Alternative Theories of CP violation

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Abstract

Recent improvements to the limit of $\Delta M_{B_s}$ imply that pure superweak theories, while not excluded, no longer provide a good fit to the data. A class of general superweak theories is introduced in which all flavor changing interactions are governed by an approximate flavor symmetry which gives a “3 mechanism”. These theories are in good agreement with data, and predict low values for $|V_{td}|$, $|V_{ub}/V_{cb}|$, $B(K^+ \to \pi^+ \nu \bar{\nu})$, $\epsilon'/\epsilon$ and CP asymmetries in B decays, and high values for $\Delta M_{B_s}$ and $f_B \sqrt{B_B}$. An important example of such a theory is provided by weak scale supersymmetric theories with soft CP violation. The CP violation originates in the squark mass matrix, and, with phases of order unity, flavor symmetries can yield a correct prediction for the order of magnitude of $\epsilon_K$.

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1 CP Violation

All observed CP violation can be described by the complex parameter $\epsilon_K$, which describes an imaginary contribution to the $\Delta S = 2$ mixing of the neutral $K$ mesons. Such a mixing implies the existence of an effective Hamiltonian

$$H_{eff}^{\Delta S=2} = \frac{1}{v^2} \sum_{ij} iC_{ij}(s\Gamma_i d)(s\Gamma_j d)$$

where $v = 247$ GeV, and $i, j$ run over possible gamma matrix structures. The dimensionless coefficients $C_{ij}$ are real in a basis where the standard model $\Delta S = 1$ effective Hamiltonian has a real coefficient. In the case that the dominant term is $\Gamma_i = \Gamma_j = \gamma^\mu (1 - \gamma^5)/2$,

$$C_{LL} = 4(1 \pm 0.3) \cdot 10^{-10} \frac{|\epsilon_K|}{2.3 \cdot 10^{-3} B_K}.$$  

The two basic issues of CP violation are

- What is the underlying physics which leads to $H_{eff}^{\Delta S=2}$? Is it a very small effect originating at the weak scale, as suggested by the form $C/v^2$, or is it a larger effect generated by physics at higher energies?

- How can the magnitude $C \approx 10^{-9}$ to $10^{-10}$ be understood?

2 The CKM Theory of CP Violation

In the standard model all information about flavor and CP violation originates from the Yukawa coupling matrices. After electroweak symmetry breaking, this is manifested in the Cabibbo-Kobayashi-Maskawa (CKM) matrix of the charged current interactions of the $W$ boson. A one loop box diagram with internal top quarks gives the dominant contribution to $H_{eff}^{\Delta S=2}$ via

$$C_{LL,SM} = \frac{g^2}{32\pi^2} S_t \text{Im}[(V_{td} V_{ts}^*)^2]$$

where $S_t \simeq 2.6$ is the result of the loop integration, and $g$ is the SU(2) gauge coupling constant. For a suitable choice of the CKM matrix elements, $V_{ij}$, the standard model can provide a description of the observed CP violation. The fundamental reason for the size of the CP violation observed in nature remains a mystery, however, and must await a theory of flavor which can explain the values of $|V_{td}|, |V_{ts}|$ and the CKM phase. If the CKM matrix
contained no small parameters one would expect $C_{LL,SM}$ to be of order $10^{-2}$ to $10^{-3}$ rather than the observed value of order $10^{-9}$ to $10^{-10}$.

Of course, measurements of CP conserving observables have shown that $|V_{ij}|$ are small for $i \neq j$, and, given the measured values of $|V_{us}|$ and $|V_{cb}|$, it is convenient to use the Wolfenstein parameterization\cite{2} of the CKM matrix, in which case (3) becomes

$$C_{LL,SM} \simeq 20 \cdot 10^{-10} (1 - \rho) \eta$$

(4)

If we assume that the CKM matrix does not have any other small parameters, the standard model yields a value of $\epsilon_K$ of the observed order of magnitude. While this is not a prediction, it is an important success of the standard model, and has made the CKM theory the leading candidate for CP violation. To our knowledge, there is no similar success in any published alternative to the CKM theory of CP violation, since in these theories the order of magnitude of $C$ can only be fixed by fitting to the measured value of $\epsilon_K$. In this letter we present such an alternative theory.

