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Decay Rates and CP Asymmetries of $B \rightarrow DK$

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Abstract

By using isospin and $SU(3)$ symmetries and taking first-order $SU(3)$ breaking into account, we can numerically determine the quark-diagram amplitudes of $B \rightarrow DK$ from current data on $B \rightarrow D\pi$. The branching ratios and CP asymmetries of $B \rightarrow DK$ are calculated, and the effect of final-state rescattering on them are illustrated.

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1. Introduction

Within the standard electroweak model, CP violation is naturally described by a non-trivial phase of the Kobayashi-Maskawa (KM) matrix [1]. The most promising way to test this picture and to distinguish it from other candidate models of CP violation is by measurements of CP asymmetries in weak decays of B mesons [2]. In addition to a variety of neutral B transitions to CP eigenstates, some exclusive $|\Delta B| = |\Delta C| = |\Delta S| = 1$ channels to non- CP eigenstates are also expected to have significant signals of CP violation [3, 4] and may even be used to extract the CP -violating phase in the KM matrix [5, 6]. Such decay modes occur only through the tree-level quark diagrams, but a prediction of their branching ratios and CP asymmetries is still difficult due to unknown final-state strong interactions (FSI). In previous numerical estimates, the effects of FSI were usually neglected and the hadronic matrix elements were evaluated with specific empirical models. Today steps towards an improvement of those naive and model-dependent calculations are necessary, in order to yield relatively reliable results and to confront them with the forthcoming experiments at various facilities of B -meson physics.

In this paper we shall calculate the decay rates and CP asymmetries of two-body nonleptonic decays $B \rightarrow DK$. Different from the previous studies, our approach combines isospin and $SU(3)$ symmetries and thus it is able to numerically determine the quark-diagram amplitudes of $B \rightarrow DK$ from current data on $B \rightarrow D\pi$. The first-order $SU(3)$ breaking and final-state rescattering effects are taken into account. We find that the branching ratios of $B_u^+ \rightarrow \bar{D}^0 K^+$ and $D_1 K^+$ are of the order 10^{-4} , and those of $B_d^0 \rightarrow D^- K^+$, $\bar{D}^0 K^0$ and $D_1 K_S$ are of the order 10^{-5} . The branching ratios of $B_u^+ \rightarrow D^0 K^+$, $D^+ K^0$ and $B_d^0 \rightarrow D^0 K^0$ are at the level 10^{-6} . The direct CP violation in $B_u^\pm \rightarrow D_1 K^\pm$ is likely to be of the magnitude $5 - 10\%$. The CP asymmetries in B_d^0 vs $\bar{B}_d^0 \rightarrow D^0 K_S$, $\bar{D}^0 K_S$ and $D_1 K_S$ are expected to reach the level $10 - 60\%$. Finally we point out the uncertainty in our approach and the possibility to apply it to other B -meson decays such $B \rightarrow D^* K$ and $B \rightarrow DK^*$.

2. Quark-diagram amplitudes

We begin with an isospin analysis of the decay modes $B_d^0 \rightarrow D^- \pi^+$, $B_d^0 \rightarrow \bar{D}^0 \pi^0$ and $B_u^+ \rightarrow \bar{D}^0 \pi^+$. The effective weak Hamiltonian responsible for these processes has the isospin structure $|I, I_z\rangle = |1, +1\rangle$, and this leads to the following isospin relations:

$$\begin{aligned} A(B_d^0 \rightarrow D^- \pi^+) &= (A_{3/2}^{D\pi} + \sqrt{2}A_{1/2}^{D\pi})/\sqrt{3}, \\ A(B_d^0 \rightarrow \bar{D}^0 \pi^0) &= (\sqrt{2}A_{3/2}^{D\pi} - A_{1/2}^{D\pi})/\sqrt{3}, \\ A(B_u^+ \rightarrow \bar{D}^0 \pi^+) &= \sqrt{3}A_{3/2}^{D\pi}, \end{aligned} \tag{1}$$

where $A_I^{D\pi}$ ($I = 3/2$ or $1/2$) stands for an isospin amplitude. Note that the above transitions occur only through three tree-level quark diagrams (see Fig. 1 for illustration). After the

