$W_R$ effects on $CP$ angles determination at a $B$ factory

T. Kurimoto
Department of Physics, Faculty of Science,
Toyama University,
Toyama 930, Japan

A. Tomita
Department of Physics, Faculty of Science,
Osaka University,
Toyonaka, Osaka 560, Japan

S. Wakaizumi
Department of Physics, School of Medical Sciences,
University of Tokushima,
Tokushima 770, Japan

Abstract

The right-handed charged current gauge boson $W_R$ can affect significantly on the determination of the $CP$ violation angles to be measured at $B$ factories if the right-handed current quark mixing matrix $V^R$ is taken to a specific form to satisfy the bounds by neutral $K$ meson systems. The $W_R$ contribution can be sizable in $B^0 - B^0$ mixing and tree level $b$ quark decay. The deviation of $CP$ angles in unitarity triangle from the standard model values can be as large as $-37^\circ$ or $+22^\circ$ for $\phi_3 (\gamma)$, and $66^\circ \sim 115^\circ$ for $\phi_1 (\beta)$ and $\phi_2 (\alpha)$.

1e-mail: krmt@sci.toyama-u.ac.jp
2e-mail: tomita@phys.wani.osaka-u.ac.jp (available until March 1996)
3e-mail: wakaizumi@medsci.tokushima-u.ac.jp
# Introduction

One of the main purposes of the $B$ factories which are now under construction at KEK\cite{1} and SLAC\cite{2} is to find a sign of new physics beyond the standard model. If a new physics significantly affects $B^0$-$\overline{B}^0$ mixing or $CP$ violation in $B$ decays\cite{3}, the angles and the sides of the so-called unitarity triangle deviate from the standard model values, and the consistency of the triangle will be lost\cite{4}. The extensive measurements at $B$ factories are going to fix all the sides and angles of the unitarity triangle. We can find a signal of new physics or at least constraints by over-checking the consistency of the triangle.

New physics effects are often considered to appear at loop level because the masses of most of the new particles in the models beyond the standard model are larger than the electro-weak scale of $O(M_W)$ to satisfy the bounds by the present experimental data. A heavy new particle would not be able to give a significant contribution to the tree level $b$ quark decay. However, this is not always the case. The decay of $b$ quark through the standard $W$ boson exchange is suppressed by the smallness of the involving Kobayashi-Maskawa (KM) matrix\cite{5} elements, $V_{cb}$ and $V_{ub}$. A new particle can contribute significantly to tree level $b$ decay if it has non-suppressed coupling with quarks. We consider the $W_R$ boson in the $SU(2)_L \times SU(2)_R \times U(1)$ models\cite{6} as an example of such a new particle in this paper.

In addition to the ordinary KM matrix there exists a flavor mixing matrix also in the coupling between right-handed quark currents and $W_R$ boson in $SU(2)_L \times SU(2)_R \times U(1)$ models, which shall be called as $V^R$ while the usual left-handed current KM matrix as $V^L$ hereafter. It has been shown that the mass of $W_R$ should be greater than 1.4 TeV to be consistent with the experimental data of $K^0$-$\overline{K}^0$ mixing if a model has manifest or pseudo manifest left-right symmetry, i.e. $V^L = V^R$ or $V^L = (V^R)^*$, respectively\cite{7}. The $W_R$ boson cannot contribute significantly to tree level $b$ decay with such a heavy mass and $V^R$. But right-handed charged current interaction has not been observed yet, so the the form of $V^R$ is not restricted to manifest or pseudo manifest type. Olness and Ebel have shown that the mass limit of $W_R$ can be lowered to 300 GeV by assuming specific forms of $V^R$\cite{8}. Langacker and Sankar have also made a detailed analysis on $W_R$ mass limit, and come to a similar conclusion that the lower limit of $W_R$ mass can be reduced by taking the following forms of $V^R$\cite{9};

$$V^R_I = \begin{pmatrix} e^{i\omega} & 0 & 0 \\ 0 & ce^{i\xi} & se^{i\sigma} \\ 0 & se^{i\varphi} & ce^{i\chi} \end{pmatrix}, \quad V^R_{II} = \begin{pmatrix} 0 & e^{i\omega} & 0 \\ ce^{i\xi} & 0 & se^{i\sigma} \\ se^{i\varphi} & 0 & ce^{i\chi} \end{pmatrix}, \quad (1)$$

