Abstract

The decays of charm mesons are describes in terms of quark-diagram amplitudes. Experimental implications of these amplitudes are also discussed.

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I. Introduction

Recently there have been many interesting experimental results in the area of charm decay, e.g. the two body decays[1][2] and the life time differences[3][4] of D^0, D^+. These experimental data have resulted in our further understanding of the charm decay mechanism.[5]-[8]

Within the symmetry of SU(3), the two-meson decays of D^0, D^+, F^+ have been classified by Wilczek and Wang in Ref. (5) in terms of five dynamical amplitudes and two weak mixing angle parameters. However the physical meaning of the five amplitudes was not illustrated. In this paper we give a quark-diagram classification of the charm decays, total decay rates as well as decay rates of definite final states. This provides a general framework into which future experimental results and strong-dynamics effects can be incorporated.

II. Classification according to quark diagrams

There are six distinct diagrams a, b, c, d, e, and f for the weak decays of a quark-antiquark system, as shown in Fig. 1. These graphs mean to include all strong interaction effects. Our current understanding of the strong interaction does not yet allow us to include explicitly their effects; however they should not change the distinctions made among these diagrams classified according weak interaction properties. Formation of hadrons in the final state is obtained by combining the various quarks and antiquarks (a quark-antiquark pair can be added if they are needed to form the particular hadronic states). In diagrams of Figs. (1a) and (2a) hadrons are formed from quark-antiquark pair (4,3) separately from those from (1,2). In diagrams Figs. (1b) and (2b) hadrons are formed from the quark-antiquark pair (1,4) and from (3,2). Therefore diagrams a and b are distinct.

a. Total Decay Rates of D^0, D^+ and F^+. The semi-leptonic decays of the D^0, D^+ and F^+ are given by a graph like the diagram a in Fig.(1) with 3 and 4 being an outgoing lepton and its antineutrino respectively. Therefore the semileptonic decay rates are the same for D^0, D^+ and F^+. The total hadronic decay rates should be given by

$$\Gamma(D^0 \to \text{hadrons}) = |V_{ud}V_{cs}(a + b + c)|^2,$$

$$\Gamma(D^+ \to \text{hadrons}) = |V_{ud}V_{cs}(a + b)|^2, \text{ and} \tag{2.1}$$

$$\Gamma(F^+ \to \text{hadrons}) = |V_{ud}V_{cs}(a + b + d)|^2,$$

where the V's are the matrix elements of the mixing matrix (for their definition see Refs. (8) and (9). Here only the mixing-angle favored diagrams are included. The experimental implications on these amplitudes are discussed in Sect. III.

b. Exclusive reactions -- two body decays. Here we discuss the decays of the D^0, D^+ and F^+ into two mesons of the 0^- octet. The six distinctive graphs are given in Fig. (2). In diagram a of Fig. (2) the $q\bar{q}$ pair (1,2) forms either a π^+ or K^+ and the $q\bar{q}$ pair (1,4) forms a another pseudoscalar meson. In diagram b of Fig. (2), on the other hand, the $q\bar{q}$ pairs (1,4) and (2,3) separately form pseudoscalar mesons. The diagrams c, d, e and f of Fig. (2) are obtained from those of Figs. 1 by putting in a $q\bar{q}$ pair with the $q\bar{q}$ pair (1,4) forming a single meson and the pair (2,3) another. The results are given in Table I. Though there are six quark diagrams, they contribute only in five independent ways as they should from SU(3) symmetry counting.[5][6] The six amplitudes a, b, c, d, e and f of these quarks graphs are related to those A, B, C, D, and E of Ref. (5) by

$$A=a+c,\ B=b-c,\ C=a-d,\ D=e+2f \text{ and } 6E=2c+6f+e. \tag{2.2}$$

Presumably the decays of more final state particles can also be considered by adding the appropriate $q\bar{q}$ lines into the final states.