KM matrix elements (V_{cb}^* and V_{ud}) are factored out, the remaining parts of quark-diagram amplitudes (a), (b) and (c) in Fig. 1 can be defined under isospin symmetry as $X_{D\pi}$, $Y_{D\pi}$ and $Z_{D\pi}$, respectively. There are definite relations between the isospin amplitudes and the quark-diagram amplitudes:

$$\begin{aligned}\sqrt{3}A_{3/2}^{D\pi} &= V_{cb}^*V_{ud} (X_{D\pi} + Y_{D\pi}) \exp(i\phi_{3/2}), \\ \sqrt{6}A_{1/2}^{D\pi} &= V_{cb}^*V_{ud} (2X_{D\pi} - Y_{D\pi} + 3Z_{D\pi}) \exp(i\phi_{1/2}),\end{aligned}\quad (2)$$

where ϕ_I ($I = 3/2$ or $1/2$) denotes the strong phase from FSI. For simplicity, we subsequently neglect the W -exchange amplitude $Z_{D\pi}$, since it is expected to be negligibly small in comparison with the spectator amplitudes $X_{D\pi}$ and $Y_{D\pi}$ [7, 8]. Then the magnitudes of $X_{D\pi}$ and $Y_{D\pi}$ can be obtained as follows:

$$\begin{aligned}X_{D\pi} &= (\sqrt{3}|A_{3/2}^{D\pi}| + \sqrt{6}|A_{1/2}^{D\pi}|) / (3|V_{cb}V_{ud}|), \\ Y_{D\pi} &= (2\sqrt{3}|A_{3/2}^{D\pi}| - \sqrt{6}|A_{1/2}^{D\pi}|) / (3|V_{cb}V_{ud}|).\end{aligned}\quad (3)$$

Note that $X_{D\pi} > Y_{D\pi}$, because the latter is associated with the color-mismatched quark process. By use of the maximum likelihood method and current experimental data, Yamamoto [9] has obtained the numerical results of $|A_{3/2}^{D\pi}|$ and $|A_{1/2}^{D\pi}|$ as well as the lower bound on $\cos(\phi_{3/2} - \phi_{1/2})$. For our purpose, we only take the central values of $|A_{3/2}^{D\pi}|$ and $|A_{1/2}^{D\pi}|$ from ref. [9] to calculate the quark-diagram amplitudes. The results are

$$X_{D\pi} \approx 1.869 \times 10^{-5} \text{ GeV}, \quad Y_{D\pi} \approx 0.576 \times 10^{-5} \text{ GeV}, \quad (4)$$

where the inputs $|V_{cb}| = 0.04$ and $|V_{ud}| = 0.974$ have been used.

We now analyze the decay amplitudes of $B \rightarrow DK$ and relate them to those of $B \rightarrow D\pi$ with the help of SU(3) symmetry. The decay modes $B_d^0 \rightarrow D^- K^+$, $B_d^0 \rightarrow \bar{D}^0 K^0$ and $B_u^+ \rightarrow \bar{D}^0 K^+$ occur only through three tree-level quark diagrams, as illustrated by Fig. 1. So do the processes $B_u^+ \rightarrow D^+ K^0$, $B_u^+ \rightarrow D^0 K^+$ and $B_d^0 \rightarrow D^0 K^0$. Factoring out the KM matrix elements ($V_{cb}^*V_{us}$ or $V_{ub}^*V_{cs}$), we define the remaining parts of quark-diagram amplitudes (a'), (b') and (c') in Fig. 1 as X_{DK} , Y_{DK} and Z_{DK} , respectively, under isospin symmetry. Then a straightforward isospin analysis gives the transition amplitudes of $B \rightarrow DK$, in terms of the quark-diagram amplitudes, as follows ⁴:

$$\begin{aligned}A(B_d^0 \rightarrow D^- K^+) &= V_{cb}^*V_{us} [(X_{DK} + Y_{DK}) \exp(i\phi_1) + (X_{DK} - Y_{DK}) \exp(i\phi_0)] / 2, \\ A(B_d^0 \rightarrow \bar{D}^0 K^0) &= V_{cb}^*V_{us} [(X_{DK} + Y_{DK}) \exp(i\phi_1) - (X_{DK} - Y_{DK}) \exp(i\phi_0)] / 2, \\ A(B_u^+ \rightarrow \bar{D}^0 K^+) &= V_{cb}^*V_{us} (X_{DK} + Y_{DK}) \exp(i\phi_1); \end{aligned}\quad (5)$$