Two further measurements of $|V_{ij}|$, with $i \neq j$, would determine both $\rho$ and $\eta$ allowing a prediction of $C_{LL,SM}$ and $\epsilon_K$. A fit to the two observables $|V_{ub}/V_{cb}|$ and $\Delta M_{B_d}$, but not $\epsilon_K$, is shown in Figure 1. For all numerical work, we use the data and parameters listed in Table 1 — for a discussion of these, and references, see \cite{3}. Unfortunately the large uncertainties make this a very weak prediction: $\eta = 0$ is allowed even at the 68% confidence level. Hence, from this one cannot claim strong evidence for CKM CP violation.

Recent observations at LEP have improved the limit on $B_s - \bar{B}_s$ mixing, so that $\Delta M_{B_s} > 10.2 \text{ ps}^{-1}$ at 95% confidence level \cite{4}. The result of a $\chi^2$ fit in the standard model to $\rho$ and $\eta$ using the three observables $|V_{ub}/V_{cb}|$, $\Delta M_{B_d}$ and $\Delta M_{B_s}$, but not $\epsilon_K$, is shown in figure 2. For $B_s$ mixing the amplitude method is used \cite{5,3}. Comparing Figures 1 and 2, it is clear that the $\Delta M_{B_s}$ limit is now very significant. At 68% confidence level the standard model is able to predict the value of $\epsilon_K$ to within a factor of 2; however, at 90% confidence level $\eta = 0$ is allowed, so that at this level there is no prediction, only an upper bound. While this is an important success of the CKM theory, it is still worth pursuing credible alternative theories of $CP$ violation.

### 3 Pure superweak theories

A superweak theory \cite{7} is one in which the CKM matrix is real, so $\eta = 0$, and $\mathcal{H}_{\Delta S = 2}$ of eq. (1) originates from physics outside the standard model. We define a pure superweak theory to be one where all flavor changing phenomena (other than $\epsilon_K$) are accurately described.
Figure 1: The 68% and 95% C.L. contours fits of $|V_{ub}/V_{cb}|$ and $\Delta M_{B_d}$ in the $\bar{\rho}/\bar{\eta}$ plane in the standard model. The curves correspond to constraints obtained from measurements of $|V_{ub}/V_{cb}|$, $\Delta M_{B_d}$ and $\Delta M_{B_s}$ (The last constraint is not included in the fit). $\bar{\rho} = \rho(1 - \lambda^2/2), \bar{\eta} = \eta(1 - \lambda^2/2)$.

Table 1: Values of observables and parameters

| | | |
|---|---|---|
| $|V_{ub}/V_{cb}|$ | 0.080 ± 0.020 | |
| $\Delta M_{B_d}$ | 0.472 ± 0.018 ps$^{-1}$ | |
| $\Delta M_{B_s}$ | > 10.2 ps$^{-1}$ at 95% C.L. | |
| $f_{B_d}/\sqrt{B_{B_d}}$ | (200 ± 50) MeV | |
| $f_{B_s}/f_{B_d}/\sqrt{B_{B_d}}$ | 1.10 ± 0.07 | |
| $A$ | 0.81 ± 0.04 | |
| $m_t(m_t)$ | 168 ± 6 GeV | |
by the real CKM matrix. Comparing Figures 1 and 2 at low $\eta$, one sees that the new limit on $B_s$ mixing has excluded superweak theories with negative $\rho$. This has important phenomenological consequences for pure superweak theories.

