sumably be transcended by the use of a renormalization-group-improved formalism.

[9]This value has been obtained by Weinberg and Nanopoulos (see Ref. 3) in the limit in which vector boson contributions to scalar decay are neglected. If the former are, in fact, included, the baryon-to-entropy ratio is shifted to the range 10^{-9} to 10^{-4}. This is to be compared with the present experimental value of $\simeq 10^{-9}$.

[10]The strategy then would be to determine precisely which (if any) of the X bosons are close (say within an order of magnitude) to the symmetry restoration temperature. If there are none such, finite-temperature effects can presumably safely be ignored. However, if this is not the case, finite-temperature effects would certainly seem to be crucial. Furthermore, in the latter event, a renormalization-group formalism would have to be used because of the breakdown of validity of the naive perturbative approach near T_c.

[11]The finite-temperature mass of the Higgs scalar is proportional to the product of the temperature and the (running) coupling constants of the theory. If asymptotic-freedom arguments persist beyond T_c, then one may conclude that $\mu(T) < kT$ unless the non-asymptotically-free self-couplings become extremely large. With $\mu(T) < kT$ the Higgs scalars would certainly be copiously produced thermally.

[12]The masslessness of the vector bosons above T_c has been called into question by certain authors [M. B. Kislinger and P. D. Morley, Phys. Rev. D 13, 2765 (1976)]. However, the difficulties in handling the infrared divergences of a non-Abelian theory renders their conclusions suspect [see A. D. Linde, Rep. Prog. Phys. 42, 389 (1975) for a discussion of this point].

[13]The lack of a sensible field-theoretic description at such high energies ($10^{16} < T < 10^{19}$ GeV) and in particular the absence of a satisfactory quantum theory of gravity confine one to making only very general speculative remarks. Having said this, it is rather remarkable all the same the Hawking (see the Proceedings of the Marcel Grossmann Meeting, Trieste, 1979), from completely different (topological) considerations, has envisaged a primordial scenario (at a length scale of M_{Planck}^{-1}) in which scalar fields have "induced" masses of $O(M_{\text{Planck}})$ whereas fermions and vector bosons are effectively massless. There is thus a highly suggestive similarity between this and the emergent scenario from grand unified gauge theories above T_c (in which the Higgs scalars are not only the *only* massive particles, but also have masses tending towards M_{Planck} as the temperature rises).

Spontaneous *CP* Nonconservation in Theories with More Than Four Quarks

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It is shown that the requirements of spontaneous *CP* breaking and natural flavor conservation lead to a class of theories where *CP* nonconservation is due solely to Higgs exchange, for an arbitrary number of fermion generations.

Although *CP* nonconservation can be easily incorporated[1] in unified gauge theories, one is still faced with the challenge of understanding the smallness[2] of the violation. It has been pointed out by Lee[3] and Weinberg,[4] that within unified gauge theories of weak and electromagnetic interactions, the Higgs bosons can provide a mechanism for a naturally small *CP*-invariance violation. In unified gauge theories, the fermion Yukawa interactions are such that Higgs-boson exchange leads to an effective Fermi interaction of strength $G_F\, m_F^2/m_H^2$ (where G_F is the Fermi coupling constant, and m_F and m_H are the fermion and Higgs-boson masses, respectively). Thus, in theories where Higgs-particle exchanges are solely responsible for *CP* nonconservation, the smallness of the violation is naturally understood; it merely reflects the fact that Higgs bosons are much heavier[5] than the light fermions. It is clear that in order for this explanation of the size of *CP* nonconservation to hold, it is necessary that *CP* nonconservation arises only through Higgs-boson exchange and from no other sector of the theory. An example of this class of theories has been given by Weinberg,[3] in a model with four quarks and three Higgs doublets. It is well known that if there are only four quarks and no right-handed currents,[6] the gauge interactions of the vector mesons automatically conserve *CP*. However, for three or more Higgs doublets,[4] *CP* invariance will be violated through Higgs-particle exchange. In a theory with three quark doublets (as it seems to be required by experimental evidence), the situation is more complicated, since in general the Cabibbo-like mixing matrix contains a *CP*-nonconserving phase δ. In this case, one loses control over the strength of *CP* nonconservation, since the phase δ is is general arbitrary.

In this paper, I will show that in spite of the proliferation of quarks, it is possible to preserve the attractive scenario of having Higgs-boson exchange as the *only source of CP nonconservation* (and thus having a natural explanation for its small strength). The result will apply to an arbitrary number of quarks, provided one adheres to the following principles: (i) spontaneous breaking of CP invariance; (ii) natural flavor conservation[7] (NFC) in the Higgs sector.

