Flavor symmetry and decays of charmed mesons to pairs of light pseudoscalars

Bhubanjyoti Bhattacharya* and Jonathan L. Rosner+

Enrico Fermi Institute and Department of Physics, University of Chicago, 5640 S. Ellis Avenue, Chicago, Illinois 60637, USA

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New data on the decays of the charmed particles D^0, D^+, and D_s^+ to pairs of light pseudoscalar mesons P allow the testing of flavor symmetry and the extraction of key amplitudes. Information on relative strong phases is obtained. One sees evidence for the expected interference between Cabibbo-favored and doubly Cabibbo-suppressed decays in the differing patterns of $D^0 \to K_{S,L}\pi^0$ and $D^+ \to K_{S,L}\pi^+$ decays.

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I. INTRODUCTION

The application of SU(3) flavor symmetry to charmed particle decays can shed light on such questions as the strong phases of amplitudes in these decays. Such strong phases are nonnegligible even in B decays to pairs of pseudoscalar mesons (P), and can be even more important in $D \to PP$ decays. In the present paper we shall extract strong phases from charmed particle decays using SU(3) flavor symmetry, primarily the U-spin symmetry involving the interchange of s and d quarks. A preliminary version of this work was presented in Ref. [1].

We recall the diagrammatic approach to flavor symmetry in Sec. II. We then treat Cabibbo-favored decays in Sec. III, turning to singly Cabibbo-suppressed decays in Sec. IV and doubly Cabibbo-suppressed decays in Sec. V. We mention some other theoretical approaches in Sec. VI, and conclude in Sec. VII.

II. DIAGRAMMATIC AMPLITUDE EXPANSION

We use a flavor-topology language for charmed particle decays [2,3]. These topologies, corresponding to linear combinations of SU(3)-invariant amplitudes, are illustrated in Fig. 1. Cabibbo-favored (CF) amplitudes, proportional to the product $V_{ud}V_{cs}^*$ of Cabibbo-Kobayashi-Maskawa (CKM) factors, will be denoted by unprimed quantities; singly Cabibbo-suppressed amplitudes proportional to $V_{us}V_{cs}^*$ or $V_{ud}V_{cd}^*$ will be denoted by primed quantities; and doubly Cabibbo-suppressed quantities proportional to $V_{us}V_{cd}^*$ will be denoted by amplitudes with a tilde. The relative hierarchy of these amplitudes is $1{:}\lambda{:} -\lambda{:} -\lambda^2$, where $\lambda = \tan\theta_C = 0.2317$ [4,5]. Here θ_C is the Cabibbo angle.

III. CABIBBO-FAVORED DECAYS

Amplitudes and their relative phases for Cabibbo-favored charm decays were discussed in Ref. [6]. That analysis found large relative phases of the C and E amplitudes relative to the dominant T term, and an approximate relation $A \simeq -E$. An analysis [1] based on the compilation in Ref. [4] was consistent with this conclusion. The advent of new branching ratios for Cabibbo-favored D_s decays [7], obtained independently of the branching ratio for $D_s^+ \to \phi\pi^+$, changes this conclusion. The relative phases of C and E with respect to T are still large and their magnitudes are not greatly changed, but now $A \simeq (-0.32 \pm 0.24)E$, in agreement with a prediction $A \simeq -0.4E$ in Ref. [8].

In Table I we show the results of extracting amplitudes $\mathcal{A} = M_D[8\pi\mathcal{B}\hbar/(p^*\tau)]^{1/2}$ from the branching ratios $\mathcal{B}$ [7,9] and lifetimes τ [4]. Here M_D is the mass of the decaying charmed particle, and p^* is the final c.m. 3-momentum.

