# Physics from Doubly Quark-Mixing Suppressed Charm Meson Decays

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## ABSTRACT

Interesting physics and predictions are discussed in the doubly quark-mixing matrix suppressed charm meson decays: into vector-pseudoscalar, pseudoscalar-pseudoscalar, vector-vector mesons.

## Introduction

When Rafe (Schindler) asked me to talk about the physics that we can learn from the doubly quark-mixing suppressed charm decays, I was both surprised and delighted. I long had the conception that the doubly suppressed decays might not be available for study experimentally for a long, long time. These decays, which we can study in our quark diagram scheme, became more of a nuisance in a manuscript and subject to cuts if the editors or referees complained about the length of the paper. It is most encouraging that the doubly suppressed decays will be one of the important agenda for this future machine. I happily "dig" out the part of a table which had those doubly-suppressed decays. In the quark diagram scheme study of nonleptonic decays, the doubly suppressed decays are an integrated and necessary part of the program in our attempt to understand the complex nonleptonic decays.

All charm meson decays can be described by six types of diagrams,[(1)] as shown in Fig. 1. These are characteristic diagrams with all strong-interacting QCD gluon effects included. The identities of these diagrams are not changed by strong interacting gluons. In Tables I, II, III, the doubly suppressed decays of $D^+, D^0, D_s^+$ are given. They are taken from Ref. (2). Do note that we had included the effects of final-state interactions and parametrized of some SU(3) symmetry breaking effects, (see the differences in the last two columns of the tables. The amplitudes with a subscript $h$ are the hairpin diagrams which we ignore in our discussions here.).

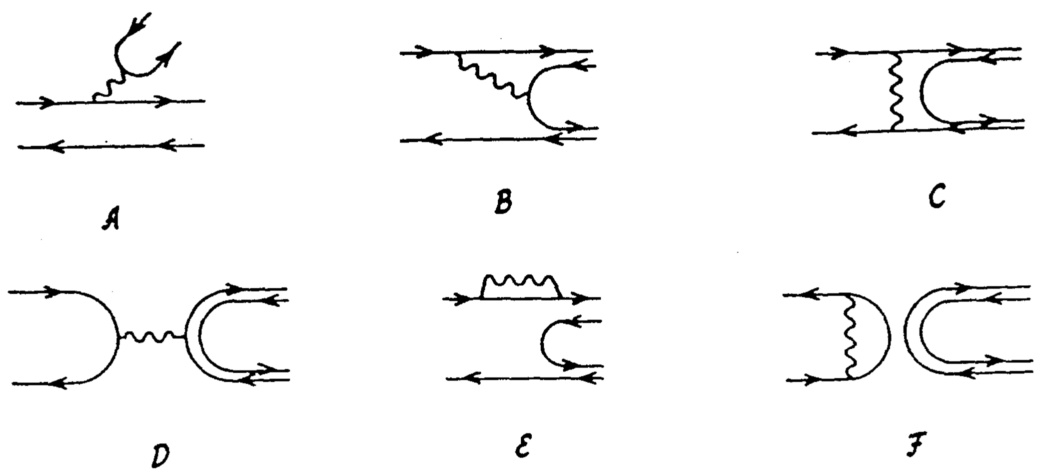


Fig. 1. The six quark diagrams for a meson decaying to two mesons.

## I. Charm meson $D \to VP$ decays, into vector and pseudoscalar bosons

Our analysis of recent data of charm mesons decaying into a vector meson and a pseudoscalar meson $D \to VP$ have established the following:[3]

- Final-state interaction is definitely important in $D \to \bar{K}^*\pi$, (as in the $D \to PP$ pseudo-pseudo meson decays).
- $D^0 \to \phi\bar{K}^0$ is solely from the $W$-exchange diagram, with final-state interactions taken into consideration. Its observation and size showed that the $W$-exchange diagram $\underline{\mathcal{C}}'$ is significant.
- $D^0 \to \bar{K}^{0*}\pi^0$, $K^{*-}\pi^+$, associated with the measurements of $D^+ \to \phi\pi^+$, $D_s^+ \to \phi\pi^+$ give the value of the $W$-exchange diagram $\mathcal{C}'$. But we found that $\mathcal{C}' \neq \underline{\mathcal{C}}'$, which implies important SU(3) breaking.
- From $D_s^+ \to \bar{K}^{0*}K^+$, and $D_s^+ \to \phi\pi^+$, $\bar{K}^{*0}\pi^+$, $D^+ \to \phi\pi^+$, we obtained that the $W$-annihilation diagram $\mathcal{D}$ is important.
- From $D_s^+ \to \rho^+\pi^0 \quad \Rightarrow \quad \mathcal{D} \approx \mathcal{D}'$
- From Fermilab E691 result $D_s^+ \overset{\times}{\longrightarrow} \pi^+\omega \quad \Rightarrow \quad |\underline{\mathcal{D}}| >> |\mathcal{D}| \approx |\mathcal{D}'|$.