III. Discussions on experimental results

First we list the currently available charm decay data [(1)-(4)]

$$B(D^+ \to e^+X) = \Gamma(D^+ \to e^+X)/\Gamma(D^+ \to \text{all}) = 0.23\pm0.06, \text{or } .158\pm.053, \tag{4.1}$$

$$B(D^0 \to e^+X) = \Gamma(D^0 \to e^+X)/\Gamma(D^0 \to \text{all}) < 0.04, \text{or } .052\pm.033. \tag{4.2}$$

The first set of data is from the LGE experiment (Ref.3) and the second set of data is from Mark II experiment (Ref. 1,2) at SLAC. From the assumption that the semileptonic decay widths are the same for both the D^+ and the D^0, the experimental results of Eqs. (4.1) and (4.2) imply

$$\Gamma(D^0 \to \text{all})/\Gamma(D^+ \to \text{all}) > 6, \text{ or } = 3.1^{+4.1}_{-1.3} . \tag{4.3}$$

We also have [(1)(2)]

$$\Gamma(D^0 \to K^-K^+)/\Gamma(D^0 \to K^-\pi^+) = 0.113\pm0.030, \tag{4.4}$$

$$\Gamma(D^0 \to \pi^-\pi^+)/\Gamma(D^0 \to K^-\pi^+) = 0.033\pm.015, \tag{4.5}$$

$$B(D^0 \to \bar{K}^0\pi^0) = 0.021\pm0.009 \tag{4.6}$$

$$B(D^0 \to K^-\pi^+) = 0.028\pm0.005, \tag{4.7}$$

$$B(D^+ \to \bar{K}^0\pi^+) = 0.021\pm0.005. \tag{4.8}$$

Combining these with the information provided by Eq. (4.3), the last two equations imply

$$\Gamma(D^0 \to K^-\pi^+)/\Gamma(D^+ \to \bar{K}^0\pi^+) > 8.8, \text{ or } \approx 4.13 \tag{4.9}$$

Now we shall discuss the implications[(10)] of these experimental results in terms of our quark diagram and SU(3) classification. For completeness, our discussions may overlap some of those already appearing in the literature.[(7)(8)] Using Eq. (2.1) and the experimental data in Eq. (4.3),

$$\Gamma(D^0 \to \text{hadrons})/\Gamma(D^+ \to \text{hadrons}) = |a+b+c|^2/|a+b|^2. \tag{4.10}$$

We find that the amplitude c in Fig. 1 must be dominant. This conclusion is also consistent with the comparison of our Table I with the data in Eq. (4.6) and Eq. (4.9):

$$\Gamma(D^0 \to K^-\pi^+)/\Gamma(D^0 \to \bar{K}^0\pi^0) = 2|a + c|^2/|b - c|^2 \approx 2, \tag{4.11}$$

and

$$\Gamma(D^0 \to K^-\pi^+)/\Gamma(D^+ \to \bar{K}^0\pi^+)$$

$$= |a + c|^2/|a + b|^2 \approx |c|^2/|a + b|^2$$

$$\approx \Gamma(D^0 \to \text{all})/\Gamma(D^+ \to \text{all}). \tag{4.12}$$

It will be very interesting to see from the F^+ decay width (see Eq. (2.1)) whether the amplitude d is also dominant. If the amplitude d dominates, from Table I, we obtain

$$\Gamma(F^+ \to \bar{K}^0K^+)/\Gamma(F^+ \to \eta^0\pi^+) \approx 3/2\,. \tag{4.13}$$

If amplitude d is comparable to amplitudes a and b, the decays $F^+ \to \bar{K}^0K^+$ and $\eta^0\pi^+$ can give information about the relative phases of amplitudes a and b.

Taking the central values of the mixing parameters of Ref. (9), the data of Eqs. (4.4), (4.5) implies, using the analysis of Ref. (5),

$$|D/A| = |e + 2f|/|a + c| \gtrsim 5, \tag{4.14}$$

i.e. the graphs e and f further dominate graph c. Similarly, the relative rates of $(D^0 \to \pi^0\pi^0)/\Gamma(D^0 \to \bar{K}^0\pi^0), \Gamma(D^0 \to \pi^0\pi^0)/\Gamma(D^0 \to \bar{K}^0\eta^0)$ can provide information of $|e+2f|/|6-c|$. Then $D^0 \to \eta^0\eta^0$, $\pi^0\pi^0$, $D^+ \to \bar{K}^0K^+$, $\eta^0\pi^+$ can provide information about the relative size of amplitudes e and f. Further, the two-body decays of F^+ can provide information on the amplitude d.

Here we only give a few examples of how such analysis can be performed. A thorough analysis can be done when more complete data are available. We see that the charm decay certainly will shed more light on the mechanism of weak non-leptonic decays.