2
where \( s = \sin \theta \) and \( c = \cos \theta \) (0 \( \leq \theta \leq 90^\circ \)). Unitarity requires \( \xi - \sigma = \varphi - \chi + \pi \). We call the former type of \( V^R \) as type I and the latter as type II in the following discussion. London and Wyler have pointed out that both types of \( V^R \) lead to sizable contributions to \( CP \) violation in \( K \) and \( B \) systems\(^{13}\). For example, the \( CP \) asymmetry in \( B \to J/\Psi K_s \) decay can be significantly altered by the presence of \( W_R \) mediated \( b \to c \bar{c} s \) tree decay with the \( V^R \) of type I.

The aim of this paper is to make a detailed study on the effects of \( W_R \) on the determination of the three \( CP \) angles to be measured at the B factories. In particular, we show that the measurement of the angle \( \phi_3 \) (or \( \gamma \)) can receive a sizable effect by \( W_R \) in the case of type II right-handed Kobayashi-Maskawa matrix, \( V^R \), even if \( W_R \) is as heavy as about 1 TeV. The \( CP \) angle \( \phi_3 \) (or \( \gamma \)) was considered to be measured on the \( B_s \) decay, \( B_s \to \rho K_S \) in many of the previous papers. But the experiments at B factories at the first stage will be made on \( \Upsilon(4S) \) which can not decay into \( B_s \). The measurement of the angle \( \phi_3 \) (or \( \gamma \)) is to be made on \( B \to DK \) decays\(^{3, 12}\). Our analysis on the angle \( \phi_3 \) (or \( \gamma \)) is based on this method.

The rest of this paper is organized as follows: In section 2 we give constraints of the parameters from \( K \) and \( B \) systems. In section 3 we estimate the \( W_R \) contribution to the \( CP \) violation angles in decays of \( b \) quark. The final section is devoted to summary and discussion.

---

**Figure 1: Unitarity triangle**

\[^{4}\text{The elements 0 in these matrices may be } O(10^{-2}). \text{ We take them 0 for the simplicity of discussion.}\]

\[^{5}\text{There are two notations for the angles of unitarity triangle. One given in ref.}^{[1]} \text{ and the another in ref.}^{[11]} \text{. We take the notation of ref.}^{[1]} \text{ as } \beta \text{ is used to express another quantity here.}\]
2 Constraints from $K$ and $B$ systems

2.1 $K^0 - \bar{K^0}$ mixing

The box diagram with one $W_L$ (standard $W$ boson) and one $W_R$ can give the major contribution to $K^0 - \bar{K^0}$ mixing in $SU(2)_L \times SU(2)_R \times U(1)$ models:\[7,13]:

$$\mathcal{H}^{eff}_{LR} = \sum_{i,j=u}^t \frac{2G^2_M M^2_W}{\pi^2} \beta_g V^L_{id} V^L_{is} V^R_{jd} V^R_{js} J(x_i, x_j; \beta) \bar{d}_R s_L \bar{d}_L s_R + (h.c.),$$

(2)

where $\beta$ is the square of the ratio of $W_L$ mass $(M_L)$ to $W_R$ mass $(M_R)$, $M^2_L/M^2_R$, $\beta_g = (g_R/g_L)^2 \beta$ and $x_i = m^2_i/M^2_L$. The loop function is defined as

$$J(x, y, \beta) \equiv \sqrt{xy}[(\eta^{(1)} + \eta^{(2)} x y \beta/4) J_1(x, y, \beta) - \frac{1}{4}(\eta^{(3)} + \eta^{(4)} \beta) J_2(x, y, \beta)],$$