and

$$\begin{aligned}A(B_u^+ \rightarrow D^+ K^0) &= V_{ub}^*V_{cs} [(-Y_{DK}) \exp(i\phi_1) + (Y_{DK} + 2Z_{DK}) \exp(i\phi_0)] / 2, \\ A(B_u^+ \rightarrow D^0 K^+) &= V_{ub}^*V_{cs} [(-Y_{DK}) \exp(i\phi_1) - (Y_{DK} + 2Z_{DK}) \exp(i\phi_0)] / 2, \\ A(B_d^0 \rightarrow D^0 K^0) &= V_{ub}^*V_{cs} (-Y_{DK}) \exp(i\phi_1). \end{aligned}\quad (6)$$

⁴Throughout this work, we use the same valence-quark notations for the light and heavy mesons as ref. [7]. This convention guarantees that the relevant mesons can form isospin multiplets without extra signs. Our formulas in eq. (6) are slightly different from those given in ref. [10] due to the different convention used there.

Here ϕ_I ($I = 1$ or 0) denotes the strong phase arising from final-state rescattering. Like the W -exchange amplitude $Z_{D\pi}$, the annihilation amplitude Z_{DK} is also argued to be negligibly small due to the suppression of helicity and (or) formfactors [7]. In the assumption of $\phi_1 = \phi_0$ (i.e., $A(B_u^+ \rightarrow D^+ K^0)$ is purely governed by Z_{DK}), a model-dependent estimation gives the branching ratio $\text{Br}(B_u^+ \rightarrow D^+ K^0) \sim 8.1 \times 10^{-9}$ [8], which is too small to be measurable. However, significant FSI effects are possible to enhance the rate of $B_u^+ \rightarrow D^+ K^0$ to the detectable level [8] and to affect other decay channels of the same nature.

Under $SU(3)$ symmetry, we get simple relations between the quark-diagram amplitudes of $B \rightarrow DK$ and $B \rightarrow D\pi$: $X_{DK} = X_{D\pi}$ and $Y_{DK} = Y_{D\pi}$. The first-order $SU(3)$ breaking corrections to such relations can be introduced by use of the factorization approximation [11]. Explicitly, we find

$$\frac{X_{DK}}{X_{D\pi}} \approx \frac{f_K}{f_\pi} \approx 1.2, \quad \frac{Y_{DK}}{Y_{D\pi}} \approx \frac{F_0^{BK}(0)}{F_0^{B\pi}(0)} \approx 1.1, \quad (7)$$

where the values of decay constants and formfactors are cited from [12, 13]. At present there is no experimental information about the magnitude of the strong phase shift $\delta \equiv \phi_1 - \phi_0$. Considering DK scattering via a t -channel exchange of Regge trajectories, Deshpande and Dib obtained $\tan \delta \approx -0.14$ with large uncertainty [10]. For our purpose, we shall let the value of δ be open in the subsequent calculations of decay rates and CP asymmetries.

3. Branching ratios of $B \rightarrow DK$

The branching ratio of a two-body decay mode $B \rightarrow DK$ is given by

$$\text{Br}(B \rightarrow DK) = \frac{\tau_B p_c}{8\pi m_B^2} |A(B \rightarrow DK)|^2, \quad (8a)$$

where τ_B is the lifetime of B meson, and

$$p_c = \frac{1}{2m_B} \sqrt{[m_B^2 - (m_D + m_K)^2][m_B^2 - (m_D - m_K)^2]} \quad (8b)$$

is the c.m. momentum of D and K mesons. With the help of eqs. (5-8), the branching ratios of $B_d^0 \rightarrow D^- K^+$, $\bar{D}^0 K^0$, $D^0 K^0$ and $B_u^+ \rightarrow \bar{D}^0 K^+$, $D^+ K^0$, $D^0 K^+$ can be calculated as functions of the unknown strong phase shift δ . Here we adopt $\tau_B \approx 1.52 \times 10^{-12}$ s for B_u and B_d mesons. The central values of meson masses can be found from ref. [12]. The values of relevant KM matrix elements are taken as $|V_{us}| = 0.22$, $|V_{cs}| = 0.973$, $|V_{cb}| = 0.04$ and $|V_{ub}| = 0.08|V_{cb}|$ [12]. Our results are shown in Fig. 2.