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References

1. See review talk by V. Lüth, Proceedings of the International Symposium on Lepton and Photon Interactions at High Energies, Fermilab, August 23 - 29, 1979.

2. See also review talk by G. Goldhaber, VI. International Conference on Experimental Meson Spectroscopy, April 25, 26, 1980, BNL.

3. See review talk by J. Kirkby, Proceedings of the International Symposium on Lepton and Photon Interactions at High Energies, Fermilab, August 23 - 29, 1979.

4. See review talk by J. Prentice, VI. International Conference on Experimental Meson Spectroscopy, April 25, 25, 1980, BNL.

5. L.-L. Chau Wang and F. Wilczek, Phys. Rev. Lett. 43, 816 (1979).

6. V. Barger, S. Pakvasa, Phys. Rev. Lett. 43, 813 (1980);
M. Suzuki, Phys. Rev. Lett. 43, 818 (1980);
C. Quigg, "Charmed Meson Decays and the Structure of the Charged Weak Current", Fermilab preprint Pub-79/62-THY, 1979.

7. N. Cabibbo and L. Maini, Phys. Lett. 73B, 418 (1978);
S. P. Rosen, Phys. Lett. 89B, 246 (1980), Phys. Rev. Lett. 44, 41 (1980);
B. Guberina, S. Nussinov, R. D. Peccei, R. Rückl, Phys. Lett. 89B, 111 (1980);
M. Bander , D. Silverman and A. Soni, Phys. Rev. Lett. 44, 7 (1980);
H. Fritzsch and P. Minkowski, "The Puzzle of Non-leptonic Decays and Its Resolution", Univ. of Bern preprint, (1980);
V. Barger, J. P. Leveille and P. M. Stevensen, "Gluon Enhancement in Charmed Meson Decays", Wisconsin preprint 00-881-124 (1979);
T. G. Rizzo, "D-Lifetimes and Cabibbo Suppressed Decays in the Massive Quark Model", Brookhaven preprint BNL-27825, April 1980.

L.-L. Chau Wang, "Flavor Mixing and Charm Decay", Proccedings of the 1980 Guangzhou (Canton) Conference on Theoretical Particle Physics, January 5 - 14, 1980.

8. There are more papers on the subject than listed in Ref. 7. For a more complete discussion see review on the subject, "Flavor Mixing and Quark Decay", VI. International Conference on Experimental Meson Spectroscopy, April 25 - 26, 1980, BNL;

9. R. E. Shrock and L.-L. Wang, Phys. Rev. Lett. 41, 1692 (1978).
R. E. Shrock, S. B. Treiman, L.-L. Wang, Phys. Rev. Lett. 42, 1589 (1979).

10. In these discussions, we have assumed that the final state interaction effects are not important. If important, such effects ought to be taken into consideration.

Table Captions

Table I: Two pseudoscalar decay amplitudes for charmed mesons in terms of the quark diagrams a - f as shown in Fig. 2. The c_1, c_2, s_1 and s_2 are related to the mixing matrix elements[(8)(9)] by $c_1 \equiv V_{ud}$, $s_1 \equiv V_{us}$, $c_2 \equiv V_{cs}$, $-s_2 \equiv V_{cd}$.

Figure Captions

Fig. 1. Quark diagrams for inclusive charm meson decaying into hadrons.

Fig. 2. Quark diagrams for charm meson decaying into two ordinary mesons.