The extracted amplitudes, with T defined to be real, are, in units of 10^{-6} GeV:

$$T = 2.78 \pm 0.13; \tag{1}$$

$$C = (2.04 \pm 0.17)\exp[i(-151.5 \pm 1.7)^\circ]; \tag{2}$$

$$E = (1.68 \pm 0.12)\exp[i(116.7 \pm 3.6)^\circ]; \tag{3}$$

$$A = (0.55 \pm 0.39)\exp[i(-64^{+32}_{-8})^\circ]. \tag{4}$$

These values update those quoted in Refs. [1,6]. The amplitudes are shown on an Argand diagram in Fig. 2. The fit has $\chi^2 = 0.64$ for 1 degree of freedom. These results are also obtained in Ref. [9]. Slightly different amplitudes are obtained if one uses all measured branching ratios except that for $D_s^+ \to \bar{K}^0 K^+$ as inputs, as in Ref. [10]. This method is algebraically convenient as one can eliminate an interference term between T and A with a suitable combination of $D_s^+ \to \pi^+\eta$ and $D_s^+ \to \pi^+\eta'$ decay rates. The predicted branching ratio, $\mathcal{B}(D_s^+ \to \bar{K}^0 K^+) = 3.39\%$, is in satisfactory agreement with experiment.

IV. SINGLY CABIBBO-SUPPRESSED DECAYS

A. SCS decays involving pions and kaons

We show in Table II the branching ratios, amplitudes, and representations in terms of reduced amplitudes for

*bhujyo@uchicago.edu
+rosner@hep.uchicago.edu

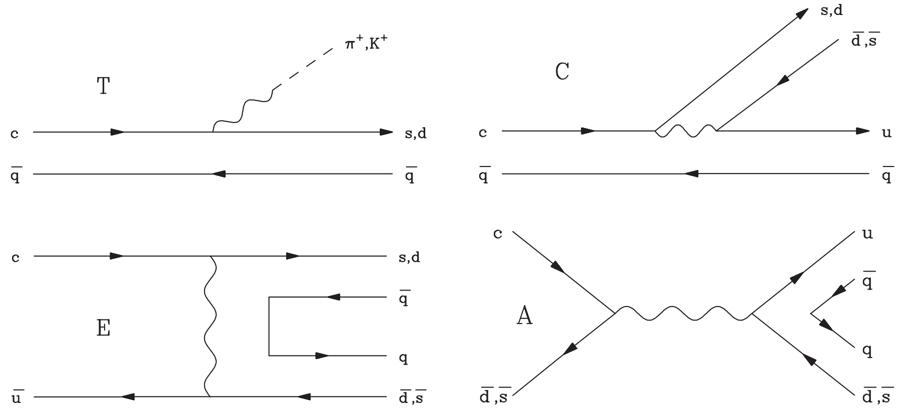

FIG. 1. Flavor topologies for describing charm decays. T: color-favored tree; C: color-suppressed tree; E: exchange; A: annihilation.

singly Cabibbo-suppressed (SCS) charm decays involving pions and kaons. The ratio of primed (SCS) to unprimed (CF) amplitudes is assumed to be $\tan\theta_C = 0.2317$. One then finds, in units of 10^{-7} GeV,

$$T' = 6.44; \tag{5}$$

$$C' = -4.15 - 2.25i; \tag{6}$$

$$E' = -1.76 + 3.48i; \tag{7}$$

$$A' = 0.55 - 1.14i. \tag{8}$$

The deviations from flavor SU(3) in Table II are well known. One predicts $\mathcal{B}(D^0 \to \pi^+\pi^-)$ larger than observed and $\mathcal{B}(D^0 \to K^+K^-)$ smaller than observed. One can account for some of this discrepancy via the ratios of decay constants $f_K/f_\pi = 1.2$ and form factors $f_+(D \to K)/f_+(D \to \pi) > 1$. Furthermore, one predicts $\mathcal{B}(D^0 \to \pi^0\pi^0)$ larger than observed and $\mathcal{B}(D^+ \to \pi^+\pi^0)$ smaller than observed, which means that the $\pi\pi$ isospin triangle [associated with the fact that there are two independent amplitudes with $I = (0, 2)$ for three decays] has a different shape from that predicted by rescaling the CF amplitudes. One predicts equal decay amplitudes for $D^+ \to K^+\bar{K}^0$ and $D_s \to \pi^+K^0$; the experimental branching ratio for the former is about 20% above the predicted value.

The decay $D^0 \to K^0\bar{K}^0$ is forbidden by SU(3); the branching ratio of $2\mathcal{B}(D^0 \to K_S^0K_S^0) = (2.92 \pm 0.64 \pm 0.18) \times 10^{-4}$ reported by CLEO [11] is more than a factor of 2 below the average in Ref. [4]. Estimates of SU(3)-breaking effects lead to predictions for $\mathcal{B}(D^0 \to K^0\bar{K}^0)$ ranging from a few parts in 10^4 [13] to 3×10^{-3} [14].

