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Isospin relation and SU(3) breaking effects of strong phases in charmless B decays

Yue-Liang Wu[1] and Yu-Feng Zhou[2]

[1] Institute of Theoretical Physics, Chinese Academy of Science, Beijing 100080, China, e-mail: ylwu@itp.ac.cn
[2] Ludwig-Maximilians-University Munich, Sektion Physik. Theresienstrasse e 37, D-80333. Munich, Germany, e-mail: zhou@theorie.physik.uni-muenchen.de

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Abstract. Isospin and flavor SU(3) relations in charmless hadronic B decays $B \to \pi\pi, \pi K$ are investigated in detail with paying attention to the SU(3) symmetry breaking effects in both amplitudes and strong phases. In general, the isospin and the flavor SU(3) structure of the effective Hamiltonian provide several relations among the amplitudes and strong phases. Whereas a global fit to the latest data shows that some relation seems not to be favorable for a consistent explanation to the current data within the standard model (SM). By considering several patterns of SU(3) breaking, the amplitudes and the corresponding strong phases are extracted and compared with the theoretical estimations. It is found that in the case of SU(3) limits and also the case with SU(3) breaking only in amplitudes, the fitting results lead to an unexpected large ratio between two isospin amplitudes $a^c_{3/2}/a^u_{3/2}$, which is about an order of magnitude larger than the SM prediction. The results are found to be insensitive to the weak phase γ. By including SU(3) breaking effects on the strong phases, one is able to obtain a consistent fit to the current data within the SM, which implies that the SU(3) breaking effect on strong phases may play an important role in understanding the observed charmless hadronic B decay modes $B \to \pi\pi$ and πK. It is possible to test those breaking effects in the near future from more precise measurements of direct CP violation in B factories.

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1 Introduction

B meson physics and CP violation are the central topics of the present day particle physics. Recently, exciting experimental results are reported from two B factories at SLAC and KEK. One of the angles β in the unitarity triangle of Cabbibo-Kobayashi-Maskawa (CKM) matrix elements is determined through decay mode $B \to J/\psi K_S$ [1,2] with a good precision and found to be consistent with the other indirect measurement within Standard Model (SM) [3]. The recent preliminary measurements of time dependent CP violation in other channels such as $B \to \phi K_S$ [4,2] also provide us useful information for an independent determination of the weak phase β and for probing new physics beyond the SM. Besides mixing induced CP violation, rare B decays and direct CP violations are also of great importance in determining other weak phase angles of the unitarity triangle and testing the Kobayashi-Maskawa (KM) mechanism [5] in SM. With the successful running of B factories, higher precision data on the rare hadronic B decay modes such as $B \to \pi\pi, \pi K$ [6,7,8,9,10,11] have been obtained, which provide us good opportunities to extract the weak phase angle γ, to test the theoretical approaches for evaluating the hadronic transition matrix elements and to explore new physics beyond the SM.

On the theoretical side, great efforts have been made to improve the calculations of hadronic matrix elements. The recently proposed methods such as QCD Factorization [12, 13] and pQCD approach [14,15] have been extensively discussed. From those methods, useful information of weak phase angles such as γ can be extracted [16,17]. Other approaches which are based on flavor isospin and SU(3) symmetries are still helpful and important [18,19,20,21, 22]. The advantage of this kind of approaches is obvious that they are model independent and more convenient in studying the interference between weak and strong phases. Recently the flavor isospin and SU(3) symmetries in charmless B decays are studied by using global fits to the experiment data [23,24,25]. In a general isospin decomposition, there exist a lot of independent free parameters. By considering the flavor isospin and SU(3) symmetries, the number of parameters is greatly reduced and the method of global fit becomes applicable. Through direct fit, the isospin or SU(3) invariant amplitudes as well as the corresponding strong phases can be extracted with a reasonable precision. The early results [23] have already indicated some unexpected large isospin amplitudes and strong phases. The fitted amplitudes and strong phases can also provide useful information for the weak phase γ [24]. However unlike isospin symmetry, the flavor SU(3) symmetry is known to be broken down sizably [26,27]. The ways of introducing SU(3) breaking may have significant influence on the final results. In the usual considerations, the main effects of SU(3) breaking are often taken into accounted only in the amplitudes. To be more general, the study of SU(3) breaking including strong phases is necessary.

In this paper, we begin with the general isospin and flavor SU(3) relations in charmless hadronic B decays $B \to \pi\pi, \pi K$. By using a general isospin decomposition, isospin invariant amplitudes are determined from latest data through global fit. Different patterns of SU(3) breaking in both amplitudes and strong phases are studied in detail. It is observed that in the SU(3) limit the current data suggest a large violation of a isospin relation which is associated with the electroweak penguin diagrams in SM. The results is found to be insensitive to the value of γ when its value lies in the range $60^\circ \lesssim \gamma \lesssim 120^\circ$. The inclusion of SU(3) breaking effects, especially the one in the strong phases can improve the agreement between experiment and theory.

2 A general isospin decomposition and isospin relations

The isospin symmetry is a good symmetry, it is helpful to start from a pure isospin discussion and then include flavor SU(3) symmetry and its breaking effects in the next step. The effective Hamiltonian for $\Delta S = 0$ nonleptonic B decays is given by

$$H_{eff} = \frac{G_F}{\sqrt{2}} \sum_{q=u,c} \lambda_q \left(C_1 O_1^q + C_2 O_2^q + \sum_{i=3}^{10} C_i O_i \right), \quad (1)$$

with $\lambda_q = V_{qb} V_{qd}^*$ is the products of CKM matrix elements and the operators are

$$\begin{aligned}
O_1^q &= (\bar{d}_\alpha q_\alpha)_{V-A} (\bar{q}_\beta b_\beta)_{V-A}, \\
O_2^q &= (\bar{d}_\beta q_\alpha)_{V-A} (\bar{q}_\beta b_\alpha)_{V-A}, \\
O_3 &= \sum_q (\bar{q}_\alpha q_\alpha)_{V-A} (\bar{d}_\beta b_\beta)_{V-A}, \\
O_4 &= \sum_q (\bar{q}_\alpha q_\beta)_{V-A} (\bar{d}_\beta b_\alpha)_{V-A}, \\
O_5 &= \sum_q (\bar{q}_\alpha q_\alpha)_{V+A} (\bar{d}_\beta b_\beta)_{V-A}, \\
O_6 &= \sum_q (\bar{q}_\alpha q_\beta)_{V+A} (\bar{d}_\beta b_\alpha)_{V-A}, \\
O_7 &= \frac{3}{2} \sum_q e_q (\bar{q}_\alpha q_\alpha)_{V+A} (\bar{d}_\beta b_\beta)_{V-A}, \\
O_8 &= \frac{3}{2} \sum_q e_q (\bar{q}_\alpha q_\beta)_{V+A} (\bar{d}_\beta b_\alpha)_{V-A}, \\
O_9 &= \frac{3}{2} \sum_q e_q (\bar{q}_\alpha q_\alpha)_{V-A} (\bar{d}_\beta b_\beta)_{V-A}, \\
O_{10} &= \frac{3}{2} \sum_q e_q (\bar{q}_\alpha q_\beta)_{V-A} (\bar{d}_\beta b_\alpha)_{V-A}, \qquad (2)
\end{aligned}$$

where $O_{1,2}^{u(c)}$, $O_{3,\ldots,6}$ and $O_{7,\ldots,10}$ are related to tree, QCD penguin and electroweak penguin diagrams respectively.

The final states of $\pi\pi$ have isospin of 2 and 0. Let us define the isospin amplitudes A_2 and A_0 as follows

$$\begin{aligned}
A_2 &\equiv \langle \pi\pi, I=2 | H_{eff}^{3/2} | B \rangle = \lambda_u a_2^u e^{i\delta_2^u} + \lambda_c a_2^c e^{i\delta_2^c}, \\
A_0 &\equiv \langle \pi, \pi, I=0 | H_{eff}^{1/2} | B \rangle = \lambda_u a_0^u e^{i\delta_0^u} + \lambda_c a_0^c e^{i\delta_0^c}, \quad (3)
\end{aligned}$$

where $a_I^q, (q = u, c$ and $I = 2, 0)$ are the amplitudes associated with λ_q. The QCD penguin operators $O_{3,\ldots,6}$ have isospin of $\Delta I = 1/2$. But the other operators may have more isospin components. Taking $O_1^u = (\bar{d}u)_{V-A}(\bar{u}b)_{V-A}$ as an example, the isospin decomposition gives $\bar{\mathbf{2}} \otimes \mathbf{2} \otimes \mathbf{2} = \mathbf{4} \oplus \mathbf{2}' \oplus \mathbf{2}$. Thus it contains a $\Delta I = 3/2$ and two independent $\Delta I = 1/2$ isospin invariant operators. Let us denote them as $\mathcal{O}(3/2), \mathcal{O}(1/2)$ and $\mathcal{O}'(1/2)$ respectively, then the other operators can be decomposed in the same way, for example:

$$\begin{aligned}
O_1^u &= \frac{1}{3} [\mathcal{O}(3/2) - \mathcal{O}(1/2) + 2\mathcal{O}'(1/2)], \\
O_2^u &= \frac{1}{3} [\mathcal{O}(3/2) + 2\mathcal{O}(1/2) - \mathcal{O}'(1/2)], \\
O_3 &= \mathcal{O}(1/2) \qquad O_4 = \mathcal{O}'(1/2), \\
O_9 &= \frac{3}{2} O_1 - \frac{1}{2} O_3 = \frac{1}{2} [\mathcal{O}(3/2) - 2\mathcal{O}(1/2) + 2\mathcal{O}'(1/2)], \\
O_{10} &= \frac{3}{2} O_2 - \frac{1}{2} O_4 = \frac{1}{2} [\mathcal{O}(3/2) + 2\mathcal{O}(1/2) - 2\mathcal{O}'(1/2)]. \\
&&(4)
\end{aligned}$$

