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Nonstandard order parameters and the origin of *CP* violation

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The consideration of chirality-preserving 2-fermion order parameters may shed new light on the strong *CP* problem and the breakdown of flavor symmetries. We describe two situations, one having the standard Kobayashi-Maskawa picture for weak *CP* violation and another having new sources of weak *CP* violation.

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With the discovery or confirmation [1] of a nonvanishing ε', it appears likely that the Kobayashi-Maskawa (KM) picture for weak *CP* violation will be confirmed at the *B*-factories. There remains one obstacle, though, and that is the strong *CP* problem. The invisible axion scenario [2] is not completely satisfactory, since it relates the smallness of the strong *CP* violating parameter $\overline{\theta}$ to a poorly understood hierarchy of symmetry breaking scales. Any alternate resolution of the problem will likely involve phases entering the mass matrix in a very particular way [3], or in a very limited way [4], in order to satisfy the constraint on argdet$M$. This restricts the phase structure of the KM matrix and typically necessitates nonstandard sources of weak *CP* violation. This has been the focus of recent work [5]. A common feature of these alternate approaches is the central role played by elementary scalar fields, since *CP* is required to be broken softly in the scalar field sector before feeding into the quark sector.

We wish to consider new possibilities for the origin of *CP* violation which may arise in the context of dynamical symmetry breaking, in the absence of elementary scalar fields. We consider possible order parameters constructed from the quark fields themselves, which may form due to the participation of the standard quarks in strong flavor interactions on roughly 1000 TeV scales. The latter is a typical flavor scale needed to account for the light quark masses. The manner in which the phases are transmitted to the quark mass matrix and other observables can differ substantially from models with scalar fields. We are motivated by the strong *CP* problem, but we will also describe the resulting picture for weak *CP* violation. We will discuss how one choice of the order parameters can lead to the standard KM picture, and how another choice implies that new sources of *CP* violation are likely to exist.

We are exploring the possibility that various flavor symmetries and *CP* are both violated dynamically on the scale of strong flavor interactions. Above these scales we assume that there is nothing but a *CP* conserving, massless gauge theory. Naively a dynamical breakdown of *CP* by strong interactions would sprinkle *CP* violating phases everywhere in the low energy theory, including the effective operators responsible for the quark masses, and result in a $\overline{\theta}$ much too large. We will suggest that the proliferation of *CP* violating phases can be constrained by the pattern of symmetry breaking.

In particular we suppose that *CP* violation originates in the phases of a pair of order parameters which are also responsible for breaking some $U(1)$ flavor symmetry. We will be considering mass matrices such that some of the elements respect a $U(1)$ symmetry while other elements do not. We will describe how the former elements are protected from *CP* violating phases, while the latter pick up a phase from one of the *CP* violating order parameters. At the end we will discuss how the $U(1)$ can be part of a gauged flavor symmetry.

Before describing the order parameters we first consider three possible sets of mass matrices, each having a vanishing argdet$M$. In each case we also give the charge of the flavor symmetry we are considering, where N_i is the ith family number. Each $\sharp$ denotes in general a different real number.

Case 1 $Q_F=N_1+N_2-N_3$

$$M^U=\begin{pmatrix} \sharp & \sharp & \sharp e^{-i\phi_U} \\ \sharp & \sharp & \sharp e^{-i\phi_U} \\ \sharp e^{i\phi_U} & \sharp e^{i\phi_U} & \sharp \end{pmatrix},$$

$$M^D=\begin{pmatrix} \sharp & \sharp & \sharp e^{-i\phi_D} \\ \sharp & \sharp & \sharp e^{-i\phi_D} \\ \sharp e^{i\phi_D} & \sharp e^{i\phi_D} & \sharp \end{pmatrix}. \qquad (1)$$

Case 2 $Q_F=-N_1+N_2+N_3$

$$M^U=\begin{pmatrix} \sharp & \sharp e^{i\phi_U} & \sharp e^{i\phi_U} \\ \sharp e^{-i\phi_U} & \sharp & \sharp \\ \sharp e^{-i\phi_U} & \sharp & \sharp \end{pmatrix},$$

$$M^D=\begin{pmatrix} \sharp & \sharp e^{i\phi_D} & \sharp e^{i\phi_D} \\ \sharp e^{-i\phi_D} & \sharp & \sharp \\ \sharp e^{-i\phi_D} & \sharp & \sharp \end{pmatrix}. \qquad (2)$$