We observe that the branching ratios of $B_d^0 \rightarrow D^- K^+$ and $B_d^0 \rightarrow \bar{D}^0 K^0$ depend sensitively on the rescattering phase shift δ , and their dependence behaviors are opposite to each other. The similar feature appears in $\text{Br}(B_u^+ \rightarrow D^0 K^+)$ and $\text{Br}(B_u^+ \rightarrow D^+ K^0)$. For $\delta \sim 0^\circ$,

the channel $B_u^+ \rightarrow D^+ K^0$ is considerably suppressed and cannot be detected in experiments. Observation of this mode would imply either significant FSI effects (δ) or non-negligible annihilation diagrams (Z_{DK}), or both of them [8]. Due to the suppression from $|V_{ub}|$ and Y_{DK} , branching ratios of the decay modes in eq. (6) are about 10^2 times smaller than those in eq. (5). Thus a lot of experimental effort has to be made in order to measure $B_d^0 \rightarrow D^0 K^0$, $B_u^+ \rightarrow D^0 K^+$ and $B_u^+ \rightarrow D^+ K^0$.

We proceed to calculate the branching ratios of $B_d^0 \rightarrow D^0 K_1$, $\bar{D}^0 K_1$, $D_1 K_1$ and $B_u^+ \rightarrow D_1 K^+$, where $K_1 = (K^0 + \bar{K}^0)/\sqrt{2}$ and $D_1 = (D^0 + \bar{D}^0)/\sqrt{2}$ denote the CP -even states of neutral K and D mesons respectively⁵. Here small CP violation in the $K^0 - \bar{K}^0$ and $D^0 - \bar{D}^0$ systems have been neglected, thus $K_1 \approx K_S$ by a suitable phase convention. The transition amplitudes of these decays can be obtained from eqs. (5) and (6) as follows:

$$\begin{aligned} A(B_d^0 \rightarrow \bar{D}^0 K_S) &= A(B_d^0 \rightarrow \bar{D}^0 K^0)/\sqrt{2}, \\ A(B_d^0 \rightarrow D^0 K_S) &= A(B_d^0 \rightarrow D^0 K^0)/\sqrt{2}; \end{aligned} \quad (9)$$

and

$$\begin{aligned} A(B_d^0 \rightarrow D_1 K_S) &= [A(B_d^0 \rightarrow \bar{D}^0 K^0) + A(B_d^0 \rightarrow D^0 K^0)]/2, \\ A(B_u^+ \rightarrow D_1 K^+) &= [A(B_u^+ \rightarrow \bar{D}^0 K^+) + A(B_u^+ \rightarrow D^0 K^+)]/\sqrt{2}. \end{aligned} \quad (10)$$

Consequently one finds $\text{Br}(B_d^0 \rightarrow \bar{D}^0 K_S) = 0.5\text{Br}(B_d^0 \rightarrow \bar{D}^0 K^0)$ and $\text{Br}(B_d^0 \rightarrow D^0 K_S) = 0.5\text{Br}(B_d^0 \rightarrow D^0 K^0)$. The values of $\text{Br}(B_d^0 \rightarrow D_1 K_S)$ and $\text{Br}(B_u^+ \rightarrow D_1 K^+)$ depend on the CP -violating phase of the KM matrix. For convenience, here we make use of the Wolfenstein parametrization, where V_{ub} and V_{td} contain the CP -violating phase ($\arg(V_{ub}^*) \equiv \gamma$ and $\arg(V_{td}^*) \equiv \beta$ [12]) and all other elements are approximately real to leading order. The current data give $5^\circ \leq \beta \leq 45^\circ$ and $20^\circ \leq \gamma \leq 165^\circ$ [14]. In our calculations, we typically take $\beta = 25^\circ$ and $\gamma = 90^\circ$. The results for $\text{Br}(B_d^0 \rightarrow D_1 K_S)$ and $\text{Br}(B_u^+ \rightarrow D_1 K^+)$ are illustrated in Fig. 3.