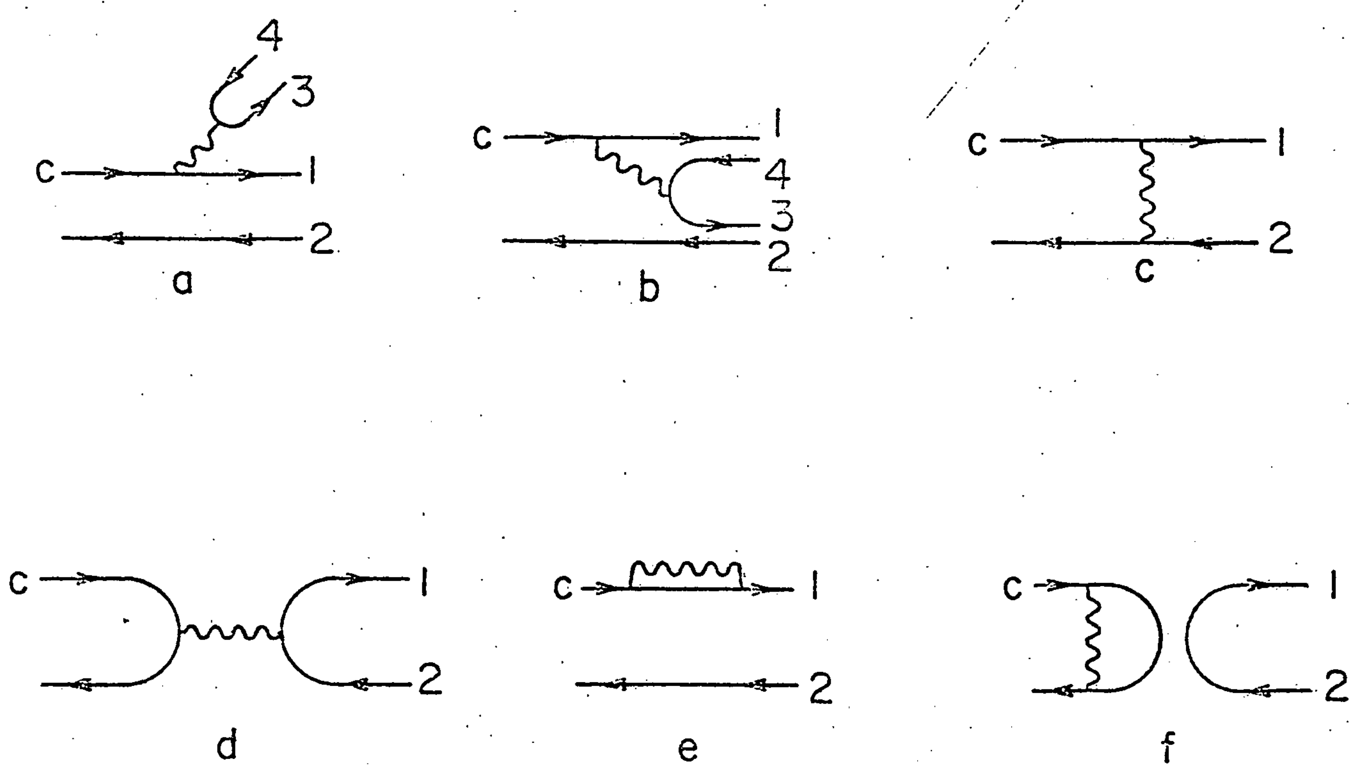

Fig (1)