We have computed $\chi^2(\rho)$ in pure superweak theories, using as input the three observables $|V_{ub}/V_{cb}|$, $\Delta M_{B_d}$ and $\Delta M_{B_s}$. We find that all negative values of $\rho$ are excluded at greater than 99% confidence level. At positive $\rho$ only the two observables $|V_{ub}/V_{cb}|$ and $\Delta M_{B_d}$, are relevant, and we find the most probable value of $\rho$ to be +0.27. However, even this value of $\rho$ corresponds to the pure superweak theory being excluded at 92% confidence level. Since the uncertainties are dominated by the theory of $f_{B_d}\sqrt{B_{B_d}}$, we take the view that this does not exclude purely superweak theories. In such theories positive values of $\rho$ are 40 times more probable than negative values, and hence large values for $f_B\sqrt{B_B} \approx 250$ MeV and small values for $|V_{ub}/V_{cb}| \approx 0.06$ are predicted. A pure superweak description of $CP$ violation implies

$$+0.20 (0.13) < \rho < 0.34 (+0.41) \quad \text{at 68\% (95\%) confidence level} \quad (5)$$

An important consequence of the new limit on $B_s$ mixing is the strong preference for positive $\rho$ and the resulting small values for $|V_{td}| \propto 1 - \rho$. This is numerically significant:
without the $B_s$ mixing result the superweak theory can also have negative values of $\rho$ which give $|V_{td}|$ about a factor of two larger than the positive $\rho$ case. With the $B_s$ result, a pure superweak theory must have $|V_{td}|$ at the lower end of the standard model range. Thus in a pure superweak theory, $\Delta M_{B_s} \propto \Delta M_{B_d}/|V_{td}|^2$ is predicted to be

\[
14 \ (10) \text{ps}^{-1} < (\Delta M_{B_s})_{PSW} < 26 \ (32) \text{ps}^{-1} \quad \text{at 68\% (95\%) confidence level (6)}
\]

By comparison, in the standard model $10.5 \ (9.5) \text{ps}^{-1} < \Delta M_{B_s} < 15 \ (19) \text{ps}^{-1}$ at 68\% (95\%) confidence level.

In the standard model, the branching ratio $B(K^+ \to \pi^+ \nu \bar{\nu})$ is given by

\[
B(K^+ \to \pi^+ \nu \bar{\nu}) = c_1 \left( (c_2 + c_3 A^2 (1 - \rho))^2 + (c_3 A^2 \eta)^2 \right)
\]

where $c_1 = 3.9 \times 10^{-11}, c_2 = 0.4 \pm 0.06$ and $c_3 = 1.52 \pm 0.07$. In pure superweak theories, since $\rho$ is positive and $\eta = 0$, the branching ratio is lowered to

\[
B(K^+ \to \pi^+ \nu \bar{\nu}) = (5.0 \pm 1.0) \cdot 10^{-11}
\]

relative to the standard model prediction of $(6.6^{+1.4}_{-1.2}) \cdot 10^{-11}$.

The recent observation of a candidate event for this decay is not sufficient to exclude pure superweak theories, but further data from this experiment could provide evidence against such theories.

4 General superweak theories

Pure superweak theories are artificial: they do not possess a symmetry which allows $\mathcal{H}_{eff}^{\Delta S=2}$ of eq. (1), while forbidding similar $\Delta B = 2$ operators. If $\epsilon_K$ is generated by new physics, why does this new physics not contribute to $B\bar{B}$ mixing? In general it would be expected to also contribute to $\Delta S = 1$ and $\Delta B = 1$ processes. In the absence of a fundamental theory of flavor, the relative sizes of the various flavor changing operators can be estimated only by introducing arguments based on approximate flavor symmetries.

We assume that the underlying theory of flavor possesses a flavor symmetry group, $G_f$, and a mass scale $M_f$. The breaking of $G_f$, whether explicit or spontaneous, is described in the low energy effective theory by a set of dimensionless parameters, $\{\epsilon\}$, each with a well defined $G_f$ transformation. The low energy effective theory of flavor is taken to be the most general operator expansion in powers of $1/M_f$ allowed by $G_f$ and $\{\epsilon\}$. In the case

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\footnote{This standard model result is smaller than that quoted in the literature because the improved limit on $B_s$ mixing increases $\rho$ even in the standard model.}
that the CKM matrix can be made real, we call these *general* superweak theories. The phenomenology of such theories depends on $G_f, M_f$ and $\{\epsilon\}$ and will typically not coincide with the pure superweak phenomenology. The $\Delta B = 2$ operators may lead to exotic CP violation in neutral $B$ meson decays and may contribute to $\Delta M_{B_d}$, allowing large values of $|V_{td}|$ invalidating (6). Similarly the $\Delta S = 1$ operators may invalidate (8), and may give an observable contribution to $\epsilon'/\epsilon$.