Continuing in that spirit I list in the following what we can learn in the future analyzing the doubly suppressed decays. From Table I of doubly suppressed $D^+ \to VP$, we have the following predictions:

The measurement of $D^+ \to \rho^0K^+$ will give a measurement of the amplitude $\mathcal{B}$, (since $\mathcal{D}$ is small and final state interactions are expected to be small in this exotic channel, i.e. $\Delta_{K\rho}^{3/2} = 0$, $\delta_{3/2}^{\rho K} =$ real). That will check with the value of the amplitude $\mathcal{B}$ obtained in Ref. (3) from studying the nonsuppressed $D \to VP$ decays.

Based upon $\mathcal{D}'$, $\mathcal{D}$ being small, we can predict

$$\Gamma(D^+ \to \omega K^+) = (s_1/c_1)^2 \cdot \frac{1}{2}\Gamma(D_s^+ \to \phi\pi^+) \overset{o}{=} \Gamma(D^+ \to \rho^0K^+),$$
$$\Gamma(D^+ \to K^{*+}\eta_8) = \frac{1}{2}\Gamma(D^+ \to K^{*+}\eta_0),$$

and their measurements will give the amplitudes $\mathcal{A}'$ and $\mathcal{A}$ respectively. Here we use the notation $\overset{o}{=}$ to denote the conditional equality if the final-state-interaction effects are absent, i.e. if $\Delta = 0$, $\delta =$ real. (We ignore the hairpin diagram contributions in this paper. This is specially a good approximation for vector boson due to the $OZI$ rule).

The observation of $D^+ \to \phi K^+$ will clearly establish the existence of the $W$-annihilation $\underline{D}$ type diagram and measure its value. That will check checking the value so far obtained in Ref.(3) from analysing nonsuppressed decays.

The interesting point in $D^0$ decay is that the observation of $D^0 \to \phi K^0$ will establish $\underline{C}$ type amplitude, and its value.

In $D_s^+$ decay we predict

$$\Gamma(D_s^+ \to K^{*+}K^0) \overset{\circ}{=} (s_1/c_1)^2 \Gamma(D^+ \to \bar{K}^{*0}\pi^+),$$
$$\Gamma(D_s^+ \to K^{*0}K^+) \overset{\circ}{=} (s_1/c_1)^2 \Gamma(D^+ \to \rho^+\bar{K}^0).$$

Here the final-state-interactions in the $K^*K$ systems are expected small, since they are all exotic channels.

## II. Charm meson $D \to PP$ decays, into pseudoscalar-pseudoscalar mesons

For analyzing the recent data of charm mesons decaying into two pseudoscalar mesons we have established the following:(3)

- Final-state interaction is important(4)(5) in $D \to \bar{K}\pi$.
- The $W$-annihilation diagram $\underline{D}$ is important in $D_s \to PP$.
- $D^0 \to K^0\bar{K}^0$ can only come from effects of final-state interaction and/or with SU(3) breaking. Its observation by Fermi lab experiments E400, E691 establish such effects.
- The loop-diagram contributions in $D$ decays only come in the SU(3)-breaking form $(\mathcal{E} - \underline{\mathcal{E}})$, $(\mathcal{F} - \underline{\mathcal{F}})$ because $V_{us}V_{cs}^* + V_{ud}V_{cd}^* \approx 0$. It is established to be small in the $D^0 \to \bar{K}^0K^0$ measurement.

For one singly suppressed decay, I had an ancient prediction:

$$\frac{\Gamma(D^+ \to \pi^+\pi^0)}{\Gamma(D^+ \to \bar{K}^0\pi^+)} = \frac{1}{2}\left|\frac{V_{cd}}{V_{cs}}\right|^2 = \frac{1}{2} \times 0.05 = 0.025.$$

Currently experimental measurement has an upper bound about twenty times of this predicted value. I would encourage experimentalists to continue to look for it.