Case 3 $Q_F=N_1-N_2+N_3$

$$M^U=\begin{pmatrix} \sharp & \sharp e^{i\phi_U} & \sharp \\ \sharp e^{-i\phi_U} & \sharp & \sharp e^{-i\phi_U} \\ \sharp & \sharp e^{i\phi_U} & \sharp \end{pmatrix},$$

$$M^D=\begin{pmatrix} \sharp & \sharp e^{i\phi_D} & \sharp \\ \sharp e^{i-i\phi_D} & \sharp & \sharp e^{-i\phi_D} \\ \sharp & \sharp e^{i\phi_D} & \sharp \end{pmatrix}. \qquad (3)$$

The key property of these matrices is that they are form invariant: addition and multiplication of matrices of the form

of M^U will again yield matrices of the same form with the same phase, and the same for M^D. This is necessary since sums of mass-type diagrams involving multiple insertions of mass matrices (and/or flavor changing order parameters) are expected to contribute to the final mass matrix. Although the phases appear in a rather trivial way, for $\phi_U-\phi_D\neq n\pi$ we will have a *CP* violating phase appearing in the KM matrix.

We would now like to identify the flavor-violating order parameters which could introduce phases into the mass matrices in this way. First, the order parameters must respect electroweak symmetry since we are supposing that they arise at the $\approx$1000 TeV flavor scale. Second, to guarantee a unique phase in each mass matrix, it is clear that there must not be two or more order parameters in either the up- or down-sectors having independent phases. We might expect for example two order parameters with opposite $U(1)$ flavor charge, but we must insist that these be Hermitian conjugates of each other so that their phases are equal and opposite.

An order parameter with these properties is one which is not normally considered, namely the chirality-preserving part of the quark propagator. In particular we suppose that the origin of *CP* violation lies in the following amplitudes coupling right-handed quarks of different families. We assume that the pattern of symmetry breaking produces these order parameters for only one pair of families labeled by indices (f_1,f_2), with $f_1\neq f_2$, which are such as to break the $U(1)$ flavor symmetry:

$$\int e^{ip\cdot x}\langle TU_{f_1}(x)\overline{U}_{f_2}(0)\rangle dx = ie^{i\phi_U}\frac{1+\gamma_5}{2}Z^U(p^2)\frac{1}{\not p} \quad (4)$$

$$\int e^{ip\cdot x}\langle TD_{f_1}(x)\overline{D}_{f_2}(0)\rangle dx = ie^{i\phi_D}\frac{1+\gamma_5}{2}Z^D(p^2)\frac{1}{\not p}. \quad (5)$$

The $U(1)$ symmetry implies that $\phi_U+\phi_D$ is freely adjustable, leaving only $\phi_U-\phi_D$ as a physical phase. Note that our symmetry is vectorial; the corresponding purely right-handed transformation is not a symmetry of the rest of the theory. If there were no weak interactions, and no other physics caused transitions between the up and down sectors, then there would be two vector $U(1)$ symmetries and then no physical phase would remain. This emphasizes the role of weak interactions in producing *CP* violation of any kind in this picture.

We expect other independent order parameters generated by the strong flavor interactions, which signal the breakdown of various other symmetries. For example there may be 4-fermion order parameters, since they can also respect electroweak symmetry, but which break other flavor and/or chiral symmetries. Such 4-fermion order parameters may play a crucial role in generating the quark masses (in the presence of some fermions with TeV scale masses) [6].

Our central assumption is that the order parameters in (4) and (5) are the only source of flavor $U(1)$ and *CP* breaking. To clarify what we mean by this we note that these order parameters are nonperturbative contributions to the full quark propagators. We can imagine rewriting the theory in terms of the full propagators; this can take the form of the Cornwall-Sackiw-Tomboolis (CJT) [7] effective action or some other similar formalism. In this alternate form of the theory, in which the breakdown of the flavor and *CP* symmetries are encoded in the Feynman rules, we are supposing that the effects of flavor $U(1)$ and *CP* symmetry breaking can be described *entirely perturbatively*. (This may be taken as a statement about the size of the effective coupling in this alternate description.) In this way we are drawing a distinction between the dynamical breakdown of flavor and *CP* as reflected by the order parameters, and the subsequent appearance of flavor and *CP* breaking in other amplitudes of the theory.