5 The effective Hamiltonian for the “3 mechanism”

The dominant flavor changing neutral current (FCNC) interactions of the down sector of the standard model result from the “3 mechanism”: small flavor breaking parameters which mix the light quarks with the heavy third generation quarks, together with a large, order unity, breaking of the flavor symmetry that distinguishes the third generation from the first two. Hence, beneath the weak scale, the standard model yields an effective Hamiltonian with dominant FCNC operators which contain a factor $V_{ti}^* V_{tj}$ for each flavor changing current $\bar{d}_i d_j$, and a factor $G_\text{f}/2 m^2_f/16\pi^2 \approx (1/16\pi^2)(1/v^2)$ from the loop integration. The relevant diagrams are all 1 loop, giving the $(1/16\pi^2)$ factor, and involve the large GIM violation of the top quark mass; since there is no small flavor violating parameter, the rest of the loop integral has an order of magnitude given by dimensional analysis as $(1/v^2)$.

Now consider physics beyond the standard model where the entire flavor structure of the theory beneath $M_f$ is controlled by $G_f$ and $\{\epsilon\}$ — both the Yukawa matrices of the standard model, $\lambda(\epsilon)$, and the non-standard model operators in $\mathcal{H}_\text{eff}(\epsilon)$. Since the dominant down sector, FCNC effects from $\lambda(\epsilon)$ are known to arise from the “3 mechanism”, we assume that $G_f$ and $\{\epsilon\}$ are chosen so that the dominant such effects from $\mathcal{H}_\text{eff}(\epsilon)$ are also from the “3 mechanism”.

The most general parameterization of the “3 mechanism” in the down sector involves four complex parameters: $\epsilon_{L_i} = |\epsilon_{L_i}| e^{i\phi_{L_i}}$ and $\epsilon_{R_i} = |\epsilon_{R_i}| e^{i\phi_{R_i}}, i = 1, 2$, which describe the mixing of $d_L$ and $d_R$ with $b_L$ and $b_R$. Assuming all phases to be of order unity, we can describe the “3 mechanism” in terms of just four real small parameters $|\epsilon_{L_i}|$ and $|\epsilon_{R_i}|$. We make the additional simplifying assumption that $|\epsilon_{L_i}| = |\epsilon_{R_i}| = \epsilon_i$, yielding the non-standard model interactions\(^4\)

\[
\mathcal{H}^{(3)}_{\text{eff}} = \frac{1}{M_f^2} \left[ C_1 (\epsilon_1 \epsilon_2)^2 (\bar{s}d)^2 + C_2 \epsilon_2^2 (\bar{s}b)^2 + C_3 \epsilon_1^2 (\bar{b}d)^2 \right]
\]

\(^4\)It is straightforward to extend this Hamiltonian to the most general case of the “3 mechanism” involving four complex parameters.
\[ + C_{11} \epsilon_1 \epsilon_2 \left( \bar{s}d(\bar{\ell}) \right) + C_{21} \epsilon_1 \epsilon_2 \left( \bar{s}b(\bar{\ell}) \right) + C_{31} \epsilon_1 \epsilon_2 \left( \bar{b}d(\bar{\ell}) \right) + \ldots \]  

(9)

where \( C_i \) are complex coefficients of order unity, and \( l \) is a lepton field. A sum on possible gamma matrix structures is understood for each operator. Since the flavor changing interactions from both the standard model and the new physics are governed by the same symmetry, we can choose \( \epsilon_1 = |V_{td}| \) and \( \epsilon_2 = |V_{ts}| \). Such interactions can arise from many choices of \( G_f \) and \( \{\epsilon\} \); the particular choice is unimportant, however, as the phenomenology rests only on three assumptions:

- There is an underlying theory of flavor based on symmetry \( G_f \) and breaking parameters \( \{\epsilon\} \).
- The dominant non-standard model FCNC operators of the down sector arise from the “3 mechanism”.
- The symmetry breaking parameters of the down sector are left-right symmetric, and have phases of order unity.