B. SCS decays involving η, η'

The amplitudes C and E extracted from Cabibbo-favored charm decays imply values of $C' = \lambda C$ and $E' = \lambda E$ which may be used in constructing amplitudes for singly Cabibbo-suppressed D^0 decays involving η and η'. In Table III we write amplitudes multiplied by factors so that they involve a unit coefficient of an amplitude SE' describing a disconnected "singlet" exchange amplitude for D^0 decays [10]. Similarly the decays $D^+ \to (\pi^+\eta, \pi^+\eta')$ and $D_s^+ \to (K^+\eta, K^+\eta')$ may be described in terms of a disconnected singlet annihilation amplitude SA', written with unit coefficient in Table III. For experimental values we have used new CLEO measurements as reported in Ref. [12] (see Table IV).

We show in Fig. 3 the construction proposed in Refs. [10] to obtain the amplitudes SE' and SA'. For SE',

TABLE I. Branching ratios [7,9], amplitudes, and graphical representations for Cabibbo-favored charmed particle decays.

Meson	Decay mode	$\mathcal{B}$ (%)	p^* (MeV)	$\lvert\mathcal{A}\rvert$ (10^{-6} GeV)	Rep.	Predicted $\mathcal{B}$ (%)
D^0	$K^-\pi^+$	3.891 ± 0.077	861.1	2.52 ± 0.02	$T + E$	3.90
	$\bar{K}^0\pi^0$	2.238 ± 0.109	860.4	1.91 ± 0.05	$(C - E)/\sqrt{2}$	2.21
	$\bar{K}^0\eta$	0.76 ± 0.11	771.9	1.18 ± 0.09	$C/\sqrt{3}$	0.76
	$\bar{K}^0\eta'$	1.87 ± 0.28	564.9	2.16 ± 0.16	$-(C + 3E)/\sqrt{6}$	1.95
D^+	$\bar{K}^0\pi^+$	2.986 ± 0.067	862.4	1.39 ± 0.02	$C + T$	2.99
D_s^+	$\bar{K}^0K^+$	2.98 ± 0.17	850.3	2.12 ± 0.06	$C + A$	3.02
	$\pi^+\eta$	1.58 ± 0.21	902.3	1.50 ± 0.10	$(T - 2A)/\sqrt{3}$	1.47
	$\pi^+\eta'$	3.77 ± 0.39	743.2	2.55 ± 0.13	$2(T + A)/\sqrt{6}$	3.61

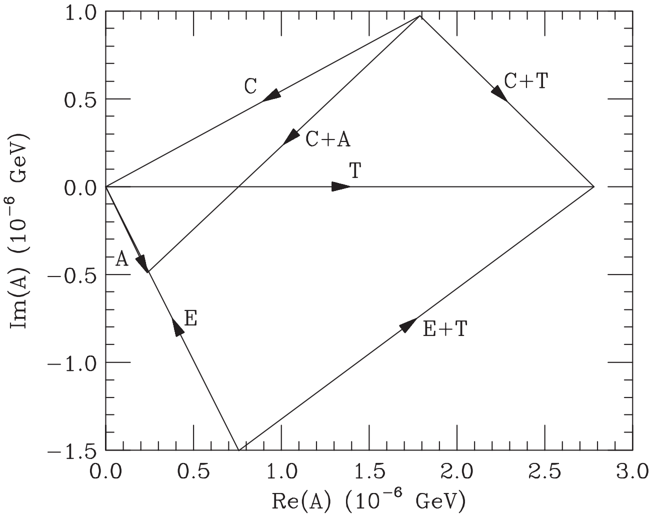

FIG. 2. Construction of Cabibbo-favored amplitudes from observed processes. The sides $C+T$, $C+A$, and $E+T$ correspond to measured processes; the magnitudes of other amplitudes listed in Table I are also needed to specify T, C, E, and A.

two solutions are found [9]: in units of 10^{-7} GeV, $SE' = (5.3 \pm 0.5) - i(3.5 \pm 0.5)$ and $SE' = (-0.7 \pm 0.4) - i(1.0 \pm 0.6)$. In the first, $|SE'|$ is uncomfortably large in comparison with the "connected" amplitudes. The only solution for $SA' \simeq -6.1 + 2.1i$ does not exhibit any suppression in comparison with the connected SCS amplitudes.