$U(1)$ breaking and *CP* violation in a general amplitude can then be deduced from the effects of all possible insertions of the order parameters. Ignoring weak corrections for the moment, the result is that *the CP violating phase is correlated with the flavor charge of the amplitude*. This is evident in the mass matrices (1)–(3). Consider also the chirality-preserving terms for the right-handed quark fields, which in the low energy theory are of the form

$$\overline{U}_{Rj}i\not\partial C^U_{jk}U_{Rk}+\overline{U}_{Rj}i\not\partial\partial^2 C'^U_{jk}U_{Rk}+\ldots \quad (6)$$

$$\overline{D}_{Rj}i\not\partial C^D_{jk}D_{Rk}+\overline{D}_{Rj}i\not\partial\partial^2 C'^D_{jk}D_{Rk}+\ldots. \quad (7)$$

The Hermitian matrices C^U and C^D, and the matrices in the nonrenormalizable terms, will have the same phase structure as the mass matrices M^U and M^D respectively. That is, they have the same phases in the same elements.

In the low energy theory one can transform the renormalizable kinetic terms to conventional flavor-diagonal form by redefining the fields $U_R\rightarrow H^U U_R$, $D_R\rightarrow H^D D_R$. The H^U and H^D matrices can be chosen to be Hermitian and they again have the same phase structure as the original M^U and M^D respectively. Under this transformation the mass matrices change, but they retain their original phase structure. Thus in the low energy theory we have quarks with normal kinetic terms, and mass matrices with a *CP* violating phase which preserves $\theta=0$. The order parameters in (4) and (5) are affecting the mass matrices both through direct insertions in mass generating diagrams and through the field redefinition we have just described.

This discussion has ignored weak interaction corrections, and in fact these generate the well known small contributions to θ [9]. In addition to a safely small finite contribution, the standard model generates ''infinite'' contributions occurring at high orders in the weak coupling. In our picture such effects simply represent the running of θ below the flavor scale; above the flavor scale θ is trivially zero if the fundamental theory is a *CP* conserving, massless gauge theory. It is the softness of the dynamically generated quantities at the flavor scale, as in (4) and (5), which turns the ''infinite'' θ of the standard model into a calculable and safely small quantity.

Any new physics which, like the weak interactions, couples together the up and down sectors would have to be carefully considered as a source of additional contributions to θ. One example is $SU(2)_R$ interactions. Another would be nonperturbative operators of the form $\overline{Q}_{Lj}Q_{Rk}\overline{Q}_{Lk}Q_{Rj}$ where j and k denote different families. These operators could connect an off-diagonal element of the up mass matrix to one in

the down mass matrix, and thus could produce contributions to both mass matrices of a form different than we have been considering. We assume that such effects are either nonexistent or sufficiently small.

The flavor physics will generate nonrenormalizable terms suppressed by the large flavor scale, such as those in (6) and (7), but these do not lead to corrections which affect the phase structure of the mass matrices. They may however produce contributions to weak *CP* observables, in addition to the phase in the KM matrix; we will return to such effects later.

We will now consider the matrices presented in (1)–(3) in more detail. Case 1 turns out to be of the most interest if our goal is to obtain a standard KM picture for weak *CP* violation. This may also be possible in case 2, but we will explain why it is more likely to have additional sources of *CP* violation in this case. In case 3, for any choice of (f_1,f_2), we are not able to obtain realistic masses and mixings, and we will not consider this case further.

For realistic mass matrices in case 1 we are forced to choose $(f_1,f_2)=(2,3)$, so that transitions occur between U_{2R} and U_{3R} and between D_{2R} and D_{3R} in the original flavor basis. For the resulting mass terms $(\bar{Q}_{Lj}M^U_{jk}U_{Rk}+\bar{Q}_{Lj}M^D_{jk}D_{Rk})+\text{H.c.}$ we specialize somewhat from the matrices in (1) and consider the following, where all parameters are real:

$$M^U=\begin{pmatrix} m^U_{11} & m^U_{12} & e^{-i\phi_U}\rho_U m^U_{12} \\ m^U_{21} & m^U_{22} & e^{-i\phi_U}\rho_U m^U_{22} \\ 0 & e^{i\phi_U}\rho_U m^U_{33} & m^U_{33} \end{pmatrix} \tag{8}$$

$$M^D=\begin{pmatrix} m^D_{11} & m^D_{12} & e^{-i\phi_D}\rho_D m^D_{12} \\ m^D_{21} & m^D_{22} & e^{-i\phi_D}\rho_D m^D_{22} \\ 0 & e^{i\phi_D}\rho_D m^D_{33} & m^D_{33} \end{pmatrix}. \tag{9}$$

We have used a common proportionality constant ρ_U in M^U, and ρ_D in M^D, although this need not be strictly true. This choice reflects how these elements can arise from the neighboring mass elements in the same row, via the right-handed transitions. Zeros have been placed in the (3,1) elements since they are likely to be small and unimportant to the results; they would arise from diagrams involving multiple insertions of the mass matrices.