One can see that the branching ratio of $B_u^+ \rightarrow D_1 K^+$ is of order 10^{-4} , and that of $B_d^0 \rightarrow D_1 K_S$ is at the level 10^{-5} to 10^{-4} for large $|\delta|$. They are indeed dominated by the processes $B_u^+ \rightarrow \bar{D}^0 K^+$ and $B_d^0 \rightarrow \bar{D}^0 K^0$, respectively.

4. CP violation in $B \rightarrow DK$

For a generic decay mode $B \rightarrow f$ and its CP -conjugate process $\bar{B} \rightarrow \bar{f}$, the basic signal of CP violation will be the observation of their decay-rate difference:

$$\Delta(f) \equiv \frac{\Gamma(B \rightarrow f) - \Gamma(\bar{B} \rightarrow \bar{f})}{\Gamma(B \rightarrow f) + \Gamma(\bar{B} \rightarrow \bar{f})}. \quad (11)$$

Here we let B and $\bar{B}$ denote B_u^+ (or B_d^0) and B_u^- (or $\bar{B}_d^0$) respectively, while f and $\bar{f}$ stand for the appropriate states of D and K mesons. Among the decay channels discussed in the

⁵The decay modes associated with the CP -odd states $K_2 = (K^0 - \bar{K}^0)/\sqrt{2}$ and $D_2 = (D^0 - \bar{D}^0)/\sqrt{2}$ can be considered in the same way.

last section, direct CP violation may manifest itself in $B_u^+ \rightarrow D_1 K^+$ vs $B_u^- \rightarrow D_1 K^-$ due to interference of the strong and weak phase shifts (i.e., δ and γ). The interplay of doubly-KM-suppressed decay and $B_d^0 - \bar{B}_d^0$ mixing can give rise to indirect CP asymmetries in $B_d^0 \rightarrow D^0 K_S$ vs $\bar{B}_d^0 \rightarrow D^0 K_S$ and $B_d^0 \rightarrow \bar{D}^0 K_S$ vs $\bar{B}_d^0 \rightarrow \bar{D}^0 K_S$. For B_d^0 and $\bar{B}_d^0$ decays to the CP eigenstate $D_1 K_S$, both direct and indirect CP -violating effects are possible to take place.

We first look at the CP asymmetry in $B_u^+ \rightarrow D_1 K^+$ vs $B_u^- \rightarrow D_1 K^-$:

$$\Delta(D_1 K^\pm) = -2|V_{cb}V_{us}V_{ub}V_{cs}|\sin\gamma\sin\delta \frac{(X_{DK} + Y_{DK})Y_{DK}}{N_{D_1 K^\pm}}, \quad (12)$$

where

$$\begin{aligned} N_{D_1 K^\pm} = & 2|V_{cb}V_{us}|^2(X_{DK} + Y_{DK})^2 + |V_{ub}V_{cs}|^2Y_{DK}^2(1 + \cos\delta) \\ & - 2|V_{cb}V_{us}V_{ub}V_{cs}|(X_{DK} + Y_{DK})Y_{DK}\cos\gamma(1 + \cos\delta). \end{aligned} \quad (13)$$

One can see that $\Delta(D_1 K^\pm)$ is sensitive to the values of γ and δ . For illustration, we typically take $\gamma = 90^\circ$ and plot the changes of $\Delta(D_1 K^\pm)$ with δ in Fig. 4. One can observe that the CP asymmetry of a few percent is possible to appear in $B_u^\pm \rightarrow D_1 K^\pm$, if significant FSI effects are present.

Because of $|A(B_d^0 \rightarrow D^0 K_S)| = |A(\bar{B}_d^0 \rightarrow \bar{D}^0 K_S)|$ in the neglect of CP nonconservation from $K^0 - \bar{K}^0$ mixing, there is no direct CP violation in B_d^0 vs $\bar{B}_d^0 \rightarrow D^0 K_S$ and B_d^0 vs $\bar{B}_d^0 \rightarrow \bar{D}^0 K_S$. After taking into account $B_d^0 - \bar{B}_d^0$ mixing [3, 4], we obtain the following time-independent CP asymmetries:

$$\begin{aligned} \Delta(D^0 K_S) = & 2x_d|V_{cb}V_{us}V_{ub}V_{cs}|\left[\sin(2\beta + \gamma) \frac{(X_{DK} + Y_{DK})Y_{DK}}{N_{D^0 K_S}} \right. \\ & \left. - \sin(2\beta + \gamma + \delta) \frac{(X_{DK} - Y_{DK})Y_{DK}}{N_{D^0 K_S}}\right], \end{aligned} \quad (14a)$$