(3)

with

$$J_1(x, y, \beta) = \frac{x \ln x}{(1-x)(1-x \beta)(x-y)} + (x \leftrightarrow y) - \frac{\beta \ln \beta}{(1-\beta)(1-x \beta)(1-y \beta)},$$

$$J_2(x, y, \beta) = \frac{x^2 \ln x}{(1-x)(1-x \beta)(x-y)} + (x \leftrightarrow y) - \frac{\ln \beta}{(1-\beta)(1-x \beta)(1-y \beta)},$$

where $\eta^{(1)-(4)}$ are QCD corrections. The box diagram with two $W_R$ cannot contribute to $K^0 - \bar{K^0}$ mixing as long as we take $V_R$ to be in the forms of eq.(1). We have neglected $W_L - W_R$ mixing as it is highly suppressed by the experimental data.\[7,13]. The real part of the matrix element $\langle K^0 | \mathcal{H}^{eff}_{LR} | \bar{K^0} \rangle$ contributes to $\Delta M_K$, while the imaginary part to the $CP$ violation parameter $\epsilon$ in $K$ decay. The constraint by $\Delta M_K$ \[8,9\] is satisfied for $M_R > 0.52$ TeV which we take as the limit from direct search\[11\] under the assumption that right-handed neutrino $\nu_R$ does not affect the $b$ semi-leptonic decay. The constraint from $\epsilon$ is much severe. $W_R$ has to be as heavy as about 5 TeV or more unless the parameters in $V^R$ are tuned\[10\]. By using the Wolfenstein parameterization\[13\] of KM matrix $V^L$,

$$V^L = \begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A \lambda^3 (\rho - i \eta) \\ -\lambda & 1 - \frac{\lambda^2}{2} & A \lambda^2 \\ A \lambda^3 (1 - \rho - i \eta) & -A \lambda^2 & 1 \end{pmatrix},$$

(4)

we find that the contribution to $\epsilon$ has the following combinations of quark mixing matrix elements:

- **type I** ($uc$ contribution): $\lambda^2 c \sin(\omega - \xi)$
type I (ut contribution): \[ A\lambda^4s[(1 - \rho)\sin(\varphi - \omega) + \eta\cos(\varphi - \omega)] \]

type II (uc contribution): \[ (1 - \frac{\lambda^2}{2})^2c\sin(\omega - \xi) \]

type II (ut contribution): \[ -A\lambda^2(1 - \frac{\lambda^2}{2})s\sin(\omega - \varphi) \]

To suppress large contribution to \( \epsilon \) from \( W_L-W_R \) box diagram we take the following solutions for \( V_R \):

**type I**

\[ \sin(\omega - \xi) = 0 \text{ and } \tan(\omega - \varphi) = \frac{\eta}{1 - \rho}, \quad (5) \]

**type II**

\[ c = 0 \text{ and } \sin(\omega - \varphi) = 0. \quad (6) \]

There are other solutions to suppress \( \epsilon \). We take these since they give most significant effects on \( CP \) violation in \( B \) decay by \( W_R \).

### 2.2 B semi-leptonic decay

\( B \) semi-leptonic decays gives the constraint on the ordinary KM matrix elements, \( |V_{cb}| \) and \( |V_{ub}| \). It is independent of the \( W_R \) effects as far as the right handed neutrinos are heavier than \( b \) quark, which we take as a reasonable assumption. Then \( B \) semi-leptonic decays constrain only the elements of \( V^L \).

### 2.3 \( B^0-\overline{B^0} \) mixing

Let us write the contribution to \( B^0-\overline{B^0} \) mixing matrix elements as

\[ M_{12}^B = M_{12}^{SM}[1 + d_{LR} + d_{RR}], \quad (7) \]

where \( d_{LR} \) and \( d_{RR} \) are the contributions by the box diagrams with one \( W_R \) and those with two \( W_R \), respectively. The contribution by \( W_R \) depends on which of \( V^R \) in type I and II we take. In the following discussions we take the gauge coupling of \( SU(2)_L (g_L) \) and that of \( SU(2)_R (g_R) \) equal for the simplicity of the following arguments. \( W_L-W_R \) mixing is neglected.