By studying the transformation from the present weak eigenstate basis to the mass eigenstate basis we can deduce properties of the KM matrix V. We find for example that, up to small corrections,

$$|V_{cb}|\approx|X_D-e^{(i(\phi_D-\phi_U))}X_U|,$$

where

$$X_U=2(m_c/m_t)[\rho_U/(1-\rho_U^2)],$$

$$X_D=2(m_s/m_b)[\rho_D/(1-\rho_D^2)].$$

In addition we find that the bulk of the contribution to $|V_{cb}|$ must come from X_U (so as to obtain realistic values for $|V_{ub}|$) which then implies that $\rho_U\approx 0.9$. Thus the effects of the right-handed transitions must be large. For two of the angles of the unitarity triangle we find

$$\alpha\approx\phi_U-\phi_D,$$

$$\gamma\approx\arg(X_D-e^{(i(\phi_D-\phi_U))}X_U).$$

The possibility that $\phi_U-\phi_D=\pi/2$ [corresponding to a relative factor of i between the order parameters in (4) and (5)] is certainly consistent with a realistic α.

We illustrate these results with the following values: $m^U_{11}=0.002$, $m^U_{12}=m^U_{21}=0$, $m^U_{22}=4.4$, $m^U_{33}=117$; $m^D_{11}=0$, $m^D_{12}=m^D_{21}=0.019$, $m^D_{22}=0.08$, $m^D_{33}=2.7$; $\rho_U=0.9$, $\rho_D=0.25$, $\phi_U=\pi/2$, $\phi_D=0$. This yields mass eigenvalues $(m_u,m_c,m_t)=(0.002,0.62,158)$ and $(m_d,m_s,m_b)=(0.0043,0.077,2.8)$, which are typical of realistic values renormalized at the TeV scale. The unitarity triangle has the following angles and sides: $\alpha=88.6°$, $\beta=21.9°$, $\gamma=69.5°$, $1:R_b:R_t=1:0.37:0.94$. (Note that in this example with $m^U_{12}=m^U_{21}=0$ the origin of Cabbibo mixing lies in the down sector. We can get similar final results with Cabbibo mixing originating in the up sector, which would require that $m^U_{12}\gg m^U_{21}$.) It is of interest to consider the KM matrix $V=L^{U\dagger}L^D$ using a phase convention in which the unitary transformations L^U and L^D have the same phase structure as M^U and M^D respectively. The phases in V then occur mostly in the 2×2 block involving the heavier quarks:

$$V=\begin{pmatrix} 0.976 & 0.218 & 0.00331 \\ -0.218-0.000007i & 0.975-0.000536i & 0.0139+0.0374i \\ -0.000196-0.00814i & -0.0143+0.0365i & 0.999+0.000521i \end{pmatrix}. \tag{10}$$

Note that V_{ud} and V_{us} are always real, no matter what the value of ϕ_U and ϕ_D. The next case we consider will be different.

For case 2 we are forced to choose $(f_1,f_2)=(1,2)$, which leads to the following matrices.

$$M^U=\begin{pmatrix} m^U_{11} & e^{i\phi_U}\rho_U m^U_{11} & 0 \\ e^{-i\phi_U}\rho_U m^U_{22} & m^U_{22} & m^U_{23} \\ e^{-i\phi_U}\rho_U m^U_{32} & m^U_{32} & m^U_{33} \end{pmatrix} \tag{11}$$

$$M^D=\begin{pmatrix} m^D_{11} & e^{i\phi_D}\rho_D m^D_{11} & 0 \\ e^{-i\phi_D}\rho_D m^D_{22} & m^D_{22} & m^D_{23} \\ e^{-i\phi_D}\rho_D m^D_{32} & m^D_{32} & m^D_{33}\end{pmatrix}. \qquad (12)$$

For Cabibbo mixing we find

$$|V_{us}|\approx|Y_D-e^{(i(\phi_D-\phi_U))}Y_U|$$

where

$$Y_U=2\frac{m_u}{m_c}\frac{\rho_U}{1-\rho_U^2},\quad Y_D=2\frac{m_d}{m_s}\frac{\rho_D}{1-\rho_D^2}. \qquad (13)$$

The Y_D term dominates and thus ρ_D is determined. For the angle β appearing in the unitarity triangle we find

$$\beta\approx\arg(Y_D-e^{(i(\phi_D-\phi_U))}Y_U).$$

If ρ_U is much smaller than 0.95 the unitarity triangle is very thin, even if $\phi_U-\phi_D\approx\pi/2$, and it is then not possible for the KM matrix to account for the observed *CP* violation. Independent of this we are able to obtain the other three real mixing parameters of the KM matrix.