C. Sum rules for $D^0 \to (\pi^0\pi^0, \pi^0\eta, \eta\eta, \pi^0\eta', \eta\eta')$

It appears from the representations of the Cabibbo-suppressed decays of D^0 into two pseudoscalars chosen from π^0, η, η' that the corresponding amplitudes depend only on C', E', and SE'. There are five such decays and one may write down sum rules relating the corresponding amplitudes. Two such sum rules are as follows:

$$4\sqrt{6}\mathcal{A}(D^0 \to \pi^0\eta') - 5\mathcal{A}(D^0 \to \eta\eta) + 4\mathcal{A}(D^0 \to \eta\eta') = 0, \quad (9)$$

$$8\mathcal{A}(D^0 \to \pi^0\pi^0) + 4\sqrt{3}\mathcal{A}(D^0 \to \pi^0\eta) + 3\mathcal{A}(D^0 \to \eta\eta) = 0. \quad (10)$$

For each sum rule, one can draw a triangle whose sides are given by the magnitudes of the amplitudes involved in the corresponding sum rule. Using the measured values of

TABLE II. Branching ratios, amplitudes, decomposition in terms of reduced amplitudes, and predicted branching ratios for singly Cabibbo-suppressed charm decays involving pions and kaons.

Meson	Decay mode	$\mathcal{B}$ (10^{-3})	p^* (MeV)	$\lvert\mathcal{A}\rvert$ (10^{-7} GeV)	Rep.	Predicted $\mathcal{B}$ (10^{-3})
D^0	$\pi^+\pi^-$	1.37 ± 0.03[a]	921.9	4.57 ± 0.05	$-(T' + E')$	2.23
	$\pi^0\pi^0$	0.79 ± 0.08[a]	922.6	3.46 ± 0.18	$-(C' - E')/\sqrt{2}$	1.27
	K^+K^-	3.93 ± 0.07[b]	791.0	8.35 ± 0.08	$(T' + E')$	1.92
	$K^0\bar{K}^0$	0.37 ± 0.06[b]	788.5	2.57 ± 0.35	0	0
D^+	$\pi^+\pi^0$	1.28 ± 0.08[a]	924.7	2.77 ± 0.09	$-(T' + C')/\sqrt{2}$	0.87
	$K^+\bar{K}^0$	6.17 ± 0.20[b]	792.6	6.58 ± 0.11	$T' - A'$	5.12
D_s^+	π^+K^0	2.44 ± 0.30[c]	915.7	5.84 ± 0.36	$-(T' - A')$	2.56
	π^0K^+	0.75 ± 0.28[c]	917.1	3.24 ± 0.60	$-(C' + A')/\sqrt{2}$	0.87

[a]From Ref. [4].
[b]Reference [11] averaged with Ref. [4].
[c]Reference [7] combined with [12].

TABLE III. Real and imaginary parts of amplitudes for SCS charm decays involving η and η', in units of 10^{-7} GeV as predicted in Ref. [10].

Amplitude	Expression	Re	Im	$\lvert\mathcal{A}_{\rm exp}\rvert$
$-\sqrt{6}\mathcal{A}(D^0 \to \pi^0\eta)$	$2E' - C' + SE'$	0.63	9.21	7.79 ± 0.54
$\frac{\sqrt{3}}{2}\mathcal{A}(D^0 \to \pi^0\eta')$	$\frac{1}{2}(C' + E') + SE'$	−2.95	0.62	3.54 ± 0.35
$\frac{3}{2\sqrt{2}}\mathcal{A}(D^0 \to \eta\eta)$	$C' + SE'$	−4.14	−2.25	5.91 ± 0.34
$-\frac{3\sqrt{2}}{7}\mathcal{A}(D^0 \to \eta\eta')$	$\frac{1}{7}(C' + 6E') + SE'$	−2.10	2.66	3.48 ± 0.38
$\sqrt{3}\mathcal{A}(D^+ \to \pi^+\eta)$	$T' + 2C' + 2A' + SA'$	−0.75	−6.77	8.21 ± 0.26
$-\frac{\sqrt{6}}{4}\mathcal{A}(D^+ \to \pi^+\eta')$	$\frac{1}{4}(T' - C' + 2A') + SA'$	2.92	−0.01	3.72 ± 0.15
$-\sqrt{3}\mathcal{A}(D_s^+ \to \eta K^+)$	$-(T' + 2C') + SA'$	1.85	4.50	8.05 ± 0.88
$\frac{\sqrt{6}}{4}\mathcal{A}(D_s^+ \to \eta' K^+)$	$\frac{1}{4}(2T' + C' + 3A') + SA'$	2.59	−1.41	3.43 ± 0.57