#### 2.3.1 Type I

The contribution \( d_{RR} \) vanishes because \( V_{2ib}^RV_{2id}^{R*} = 0 \) for any \( i = u, c, t \). By replacing \( s \) with \( b \) in eq.(2) we can calculate \( d_{LR} \), which is written as

\[ d_{LR} = \frac{V_{ub}^L V_{td}^{L*} s e^{i(\sigma - \omega)}}{(V_{tb}^L V_{td}^{L*})^2} r_{ac} + \frac{V_{ub}^L V_{td}^{L*} c e^{i(\chi - \omega)}}{(V_{tb}^L V_{td}^{L*})^2} r_{ut}, \quad (8) \]
where \( r_{uc} \) (\( r_{ut} \)) are the ratios of the \( W_R \) contribution to the standard model one of \( u, c \) (\( u, t \)) quarks up to quark mixing matrix elements. We find \(| r_{uc} |\) is \( O(10^{-6}) \) or less and \(| r_{ut} |\) is \( O(10^{-5}) \) or less for \( M(W_R) > 0.5 \) TeV, while the absolute magnitudes of the coefficients of \( r_{uc} \) and \( r_{ut} \) in eq.(8) are \( O(10) \) and \( O(1) \), respectively. (Note that \(| V_{td}^L |\) should be \( O(\lambda^3) \) to realize the experimental value of \( \epsilon \) in \( K \) system.) Therefore, we can neglect the \( W_R \) contribution to \( B^0 - \bar{B}^0 \) mixing in the case of type I.

### 2.3.2 Type II

We take the solution given in eq.(6) to suppress the large contribution to \( \epsilon \). Then the contribution \( d_{RR} \) vanishes. The contribution \( d_{LR} \) is given in the Wolfenstein parameterization of \( V^L \) as,

\[
d_{LR} = \frac{V_{tb}^L V_{td}^L e^{i(\sigma - \varphi)}}{(V_{tb}^L V_{td}^L)^2} r_{ct} = -\frac{e^{i(\sigma - \varphi - \phi_{SM})}}{A^2 \lambda^5 [(1 - \rho)^2 + \eta^2]} r_{ct},
\]

where \( \phi_{SM} = \text{arg}(M_{12}^{SM}) \). The ratio \( r_{ct} \) is \( O(10^{-3}) \) as shown in Fig.2.

![Figure 2: The ratio of \( W_R \) contribution to \( W_L \) contribution up to quark mixing matrix elements.](image)

We have used \( \eta^{(1)} = 1.1, \eta^{(2)} = 0.26, \eta^{(3)} = 1.1, \eta^{(4)} = 1.0 \) for \( W_R \) contribution [13], \( \eta_{tt} = 0.8 \) for \( W_L \) contribution [14] as the values of QCD corrections, \( m_c = 1.5 \) GeV and \( m_b = 4.6 \) GeV in calculating \( r_{ct} \). The factor \( 1/(A^2 \lambda^5 [(1 - \rho)^2 + \eta^2]) \) is \( O(10^3) \). The experimental value of \( B^0 - \bar{B}^0 \) mixing can be realized depending on the parameters in \( V^L \) and \( V^R \). We fix \( \lambda = 0.22, A = 0.8 \), and investigate the following two cases;

\[
r_B \equiv \sqrt{(1 - \rho)^2 + \eta^2} = \begin{cases} 1.3 : \text{case (a)} \\ 1.0 : \text{case (b)} \end{cases}
\]
The above two cases are shown in Fig.3 with the allowed regions by $\epsilon$ in $K$ decay and $B$ semi-leptonic decay, where we take $m_t = 150 \sim 200$ GeV and $B_K = 0.6 \sim 1.0$. We find that the allowed region of $\phi_1$ ($\beta$) is $7^\circ \sim 15^\circ$ for case (a), $13^\circ \sim 25^\circ$ for case (b). The phase of $M_{12}^{SM}$, $\phi_{SM}$, is given by $\arg[(V^L_{tb}V^{L*}_{td})^2] = 2\phi_1$ in the phase convention of $V^L$ in eq.(1).