We illustrate the case of a fat unitarity triangle with the following values: $m^U_{11}=-0.03$, $m^U_{11}=-0.035$, $m^U_{23}=m^U_{32}=8.1$, $m^U_{33}=157$; $m^D_{11}=-0.0133$, $m^D_{11}=-0.035$; $m^D_{23}=m^D_{32}=0.26$, $m^D_{33}=2.75$; $\rho_U=0.95$, $\rho_D=0.76$, $\phi_U=\pi/2$, $\phi_D=0$. This yields mass eigenvalues $(m_u,m_c,m_t)=(0.0021,0.62,158)$ and $(m_d,m_s,m_b)=(0.0044,0.076,2.8)$. The unitarity triangle has the following angles and sides $\alpha=75.0°$, $\beta=16.8°$, $\gamma=88.2°$, $1:R_b:R_t=1:0.30:1.03$. Note that in contrast to case 1 (with the same phase convention as used there) the phases in the KM matrix now appear mostly in the 2×2 block involving the lighter quarks:

$$V=\begin{pmatrix} 0.975+0.0140i & 0.211-0.0645i & -0.000667-0.00262i \\ -0.211-0.0646i & 0.974-0.0140i & 0.0398+0.000044i \\ 0.00910+0.000018i & -0.0388+0.000004i & 0.999\end{pmatrix}. \qquad (14)$$

In the standard model it is conventional to absorb phases into the quark fields so as to move phases in V into more standard positions, and in particular remove phases from the V_{ud} and V_{us} elements. But in our case the new flavor physics generates additional nonrenormalizable operators which are not invariant under these phase redefinitions. In particular let us consider the flavor changing chromomagnetic moment operators in the down sector, which have been considered as a new physics contribution to ε'/ε [8], $g_s\tilde{C}^D_{jk}\overline{D}_{Lj}\sigma^{\mu\nu}T^aD_{Rk}G^a_{\mu\nu}$. The origin of these operators should be closely associated with the origin of the down-type quark masses. Thus very roughly $\tilde{C}^D_{jk}\approx\sqrt{m_im_j}/\Lambda^2$, where Λ should be of order the electroweak symmetry breaking scale. Although $\tilde{C}^D$ will have the same phase structure as M^D, there is no reason for $\tilde{C}^D$ to be exactly proportional to M^D, and in the basis in which M^D is diagonal we expect $\tilde{C}^D$ to have nondiagonal entries. With the quark phase choice $\phi_D=0$, $\tilde{C}^D$ is real, while the phases in the KM matrix are nonstandard. We can use phase redefinitions on the quark fields (which leave the diagonal mass matrix and θ invariant) to move the phases in the KM matrix to more standard positions. Then an explicit *CP* violating phase will show up in $\tilde{C}^D_{ds}$. The magnitude of this phase is $|\arg(V_{us})|$ in the original basis, and this, as it turns out, is closely approximated by β. Thus the same angle which determines the extent of *CP* violation in the KM matrix also determines the *CP* violating phase in the new operator.

We may estimate the Λ required for this effect to account for the observed ε'/ε [1]. Assuming that $|\mathrm{Im}(\tilde{C}^D_{ds})|\approx\sqrt{m_dm_s}\beta/\Lambda^2$ we deduce from the analysis in [8] that $\Lambda/\sqrt{\beta}\approx5$ TeV. Since this is above the electroweak breaking scale, this new contribution to ε' can easily be large enough, even for values of β which make the KM contribution tiny.