Among those operators, $\mathcal{O}(3/2)$ has the highest isospin $\Delta I = 3/2$. In the decays $B \to \pi\pi$ it is the *only* operator which can contribute to the final isospin $I = 2$ states. Rewrite the effective Hamiltonian in terms of isospin invariant operators in (4) and pick up the isospin 2 parts, one finds

$$\begin{aligned}
A_2 = &\frac{G_F}{\sqrt{2}} \left[\frac{1}{3} \lambda_u (C_1 + C_2 + C_9 + C_{10})) + \frac{1}{2} \lambda_c (C_9 + C_{10})) \right] \\
&\langle I = 2 | \mathcal{O}(3/2) | B \rangle, \qquad (5)
\end{aligned}$$

and

$$\frac{a_2^c}{a_2^u} \equiv R_{EW} = \frac{3}{2} \cdot \frac{C_9 + C_{10}}{C_1 + C_2 + C_9 + C_{10}}. \quad (6)$$

Taking the Wilson coefficients at $\mu = m_b$, one has $C_1 = 1.144, C_2 = -0.308, C_9 = -1.28\alpha, C_{10} = 0.328\alpha$. Thus

$$R_{EW} = -1.25 \times 10^{-2}, \quad \text{and} \quad \delta_2^c = \delta_2^u. \quad (7)$$

This relation is well known and has been extensively discussed [28,21,24,25,22]. Here we would like to emphasize the importance of this relation in a model independent analysis, namely:

1) The relation is obtained without the knowledge of the matrix element $\langle I=2|\,\mathcal{O}(3/2)\,|B\rangle$. It only depends on the isospin structure of the effective Hamiltonian and the final states. Thus it is independent of any model calculations, such as naive factorization or pQCD factorization etc.

2) It can not be affected by the final state inelastic rescattering processes with lower isospin as it is only related to the highest isospin component $\Delta I=3/2$. For example, it is expected that the processes of $B\to DD\to\pi\pi$ may be considerable in B decays[29,30]. Whereas the effective Hamiltonian of $B\to DD$ have isospin 1/2, its contribution to final state with $I=2$ vanishes, thus the above mentioned relation remains unchanged. The elastic rescattering process $B\to\pi\pi\to\pi\pi$ can contribute to the highest isospin amplitude, but their effects can be absorbed into the effective value of $\langle I=2|\,\mathcal{O}(3/2)\,|B\rangle$ and will not affect the value of R_{EW} which is the ratio of two isospin amplitudes sharing the same matrix elements. Thus this relation is less likely to be modified in the presence of final state interaction (FSI).

3) In the usual digram language, the decay $B\to\pi^-\pi^0$ receives contributions from several diagrams, i.e., $A(\pi^-\pi^0)=T+T^C+P_{EW}+P_{EW}^C$ (here "T" and "P_{EW}" stand for tree and electroweak penguin diagrams, the superscription "C" stands for the corresponding color suppressed one). It is expected that the interference between them may result in a small direct CP violation. However from relation $\delta_2^c=\delta_2^u$, it is easy to see that as long as the isospin symmetry is imposed, there is *no* direct CP violation in $B\to\pi^-\pi^0$. This conclusion purely relies on the isospin considerations and thus looks quite robust. A similar observation was also made within SU(3) symmetry in [25]. However when comparing to the possible nonnegligible SU(3) breaking effects, the conclusion based on isospin symmetry seems more reliable.

4) The value of R_{EW} is the ratio between the electroweak penguin and tree diagrams. It is then sensitive to new physics effects beyond the SM in electroweak penguin sector. The new physics effects on R_{EW} have been discussed in [31,32,33,34], it seems quite sensitive to several new physics models. A precise determination of R_{EW} from experiments may be helpful to single out possible new physics or study flavor symmetry breaking in charmless B decays. To describe the possibility that the value of R_{EW} extracted from experiments could be different from the SM calculations, we introduce a factor κ as follows

$$R_{EW}^{exp}=\kappa\cdot R_{EW}\simeq -0.0125\cdot\kappa, \tag{8}$$

where R_{EW}^{exp} stands for its value extracted from experiments and obviously $\kappa=1$ in SM.

Let us consider the operators with lower isospins. Note that the operators O_1^c and O_2^c have isospin of 1/2. As final states $\pi\pi$ are charmless and have isospin 2 and 0, those operators can not contribute directly. However, through inelastic final state interaction (FSI) processes such as $B\to DD\to\pi\pi$, their contributions to the final state with isospin 0 may be non-negligible. At present stage, there is no good theoretical estimation of such kind of processes. The operator O_5 and O_6 also have isospin 1/2 but with different Lorenz structure. In general, the matrix elements of $O_{5,6}$ are different from $O_{3,4}$. Thus the isospin amplitude A_0 receives contributions from many different operators with the same isospin 1/2. The matrix elements of those operators may develop different strong phases. Although for each operator there exist relations between λ_u and λ_c parts, there is no simple relation for their sum. In the most general case a_0^u and a_0^c are independent of each other and $\delta_0^u\neq\delta_0^c$.

A similar discussion can be made in decay modes $B\to\pi K$, where the effective Hamiltonian has isospin $\Delta I=1,0$. In this case one can define three isospin components

$$\begin{aligned}
A_{3/2} &\equiv \langle \pi K, I=3/2|\,H_{eff}^{\Delta I=1}\left|\overline{B}^0\right\rangle \\
&= \lambda_u a_{3/2}^u e^{i\delta_{3/2}^u}+\lambda_c a_{3/2}^c e^{i\delta_{3/2}^c}, \\
A_{1/2} &\equiv \langle \pi K, I=1/2|\,H_{eff}^{\Delta I=0}\left|\overline{B}^0\right\rangle \\
&= \lambda_u a_{1/2}^u e^{i\delta_{1/2}^u}+\lambda_c a_{1/2}^c e^{i\delta_{1/2}^c}, \\
B_{1/2} &\equiv \langle \pi K, I=1/2|\,H_{eff}^{\Delta I=1}\left|B^-\right\rangle \\
&= \lambda_u b_{1/2}^u e^{i\delta'^u_{1/2}}+\lambda_c b_{1/2}^c e^{i\delta'^c_{1/2}}
\end{aligned} \tag{9}$$

As there are two kind of Lorenz structure $(\overline{q}q)(\overline{s}b)$ and $(\overline{s}q)(\overline{q}b)$ with the same isospin, there are two independent operators with highest isospin $\Delta I=1$. One can not construct a similar relation of (6) within isospin symmetry. However, as it will be discussed below, one can obtain from SU(3) symmetry some useful relations.

From the above discussions the general form of isospin decomposition of the decay amplitudes for $B\to\pi\pi(\pi K)$ decays reads

$$A^{\pi\pi(\pi K)}=\lambda_u^{(s)}A_u^{\pi\pi(\pi K)}+\lambda_c^{(s)}A_c^{\pi\pi(\pi K)}, \tag{10}$$

where $\lambda_u^{(s)}=V_{ub}V_{ud(s)}^*$, $\lambda_c^{(s)}=V_{cb}V_{cd(s)}^*$ and

$$\begin{aligned}
A_q^{\pi^-\pi^+} &= \sqrt{\frac{2}{3}}a_0^q e^{i\delta_0^q}+\sqrt{\frac{1}{3}}a_2^q e^{i\delta_2^q}, \\
A_q^{\pi^0\pi^0} &= \sqrt{\frac{1}{3}}a_0^q e^{i\delta_0^q}-\sqrt{\frac{2}{3}}a_2^q e^{i\delta_2^q}, \\
A_q^{\pi^-\pi^0} &= -\sqrt{\frac{3}{2}},a_2^q e^{i\delta_2^q},
\end{aligned} \tag{11}$$

and

$$\begin{aligned}
A_q^{\pi^+K^-} &= \sqrt{\frac{2}{3}}a_{1/2}^q e^{i\delta_{1/2}^q}+\sqrt{\frac{1}{3}}a_{3/2}^q e^{i\delta_{3/2}^q}, \\
A_q^{\pi^0\overline{K^0}} &= \sqrt{\frac{1}{3}}a_{1/2}^q e^{i\delta_{1/2}^q}-\sqrt{\frac{2}{3}}a_{3/2}^q e^{i\delta_{3/2}^q}, \\
A_q^{\pi^0K^-} &= -\sqrt{\frac{1}{3}}b_{1/2}^q e^{i\delta_{1/2}^q}-\sqrt{\frac{2}{3}}a_{3/2}^q e^{i\delta_{3/2}^q}, \\
A_q^{\pi^-\overline{K^0}} &= \sqrt{\frac{2}{3}}b_{1/2}^q e^{i\delta_{1/2}^q}-\sqrt{\frac{1}{3}}a_{3/2}^q e^{i\delta_{3/2}^q}.
\end{aligned} \tag{12}$$

with $q=u,c$. By using relation (6) and dropping a global phase which is unphysical, there are totally 17 free parameters.