![Graph with allowed regions in $\rho$-$\eta$ plane](image)

Figure 3: Allowed region in $\rho$-$\eta$ plane consistent with $\epsilon$ in $K$ decay and $B$ semi-leptonic decay. The dashed lines shows the curves $(1 - \rho)^2 + \eta^2 = 1.3^2$ and $1.0^2$. The three angles of unitarity triangle are also shown.

The ratio of the experimental data, $M_{12}^{B(exp)}$, for $\Delta M_B = 0.462 \pm 0.026$ps$^{-1}$ to the standard model contribution is given for $m_t = 150, 175, 200$ GeV, $r_B = 1.3, 1.0$, $f_B = 140 \sim 200$ MeV and $B_B = 0.7 \sim 1.1$ in Table 1:

| $r_B$ | $m_t$ (GeV) | $M_{12}^{B}$/(GeV) | $M_{12}^{SM}$/(GeV) |
|-------|-------------|------------------|------------------|
| 1.3   | 175         | 0.42 $\sim$ 1.5 | 0.33 $\sim$ 1.2 |
| 1.0   | 175         | 0.70 $\sim$ 2.5 | 0.55 $\sim$ 2.0 |
|       | 200         | 0.45 $\sim$ 1.6 | 0.27 $\sim$ 0.96 |

Table 1: $|M_{12}^{B(exp)} / M_{12}^{SM}|$

The equations (7) and (9) give

$$\frac{|M_{12}^B|}{|M_{12}^{SM}|} = \left| 1 - e^{i(\sigma - \varphi - \phi_{SM})} \frac{r_{ct}}{A^2 \lambda^5 [(1 - \rho)^2 + \eta^2]} \right|.$$  \hspace{1cm} (11)

We require the right-hand side of eq.(11) should be within the values give in Table 1. Taking as an example $m_t = 175$ GeV, $r_B = 1.3$ and $M_R = 1.2$ TeV, we obtain the allowed region of phases in $V^R$ as seen in Fig.4. It gives the
range of the angle $\sigma - \varphi - \phi_{SM} = 154^\circ \sim 206^\circ$, which gives the deviation of
the arg $M_{12}$ from the standard model value, $\delta \phi_{SM} = 131^\circ \sim 229^\circ$.

There should be overlap between the shaded region and the circle whose
center is (1,0) in Fig.4 for the consistency with the experimental value of
$\Delta M_B$. The radius of the circle depends on $W_R$ mass, so that we can derive
the bound of $M_R$, which is shown in Table 2.

| $r_B$ | $m_t = 150$ (GeV) | 175 | 200 |
|-------|------------------|-----|-----|
| 1.3   | $> 1.1$          | $> 1.1$ | $11 > M_R > 1.0$ |
| 1.0   | $> 1.3$          | $> 1.2$ | $> 1.2$ |

Table 2: $W_R$ mass bound (TeV)

Note that we need a new physics contribution to cancel too large $W_L$ contri-
bution in the case of $m_t = 200$ GeV and $r_B = 1.3$.