Now from the Tables of doubly suppressed decays, we can anticipate the following predictions:

In $D^+$ decays : $\Gamma(D^+ \to K^+\pi^0) \overset{0}{=} \Gamma(D^+ \to K^+\eta_8) = \Gamma(D^+ \to K^+\eta_0)$,
which measure the amplitude $\mathcal{A}$, since amplitude $\mathcal{D}$ is small.

In $D^0$ decays:

$$\Gamma(D^0 \to K^+\pi^-) = (s_1/c_1)^2\Gamma(D^0 \to K^-\pi^+), \quad \Gamma(D^0 \to K^0\pi^0) = (s_1/c_1)^2\Gamma(D^0 \to \bar{K}^0\pi^0),$$

$$\Gamma(D^0 \to K^0\eta_8) = (s_1/c_1)^2\Gamma(D^0 \to \overline{K}^0\eta_8), \quad \Gamma(D^0 \to K^0\eta_0) = (s_1/c_1)^2\Gamma(D^0 \to \overline{K}^0\eta_0);$$

In $D_s^+$ decays : $\Gamma(D_s \to K^0K^+) \overset{0}{=} \; = (s_1/c_1)^2\Gamma(D^+ \to \bar{K}^0\pi^+)$;

## III. Charm meson $D \to VV$ decays, into vector-vector mesons

The quark-diagram scheme description for $D$ decaying into vector-vector mesons is the neatest comparing to those of decays into vector-pseudoscalar meson and decays into pseudoscalar-pseudoscalar mesons. From Table III for doubly suppressed $D \to VV$ decays, we have the following predictions:

The observation of $D^+ \to \phi K^{*+}$ will establish and measure the $W$-annihilation diagram $\mathcal{D}$.

The observation of $D^0 \to \phi K^{*0}$ will establish and measure the $W$-exchange diagram $\mathcal{C}$, and we predict

$$\Gamma(D^0 \to \phi K^{*0}) = \left(s_1/c_1\right)^2\Gamma(D^0 \to \phi\overline{K}^{*0}); \quad \Gamma(D^0 \to \omega K^{*0}) = \left(s_1/c_1\right)^2\Gamma(D^0 \to \omega\overline{K}^{*0});$$

$$\Gamma(D^0 \to \rho^-K^{*+}) = \left(s_1/c_1\right)^2\Gamma(D^0 \to K^{*-}\rho^+); \quad \Gamma(D^0 \to \rho^0K^{*0}) = \left(s_1/c_1\right)^2\Gamma(D^0 \to \overline{K}^{*0}\rho^0);$$

We also predict

$$\Gamma(D_s^+ \to K^{*+}K^{*0}) = \left(s_1/c_1\right)^2\Gamma(D^+ \to \rho^+\overline{K}^{*0}).$$

## Conclusion

We see that the doubly suppressed decays provide many interesting physical and important information. Measurements of doubly Cabibbo suppressed decays are important in our effort to understand the nonleptonic decay machanism.

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## Table I. Doubly-Suppressed Charm Meson Decays into a Vector Boson and a Pseudoscalar Meson