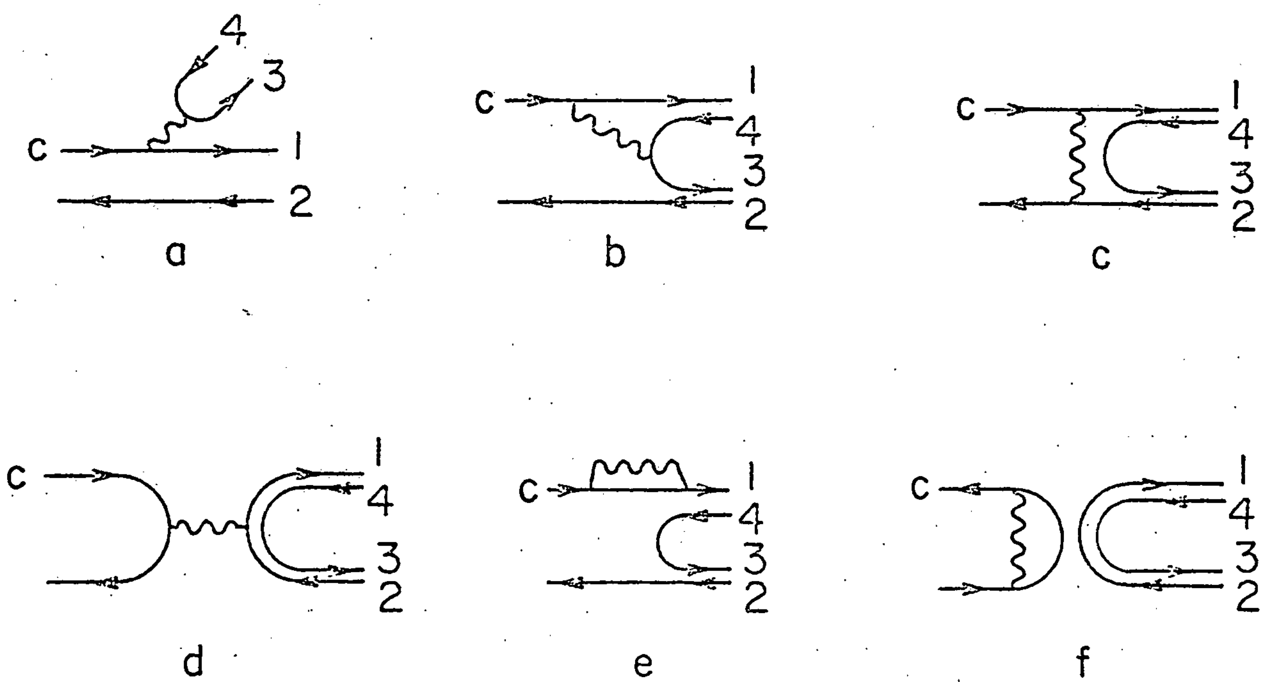

Fig (2)

Table I

(a) D^0 Decays

$K^-\pi^+$	$c_1c_2(a+c)$
$\bar{K}^0\pi^0$	$\frac{1}{\sqrt{2}}c_1c_2(b-c)$
$\bar{K}^0\eta^0$	$\frac{1}{\sqrt{6}}c_1c_2(b-c)$
K^-K^+	$s_1c_2(a+c+e+2f) - c_1s_2(e+2f)$
$\pi^-\pi^+$	$s_1c_2(e+2f) - c_1s_2(a+c+e+2f)$
$\bar{K}^0K^0$	$\frac{1}{2}(s_1c_2-c_1s_2)(2c+4f)$
$\pi^0\pi^0$	$\frac{1}{\sqrt{2}}[s_1c_2(e+2f) + c_1s_2(b-c-e-2f)]$
$\eta^0\eta^0$	$\sqrt{2}\,[s_1c_2(\frac{2}{3}c - \frac{1}{3}b + \frac{1}{6}e + f)$ $- c_1s_2(\frac{1}{6}b + \frac{1}{6}c + \frac{1}{6}e + f)]$
$\pi^0\eta^0$	$\frac{1}{\sqrt{3}}[s_1c_2(-b+e) + c_1s_2(c-e)]$
$K^+\pi^-$	$s_1s_2(a+c)$
$K^0\pi^0$	$\frac{1}{\sqrt{2}}s_1s_2(b-c)$
$K^0\eta^0$	$\frac{1}{\sqrt{6}}s_1s_2(b-c)$

TABLE I (continued)

Page 2

(b) D^+ Decays

$\bar{K}^0\pi^+$	$c_1c_2(a+b)$
$\bar{K}^0K^+$	$s_1c_2(a+e) - c_1s_2(d+e)$
$\pi^0\pi^+$	$\frac{1}{\sqrt{2}} c_1s_2(a+b)$
$\eta^0\pi^+$	$\frac{1}{\sqrt{6}} s_1c_2(-2b+2e) - c_1s_2(a+b+2d+2e)$
$K^+\pi^0$	$\frac{1}{\sqrt{2}} s_1s_2(a-d)$
$K^0\eta^0$	$\frac{1}{\sqrt{6}} \|s_1s_2(a-d)\|^2$
$K^0\pi^+$	$s_1s_2(b+d)$

TABLE I (continued)

Page 3

(c) F^+ Decays

$\bar{K}^0K^+$	$c_1c_2(b+d)$
$\pi^0\pi^+$	0
$\eta^0\pi^+$	$\sqrt{\frac{2}{3}}\, c_1c_2(a-d)$
$K^0\pi^+$	$s_1c_2(d+e) - c_1s_2(a+e)$
$K^+\pi^0$	$\frac{1}{\sqrt{2}}\,[s_1c_2(d+e) + c_1s_2(b-e)]$
$K^+\eta^0$	$\frac{1}{\sqrt{6}}\,[s_1c_2(2a+2b + d + e) + c_1s_2(b-e)]$
K^0K^+	$s_1s_2(a+b)$