3 Flavor SU(3) symmetry and its breaking effects

The advantage of the isospin decomposition allows one to study $SU(3)$ relations and $SU(3)$ breaking effects in a convenient way that the isospin symmetry clearly persists. In SU(3) limit with annihilation topology ignored, the isospin amplitudes satisfy the following relations:

$$\begin{aligned} a_0^u e^{i\delta_0^u} &= a_{1/2}^u e^{i\delta_{1/2}^u}, \\ a_0^c e^{i\delta_0^c} &= a_{1/2}^c e^{i\delta_{1/2}^c}, \\ a_2^u e^{i\delta_2^u} &= a_{3/2}^u e^{i\delta_{3/2}^u}, \\ a_2^c e^{i\delta_2^c} &= a_{3/2}^c e^{i\delta_{3/2}^c}. \end{aligned} \tag{13}$$

If these relations are adopted, the number of free parameters is reduced to be nine. From (6) and the above relation, one finds that

$$\frac{a_{3/2}^c}{a_{3/2}^u} = \frac{a_2^c}{a_2^u} = R_{EW}. \tag{14}$$

Thus the highest isospin amplitudes for the $B \to \pi K$ decays satisfy the same relation as the one in the $B \to \pi\pi$ decay. When SU(3) breaking effects are considered, the above relations have to be modified. At present stage, it is not very clear how to describe the SU(3) breaking effects. a widely used approach is introducing a breaking factor ξ which characterizes the ratio between $B \to \pi K$ and $\pi\pi$ decay amplitudes, i.e.,

$$a_{1/2}^{u(c)} = \xi a_0^{u(c)}, \quad a_{3/2}^{u(c)} = \xi a_2^{u(c)}, \tag{15}$$

but their strong phases are assumed to remain satisfying the SU(3) relations

$$\delta_{1/2}^{u(c)} = \delta_0^{u(c)}, \quad \delta_{3/2}^{u(c)} = \delta_2^{u(c)}. \tag{16}$$

Typically $\xi = f_K/f_\pi \simeq 1.23$ with f_π and f_K being the pion and kaon meson decay constants, which comes from the naive factorization calculations. It is easy to see that this pattern of SU(3) breaking is a quite special one. The value of ξ is highly model dependent. It can only serve as an order of magnitude estimation and it is even not clear whether a single factor can be applied to all the isospin amplitudes. The equal strong phase assumption implies that the SU(3) breaking effects on strong phase are all ignored, which may be far away from the reality. In a more general case, all the strong phases could be different when SU(3) is broken down. The breaking effects on strong phases may have significant effects on the prediction for the direct CP violations in those decay modes.

To describe the possible violations of relations in (16) or the SU(3) breaking effects on strong phases, we may introduce the following phase differences $\Delta_I^q (q = u, c$ and $I = 3/2, 1/2)$:

$$\delta_0^q = \delta_{1/2}^q + \Delta_{1/2}^q, \quad \delta_2^q = \delta_{3/2}^q + \Delta_{3/2}^q \qquad (q = u, c). \tag{17}$$

On the other hand, the SU(3) breaking effects in amplitudes may also be given in a more general way

$$a_{1/2}^q = \xi^q a_0^{u(c)}, \quad a_{3/2}^q = \xi^q a_2^q \qquad (q = u, c) \tag{18}$$

The SU(3) limit corresponds to the case that all Δ_I^q vanish and $\xi^q = 1$. In general, the simple SU(3) breaking pattern in (15) and (16) may become unreliable. Note that in the simple SU(3) breaking pattern in (15) and (16) the relation of (14) remains to be unchanged as it is the ratio of two isospin amplitudes. The calculation based on the naive factorization shows a very small breaking of this relation [28]. For simplicity, in the following discussions we should not discuss the violation of amplitude relation in (14), but the exact value of R_{EW} (i.e. R_{EW}^{exp} or κ) will be studied in detail and also the possible violation of strong phases will be discussed.

Without any model calculations, all the isospin amplitudes and the strong phases are unknown free parameters. Those parameters can in principle be extracted from the experimental data, namely through a global fit of the data on branching ratios as well as direct CP violations of the related decay modes. The precision of the fitted parameters depend on the precision of the current data. Especially for the values of strong phases which strongly depend on the measurements of direct CP violation.

4 Value of κ in different patterns of SU(3) breaking

The basic idea of the global fit is the maximal likelihood or minimal χ^2 method. For a set of measurements on observables $Y_i (i = 1, m)$ which contain n parameters $\alpha_j (j = 1, n)$, a quantity χ^2 is constructed as follows

$$\chi^2 = \sum_i \left(\frac{Y_i^{th}(\alpha_j) - Y_i^{ex}}{\sigma_i} \right)^2, \tag{19}$$

where $Y_i^{th}(\alpha_j)$ and Y_i^{ex} are corresponding to the theoretical and experimental values of the observable Y_i which, in our present case, is a decay rate or direct CP violation in charmless B decays. σ_i is the corresponding error of the measurements. The set of α_j which minimize the value of χ^2 corresponds to the best estimated value for α_j.

From the general isospin decomposition of (11) and (12) and the isospin relation of (6) as well as the SU(3) relation (13), there are nine free parameters left

$$a_{1/2}^u,\ \delta_{1/2}^u,\ a_{3/2}^u,\ \delta_{3/2}^u,\ a_{1/2}^c,\ b_{1/2}^u,\ {\delta'}_{1/2}^u,\ b_{1/2}^c,\ {\delta'}_{1/2}^c$$

Here we set $\delta_{1/2}^c = 0$ as a phase convention since one of the phases can always be removed without affecting the physics. All the other phases are defined within the range $(-\pi, +\pi)$. The theoretical values of those parameters have been calculated in [23] which are normalized to the branching ratio of B decays and in units of 10^{-3}. The calculation shows a hierarchical structure with $a_I^u \gg a_I^c$ which corresponds to $T \gg P$ in diagram language. The

Table 1. gloal fit of isospin amplitudes and strong phases in charmless B decays with $\gamma = 60°$

parameter	value(a)	value(b)	value(c)	value(d)
$a^u_{1/2}$	$517.0^{+81.5}_{-80.6}$	$401.5^{+125.1}_{-205.2}$	$293.8^{+58.8}_{-55.9}$	$415.0^{+77.8}_{-77.8}$
$\delta^u_{1/2}$	$2.42^{+0.3}_{-0.2}$	$1.22^{+0.3}_{-1.5}$	$0.7^{+0.5}_{-0.3}$	$0.6^{+0.4}_{-0.3}$
$a^c_{1/2}$	$0.85^{+2.9}_{-2.9}$	$-0.28^{+2.9}_{-2.8}$	$-2.62^{+2.46}_{-1.97}$	$1.18^{+1.24}_{-0.36}$
$a^u_{3/2}$	$536.8^{+38.6}_{-41.8}$	$667.2^{+48.1}_{-51.8}$	$432.4^{+48.8}_{-51.7}$	$545.9^{+51.4}_{-54.6}$
$\delta^u_{3/2}$	$3.09^{+0.3}_{-0.3}$	$0.01^{+1.2}_{-0.3}$	$1.43^{+0.1}_{-0.1}$	$1.43^{+0.1}_{-0.1}$
$b^c_{1/2}$	$-141.0^{+4.2}_{-4.2}$	$-148.0^{+4.2}_{-4.1}$	$-132.1^{+15.5}_{-10.9}$	$-127.3^{+16.6}_{-12.1}$
$\delta'^u_{1/2}$	$2.8^{+0.4}_{-0.5}$	$-0.28^{+1.0}_{-0.4}$	$-0.1^{+0.2}_{-0.2}$	$-0.2^{+0.2}_{-0.2}$
ξ	1.0(fix)	1.23(fix)	1.0(fix)	1.23(fix)
κ	1.0(fix)	1.0 (fix)	$12.0^{+5.3}_{-4.4}$	$10.7^{+3.6}_{-3.2}$
χ^2_{min}	5.8	9.2	0.61	0.85

Table 2. The branching ratios for $B \to PP$ in units of 10^{-6} [38,39,40,11].