TABLE IV. Branching ratios and amplitudes for D^0, D^+, and D_s^+ SCS decays involving η and η'.

Meson	Decay mode	$\mathcal{B}$ (10^{-4})	p^* (MeV)	$\lvert\mathcal{A}\rvert$ $(10^{-7}$ GeV)
D^0	$\pi^0\eta$	6.10 ± 0.85[a]	846.2	3.18 ± 0.22
	$\pi^0\eta'$	8.1 ± 1.6[b]	678.0	4.09 ± 0.41
	$\eta\eta$	16.7 ± 1.9[b]	754.6	5.57 ± 0.32
	$\eta\eta'$	12.6 ± 2.7[b]	536.8	5.74 ± 0.62
D^+	$\pi^+\eta$	34.3 ± 2.1[a]	848.4	4.74 ± 0.15
	$\pi^+\eta'$	45.2 ± 3.6[a]	680.5	6.08 ± 0.24
D_s^+	$K^+\eta$	14.1 ± 3.1[c]	835.0	4.65 ± 0.51
	$K^+\eta'$	15.8 ± 5.3[c]	646.1	5.60 ± 0.94

[a]Average of Refs. [4,9].
[b]Reference [9].
[c]Reference [7] combined with [12].

amplitudes one finds that the angles of such triangles are nontrivial (i.e., none of them are very near zero or 180°). One may thus infer that the relevant amplitudes have nontrivial relative strong phases.

One can also write a sum rule that relates the squares of magnitudes of the amplitudes instead of the amplitudes themselves:

$$8|\mathcal{A}(D^0 \to \pi^0\eta')|^2 + 16|\mathcal{A}(D^0 \to \pi^0\pi^0)|^2 = 16|\mathcal{A}(D^0 \to \pi^0\eta)|^2 + 9|\mathcal{A}(D^0 \to \eta\eta)|^2. \quad (11)$$

The magnitudes of the decay amplitudes are well quantified. The above relationship thus may easily be tested using the amplitudes from Table II ($D^0 \to \pi^0\pi^0$) and Table IV ($D^0 \to \pi^0\eta$, $\pi^0\eta'$, $\eta\eta$). In the present case we find

$$8|\mathcal{A}(D^0 \to \pi^0\eta')|^2 + 16|\mathcal{A}(D^0 \to \pi^0\pi^0)|^2 = 325 \pm 33, \quad (12)$$

$$16|\mathcal{A}(D^0 \to \pi^0\eta)|^2 + 9|\mathcal{A}(D^0 \to \eta\eta)|^2 = 440 \pm 39, \quad (13)$$

in units of 10^{-14} GeV^2. Evidently there is little more than a two-sigma deviation from the identity. This is another signature of deviation from flavor-SU(3) symmetry since one has already assumed such a symmetry in writing representations for the relevant decays.