| Channels | | Quark-mixing factor ($\lvert V_{us}\rvert \simeq \lvert V^*_{cd}\rvert \approx s_1$ used) | amplitudes with SU(3) Symmetry and no final-state Interactions | Amplitudes with SU(3) breaking and final-state interactions |
|---|---|---|---|---|
| $D^+$ | $\to \phi K^+$ | $-(s_1)^2\times$ | $\{\underline{D} + D_h\}$ | $\to \{\underline{D} + D_{\underline{h}}\}e^{i\delta^{\phi K}}$ |
| | $\to \omega K^+$ | $-(1/\sqrt{2})(s_1)^2\times$ | $\{A' + D' + 2D_h\}$ | $\to \{A' + D' + 2D_h\}e^{i\delta^{\omega K}}$ |
| | $\to K^{*+}\eta_8$ | $-(1/\sqrt{6})(s_1)^2\times$ | $\{A + D - 2D'\}$ | $\to \{A + D - 2D' + 2D'_h - 2D'_{\underline{h}}\}e^{i\delta^{K^*\eta_8}}$ |
| | $\to K^{*+}\eta_0$ | $-(1/\sqrt{3})(s_1)^2\times$ | $\{A + D + D' + 3D'_h\}$ | $\to \{A + D + D' + 2D'_h + D'_{\underline{h}}\}e^{i\delta^{K^*}\eta_0}$ |
| | $\to \rho^+ K^0$ | $-(s_1)^2\times$ | $\{B + D'\}$ | $\to (B + D') + (A' - \{B - 2D')(1/3)(1 - e^{-i\Delta_{\rho K}})\}e^{i\delta^{\rho K}_{3/2}}$ |
| | $\to \rho^0 K^+$ | $(1/\sqrt{2})(s_1)^2\times$ | $\{A' - D'\}$ | $\to \{(A' - D') + (A' - B - 2D')(2/3)(1 - e^{-i\Delta_{\rho K}})\}e^{i\delta^{\rho K}_{3/2}}$ |
| $D^0$ | $\to \phi\ K^0$ | $-(s_1)^2\times$ | $\{\underline{C} + C_h\}$ | $\to \{\underline{C} + C_{\underline{h}}\}e^{i\delta^{\phi K}}$ |
| | $\to \omega\ \{K^0$ | $-(1/\sqrt{2})(s_1)^2\times$ | $\{B + C' + 2C_h\}$ | $\to \{B + C' + 2C_h\}e^{i\delta^{\omega}\Delta_{\rho K}}$ |
| | $\to K^{*+}\pi^-$ | $-(s_1)^2\times$ | {same as $K^{*-}\pi^+$ but with primed and unprimed amplitudes interchange} | |
| | $\to K^{*0}\pi^0$ | $-(1/\sqrt{2})(s_1)^2\times$ | {same as $\{BArK^{*0}\pi^0$ but with primed and unprimed amplitudes interchange} | |
| | $\to K^{*0}\eta_8$ | $-(1/\sqrt{6})(s_1)^2\times$ | $\{B' + C - 2\underline{C}'\}$ | $\to \{B' + C - 2\{BC' + 2C'_h - 2C'_{\underline{h}}\}e^{i\delta^{K^*\eta_8}_{1/2}}$ |
| | $\to K^{*0}\eta_0$ | $-(1/\sqrt{3})(s_1)^2\times$ | $\{B' + C + \underline{C}' + 3C'_h\}$ | $\to \{B' + C + \underline{C}' + 2C'_h + C'_{\underline{h}}\}e^{i\delta^{K^*\eta_0}}$ |
| | $\to \rho^- K^+$ | $-(s_1)^2\times$ | $\{A' + C'\}$ | $\to (A' + C') - 2/3(A' + B)(1 - e^{i\Delta_{\rho K}})\}e^{i\delta^{\rho K}_{1/2}}$ |
| | $\to \rho^0 K^0$ | $-(1/\sqrt{2})(s_1)^2\times$ | $\{B - C'\}$ | $\to \{(B - C') - 1/3(A' + B)(1 - e^{i\Delta_{\rho K}})\}e^{i\delta^{\rho K}_{1/2}}$ |
| $D_s^+$ | $\to K^{*+}K^0$ | $-(s_1)^2\times$ | $\{A + B\}$ | $\to \{(A + B) + \frac{1}{2}(A' + B' - A - B)(1 - e^{-i\Delta_{K^*K}})\}e^{i\delta^{K^*K}_1}$ |
| | $\to K^{*0}K^+$ | $-(s_1)^2\times$ | $\{A' + B'\}$ | $\to \{(A' + B') - \frac{1}{2}(A' + B' - A - B)(1 - e^{-i\Delta_{K^*K}})\}e^{i\delta^{K^*K}_1}$ |