Br and Acp	CLEO	Belle	Babar	Averaged
$Br(\pi^+\pi^-)$	$4.5^{+1.4+0.5}_{-1.2-0.4}$	$4.4 \pm 0.6 \pm 0.3$	$4.7 \pm 0.6 \pm 0.2$	4.6 ± 0.4
$Br(\pi^0\pi^0)$	$< 4.4(2.2^{+1.7+0.7}_{-1.3-0.7})$	$< 4.4(2.9 \pm 1.5 \pm 0.6)$	$< 3.6(1.6^{+0.7+0.6}_{-0.6-0.3})$	$< 3.6(1.96 \pm 0.73)$
$Br(\pi^-\pi^0)$	$4.6^{+1.8+0.6}_{-1.6-0.7}$	$5.3 \pm 1.3 \pm 1.5$	$5.5^{+1.0}_{-0.9} \pm 0.6$	5.3 ± 0.8
$Br(\pi^+K^-)$	$18.0^{+2.3+1.2}_{-2.1-0.9}$	$18.5 \pm 1.0 \pm 0.7$	$17.9 \pm 0.9 \pm 0.7$	18.2 ± 0.8
$Br(\pi^0\overline{K}^0)$	$12.8^{+4.0+1.7}_{-3.3-1.4}$	$12.6 \pm 2.4 \pm 1.4$	$10.4^{+1.5}_{-1.5} \pm 0.8$	11.5 ± 1.7
$Br(\pi^-\overline{K}^0)$	$18.8^{+3.7+2.1}_{-3.3-1.8}$	$22.0 \pm 1.9 \pm 1.1$	$17.5^{+1.8}_{-1.7} \pm 1.3$	20.6 ± 1.4
$Br(\pi^0K^-)$	$12.9^{+2.4+1.2}_{-2.2-1.1}$	$12.8 \pm 1.4^{+1.4}_{-1.0}$	$12.8^{+1.2}_{-1.1} \pm 1.0$	12.8 ± 1.1
$A_{CP}(\pi^-\pi^0)$		$0.31 \pm 0.31 \pm 0.05$	$-0.03^{+0.27}_{-0.26} \pm 0.10$	0.13 ± 0.21
$A_{CP}(\pi^+\pi^-)$		$0.94^{+0.25}_{-0.31} \pm 0.09$	$-0.02 \pm 0.29 \pm 0.07$	0.42 ± 0.22
$A_{CP}(\pi^-\overline{K}^0)$	0.18 ± 0.24	$0.46 \pm 0.15 \pm 0.02$	$-0.17 \pm 0.10 \pm 0.02$	0.04 ± 0.08
$A_{CP}(\pi^0K^-)$	-0.29 ± 0.23	$-0.04 \pm 0.19 \pm 0.03$	$-0.09 \pm 0.09 \pm 0.01$	-0.1 ± 0.07
$A_{CP}(\pi^+K^-)$	-0.04 ± 0.16	$-0.06 \pm 0.08 \pm 0.01$	$-0.102 \pm 0.05 \pm 0.016$	-0.09 ± 0.04

value of $b^u_{1/2}$ is found to be significantly smaller than $a^u_{1/2}$. Due to further suppression of small CKM matrix element, the contribution of $b^u_{1/2}$ is quite small. Unlike $a^u_{1/2}$ which is connected to $B \to \pi\pi$ amplitudes through SU(3) symmetry, $b^u_{1/2}$ only appears in the charged decay modes $B \to \pi^0K^-, \pi^-\overline{K}^0$, its value only has a little effect on the fit of other parameters. It have been checked that the fitted values for other parameters are quite stable even under the significant changes of $b^u_{1/2}$[23]. Thus it is a good approximation to fix $b^u_{1/2}$ at its theoretical value $b^u_{1/2} \simeq 416$ and $\delta'^u_{1/2} \simeq 0$. With this approximation, only seven free parameters are left in the flavor SU(3) symmetry limit.

In the following section, the global fit of charmless B decay modes are made under several different cases of SU(3) breaking. The latest data of the decays $B \to \pi\pi, \pi K$ used in the fits are summarized in Table 2. Among other parameters concerning CKM matrix elements, the most uncertain one is the weak phase γ. The most recent updated global fit on CKM matrix elements is summarized in [35], which gives $\overline{\rho} = 0.199 \pm 0.04$ and $\overline{\eta} = 0.345 \pm 0.026$, corresponds to $\gamma \simeq 60°$. In this work, the various SU(3) relations are examined with the value of γ varying from 60° to 120°. For a concrete illustration, three interesting cases are discussed:

Case 1. The value of γ is taken to be 60° and κ is fixed to be unity. The global fit is done with $\xi = 1$ and $\xi = f_K/f_\pi = 1.23$ which corresponds to the exact SU(3) symmetry and the simple SU(3) breaking. The results are shown in the first (a) and second (b) column of Table 1. In both cases large strong phases are resulted with the minimal of χ^2 around 5.8(9.2) for $\xi = 1(1.23)$. From the fit

Table 3. global fits of isospin amplitudes and strong phases with different γs. The value of ξ is fixed at 1.0

	$\gamma = 75°$	$\gamma = 90°$	$\gamma = 105°$	$\gamma = 120°$
$a^u_{1/2}$	$467.8^{+84.8}_{-87.9}$	$526.7^{+93.3}_{-100.1}$	$589.6^{+104.4}_{-117.4}$	$654.1^{+116.6}_{-141.2}$
$\delta^u_{1/2}$	$57.0^{+0.3}_{-0.2}$	$63.3^{+0.3}_{-0.2}$	$69.5^{+0.3}_{-0.2}$	$69.5^{+0.3}_{-0.2}$
$a^c_{1/2}$	$-112.7^{+17.9}_{-12.8}$	$-107.9^{+18.3}_{-13.2}$	$-104.3^{+19.1}_{-13.7}$	$-103.4^{+19.8}_{-13.8}$
$a^u_{3/2}$	$581.3^{+48.2}_{-52.2}$	$631.0^{+47.9}_{-52.0}$	$691.2^{+50.9}_{-55.3}$	$745.0^{+58.7}_{-63.5}$
$\delta^u_{3/2}$	$-8066.2^{+0.1}_{-0.1}$	$-180.8^{+0.1}_{-0.1}$	$-218.5^{+0.1}_{-0.2}$	$-331.6^{+0.1}_{-0.2}$
$b^c_{1/2}$	$-121.6^{+16.8}_{-12.7}$	$-117.1^{+17.3}_{-13.4}$	$-114.3^{+18.3}_{-14.1}$	$-114.6^{+19.6}_{-14.6}$
${\delta'}^u_{1/2}$	$213.4^{+0.2}_{-0.2}$	$175.6^{+0.2}_{-0.3}$	$225.9^{+0.2}_{-0.3}$	$5183.4^{+0.3}_{-0.3}$
κ	$10.5^{+2.9}_{-2.8}$	$9.8^{+2.4}_{-2.4}$	$8.7^{+2.0}_{-2.1}$	$7.4^{+1.9}_{-2.1}$
χ^2_{min}	0.80	0.77	0.79	0.83

result, the corresponding direct CP violation can also be obtained. The best fitted direct CP violation for example, in case (c) is given by

$$\begin{array}{ll} A_{CP}(\pi^+\pi^-) \simeq 0.3 & A_{CP}(\pi^0\pi^0) \simeq 0.4 \\ A_{CP}(\pi^+K^-) \simeq -0.1 & A_{CP}(\pi^0\overline{K}^0) \simeq -0.1 \\ A_{CP}(\pi^0K^-) \simeq -0.0 & A_{CP}(\pi^-\overline{K}^0) \simeq 0.1 \end{array} \quad (20)$$

Case 2

a) The value of γ is fixed at 60° but the value of κ taken as a free parameter which is to be determined from global fit with $\xi = 1.0$ and 1.23. The results are shown in the third (c) and fourth (d) column of Table 1. In this case, the best fitted value of κ is found to be quite large with a very low $\chi^2_{min} \simeq 1$, which indicates that a large κ is in a better agreement with the current data. The numerical results for the best fitted value are

$$\kappa = 12.0(10.7) \qquad \text{for } \xi = 1.0(1.23), \quad (21)$$

which is about an order of magnitude larger than the expected one from the SM. While the results confirm our earlier numerical results obtained in [23] where the equal phase assumption such as $\delta^u_0 = \delta^c_0$ has been adopted to reduce the number of free parameters. Here the fit is made in the most general case where $\delta^u_i \neq \delta^c_i$ and thus more reliable.

b) To examine whether the above results hold only for a particular value of the weak phase $\gamma = 60°$, similar fits are made with $\gamma = 75°, 90°, 105°$ and 120°. The results listed in Table 3 clearly show that the γ dependence is rather weak. For all the values of γ the best fitted values of κ are found to be large. Even at $\gamma = 120°$ the best fitted value of $\kappa \simeq 7.4$ is still much higher than unity. While the global fit based on naive factorization and QCD factorization calculations prefer a large value of $\gamma > 90°$[36,16], the model independent estimations show a less sensitivity of weak phase γ [37,24,23]. For example, in our earlier analysises based on diagram decomposition[37] and SU(3) symmetry[24] in $B \to \pi\pi, \pi K$ decays, two allowed ranges of γ are found, the one with $\gamma < 90°$ and the other one with $\gamma > 90°$. Both values of γ with appropriate strong phases can reproduce the experimental data. The resulted large κ which is insensitive to the weak phase γ implies that the breaking effects of flavor SU(3) symmetry may be considerable.