In the standard model, the dominant FCNC of the down sector arises from the “3 mechanism”, so that it is useful to describe the effective theory beneath the weak scale by eq. (9) with

\[ \epsilon_1 = V_{td} \quad \epsilon_2 = V_{ts} \quad \frac{1}{M_f^2} \frac{1}{16\pi^2} \frac{1}{v^2} \]  

(10)

and \( C_i \) real. This special case of the “3 mechanism” has a restricted set of gamma structures due to the left-handed nature of the weak interaction.

6 Phenomenology of the “3 mechanism” in superweak theories

We have argued that pure superweak theories are artificial, and we now study superweak theories where FCNC interactions are generated by the “3 mechanism” and yield \( \mathcal{H}_{\text{eff}}^{(3)} \) of (9). Why should such theories have \( V_{ij} \) real when \( C_i \) are complex? One possibility is that \( G_f \) forces the Yukawa matrices \( \lambda(\epsilon) \) to have a sufficiently simple form that they can be made real by field redefinitions. Another possibility will be discussed later.

\(^{\text{3}}\)We do not consider lepton flavor violation in this letter.
Since $\mathcal{H}_{\text{eff}}^{(3)}$ will be the origin of all CP violation, one may wonder if it could also account for all of $\Delta M_{B_{d,s}}$. This is not possible — charged current measurements, together with the unitarity of $V$, imply $|V_{td}|$ and $|V_{ts}|$ are sufficiently large that $W$ exchange contributes a significant fraction of $\Delta M_{B_{d,s}}$.

Given that the FCNC of both the standard model and exotic interactions have the form of (9), it would appear that the exotic interactions must give a large fraction of $\Delta M_{B_{d,s}}$ since they are responsible for all of $\epsilon_K$. This is not the case; in the standard model the $\Delta S = 2$ and $\Delta B = 2$ operators have chirality $LL$, whereas for a generic “3 mechanism” they will have all chiral structures. It is known that the $LR$, $\Delta S = 2$, operator has a matrix element which is enhanced by about an order of magnitude relative to that of the $LL$ operator [10], and that there is no similar enhancement in the $\Delta B = 2$ case. Furthermore, the $LR$ operator is enhanced by QCD radiative corrections in the infrared [11]; with the enhancement at 1 GeV about a factor of 3 larger than at 5 GeV. Hence we conclude In a generic superweak theory, we expect that $\mathcal{H}_{\text{eff}}^{(3)}$ leads to $\approx 3\%$ contributions to $\Delta M_{B_{d,s}}$.

There is considerable uncertainty in this percentage because of the uncertainty in the overall enhancement of the $\Delta S = 2$ and $\Delta B = 2$ contributions from the $LR$ operator, and because of the unknown order unity $C_i$ coefficients. Given this result, we must evaluate how well these generic superweak theories can account for the data, and to what extent they lead to predictions.

Let $\Delta_{d,s}$ and $\delta_{d,s}$ be the standard model and new physics contributions to