To account for ε itself, we need a superweak, $\Delta S=2$, 4-fermion operator. Such operators emerge naturally from the exchange of new flavor gauge bosons, which can lead for example to a $(1/M^2)(\overline{D}_{1R}\gamma_\mu D_{1R}-\overline{D}_{2R}\gamma_\mu D_{2R})^2$ operator in the original flavor basis (M characterizes the flavor scale). In the mass eigenstate basis this will produce a $\Delta S=2$ operator, which then picks up a phase due to the phase redefinitions we have just discussed. Accounting for large mixing between D_{1R} and D_{2R}, due to a large ρ_D, we obtain roughly $M/\sqrt{\beta}\approx10^4$ TeV. Since this is above the expected scale of new flavor physics, the superweak contribution to ε can easily be large enough, even for values of β which make the KM contribution tiny.

If we look back at case 1 we see that both V_{uu} and V_{us} are real in the original flavor basis, and thus the interference between the new operators and standard model amplitudes introduces no new phases. Thus the new contributions to ε and ε' occurring in case 2 do not occur in case 1. For case 2, although it is conceivable for the KM matrix by itself to account for *CP* violation, we have seen that it may be more natural to have the bulk of *CP* violation originate in additional operators.

Let us step back for a moment and consider the larger picture. Quark masses are generated by 4-fermion interactions in the presence of some dynamically generated TeV scale fermion masses. It is natural to assume that these TeV scale fermions are nothing but a fourth family of quarks (t',b') and leptons, in which case the possible origin of the

$U(1)$ flavor symmetry we have been discussing becomes clearer. By extending the $U(1)$ flavor symmetry to the fourth family it can become weak anomaly free and thus can correspond to part of some gauged flavor symmetry. For example the $U(1)$ flavor charge in case 1 becomes $N_1+N_2-N_3-N_4$, which is light family number minus heavy family number. This can correspond to the diagonal generator of a $SU(2)$ flavor symmetry which acts on two pairs of families, such that the flavor eigenstates for quarks (Q_1,Q_3) and (Q_2,Q_4) are flavor doublets. Alternatively if (Q_1,Q_3) transforms as the complex conjugate of (Q_2,Q_4) under $SU(2)$ then the diagonal $SU(2)$ generator is $-N_1+N_2+N_3-N_4$, and this gives us case 2.

The four-fermion interactions respecting the $U(1)$ would generate mass matrices of the following form [with the ordering (Q_1,Q_2,Q_3,Q_4)], for case 1 and case 2 respectively,

$$\begin{pmatrix} \# & \# & 0 & 0 \\ \# & \# & 0 & 0 \\ 0 & 0 & \# & \# \\ 0 & 0 & \# & \# \end{pmatrix}, \quad \begin{pmatrix} \# & 0 & 0 & \# \\ 0 & \# & \# & 0 \\ 0 & \# & \# & 0 \\ \# & 0 & 0 & \# \end{pmatrix}. \tag{15}$$

To this we must add the effects of the right-handed transitions, which involve the $(f_1,f_2)=(2,3)$ flavors in case 1 and the $(f_1,f_2)=(1,2)$ flavors in case 2. In both cases it is natural for the mixing between the fourth family and the lighter families to be small, in which case our previous discussion will continue to hold.

Finally, suppose that the fourth family mass also breaks the $U(1)$ flavor symmetry. This would occur in the case of complex conjugate $SU(2)$ representations if the fourth family quark mass term was $\overline{Q}_{4L}Q_{3R}+\text{H.c.}$ (Then of course the Q_3 and Q_4 families in the original flavor basis are no longer close to being the mass eigenstates.) By reordering the righthanded fields, $(Q_{1R},Q_{2R},Q_{3R},Q_{4R}) \rightarrow (Q_{2R},Q_{1R},Q_{4R},Q_{3R})$, it then turns out that the mass matrix takes the same form as the second matrix in (15). We only mention this case here to make contact with the model in [6].[1]

In conclusion we have related *CP* violation to a phase mismatch in certain flavor changing order parameters involving right-handed quarks. The absence of strong *CP* violation is related to the very particular way these order parameters feed phases into the mass matrices. We described two cases, one with a standard KM picture of weak *CP* violation, and the other where additional sources of *CP* violation in the *K* system are likely. In the latter case there may be smaller than expected *CP* violation in the *B* system. In both cases we related the angles of the unitarity triangle to the phases in the flavor changing order parameters. We cannot claim a final resolution of the strong *CP* problem without a complete and unambiguous theory of quark masses, and thus we await the results from the *B* factories for further guidance.

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[1]Note that in that reference various symmetry breaking effects in the quark sector were postulated to feed in from the fourth family lepton sector. In the present discussion those contributions are not needed, due to the chirality-preserving order parameters.

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