Let us discuss the possibility of a large κ or $a^c_{2(3/2)}$ from the phenomenological point of view. It is well known that due to the suppression of small CKM matrix element V_{ub}, the decays $B \to \pi K$ are dominated by QCD penguin diagrams. The naive factorization calculations indicate that the dominant terms in the decay amplitudes are those with the CKM factor λ^s_c. If $a^c_{2(3/2)}$ is negligible small, one finds that $Br(\pi^+K^-) \simeq 2 \cdot Br(\pi^0\overline{K}^0)$. When $a^c_{3/2}$ is large, namely κ is large, the interference between $a^c_{1/2}$ and $a^c_{3/2}$ will be important. From (12) it follows that when both the amplitude $a^c_{3/2}$ and the strong phase $\delta^c_{3/2} - \delta^c_{1/2}$ become large, such an interference will enhance the branching ratios of $B \to \pi^0\overline{K}^0$, and suppress the ones of $B \to \pi^+K^-$. Similarity occurs in the decay mode $B \to \pi^0\pi^0$. As the tree diagram contributions in this decay mode are color suppressed, the penguin contributions are more important than the ones in other modes $B \to \pi^-\pi^0$ and $\pi^-\pi^+$. Thus large value of κ and $\delta^c_{3/2} - \delta^c_{1/2}$ will also enhance the branching ratio of $B \to \pi^0\pi^0$. From the relation of (14) and the definition of $\delta^c_{1/2} = 0$, one has $\delta^c_{3/2} - \delta^c_{1/2} = \delta^c_{3/2} = \delta^u_{3/2}$. As the fitting results also give large $\delta^u_{3/2} = 1.43(\simeq 80°)$ for $\xi = 1.0$, such an anomaly is closely related to the observed enhancement of $B \to \pi^0\overline{K}^0$. For decay mode $B \to \pi^0\pi^0$, the current data can only give an upper bound of $Br(B \to \pi^0\pi^0) < 3.6 \times 10^{-6}$ [38,39,40], however, the primitive measurements from CLEO, Babar and Belle also show an indication of a large averaged value of $Br(B \to \pi^0\pi^0) = 1.96 \times 10^{-6}$ (see Table 2), which need to be confirmed by the future experiments. From the most recent experimental data in Table 2, one has

$$\frac{2Br(\pi^0\overline{K}^0)}{Br(\pi^+K^-)} \simeq 1.09, \quad \frac{Br(\pi^0\pi^0)}{Br(\pi^-\pi^+)} < 0.87(\simeq 0.43), \quad (22)$$

Table 4. Best fit values of isospin amlitudes with different value of $\Delta^u_{1/2}$, $\Delta^c_{1/2}$,$\Delta^u_{3/2}$,$\Delta^c_{3/2}$with gamma fixed at $\frac{\pi}{3}(60°)$.

$\Delta^u_{1/2}$	$-\pi/3$	$-\pi/6$	$+\pi/6$	$+\pi/3$
$a^u_{1/2}$	$634.7^{+97.0}_{-114.5}$	$722.5^{+89.4}_{-104.3}$	$628.9^{+102.4}_{-105.2}$	$625.5^{+96.0}_{-98.7}$
$\delta^u_{1/2}$	$3.6^{+0.2}_{-0.3}$	$3.4^{+0.2}_{-0.2}$	$2.1^{+0.3}_{-0.2}$	$1.5^{+0.3}_{-0.3}$
$a^c_{1/2}$	$-112.7^{+26.8}_{-15.3}$	$-126.3^{+12.2}_{-6.0}$	$-135.3^{+3.4}_{-3.3}$	$-138.3^{+3.6}_{-3.6}$
$a^u_{3/2}$	$564.8^{+69.8}_{-74.6}$	$592.5^{+63.1}_{-69.2}$	$657.0^{+48.2}_{-52.3}$	$661.2^{+46.8}_{-50.3}$
$\delta^u_{3/2}$	$1.5^{+0.2}_{-0.2}$	$1.7^{+0.3}_{-0.2}$	$3.3^{+0.3}_{-0.3}$	$3.4^{+0.3}_{-0.3}$
$b^c_{1/2}$	$-129.5^{+24.3}_{-14.6}$	$-143.1^{+11.8}_{-6.2}$	$-141.1^{+4.2}_{-4.1}$	$-141.1^{+4.2}_{-4.1}$
${\delta'}^u_{1/2}$	$-0.1^{+0.4}_{-0.4}$	$0.2^{+0.5}_{-0.3}$	$3.0^{+0.4}_{-0.4}$	$3.0^{+0.4}_{-0.4}$
κ	$9.8^{+5.6}_{-4.7}$	$5.3^{+4.2}_{-2.7}$	$1.6^{+0.4}_{-0.4}$	$1.5^{+0.4}_{-0.4}$
χ^2_{min}	2.3	3.3	4.1	5.2
$\Delta^c_{1/2}$	$-\pi/3$	$-\pi/6$	$+\pi/6$	$+\pi/3$
$a^u_{1/2}$	$686.1^{+103.7}_{-122.1}$	$668.0^{+102.4}_{-113.1}$	$581.8^{+97.9}_{-99.0}$	$503.2^{+99.2}_{-101.0}$
$\delta^u_{1/2}$	$2.1^{+0.2}_{-0.2}$	$2.3^{+0.2}_{-0.2}$	$2.5^{+0.3}_{-0.2}$	$2.5^{+0.3}_{-0.3}$
$a^c_{1/2}$	$-134.2^{+3.5}_{-3.5}$	$-134.0^{+3.4}_{-3.3}$	$-133.7^{+3.3}_{-3.3}$	$-134.4^{+3.4}_{-3.3}$
$a^u_{3/2}$	$651.1^{+49.2}_{-53.5}$	$651.1^{+49.0}_{-53.3}$	$651.6^{+49.1}_{-53.2}$	$650.6^{+49.1}_{-53.3}$
$\delta^u_{3/2}$	$3.1^{+0.3}_{-0.3}$	$3.2^{+0.3}_{-0.3}$	$3.2^{+0.3}_{-0.3}$	$3.2^{+0.3}_{-0.3}$
$b^c_{1/2}$	$-141.3^{+4.2}_{-4.1}$	$-141.3^{+4.2}_{-4.1}$	$-141.2^{+4.2}_{-4.1}$	$-141.2^{+4.2}_{-4.1}$
${\delta'}^u_{1/2}$	$2.8^{+0.4}_{-0.5}$	$2.8^{+0.4}_{-0.4}$	$2.9^{+0.4}_{-0.4}$	$2.9^{+0.4}_{-0.4}$
κ	$1.5^{+0.4}_{-0.4}$	$1.5^{+0.4}_{-0.4}$	$1.6^{+0.4}_{-0.4}$	$1.6^{+0.4}_{-0.4}$
χ^2_{min}	16.5	7.7	2.4	3.2
$\Delta^u_{3/2}$	$-\pi/3$	$-\pi/6$	$+\pi/6$	$+\pi/3$
$a^u_{1/2}$	$547.8^{+108.8}_{-100.4}$	$594.8^{+102.4}_{-100.8}$	$670.1^{+98.6}_{-109.8}$	$701.1^{+97.9}_{-117.3}$
$\delta^u_{1/2}$	$2.0^{+0.9}_{-0.3}$	$2.2^{+0.3}_{-0.2}$	$2.6^{+0.2}_{-0.2}$	$2.8^{+0.2}_{-0.2}$
$a^c_{1/2}$	$-135.9^{+3.5}_{-3.5}$	$-134.7^{+3.4}_{-3.3}$	$-132.7^{+3.3}_{-3.2}$	$-131.7^{+3.3}_{-3.2}$
$a^u_{3/2}$	$661.9^{+49.4}_{-53.3}$	$656.0^{+48.9}_{-53.1}$	$648.9^{+49.4}_{-53.5}$	$648.2^{+49.9}_{-54.2}$
$\delta^u_{3/2}$	$3.6^{+0.4}_{-0.7}$	$3.4^{+0.3}_{-0.3}$	$3.0^{+0.2}_{-0.3}$	$2.7^{+0.2}_{-0.3}$
$b^c_{1/2}$	$-141.0^{+4.2}_{-4.1}$	$-141.1^{+4.2}_{-4.1}$	$-141.5^{+4.3}_{-4.2}$	$-142.1^{+4.3}_{-4.3}$
${\delta'}^u_{1/2}$	$3.2^{+0.4}_{-0.4}$	$3.1^{+0.4}_{-0.4}$	$2.7^{+0.4}_{-0.5}$	$2.4^{+0.4}_{-0.6}$
κ	$1.6^{+0.4}_{-0.4}$	$1.6^{+0.4}_{-0.4}$	$1.6^{+0.4}_{-0.4}$	$1.6^{+0.4}_{-0.4}$
χ^2_{min}	2.7	2.3	4.9	7.9
$\Delta^c_{3/2}$	$-\pi/3$	$-\pi/6$	$+\pi/6$	$+\pi/3$
$a^u_{1/2}$	$632.0^{+100.6}_{-106.1}$	$632.9^{+100.4}_{-105.3}$	$634.3^{+99.9}_{-104.5}$	$634.8^{+99.5}_{-104.6}$
$\delta^u_{1/2}$	$2.4^{+0.2}_{-0.2}$	$2.4^{+0.2}_{-0.2}$	$2.4^{+0.2}_{-0.2}$	$2.4^{+0.2}_{-0.2}$
$a^c_{1/2}$	$-133.7^{+3.3}_{-3.3}$	$-133.7^{+3.3}_{-3.3}$	$-133.6^{+3.3}_{-3.3}$	$-133.5^{+3.3}_{-3.3}$
$a^u_{3/2}$	$659.9^{+49.0}_{-53.2}$	$653.9^{+49.0}_{-53.2}$	$653.9^{+48.9}_{-53.1}$	$659.6^{+48.9}_{-53.0}$
$\delta^u_{3/2}$	$3.2^{+0.2}_{-0.3}$	$3.2^{+0.2}_{-0.3}$	$3.2^{+0.3}_{-0.3}$	$3.2^{+0.2}_{-0.3}$
$b^c_{1/2}$	$-141.2^{+4.2}_{-4.1}$	$-141.2^{+4.2}_{-4.1}$	$-141.2^{+4.2}_{-4.1}$	$-141.2^{+4.2}_{-4.1}$
${\delta'}^u_{1/2}$	$2.9^{+0.4}_{-0.4}$	$2.9^{+0.4}_{-0.4}$	$2.9^{+0.4}_{-0.4}$	$2.9^{+0.4}_{-0.4}$
κ	$1.6^{+0.4}_{-0.3}$	$1.6^{+0.4}_{-0.4}$	$1.5^{+0.4}_{-0.4}$	$1.5^{+0.4}_{-0.3}$
χ^2_{min}	2.5	2.6	3.4	3.8