3 Effects on $CP$ angles

3.1 $\phi_1$

The $CP$ angle $\phi_1$ ($\beta$) is measured in the decay, $B^0(B^0) \rightarrow J/\Psi K_S$. It is
$b(\bar{b}) \rightarrow c\bar{c}s(\bar{s})$ decay in the quark picture. The involving quark mixing matrix
elements are $V_{cb}$ and $V_{cs}$. The experiments fix the angle $\phi_1^{exp}$ which coincides
with the angle $\phi_1$ of the unitarity triangle in the case of standard model. It is related to $M_{12}^B$ and the decay amplitudes as follows:

$$\sin 2\phi_1^{\exp} = -\text{Im} \left[ \frac{M_{12}^B}{M_{12}^B} \frac{A(B^0 \rightarrow J/\Psi K_S)}{A(B^0 \rightarrow J/\Psi K_S)} \right].$$

Penguin diagram also contributes to this decay in addition to the tree graphs. The phase of $W_L(W_R)$ penguin amplitude has the same phase with $W_L(W_R)$ tree amplitudes. In the case of $V_R$ of type I the ratio of $W_L$ contribution to $W_R$ contribution in decay amplitudes is given as

$$W_L \text{ contribution} : W_R \text{ contribution} = \frac{g_L^2}{M_L^2} V_{cb} V_{cs}^* (1 + P) : \frac{g_R^2}{M_R^2} V_{cb} V_{cs}^* (1 + P').$$

where $P$ ($P'$) is $W_L$ ($W_R$) penguin contribution. We have $P \sim P' \propto \alpha_S \ln(m_t^2/m_c^2)$ in the first approximation, so that we take $(1+P')/(1+P) = 1$. By putting $\lambda = 0.22$, $A = 0.8$, $c = s = 1/\sqrt{2}$ and $M_R > 0.52$ TeV we find $W_R$ contribution is 30% or less of the $W_L$ contribution, which corresponds to $18^\circ$ or less deviation of $\phi_1^{\exp}$ from $\phi_1$. Note that the constraints given in the previous section do not affect this conclusion except for $W_R$ mass bound because $W_R$ does not contribute significantly to $B^0 - \bar{B}^0$ mixing and the solution (3) to suppress $\epsilon$ is independent of $\sigma - \xi$.

In the case of $V_R$ of type II there are no tree nor penguin contributions by $W_R$ in this decay mode. But there can be significant contribution to $B^0 - \bar{B}^0$ mixing which gives rise to deviation of $\phi_1^{\exp}$ from the standard model value, $\delta \phi_1 = \delta \phi_{SM}/2 = 66^\circ \sim 115^\circ$, as discussed in sec.2.3.2.

### 3.2 $\phi_2$

Measurement of the asymmetry in $B^0, \bar{B}^0 \rightarrow \pi\pi$ gives the angle $\phi_2^{\exp}$. The involving quark mixing matrix elements are $V_{ub}$ and $V_{ud}$. No tree nor penguin $W_R$ contributions exist in this decay mode in both cases of type I and type II. There is no significant contribution to $B^0 - \bar{B}^0$ mixing in the case of type I, so that $\phi_2^{\exp}$ coincides with $\phi_2$. But large contribution is possible in type II case, which leads to large deviation between $\phi_2^{\exp}$ and $\phi_2$ just as estimated in the preceding subsection for $\phi_1$.

### 3.3 $\phi_3$

The $CP$ angle $\phi_3^{\exp}$ is fixed through the decays of $B$ mesons into neutral $D$ ($D^0, \bar{D}^0, CP$ eigenstates of $D$) and $K$. The involving quark mixing matrix
elements are $V_{cb}V_{us}^*$, $V_{ub}V_{cs}^*$ and their complex conjugates. Penguin contribution is absent in this decay mode. There is no $W_R$ contribution in the case of type I, while there is a tree level contribution in the case of type II.

$$W_L \text{ contribution} : W_R \text{ contribution} = \frac{g_L^2}{M_L^2} V_{cb}^* V_{us} V_{tb}^* V_{cs} = \frac{g_R^2}{M_R^2} V_{cb}^* V_{us}$$

$$= 1 : \beta_g \frac{e^{i(\sigma - \omega)}}{A\lambda^3}.$$  \hspace{1cm} (14)