$$\begin{aligned} \Delta(\bar{D}^0 K_S) = & 2x_d|V_{cb}V_{us}V_{ub}V_{cs}|\left[\sin(2\beta + \gamma) \frac{(X_{DK} + Y_{DK})Y_{DK}}{N_{\bar{D}^0 K_S}} \right. \\ & \left. - \sin(2\beta + \gamma - \delta) \frac{(X_{DK} - Y_{DK})Y_{DK}}{N_{\bar{D}^0 K_S}}\right], \end{aligned} \quad (14b)$$

where

$$N_{D^0 K_S} = 2(2 + x_d^2)|V_{ub}V_{cs}|^2Y_{DK}^2 + x_d^2|V_{cb}V_{us}|^2[(X_{DK}^2 + Y_{DK}^2) - (X_{DK}^2 - Y_{DK}^2)\cos\delta], \quad (15a)$$

$$N_{\bar{D}^0 K_S} = (2 + x_d^2)|V_{cb}V_{us}|^2[(X_{DK}^2 + Y_{DK}^2) - (X_{DK}^2 - Y_{DK}^2)\cos\delta] + 2x_d^2|V_{ub}V_{cs}|^2Y_{DK}^2. \quad (15b)$$

Here β corresponds to the weak phase of $B_d^0 - \bar{B}_d^0$ mixing. If $\delta = 0$ is assumed, then both $\Delta(D^0 K_S)$ and $\Delta(\bar{D}^0 K_S)$ are purely proportional to $\sin(2\beta + \gamma)$. In this case, the input of $\beta = 25^\circ$ and $\gamma = 90^\circ$ leads these two asymmetries to 40% and 15% respectively. The significant influence of nonvanishing δ on $\Delta(D^0 K_S)$ and $\Delta(\bar{D}^0 K_S)$ are shown in Fig. 4. Clearly the ignorance of FSI effects will give rise to misleading results.

Finally we calculate the decay-rate difference between $B_d^0 \rightarrow D_1 K_S$ and $\bar{B}_d^0 \rightarrow D_1 K_S$, which is composed of both direct and indirect CP asymmetries. The result of $\Delta(D_1 K_S)$ can be given as follows:

$$\begin{aligned} \Delta(D_1 K_S) = & -2|V_{cb}V_{us}V_{ub}V_{cs}|\sin\gamma\sin\delta\frac{(X_{DK}-Y_{DK})Y_{DK}}{N_{D_1 K_S}} \\ & - x_d \left[|V_{cb}V_{us}|^2 \sin(2\beta) \frac{X_{DK}^2(1-\cos\delta) + Y_{DK}^2(1+\cos\delta)}{N_{D_1 K_S}} \right. \\ & + 2|V_{ub}V_{cs}|^2 \sin 2(\beta+\gamma) \frac{Y_{DK}^2}{N_{D_1 K_S}} \\ & \left. - 2|V_{cb}V_{us}V_{ub}V_{cs}|\sin(2\beta+\gamma) \frac{X_{DK}(1-\cos\delta) + Y_{DK}(1+\cos\delta)}{N_{D_1 K_S}} Y_{DK} \right] \end{aligned} \quad (16)$$

with

$$\begin{aligned} N_{D_1 K_S} = & (1+x_d^2) \left\{ |V_{cb}V_{us}|^2 [X_{DK}^2(1-\cos\delta) + Y_{DK}^2(1+\cos\delta)] + 2|V_{ub}V_{cs}|^2 Y_{DK}^2 \right. \\ & \left. - 2|V_{cb}V_{us}V_{ub}V_{cs}|\cos\gamma[X_{DK}(1-\cos\delta) + Y_{DK}(1+\cos\delta)]Y_{DK} \right\}. \end{aligned} \quad (17)$$

In $\Delta(D_1 K_S)$ the term proportional to x_d is induced by the interplay of decay and $B_d^0 - \bar{B}_d^0$ mixing, and that proportional to $\sin\delta$ is of direct CP violation. These two sources of CP asymmetries are separable by measurements of time distributions of $B_d^0 \rightarrow D_1 K_S$ and $\bar{B}_d^0 \rightarrow D_1 K_S$ [15]. Still taking $\beta = 25^\circ$ and $\gamma = 90^\circ$, we illustrate the magnitude of $\Delta(D_1 K_S)$ as a function of δ in Fig. 4. We see that large CP violation of the magnitude 25% to 60% can take place in this CP -eigenstate mode.