Table 5. Best fit values of isospin amlitudes with different value of $\Delta^u_{1/2}$, $\Delta^c_{1/2}$,$\Delta^u_{3/2}$,$\Delta^c_{3/2}$with gamma fixed at $\frac{\pi}{2}(90°)$.

$\Delta^u_{1/2}$	$-\pi/3$	$-\pi/6$	$+\pi/6$	$+\pi/3$
$a^u_{1/2}$	$567.4^{+103.0}_{-108.2}$	$515.1^{+89.7}_{-88.2}$	$604.4^{+80.0}_{-87.0}$	$638.9^{+87.2}_{-312.4}$
$\delta^u_{1/2}$	$1.8^{+0.6}_{-0.5}$	$1.0^{+0.5}_{-0.4}$	$0.4^{+0.4}_{-0.3}$	$0.4^{+0.6}_{-0.4}$
$a^c_{1/2}$	$-42.0^{+4.7}_{-11.9}$	$-42.6^{+5.7}_{-15.0}$	$-39.2^{+3.8}_{-6.8}$	$-40.2^{+4.7}_{-0.0}$
$a^u_{3/2}$	$590.2^{+53.2}_{-58.9}$	$595.4^{+52.2}_{-57.6}$	$573.2^{+55.7}_{-61.9}$	$574.3^{+142.9}_{-64.5}$
$\delta^u_{3/2}$	$-0.3^{+0.5}_{-0.5}$	$-0.4^{+0.5}_{-0.5}$	$-0.2^{+0.5}_{-0.4}$	$0.3^{+1.4}_{-0.5}$
$b^c_{1/2}$	$-60.8^{+14.3}_{-12.9}$	$-60.5^{+14.7}_{-14.8}$	$-60.2^{+14.0}_{-12.1}$	$-64.0^{+14.3}_{-78.7}$
$\delta'^u_{1/2}$	$-2.5^{+0.6}_{-0.5}$	$-2.6^{+0.6}_{-0.4}$	$-2.4^{+0.6}_{-0.5}$	$-1.9^{+2.2}_{-0.6}$
κ	$16.1^{+1.9}_{-1.5}$	$16.0^{+1.8}_{-1.4}$	$16.7^{+2.1}_{-1.6}$	$16.5^{+2.3}_{-12.9}$
χ^2_{min}	3.1	3.4	1.3	3.1
$\Delta^c_{1/2}$	$-\pi/3$	$-\pi/6$	$+\pi/6$	$+\pi/3$
$a^u_{1/2}$	$541.5^{+79.6}_{-79.3}$	$544.6^{+83.5}_{-83.3}$	$559.8^{+82.0}_{-85.3}$	$571.5^{+79.0}_{-82.8}$
$\delta^u_{1/2}$	$0.5^{+0.4}_{-0.3}$	$0.5^{+0.4}_{-0.3}$	$0.6^{+0.4}_{-0.4}$	$0.7^{+0.4}_{-0.4}$
$a^c_{1/2}$	$-41.2^{+5.0}_{-13.2}$	$-41.6^{+5.3}_{-14.2}$	$-40.4^{+4.4}_{-9.2}$	$-39.8^{+4.2}_{-8.0}$
$a^u_{3/2}$	$586.2^{+53.8}_{-59.8}$	$585.4^{+53.9}_{-59.9}$	$581.3^{+54.6}_{-60.7}$	$578.4^{+54.8}_{-61.0}$
$\delta^u_{3/2}$	$-0.4^{+0.5}_{-0.5}$	$-0.4^{+0.5}_{-0.5}$	$-0.3^{+0.5}_{-0.4}$	$-0.3^{+0.5}_{-0.4}$
$b^c_{1/2}$	$-60.2^{+14.4}_{-13.6}$	$-60.3^{+14.5}_{-14.1}$	$-59.7^{+14.2}_{-12.5}$	$-59.2^{+14.1}_{-12.4}$
$\delta'^u_{1/2}$	$-2.6^{+0.6}_{-0.5}$	$-2.6^{+0.6}_{-0.5}$	$-2.5^{+0.6}_{-0.5}$	$-2.5^{+0.5}_{-0.5}$
κ	$16.3^{+2.0}_{-1.5}$	$16.3^{+2.0}_{-1.5}$	$16.4^{+2.0}_{-1.5}$	$16.6^{+2.1}_{-1.6}$
χ^2_{min}	1.5	1.6	2.8	3.8
$\Delta^u_{3/2}$	$-\pi/3$	$-\pi/6$	$+\pi/6$	$+\pi/3$
$a^u_{1/2}$	$478.7^{+112.6}_{-127.4}$	$486.9^{+108.3}_{-119.6}$	$528.2^{+102.3}_{-117.1}$	$555.2^{+99.5}_{-118.9}$
$\delta^u_{1/2}$	$1.8^{+1.2}_{-0.3}$	$2.1^{+0.4}_{-0.2}$	$2.5^{+0.2}_{-0.2}$	$2.8^{+0.2}_{-0.2}$
$a^c_{1/2}$	$-137.7^{+3.2}_{-3.1}$	$-137.8^{+3.2}_{-3.1}$	$-137.7^{+3.2}_{-3.1}$	$-137.4^{+3.2}_{-3.1}$
$a^u_{3/2}$	$667.1^{+49.2}_{-52.9}$	$667.0^{+48.5}_{-52.7}$	$656.9^{+49.4}_{-53.7}$	$647.8^{+50.2}_{-54.6}$
$\delta^u_{3/2}$	$3.6^{+0.4}_{-0.7}$	$3.5^{+0.3}_{-0.4}$	$3.0^{+0.2}_{-0.3}$	$2.8^{+0.2}_{-0.3}$
$b^c_{1/2}$	$-144.3^{+4.2}_{-4.1}$	$-144.3^{+4.2}_{-4.1}$	$-144.3^{+4.2}_{-4.1}$	$-144.4^{+4.2}_{-4.1}$
$\delta'^u_{1/2}$	$3.2^{+0.4}_{-0.7}$	$3.1^{+0.4}_{-0.4}$	$2.7^{+0.3}_{-0.4}$	$2.5^{+0.4}_{-0.5}$
κ	$0.9^{+0.4}_{-0.4}$	$0.9^{+0.4}_{-0.4}$	$1.0^{+0.4}_{-0.3}$	$1.0^{+0.4}_{-0.4}$
χ^2_{min}	2.7	2.1	5.3	9.1
$\Delta^c_{3/2}$	$-\pi/3$	$-\pi/6$	$+\pi/6$	$+\pi/3$
$a^u_{1/2}$	$632.0^{+100.6}_{-106.1}$	$632.9^{+100.4}_{-105.3}$	$634.3^{+99.9}_{-104.5}$	$634.8^{+99.5}_{-104.6}$
$\delta^u_{1/2}$	$2.4^{+0.2}_{-0.2}$	$2.4^{+0.2}_{-0.2}$	$2.4^{+0.2}_{-0.2}$	$2.4^{+0.2}_{-0.2}$
$a^c_{1/2}$	$-133.7^{+3.3}_{-3.3}$	$-133.7^{+3.3}_{-3.3}$	$-133.6^{+3.3}_{-3.3}$	$-133.5^{+3.3}_{-3.3}$
$a^u_{3/2}$	$659.9^{+49.0}_{-53.2}$	$653.9^{+49.0}_{-53.2}$	$653.9^{+48.9}_{-53.1}$	$659.6^{+48.9}_{-53.0}$
$\delta^u_{3/2}$	$3.2^{+0.2}_{-0.3}$	$3.2^{+0.2}_{-0.3}$	$3.2^{+0.3}_{-0.3}$	$3.2^{+0.2}_{-0.3}$
$b^c_{1/2}$	$-141.2^{+4.2}_{-4.1}$	$-141.2^{+4.2}_{-4.1}$	$-141.2^{+4.2}_{-4.1}$	$-141.2^{+4.2}_{-4.1}$
$\delta'^u_{1/2}$	$2.9^{+0.4}_{-0.4}$	$2.9^{+0.4}_{-0.4}$	$2.9^{+0.4}_{-0.4}$	$2.9^{+0.4}_{-0.4}$
κ	$1.6^{+0.4}_{-0.3}$	$1.6^{+0.4}_{-0.4}$	$1.5^{+0.4}_{-0.4}$	$1.5^{+0.4}_{-0.3}$
χ^2_{min}	2.5	2.6	3.4	3.8