To estimate the deviation $\delta\phi_3 \equiv \phi_3^{exp} - \phi_3$ we define $\beta_g/(A\lambda^3) \equiv r_3$ and replace $V_{cb}^* V_{us}$ by $V_{cb}^* V_{us}[1 + r_3 e^{i(\sigma - \omega)}] = V_{cb}^* V_{us}[1 \pm r_3 e^{i(\sigma - \varphi)}]$, where eq. (8) has been used. The discussion at sec.2.3.2 gives $\sigma - \varphi - \phi_{SM} = 154^\circ \sim 206^\circ$ and $\phi_{SM} = 2\phi_1 = 14^\circ \sim 30^\circ$ for $m_t = 175$ GeV, $r_B = 1.3$ and $M_R = 1.2$ TeV. Then $\sigma - \varphi = 168^\circ \sim 236^\circ$, and we find $\delta\phi_3 = -32^\circ \sim +19^\circ$ from Fig.5. We have analyzed $\delta\phi_3$ for other set of parameters. The results are given in Table 3.

![Figure 5: $\delta\phi_3$ for $r_B = 1.3$ and $M_R = 1.2$ TeV in the case of type II. The solid parts of the circle express $r_3 e^{i(\sigma - \varphi)}$ with $\sigma - \varphi = 168^\circ \sim 236^\circ$ (mod 180°).](image)

| $r_B$ | $m_t = 150$ (GeV) | $m_t = 175$ | $m_t = 200$ |
|-------|-------------------|--------------|--------------|
| 1.3   | $-32^\circ \sim +17^\circ$ ($M_R = 1.2$) | $-32^\circ \sim +19^\circ$ ($M_R = 1.2$) | $-37^\circ \sim -12^\circ$ |
|       | $-11^\circ \sim +11^\circ$ ($M_R = 2.0$) | $-11^\circ \sim +11^\circ$ ($M_R = 2.0$) | $+3^\circ \sim +14^\circ$ ($M_R = 1.1$) |
| 1.0   | $-23^\circ \sim +22^\circ$ ($M_R = 1.4$) | $-27^\circ \sim -10^\circ$ | $-27^\circ \sim -5^\circ$ |
|       | $-11^\circ \sim +11^\circ$ ($M_R = 2.0$) | $+4^\circ \sim +19^\circ$ ($M_R = 1.3$) | $+2^\circ \sim +20^\circ$ ($M_R = 1.3$) |

Table 3: The values of $\delta\phi_3$. The masses of $W_R$ boson ($M_R$) is given in unit of TeV.
4 Summary and discussion

We have investigated the effects of $W_R$ on $CP$ violation in $B$ decays. The right-handed charged current gauge boson $W^R$ can affect significantly on the determination of the $CP$ violation angles to be measured at $B$ factories if the right-handed current quark mixing matrix $V^R$ is chosen to satisfy the bounds by neutral $K$ meson system with relatively light $W_R$ of $M_R = 0.5 \sim 1.5$ TeV. The $W_R$ contribution can be sizable in $B^0$-$\bar{B}^0$ mixing and tree level $b$ quark decay. In the case of $V^R$ of type I the $CP$ angle $\phi_1 (\beta)$ can deviate from the standard model value by as large as $18^\circ$ for $M_R = 0.52$ TeV. In the case of $V^R$ of type II the $CP$ angle $\phi_1 (\beta)$ and $\phi_2 (\alpha)$ can deviate by $66^\circ \sim 115^\circ$ and $\phi_3 (\gamma)$ by $-32^\circ \sim +19^\circ$ for $M_R = 1.2$ TeV. These results have been obtained under specific sets of parameters for the simplicity of calculation; $A = 0.8$, $\sqrt{(1 - \rho)^2 + \eta^2} = 1.0, 1.3$, $B_K = 0.6 \sim 1.0$, $B_B = 0.7 \sim 1.1$, $g_L = g_R$ and neglecting $W_L$-$W_R$ mixing. The values of deviation will be modified if we enlarge or restrict the region of these parameters.