5. Further discussions

By use of isospin invariance, SU(3) symmetry and current data on $B \rightarrow D\pi$, we have calculated the branching ratios and CP asymmetries of $B \rightarrow DK$. In this approach, the uncertainty associated with hadronic matrix elements can be approximately avoided and the second-order SU(3) breaking effect is expected to be insignificant. The main uncertainties in our numerical results come from the unknown phase shift of final-state rescattering and imprecise values of the KM matrix elements. We find that the ignorance of significant FSI effects may give rise to misleading predictions for both the decay rates and CP asymmetries.

In our isospin analyses we have assumed that channel mixing is induced only by rescattering of the final states DK . A more detailed analysis shows that mixing between the decay channels $B_d \rightarrow DK$ and $B_d \rightarrow D_s \pi$ is also likely to take place [16]. A justification of the latter type of FSI effect is impossible at present, but sufficient data on $B \rightarrow DK$ in the near future will allow us to check the validity of the isospin triangle relations given in eqs. (5) and (6).

For simplicity, this work concentrates on isospin symmetry among the different DK states and SU(3) symmetry between the quark-diagram amplitudes of $B \rightarrow DK$ and $B \rightarrow D\pi$. The similar isospin and SU(3) relations are expected to hold for $B \rightarrow D^* K$ and $B \rightarrow D^* \pi$.

as well as $B \rightarrow DK^*$ and $B \rightarrow D\rho$. In addition, the approximate SU(3) relations between $B_d \rightarrow DK^*$ and $B_s \rightarrow D\phi$ may be obtained. Thus it is possible to estimate the decay rates and CP asymmetries of $B \rightarrow D^*K$, $B \rightarrow DK^*$ and $B_s \rightarrow D\phi$ with the help of current data on $B \rightarrow D^*\pi$ and $B \rightarrow D\rho$, but complications arising from the polarizations of vector particles have to be taken into account [17]. Of course, all the above decay modes are of much interest for the study of CP violation in the B -meson system.

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Figure 1: Effective quark diagrams associated with the decay amplitudes of (1) $B \rightarrow D\pi$ through $\bar{b} \rightarrow \bar{c}u\bar{d}$ (see (a), (b) and (c)) and (2) $B \rightarrow DK$ through $\bar{b} \rightarrow \bar{c}u\bar{s}$ or $\bar{b} \rightarrow \bar{u}c\bar{s}$ (see (a'), (b') and (c')). The flavors of different lines may vary depending on the processes, and the isospin symmetry holds for the relevant initial and final states.

Figure 2: Branching ratios of $B \rightarrow DK$ as functions of the strong phase shift $\delta \equiv \phi_1 - \phi_0$: (a) $B_u^+ \rightarrow \bar{D}^0 K^+$, (b) $B_d^0 \rightarrow D^- K^+$, (c) $B_d^0 \rightarrow \bar{D}^0 K^0$; (d) $B_d^0 \rightarrow D^0 K^0$, (e) $B_u^+ \rightarrow D^0 K^+$, and (f) $B_u^+ \rightarrow D^+ K^0$. The relevant inputs can be found in the text.

Figure 3: Branching ratios of (a) $B_u^+ \rightarrow D_1 K^+$ and (b) $B_d^0 \rightarrow D_1 K_S$ as functions of the strong phase shift $\delta \equiv \phi_1 - \phi_0$. The relevant inputs can be found in the text.

Figure 4: CP asymmetries of $B \rightarrow DK$ as functions of the strong phase shift $\delta \equiv \phi_1 - \phi_0$: (a) B_d^0 vs $\bar{B}_d^0 \rightarrow D^0 K_S$, (b) B_d^0 vs $\bar{B}_d^0 \rightarrow \bar{D}^0 K_S$, (c) $B_u^\pm \rightarrow D_1 K^\pm$, and (d) B_d^0 vs $\bar{B}_d^0 \rightarrow D_1 K_S$. The relevant inputs can be found in the text.