Table 6. Best fit values of isospin amlitudes with different value of $\Delta^u_{1/2}$, $\Delta^c_{1/2}$,$\Delta^u_{3/2}$,$\Delta^c_{3/2}$with gamma fixed at $\frac{2\pi}{3}(120°)$.

$\Delta^u_{1/2}$	$-\pi/3$	$-\pi/6$	$+\pi/6$	$+\pi/3$
$a^u_{1/2}$	$440.7^{+127.5}_{-118.0}$	$459.6^{+110.4}_{-140.6}$	$434.6^{+113.6}_{-144.0}$	$471.2^{+132.6}_{-156.4}$
$\delta^u_{1/2}$	$3.6^{+0.3}_{-0.3}$	$2.3^{+0.2}_{-0.2}$	$1.4^{+0.3}_{-0.3}$	$0.8^{+0.4}_{-0.4}$
$a^c_{1/2}$	$-133.1^{+41.6}_{-13.1}$	$-141.2^{+3.3}_{-3.2}$	$-137.7^{+3.4}_{-3.3}$	$-134.9^{+3.8}_{-3.7}$
$a^u_{3/2}$	$693.2^{+74.6}_{-58.1}$	$668.2^{+48.7}_{-52.8}$	$670.7^{+48.2}_{-52.1}$	$668.0^{+48.8}_{-52.7}$
$\delta^u_{3/2}$	$1.6^{+0.3}_{-0.4}$	$3.2^{+0.2}_{-0.3}$	$3.3^{+0.3}_{-0.3}$	$3.1^{+0.3}_{-0.4}$
$b^c_{1/2}$	$-132.6^{+38.5}_{-20.5}$	$-148.3^{+4.2}_{-4.1}$	$-148.4^{+4.2}_{-4.1}$	$-148.3^{+4.2}_{-4.1}$
$\delta'^u_{1/2}$	$0.1^{+0.8}_{-0.7}$	$2.8^{+0.4}_{-0.4}$	$2.9^{+0.4}_{-0.4}$	$2.8^{+0.4}_{-0.5}$
κ	$4.3^{+5.4}_{-3.4}$	$0.2^{+0.3}_{-0.3}$	$0.2^{+0.3}_{-0.3}$	$0.2^{+0.3}_{-0.3}$
χ^2_{min}	3.3	2.0	2.3	2.0
$\Delta^c_{1/2}$	$-\pi/3$	$-\pi/6$	$+\pi/6$	$+\pi/3$
$a^u_{1/2}$	$564.5^{+116.6}_{-135.2}$	$622.6^{+119.0}_{-142.3}$	$623.3^{+122.0}_{-150.3}$	$629.2^{+84.5}_{-87.9}$
$\delta^u_{1/2}$	$0.3^{+0.4}_{-0.2}$	$0.3^{+0.3}_{-0.2}$	$0.6^{+0.4}_{-0.2}$	$0.8^{+0.5}_{-0.4}$
$a^c_{1/2}$	$-103.6^{+21.3}_{-15.6}$	$-102.8^{+20.1}_{-14.5}$	$-100.4^{+26.2}_{-15.6}$	$-35.7^{+3.9}_{-7.2}$
$a^u_{3/2}$	$744.1^{+58.6}_{-63.7}$	$746.1^{+58.4}_{-63.3}$	$759.2^{+59.2}_{-63.7}$	$770.7^{+52.2}_{-57.6}$
$\delta^u_{3/2}$	$1.4^{+0.1}_{-0.2}$	$1.4^{+0.1}_{-0.2}$	$1.4^{+0.1}_{-0.2}$	$-0.2^{+0.5}_{-0.5}$
$b^c_{1/2}$	$-114.2^{+20.5}_{-15.8}$	$-113.9^{+19.7}_{-15.1}$	$-111.1^{+24.4}_{-16.2}$	$-62.9^{+13.1}_{-12.1}$
$\delta'^u_{1/2}$	$-0.3^{+0.3}_{-0.3}$	$-0.3^{+0.3}_{-0.3}$	$-0.3^{+0.3}_{-0.4}$	$-2.5^{+0.6}_{-0.5}$
κ	$7.4^{+2.0}_{-2.4}$	$7.5^{+1.9}_{-2.2}$	$7.7^{+2.0}_{-2.1}$	$11.7^{+1.1}_{-0.9}$
χ^2_{min}	1.4	1.3	4.2	3.6
$\Delta^u_{3/2}$	$-\pi/3$	$-\pi/6$	$+\pi/6$	$+\pi/3$
$a^u_{1/2}$	$530.5^{+124.3}_{-186.7}$	$473.1^{+113.1}_{-154.9}$	$414.5^{+105.7}_{-133.1}$	$403.5^{+104.3}_{-139.0}$
$\delta^u_{1/2}$	$1.4^{+0.3}_{-0.3}$	$1.7^{+0.2}_{-0.2}$	$2.2^{+0.2}_{-0.2}$	$2.5^{+0.3}_{-0.2}$
$a^c_{1/2}$	$-136.7^{+3.6}_{-3.4}$	$-138.5^{+3.3}_{-3.2}$	$-140.6^{+3.3}_{-3.2}$	$-141.1^{+3.3}_{-3.2}$
$a^u_{3/2}$	$669.3^{+49.0}_{-52.7}$	$671.1^{+48.4}_{-52.4}$	$663.6^{+49.3}_{-53.4}$	$655.8^{+50.3}_{-54.5}$
$\delta^u_{3/2}$	$3.7^{+0.4}_{-0.4}$	$3.5^{+0.3}_{-0.3}$	$3.0^{+0.2}_{-0.3}$	$2.7^{+0.2}_{-0.4}$
$b^c_{1/2}$	$-148.4^{+4.2}_{-4.1}$	$-148.4^{+4.2}_{-4.1}$	$-148.1^{+4.3}_{-4.1}$	$-147.5^{+4.4}_{-4.2}$
$\delta'^u_{1/2}$	$3.2^{+0.4}_{-0.4}$	$3.1^{+0.4}_{-0.4}$	$2.7^{+0.4}_{-0.5}$	$2.4^{+0.4}_{-0.7}$
κ	$0.2^{+0.4}_{-0.4}$	$0.2^{+0.4}_{-0.4}$	$0.2^{+0.3}_{-0.3}$	$0.3^{+0.4}_{-0.4}$
χ^2_{min}	1.5	1.3	4.5	8.0
$\Delta^c_{3/2}$	$-\pi/3$	$-\pi/6$	$+\pi/6$	$+\pi/3$
$a^u_{1/2}$	$435.6^{+108.7}_{-140.3}$	$435.5^{+108.9}_{-140.5}$	$435.6^{+109.0}_{-140.5}$	$435.7^{+109.0}_{-140.3}$
$\delta^u_{1/2}$	$1.9^{+0.2}_{-0.2}$	$1.9^{+0.2}_{-0.2}$	$1.9^{+0.2}_{-0.2}$	$1.9^{+0.2}_{-0.2}$
$a^c_{1/2}$	$-139.8^{+3.3}_{-3.2}$	$-139.8^{+3.3}_{-3.2}$	$-139.7^{+3.3}_{-3.2}$	$-139.6^{+3.3}_{-3.2}$
$a^u_{3/2}$	$667.6^{+48.9}_{-53.1}$	$668.7^{+48.7}_{-52.8}$	$669.1^{+48.6}_{-52.7}$	$668.6^{+48.8}_{-52.8}$
$\delta^u_{3/2}$	$3.3^{+0.3}_{-0.3}$	$3.3^{+0.3}_{-0.3}$	$3.3^{+0.3}_{-0.3}$	$3.3^{+0.3}_{-0.3}$
$b^c_{1/2}$	$-148.3^{+4.2}_{-4.1}$	$-148.3^{+4.2}_{-4.1}$	$-148.4^{+4.2}_{-4.1}$	$-148.4^{+4.2}_{-4.1}$
$\delta'^u_{1/2}$	$2.9^{+0.4}_{-0.4}$	$2.9^{+0.4}_{-0.4}$	$2.9^{+0.4}_{-0.4}$	$2.9^{+0.4}_{-0.4}$
κ	$0.2^{+0.4}_{-0.4}$	$0.2^{+0.3}_{-0.3}$	$0.2^{+0.3}_{-0.3}$	$0.2^{+0.3}_{-0.3}$
χ^2_{min}	2.2	2.2	2.2	2.2