**Table II. Doubly-Suppressed Charm Meson Decays to Two Pseudoscalars**

| | Channels | Quark-mixing factor ($\lvert V_{us}\rvert \simeq \lvert V_{cd}^*\rvert \approx s_1$ used) | Amplitudes with SU(3) Symmetry and no final-state Interactions | | Amplitudes with SU(3) breaking and final-state interactions |
|---|---|---|---|---|---|
| $D^+$ | $\to K^0\pi^+$ | $-(s_1)^2\times$ | $\{B+D\}$ | $\to$ | $\{(B+D)+(A-B-2D)(1/3)(1-e^{-i\Delta_{K\pi}})\}e^{i\delta^{K\pi}_{3/2}}$ |
| | $\to K^+\pi^0$ | $(1/\sqrt{2})(s_1)^2\times$ | $\{A-D\}$ | $\to$ | $\{(A-D)+(A-B-2D)(2/3)(1-e^{-i\Delta_{K\pi}})\}e^{i\delta^{K\pi}_{3/2}}$ |
| | $\to K^+\eta_8$ | $-(1/\sqrt{6})(s_1)^2\times$ | $\{A-D\}$ | $\to$ | $\{A-D+2D_h-2D_{\underline{h}}\}e^{i\delta^{K\eta_8}}$ |
| | $\to K^+\eta_0$ | $-(1/\sqrt{3})(s_1)^2\times$ | $\{A+2D+3D_h\}$ | $\to$ | $\{A+2D+2D_h+D_{\underline{h}}\}e^{i\delta^{K\eta_0}}$ |
| $D^0$ | $\to K^+\pi^-$ | $-(s_1)^2\times$ | $\{A+C\}$ | $\to$ | same as for $K^-\pi^+$ |
| | $\to K^0\pi^0$ | $-(1/\sqrt{2})(s_1)^2\times$ | $\{B-C\}$ | $\to$ | same as for $\bar{K}^0\pi^0$ |
| | $\to K^0\eta_8$ | $-(1/\sqrt{6})(s_1)^2\times$ | $\{B-C\}$ | $\to$ | same as for $\bar{K}^0\eta_8$ |
| | $\to K^0\eta_0$ | $-(1/\sqrt{3})(s_1)^2\times$ | $\{B+2C+3C_h\}$ | $\to$ | same as for $\bar{K}^0\eta_0$ |
| $D_s^+$ | $\to K^+K^0$ | $-(s_1)^2\times$ | $\{A+B\}$ | $\to$ | $\{(A+B)\}e^{i\delta_1^{KK}}$ |

**Table III. Doubly-Suppressed Charm Meson Decays into Two Vector Bosons**

| Channels | Quark-mixing factor ($\lvert V_{us}\rvert \simeq \lvert V_{cd}^*\rvert \approx s_1$ used) | Amplitudes with SU(3) Symmetry and no final-state Interactions | | Amplitudes with SU(3) breaking and final-state interactions |
|---|---|---|---|---|
| $D^+ \to \phi K^{*+}$ | $-(s_1)^2\times$ | $\{\underline{D} + D_h\}$ | $\to$ | $\{\underline{D} + D_{\underline{h}}\}e^{i\delta^{\phi K^*}}$ |
| $\to \omega K^{*+}$ | $-(1/\sqrt{2})(s_1)^2\times$ | $\{A + D + 2D_h\}$ | $\to$ | $\{A + D + 2D_h\}e^{i\delta^{\omega K^*}}$ |
| $\to \rho^+ K^{*0}$ | $-(s_1)^2\times$ | $\{B + D\}$ | $\to$ | $\{(B + D) + (A - B - 2D)(1/3)(1 - e^{-i\Delta_{\rho K^*}})\}e^{i\delta_{3/2}^{\rho K^*}}$ |
| $\to \rho^0 K^{*+}$ | $(1/\sqrt{2})(s_1)^2\times$ | $\{A - D\}$ | $\to$ | $\{(A - D) + (A - B - 2D)(2/3)(1 - e^{-i\Delta_{\rho K^*}})\}e^{i\delta_{3/2}^{\rho K^*}}$ |
| $D^0 \to \phi K^{*0}$ | $-(s_1)^2\times$ | $\{\underline{C} + C_h\}$ | $\to$ | $\{\underline{C} + C_h\}e^{i\delta^{\phi K^*}}$ |
| $\to \omega \bar{K}^{*0}$ | $-(1/\sqrt{2})(s_1)^2\times$ | $\{B + C + 2C_h\}$ | $\to$ | $\{B + C' + 2C_h\}e^{i\delta^{\omega K^*}}$ |
| $\to \rho^- K^{*+}$ | $-(s_1)^2\times$ | $\{A + C\}$ | $\to$ | $\{(A + C) - 2/3(A + B)(1 - e^{i\Delta_{\rho K^*}})\}e^{i\delta_{1/2}^{\rho K^*}}$ |
| $\to \rho^0 K^{*0}$ | $-(1/\sqrt{2})(s_1)^2\times$ | $\{B - C\}$ | $\to$ | $\{(B - C) - 1/3(A + B)(1 - e^{i\Delta_{\rho K^*}})\}e^{i\delta_{1/2}^{\rho K^*}}$ |
| $D_s^+ \to K^{*+} K^{*0}$ | $-(s_1)^2\times$ | $\{A + B\}$ | $\to$ | $\{(A + B)\}e^{i\delta_1^{K^* K^*}}$ |