V. DOUBLY CABIBBO-SUPPRESSED DECAYS

In Table V we expand amplitudes for doubly Cabibbo-suppressed decays in terms of the reduced amplitudes $\tilde{T} \equiv$

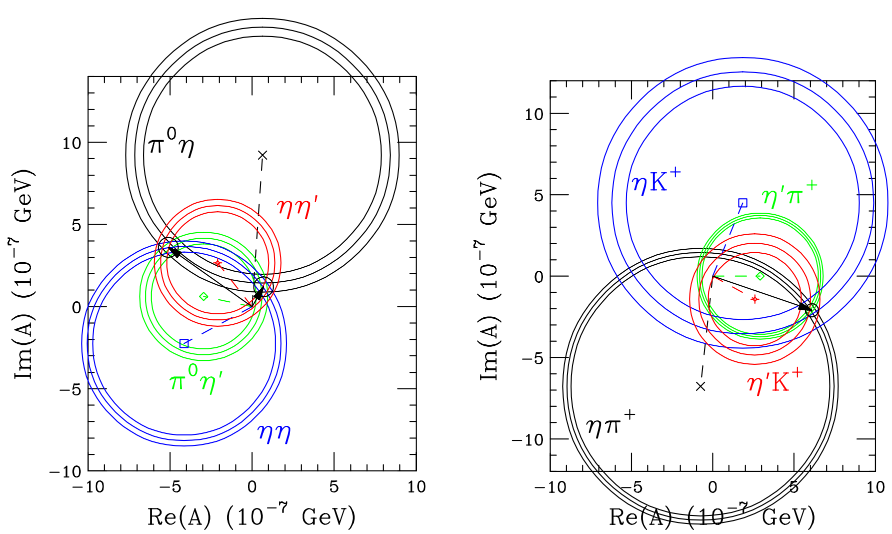

FIG. 3 (color online). Graphical construction to obtain the disconnected singlet annihilation amplitudes SE' (left) and SA' (right) from magnitudes of SCS D^0, D^+, and D_s^+ decays involving η and η'. Left: D^0 decays to indicated final states. Right: D^+ or D_s^+ decays to indicated final states. The small circles with arrows pointing to them show the solution regions. The arrows denote the complex amplitudes $-SE'$ (left) and $-SA'$ (right).

TABLE V. Branching ratios, amplitudes, and representations in terms of reduced amplitudes for doubly Cabibbo-suppressed decays.

Meson	Decay mode	$\mathcal{B}$ (10^{-4})	p^* (MeV)	$\lvert\mathcal{A}\rvert$ $(10^{-7}$ GeV)	Rep.
D^0	$K^+\pi^-$	1.45 ± 0.04[a]	861.1	1.54 ± 0.02	$\tilde{T} + \tilde{E}$
	$K^0\pi^0$	[b]	860.4	[b]	$(\tilde{C} - \tilde{E})/\sqrt{2}$
	$K^0\eta$	[b]	771.9	[b]	$\tilde{C}/\sqrt{3}$
	$K^0\eta'$	[b]	564.9	[b]	$-(\tilde{C} + 3\tilde{E})/\sqrt{6}$
D^+	$K^0\pi^+$	[b]	862.6	[b]	$\tilde{C} + \tilde{A}$
	$K^+\pi^0$	2.37 ± 0.32[a]	864.0	1.23 ± 0.08	$(\tilde{T} - \tilde{A})/\sqrt{2}$
	$K^+\eta$	[c]	775.8	-	$-\tilde{T}/\sqrt{3}$
	$K^+\eta'$	[c]	570.8	-	$(\tilde{T} + 3\tilde{A})/\sqrt{6}$
D_s^+	K^0K^+	[b]	850.3	[b]	$\tilde{T} + \tilde{C}$

[a]Reference [4].
[b]Amplitude involves interference between DCS process shown and the corresponding CF decay to $\bar{K}^0 + X$.
[c]Studied in Reference [15].

$-\tan^2\theta_C T$, $\tilde{C} \equiv -\tan^2\theta_C C$, $\tilde{E} \equiv -\tan^2\theta_C E$, and $\tilde{A} \equiv -\tan^2\theta_C A$.

With $\tan\theta_C = 0.2317$ one predicts $|\mathcal{A}(D^0 \to K^+\pi^-)| = 1.35 \times 10^{-7}$ GeV and $|\mathcal{A}[D^+ \to K^+(\pi^0, \eta, \eta')]| = (0.98, 0.86, 0.83) \times 10^{-7}$ GeV. The experimental amplitudes for $D^0 \to K^+\pi^-$ and $D^+ \to K^+\pi^0$ are, respectively, 14% and $(26 \pm 8)\%$ above the flavor-SU(3) predictions. Reference [15] has demonstrated the feasibility of testing the predictions for $D^+ \to K^+(\eta, \eta')$ with the full CLEO-c data sample.