One notable point of the $W_R$ effects is the fact that the sum of the measured three $CP$ angles does not become $180^\circ$. It has often been pointed out that a key of new physics search in $B$ meson system is a check of sum of three $CP$ angles\cite{4}. However, the sum of the angles measured on $\Upsilon(4S)$, where the $CP$ angle $\phi_3 (\gamma)$ is fixed through $B \to DK$ decay, becomes $180^\circ$ even with sizable new physics contributions if new physics affects on $B^0$-$\bar{B}^0$ mixing alone as can be seen in the definitions of the $CP$ angles to measure. This result can be extended to 4 or more generation models, vector-quark models and so on where Kobayashi-Maskawa matrix is not necessarily unitary in the first $3 \times 3$ part\cite{17}. $SU(2)_L \times SU(2)_R \times U(1)$ models will be one of promising candidates of new physics if sum of the three $CP$ angles measured in coming experiments does not become $180^\circ$.

Acknowledgement

The authors would like to thank Dr. M. Tanaka for useful comments on QCD correction factors in $SU(2)_L \times SU(2)_R \times U(1)$ models. T.K.’s work is supported in part by Grant-in Aids for Scientific Research from the Ministry of Education, Science and Culture (No. 07804016 and 07304029).
References

[1] Letter of Intent for a Study of CP Violation in B Meson Decays, KEK Report 94-2 (1994).

[2] Letter of Intent for the Study of CP Violation and Heavy Flavor Physics at PEP II, SLAC-443 (1994).

[3] A.B. Carter and A.I. Sanda, Phys. Rev. Lett. 45 952 (1980), Phys. Rev. D23 1567 (1981);
I.I. Bigi and A.I. Sanda, Nucl. Phys. B193 85 (1981), Nucl. Phys. B281 41 (1987).

[4] For reviews see
  Y. Nir, Proc. of the Workshop on B physics at Hadron Accelerators, eds.
  P. McBride and C.S. Mishra, SSCL-SR-1225, Fermilab-CONF-93/267, 185 (1993);
  Y. Nir and H.R. Quinn, Ann. Rev. Nucl. Part. Sci. 42 211 (1992).

[5] M. Kobayashi and T. Maskawa, Prog.Theor.Phys. 49, 652 (1973).

[6] R.N. Mohapatra and J.C. Pati, Phys. Rev. D11 566 (1975), D11 2558 (1975);
G. Senjanovic and R.N. Mohapatra, Phys. Rev. D12 1502 (1975);
G. Senjanovic, Nucl. Phys. B153 334 (1979).

[7] G. Beall, M. Bander and A. Soni, Phys. Rev. Lett. 48 848 (1982).

[8] F.I. Olness and M.E. Ebel, Phys. Rev. D30 1034 (1984).

[9] P. Langacker and S.U. Sankar, Phys. Rev. D40 1569 (1989).

[10] D. London and D. Wyler, Phys. Lett. B232 503 (1989).

[11] L. Montanet et.al., Phys. Rev. D50 1173 (1994) and 1995 off-year partial update for 1996 edition available on the PDG WWW pages (URL: http://pdg.lbl.gov/).

[12] M. Gronau and D. London, Phys. Lett. B253 483 (1991);
M. Gronau and D. Wyler, Phys. Lett. B265 172 (1991);
I. Dunietz, Phys. Lett. B270 75 (1991).

[13] G. Ecker and W. Grimus, Nucl. Phys. B258 328 (1985);
H. Nishiura, E. Takasugi and M. Tanaka, Prog. Theor. Phys. 84 116 (1990), Prog.Theor.Phys. 84 502 (1990), Prog.Theor.Phys. 85 343 (1991).
[14] A. Datta, E.A. Paschos, J.-M. Schwartz and M.N. Sinha Roy, hep-ph/9509420 (1995), DO-TH 95/12.

[15] L. Wolfenstein, Phys. Rev. Lett. 51 1945 (1983).

[16] T.E. Browder and K. Honscheid, UH 511-816-95, OHSTPY-HEP-E-95-010 (1995).

[17] T. Kurimoto and A. Tomita, in preparation.