$$\Delta M_{B_{d,s}} = \Delta_{d,s} + \delta_{d,s} \quad (11)$$

First we consider a perturbation around the pure superweak case, where the fractional contributions from new physics $F_{d,s} = \delta_{d,s}/\Delta M_{B_{d,s}}$ are small. The central value of $\rho$, from $\Delta M_{B_d}$ alone, changes by $\Delta\rho = 0.5 F_d$ for very small $F_d$ ($\Delta\rho \approx 0.3 F_d$ for $F_d \approx 0.1$). For positive $F_d$, this improves the fit of general superweak theories to $\Delta M_{B_d}$ and $|V_{ub}/V_{cb}|$. For example, $F_d = 0.1$ gives a central value of $\rho = 0.28$ with $\chi^2(\rho = 0.28) \approx 2.4$, which corresponds to 68% C. L. Since the allowed range of $\rho$ is little changed from eq. (5), the prediction of small $|V_{td}|$ persists in these general superweak theories, so that the prediction of eq. (7) for low values of $B(K^+ \to \pi^+ \nu\bar{\nu})$ applies. Similarly, since $\rho$ is little altered, the prediction for $B_s$ mixing is $\Delta M_{B_s} = (\Delta M_{B_s})_{PSW}(1 - F_d + F_s)$, where the pure superweak prediction $(\Delta M_{B_s})_{PSW}$ is given in eq. (6). In this case the general superweak theory also predicts large values of $\Delta M_{B_s}$, although for negative $F_s$, it is not quite so large as $(\Delta M_{B_s})_{PSW}$.

There is a second class of general superweak theories which is not a perturbation about
the parameters of the pure superweak theories. In general superweak theories, the limit \( \Delta M_{B_s} > 10.2 \) ps\(^{-1}\) can be expressed as \( \rho > -0.06 + 0.5(F_d - F_s) \). For negative \( F_d \) and positive \( F_s \), the negative \( \rho \) region could become allowed. For example, \( F_s = -F_d = 0.1 \) (0.05) gives a theory in which \( \rho \) has a probability 25% (9%) of being negative. This class of superweak theories requires values of \( |F_{d,s}| \) which are larger than our expectation, and appear somewhat improbable. They have \( |V_{td}| \) and \( B(K^+ \to \pi^+ \nu \bar{\nu}) \) at the upper end of the standard model range. In these theories \( \Delta M_{B_s} \) is likely to be low, although it depends on \( F_{d,s} \).

7 Supersymmetry with a “3 mechanism”

In general, the alternative theory of \( CP \) violation of \( \mathcal{H}_{eff}^{(3)} \) from the “3 mechanism” is not a strong competitor to the CKM theory of \( CP \) violation. The CKM theory, with two small measured parameters, \( |V_{us}| \) and \( |V_{cb}| \), yields the correct order of magnitude for \( \epsilon_K \), while superweak theories with the “3 mechanism” apparently require a new scale \( M_f \approx 30v \approx 10 \) TeV. However, there is the interesting possibility that the new physics generates FCNC operators only at 1 loop, as in the standard model. This would give \( M_f \approx 4\pi m_f \), with the mass of the new quanta close to the weak scale at \( m_f \approx 1 \) TeV. We therefore take the view that the “3 mechanism” generating FCNC operators at 1 loop at the weak scale is a credible alternative to the CKM theory of \( CP \) violation. While not as minimal as the CKM theory, it correctly accounts for the order of magnitude of \( \epsilon_K \).

Let \( l \) represent \( d, s \) or \( b \), left or right handed. New interactions of the form \( \bar{l}lH \), where \( H \) is some new heavy field, will generate FCNC at tree level, whereas \( lHH \) generates them at 1 loop. Thus the exotic new heavy particles at the weak scale should possess a parity so that they appear only in pairs.

Weak scale supersymmetry allows a symmetry description of the weak scale, and leads to a successful prediction for the weak mixing angle. Furthermore, it incorporates the economical Higgs description of flavor of the standard model. \( R \) parity ensures that superpartners appear pairwise in interactions, so that the dominant supersymmetric contributions to FCNC processes occur only at one loop. Supersymmetric theories have several new generation mixing matrices — in particular \( W_{L,R} \) at the gluino interaction \( (\tilde{d}_L^R W_{L,R} d_L^R)\tilde{g} \). A flavor symmetry, \( G_f \), can ensure that the largest contribution from superpartner exchange to FCNC occurs via the “3 mechanism” [12, 13]. If the small symmetry breaking parameters
are left-right symmetric and real, this gives $H^{(3)}_{eff}$ of (9) with