A. $D^0 \to (K^0\pi^0, \bar{K}^0\pi^0)$ interference

The decays $D^0 \to K^0\pi^0$ and $D^0 \to \bar{K}^0\pi^0$ are related to one another by the U-spin interchange $s \leftrightarrow d$, and SU(3) symmetry breaking is expected to be extremely small in this relation [16]. Graphs contributing to these processes are shown in Fig. 4.

The CLEO Collaboration [17] has reported the asymmetry

$$R(D^0) \equiv \frac{\Gamma(D^0 \to K_S\pi^0) - \Gamma(D^0 \to K_L\pi^0)}{\Gamma(D^0 \to K_S\pi^0) + \Gamma(D^0 \to K_L\pi^0)} \tag{14}$$

to have the value $R(D^0) = 0.108 \pm 0.025 \pm 0.024$, consistent with the expected value [16,18] $R(D^0) = 2\tan^2\theta_C \simeq 0.107$. One expects the same $R(D^0)$ if π^0 is replaced by η or η' [16].

B. $D^+ \to (K^0\pi^+, \bar{K}^0\pi^+)$ interference

In contrast to the case of $D^0 \to (K^0\pi^0, \bar{K}^0\pi^0)$, the decays $D^+ \to (K^0\pi^+, \bar{K}^0\pi^+)$ are not related to one another by a simple U-spin transformation. Amplitudes contributing to these processes are shown in Fig. 5. Although both processes receive color-suppressed (C or $\tilde{C}$) contributions, the Cabibbo-favored process receives a color-favored tree (T) contribution, while the doubly Cabibbo-suppressed (DCS) process receives an annihilation ($\tilde{A}$) contribution. In order to calculate the asymmetry between K_S and K_L production in these decays due to interference between CF and DCS amplitudes, one can use the determination of the CF amplitudes discussed previously and the relation between them and DCS amplitudes. Thus, we define

$$R(D^+) \equiv \frac{\Gamma(D^+ \to K_S\pi^+) - \Gamma(D^+ \to K_L\pi^+)}{\Gamma(D^+ \to K_S\pi^+) + \Gamma(D^+ \to K_L\pi^+)} \tag{15}$$

and predict

$$R(D^+) = -2\,\mathrm{Re}\frac{\tilde{C} + \tilde{A}}{T + C} = 2\tan^2\theta_C\,\mathrm{Re}\frac{C + A}{T + C} = -0.006^{+0.033}_{-0.028}, \tag{16}$$

where the error is assumed to be dominated by its dominant source, the uncertainty in $|A|$ (see Fig. 2). This is consistent with the observed value $R(D^+) = 0.022 \pm 0.016 \pm 0.018$ [17]. The relative phase of $C + A$ and $T + C$ is nearly 90°, as can be seen from Fig. 2. The real part of their ratio hence is small. If one uses instead amplitudes based on fitting all CF decays except $D_s^+ \to \bar{K}^0K^+$, as in Ref. [10], one predicts instead $R(D^+) = 0.013 \pm 0.035$.

A similar exercise can be applied to the decays $D_s^+ \to K^+K^0$ and $D_s^+ \to K^+\bar{K}^0$, which are related by U-spin to the D^+ decays discussed here. The corresponding ratio

$$R(D_s^+) \equiv \frac{\Gamma(D_s^+ \to K_SK^+) - \Gamma(D_s^+ \to K_LK^+)}{\Gamma(D_s^+ \to K_SK^+) + \Gamma(D_s^+ \to K_LK^+)} \tag{17}$$

is predicted to be

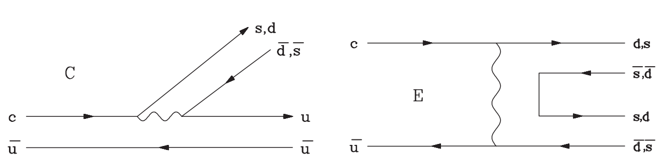

FIG. 4. Graphs contributing to $D^0 \to (K^0\pi^0, \bar{K}^0\pi^0)$.