which may be compared with the recent theoretical estimations by using QCD factorization [16,41]

$$\frac{2Br(\pi^0\overline{K}^0)}{Br(\pi^+K^-)} \simeq 0.52, \quad \frac{Br(\pi^0\pi^0)}{Br(\pi^-\pi^+)} \simeq 0.01. \tag{23}$$

It is clear that the data present the unexpected large ratio for the decay modes $B \to \pi^0\overline{K}^0$, which significantly deviates from the QCD factorization predictions. The current data also imply the probability that $B \to \pi^0\pi^0$ could be much larger than the expected one from QCD factorization.

The value of κ is sensitive to the contributions from electroweak penguin diagrams. Since many new physics models can give significant corrections to this sector, it may be helpful to study new physics effects on κ. However, to explore any new physics effects and arrive at a definitive conclusion for the existence of new physics from the hadronic decays, it is necessary to check all the theoretical assumptions and make the most general considerations. It is noted that the above results are obtained by assuming SU(3) symmetry with its breaking only in amplitudes. Therefore, we shall first extend the above results to a more general case of SU(3) symmetry breaking before claiming any possible new physics signals.

Case 3

a) The value of gamma is fixed at 60° and the SU(3) breaking effects on strong phases are turned on, i.e., $\Delta_I^q \neq 0$. In this case, it is difficult to extract those breaking factors with a reasonable precision as we have no enough data (especially data of direct CP violations) at hand. For illustrations, we then take some typical values for Δ_I^q to show how the best fitted values of κ depend on the ways of SU(3) breaking in strong phases. For simplicity and also to see how the SU(3) symmetry breaking of each strong phase affects the best fitting value of κ, we take four typical values for each Δ_I^q, i.e., $\Delta_I^q = -\pi/3, -\pi/6, +\pi/6$ and $+\pi/3$, with others angles being fixed to be zero. The numerical results can be seen in Table 4. It follows from the table that the inclusion of nonzero Δ_I^q can greatly modify the best fitted value of κ. In some cases, the best fitted values are found to be close to unity. For example, in cases of $\Delta_{1/2}^u = +\pi/6$, $\Delta_{1/2}^c = +\pi/6, +\pi/3$ and $\Delta_{3/2}^c = +\pi/6, +\pi/3$, the best fitted values of κ are around 1.5 with the minimal $\chi^2_{min} \leq 4$. The direct CP violation for $\Delta_{1/2}^u = +\pi/6(\Delta_{1/2}^c = +\pi/6)$ is as follows.

$$\begin{aligned}
&A_{CP}(\pi^+\pi^-) \simeq 0.1(0.5), && A_{CP}(\pi^0\pi^0) \simeq 0.5(0.2),\\
&A_{CP}(\pi^+K^-) \simeq -0.1(-0.1), && A_{CP}(\pi^0\overline{K}^0) \simeq -0.2(-0.1),\\
&A_{CP}(\pi^0K^-) \simeq -0.1(-0.0), && A_{CP}(\pi^-\overline{K}^0) \simeq 0.1(0.1).
\end{aligned} \tag{24}$$

Compared with the ones with SU(3) syemmetry in (20), the predicted values of direct CP violation can be quite different. The above results indicate that if we want to explain the current data within the scope of SM, the SU(3) breaking effects on strong phases may play an important role. At present, the calculation of SU(3) breaking on strong phases is not reliable without well considering the nonperturbative effects and it is hard to estimate how large it could be. The phenomenological approach adopt in this paper may provide us some clues to understand the SU(3) symmetry breaking due to final state interactions.

b) To illustrate the possible γ dependence, two other fits are made with $\gamma = 90°$ and $120°$. The numerical results are shown in Tables 5 and 6. In the case of $\gamma = 90°$, some results are found with $\kappa \simeq 1.0$ and small χ^2_{min}. For example, for $\Delta_{3/2}^u = -\pi/3, -\pi/6$ and $\Delta_{3/2}^c = -\pi/3, -\pi/6$ the best fitted value of κ are around 1.0 with the minimal $\chi^2_{min} \simeq 3.0$. However, in the case of $\gamma = 120°$, no solution is found with both small χ^2_{min} and $\kappa \approx 1$. As only several typical values of $\Delta_{1/2(3/2)}^{u(c)}$ are used in the fit, one should not draw a conclusion that the case of $\gamma = 120°$ is not likely to be consistent with current data even the SU(3) breaking effects of strong phases are taken into account. However, it is clear that for very large value of γ, the allowed parameter space for the strong phase differences $\Delta_{1/2(3/2)}^{u(c)}$ is much smaller.

The results summaried in Tables 4, 5 and 6 also indicate the prefered values of some strong phases. For instance, the best fited value of κ is found to be insensitive to the value of $\Delta_{3/2}^u$. When γ is taken to be 60° and 90° the best fitted value of κ is close to unity for all the values of $\Delta_{3/2}^u$, with a small χ^2_{min}. But for $\Delta_{3/2}^u = -60°$, the χ^2_{min} has a minimal of 2.3(2.1) for $\gamma = 60°(90°)$. It implies that the favoured value for $\Delta_{3/2}^u$ should be close to $-60°$ from the current data. Simiarlily, the fit results favour a large negative value of $\Delta_{3/2}^c$ and a small positive $\Delta_{1/2}^c$ and $\Delta_{1/2}^u$.

5 Conclusions

In summary, we have investigated the isospin and flavor SU(3) relations and their validity in the charmless hadronic B decays $B \to \pi\pi, \pi K$. Through a global fit to the latest data, the amplitudes as well as the corresponding strong phases are extracted with different patterns of SU(3) breaking.

It has been shown that in the case of SU(3) limits and the case with SU(3) breaking only in amplitudes, the fitting results require a large value for the ratio of two isospin amplitudes $a_{3/2}^c/a_{3/2}^u$. The rescaled ratio κ which is equal to 1 in SM is found in this case to be

$$\kappa = 12.0(10.7) \qquad \text{for} \ \ \xi = 1.0(1.23),$$

with a minimal χ^2 around 1. Such a value of κ is about an order of magnitude greater than the SM prediction. This results is insensitive to the weak phase γ. The SU(3) breaking effects on strong phases have been studied in several cases. It has been seen that the best fitted value of κ can significantly be lowed or even close to the SM prediction $\kappa = 1$ with a minimum χ^2 at about 4. It implies that to understand the current data within SM, the SU(3) breaking effects of the strong phases must be considered and it is likely to play an important role. The direct test on the SU(3) breaking of the strong phases require more precise measurements of direct CP violation. With the accumulating of the data in B factories, this may become possible in the near future.

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