$$|W_{L,R_{31}}| \approx \epsilon_1 = |V_{td}|$$

$$|W_{L,R_{32}}| \approx \epsilon_2 = |V_{ts}|$$

$$\frac{1}{M_f^2} = \frac{1}{16\pi^2} \frac{1}{\tilde{m}^2}$$

(12)

where $\tilde{m}$ is the average mass of the colored superpartners in the loop. As the superpartners are at the weak scale, $\tilde{m} \approx v$, and comparing with (10) one finds that, with weak scale supersymmetry, it may well be that $\epsilon_K$ receives comparable standard model and supersymmetric contributions.

Here we stress that weak scale supersymmetry can provide an important example of the general superweak theories discussed in this letter. The absence of CKM $CP$ violation would be guaranteed if $CP$ violation were soft — restricted to operators of dimension two and three. The Yukawa matrices would then be real, so that there would be no $CP$ violation from diagrams with internal quarks, but the scalar mass matrices would contain phases, so that $CP$ violation would arise from diagrams with internal squarks. Soft $CP$ violation in supersymmetric theories, with FCNC operators arising from the “3 mechanism”, represents a well-motivated and credible alternative to CKM $CP$ violation, and will be explored in detail elsewhere.

### 8 Summary

Fits of the CKM matrix to $|V_{ub}/V_{cb}|$, $\Delta M_{B_d}$ and $\Delta M_{B_s}$ show that at 68% C.L. the standard model correctly predicts $\epsilon_K$ to better than a factor of two, while at 90% C.L. not even the order of magnitude can be predicted. On one hand the standard model is highly successful; on the other, there is still room for an alternative theory of $CP$ violation.

The recent improvement on the limit on $\Delta M_{B_s}$.

Given the order of magnitude enhancement of the matrix element of the $LR$ operator relative to the $LL$, and given the further order of magnitude enhancement of $C_{LR}$ relative to $C_{LL}$ from QCD scaling, one generically expects the supersymmetric contribution to be larger. However, these factors may be outweighed by colored superpartner masses somewhat larger than $v$, some degree of degeneracy between the third generation scalars and those of the lighter generations, and by $W_{ij}$ somewhat less than $V_{ij}$. We note that the QCD enhancement of $C_{LR}$ for the $\Delta S = 2$ operator[11] was not included in [12, 13, 14].

This is an alternative view to the one presented in [13], where the specific flavor symmetry forces forms for $V$ and $W$ matrices such that even the supersymmetric contribution to $\epsilon_K$ involves a phase originating from the Yukawa couplings.
We have argued that pure superweak theories are artificial, and have introduced general superweak theories, in which all FCNC are governed by an approximate flavor symmetry and the “3 mechanism.” In this case the new physics induces other flavor changing operators in addition to the $\Delta S = 2$ operator responsible for $\epsilon_K$; in particular, $O(3)\%$ contributions to $B_{d,s}$ mixing are expected. There are two important classes of general superweak theories, one with positive $\rho$ and the other with negative $\rho$. The first can be viewed as a perturbation about the superweak case, with an improved fit to data, while retaining the characteristic predictions mentioned above. The negative $\rho$ possibility appears less likely, and arises only if the new physics contributes more than 10% of $\Delta M_{B_{d,s}}$. In this case future data should show a high value for $B(K^+ \to \pi^+\nu\bar{\nu})$ and low values for $\Delta M_{B_s}$, $f_B\sqrt{\epsilon_B}$, $|V_{ub}/V_{cb}|$, and $\epsilon'/\epsilon$. All these superweak theories predict low values for the $CP$ asymmetries in $B$ meson decays.

Weak scale supersymmetric theories with softly broken $CP$ can provide an important example of general superweak theories. As in the CKM theory, assuming phases of order unity yields a correct prediction for the order of magnitude of $\epsilon_K$. In addition they have $\theta = 0$ at tree level, and it is interesting to seek a flavor symmetry which would sufficiently protect $\theta$ from radiative corrections to solve the strong $CP$ problem.

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