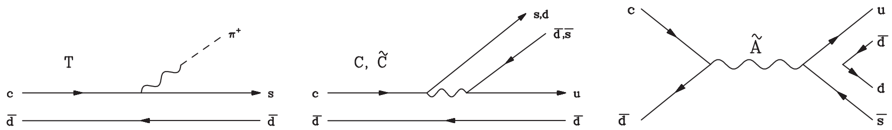

FIG. 5. Amplitudes T and C contributing to $D_s^+ \to \bar{K}^0\pi^+$; amplitudes $\tilde{C}$ and $\tilde{A}$ contributing to $D^+ \to K^0\pi^+$.

$$R(D_s^+) = -2\,\mathrm{Re}\frac{\tilde{C}+\tilde{T}}{A+C} = 2\tan^2\theta_C\,\mathrm{Re}\frac{C+T}{A+C} = -0.003^{+0.019}_{-0.017}. \tag{18}$$

Using amplitudes based on all CF decay rates except that for $D_s^+ \to \bar{K}^0K^+$, one predicts instead $R(D_s^+) = 0.005 \pm 0.017$.

VI. OTHER THEORETICAL APPROACHES

One can invoke effects of final state interactions to explain arbitrarily large SU(3) violations [if, for example, a resonance with SU(3)-violating couplings dominates a decay such as $D^0 \to \pi^+\pi^-$ or $D^0 \to K^+K^-$]. As one example of this approach [19], both resonant and nonresonant scattering can account for the observed ratio $\Gamma(D^0 \to K^+K^-)/\Gamma(D^0 \to \pi^+\pi^-) = 2.87 \pm 0.08$. This same approach predicted $\mathcal{B}(D^0 \to K^0\bar{K}^0) = 9.8 \times 10^{-4}$, a level of SU(3) violation consistent with the world average of Ref. [4] but far in excess of the recent CLEO value [11]. The paper of Ref. [19] may be consulted for many predictions for PV and PS final states in charm decays, where V denotes a vector meson and S denotes a scalar meson. Results for PV decays also may be found in Refs. [6,10,20,21].

The recent discussion of Ref. [8] entails a prediction $A \simeq -0.4E$, essentially as a consequence of a Fierz identity and QCD corrections. Tree amplitudes are obtained from factorization and semileptonic $D \to \pi$ and $D \to K$ form factors. The main source of SU(3) breaking in $\tilde{T}/T$ is assumed to come from $f_K/f_\pi = 1.22$. Predictions include asymmetries $R(D^{0,+}) = (2\tan^2\theta_C, 0.068 \pm 0.007)$, and—via a sum rule for $D^0 \to K^\mp\pi^\pm$ and $D^+ \to K^+\pi^0$—a prediction of the relative strong phase δ between $D^0 \to K^+\pi^-$ and $D^0 \to K^-\pi^+$, $|\delta| \simeq 7$–$20°$ (to be compared with 0 in exact SU(3) symmetry [22]).

VII. SUMMARY

We have shown that the relative magnitudes and phases of amplitudes contributing to charm decays into two pseudoscalar mesons are describable by flavor symmetry. We have verified that there are large relative phases between the color-favored tree amplitude T and the color-suppressed amplitude C, as well as between T and E. The phase of A is nearly opposite to that of E, as originally found in Ref. [6], but its magnitude is only about $1/3$ that of E, whereas it was nearly that of E in Refs. [1,6]. The difference is due primarily to new measurements of absolute branching ratios for Cabibbo-favored (CF) D_s decays by the CLEO Collaboration [7].

The largest symmetry-breaking effects are visible in singly Cabibbo-suppressed (SCS) decays, particularly in the $D^0 \to (\pi^+\pi^-/K^+K^-)$ ratio which are at least in part understandable through form factor and decay constant effects. Decays involving η, η' are mostly describable with small "disconnected" amplitudes, a possible exception being in SCS D^+ and D_s^+ decays.

One sees evidence for the expected interference between Cabibbo-favored and doubly Cabibbo-suppressed decays in $D^{0,+} \to K_{S,L}\pi^{0,+}$ decays. This interference leads to a measurable rate asymmetry in the decays $D^0 \to K_{S,L}\pi^0$ but none in $D^+ \to K_{S,L}\pi^+$.

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