In order to prove my statement, I will start by analyzing the minimal model which conforms to these two principles. I will consider a gauge theory based on $\mathrm{SU}(2)_L \otimes \mathrm{U}(1)$, including an arbitrary number of quarks, with the left-handed components forming SU(2) doublets $\psi_{iL} = (p_i, n_i)_L$, while the right-handed components transform as singlets. The simplest way to satisfy the constraints of NFC is to arrange things so that all quarks of a given charge receive contributions to their mass from the vacuum expectation value of a single neutral Higgs meson. In this case, the biunitary transformation which diagonalizes the quark mass matrix will also diagonalize the Yukawa couplings of the neutral Higgs. Let φ_1 (φ_2) be the Higgs scalar responsible for the mass generation of charge $\frac{1}{3}$ ($\frac{2}{3}$) quarks. In order to generate CP nonconservation through Higgs-particle exchange,[4] a third Higgs doublet (which is chosen not to couple to fermions) is introduced. It is clear that in order to have these selective Higgs couplings, in a natural way, one has to introduce an appropriately chosen set of discrete symmetries. A possible choice is

$$\begin{aligned} D_1\colon\ & \psi_{iL} \to \psi_{iL};\ n_{iR} \to n_{iR};\ p_{iR} \to -p_{iR}; \\ & \varphi_1 \to \varphi_1;\ \varphi_2 = -\varphi_2;\ \varphi_3 \to \varphi_3. \\ D_2\colon\ & \psi_{iL} \to \psi_{iL};\ n_{iR} \to n_{iR};\ p_{iR} \to p_{iR}; \\ & \varphi_1 \to \varphi_1;\ \varphi_2 \to \varphi_2;\ \varphi_3 \to -\varphi_3. \end{aligned} \tag{1}$$

The most general quark Yukawa interactions consistent with D_i and $\mathrm{SU}(2)\otimes\mathrm{U}(1)$ gauge invariance can be written

$$\mathcal{L} = \sum_{ij} \bar{\psi}_{iL} \Gamma_{ij}{}^1 \varphi_1 n_{jR} + \bar{\psi}_{iL} \Gamma_{ij}{}^2 \tilde{\varphi}_2 p_{jR}, \tag{2}$$

where $\tilde{\varphi}_2 = i\sigma_2 \varphi_2{}^*$. The Yukawa coupling constants Γ_{ij} are chosen to be real, so that CP invariance is a good symmetry of the Lagrangian. After spontaneous symmetry breaking, the neutral components of the Higgs doublets acquire vacuum expectation values:

$$\langle \varphi_\alpha{}^0 \rangle = v_\alpha \exp(i\theta_\alpha), \quad \alpha = 1, 2, 3 \tag{3}$$

and the mass terms are given by

$$\sum_{i,j} \{ \bar{n}_{iL} (v_1 \Gamma_{ij}{}^1) \exp(i\theta_1) n_{jR} + \bar{p}_{iL} (v_2 \Gamma_{ij}{}^2) \exp(-i\theta_2) p_{jR} \}. \tag{4}$$

I now make the following phase redefinition of the quark fields:

$$\begin{aligned} & n_{iL}' = n_{iL};\ p_{iL}' = p_{iL}. \\ & n_{jR}' = \exp(i\theta_1) n_{jR};\ p_{jR}' = \exp(-i\theta_2) p_{jR}. \end{aligned} \tag{5}$$

In terms of the primed fields the mass matrices are real and can therefore be diagonalized by a biorthognal transformation:

$$\begin{aligned} & n_{iL}' = (O_L{}^d)_{ij} d_{jL};\ n_{iR}' = (O_R{}^d)_{ij} d_{jR}, \\ & p_{iL}' = (O_L{}^u)_{ij} u_{jL};\ p_{iR}' = (O_R{}^u)_{ij} u_{jR}, \end{aligned} \tag{6}$$

where u_i, d_i are the eigenstates of the mass matrix. The weak left-handed charge current can be written

$$J_{\mu L} = \bar{u}_{iL} \gamma_\mu (O_C)_{ij} d_{jL}, \tag{7}$$

where O_C is given by $O_C = (O_L{}^u)^T O_L{}^d$. Since the generalized Cabibbo matrix O_C is real, it is clear that the gauge interactions will conserve CP, for any arbitrary number of quarks.

I will now show that this result holds in general, and applies to theories with an arbitrary number of Higgs doublets, provided that one conforms to NFC and spontaneous CP-symmetry breaking. Consider the Yukawa interactions corresponding to an arbitrary number of fermion generations and Higgs doublets:

$$L_y = \sum_{i,j,\alpha,\beta} \{ \bar{\psi}_{iL} (\Gamma_\alpha{}^d)_{ij} \varphi_\alpha n_{jR} + \bar{\psi}_{iL} (\Gamma_\beta{}^u)_{ij} p_{jR} \tilde{\chi}_\beta \}, \tag{8}$$

where $\tilde{\chi}_\beta = i\sigma_2\chi_\beta^*$. The sets of Higgs doublets φ_α, χ_β may have elements in common or may be disjoint. The square matrices $\Gamma_\alpha^{u,d}$ correspond to the Yukawa couplings of the up and down quarks, and are chosen to be real, so that *CP* invariance holds at the Lagrangian level. In order to have NFC, the set of square real matrices Γ_α^d should be simultaneously bidiagonalizable (and similarly for Γ_β^u), i.e., there should be orthogonal $O_{L,R}$ matrices which satisfy

$$(O_L^d)^T\Gamma_\alpha^d O_R^d = M_\alpha^d,$$
$$(O_L^u)^T\Gamma_\beta^u O_R^u = M_\beta^u, \tag{9}$$

where M_α^d, M_β^u are diagonal matrices. This is a very strict constraint on the $\Gamma_\alpha^{d,u}$ and in order for it to be satisfied a carefully chosen discrete symmetry has to be introduced. The classification of these discrete groups (and corresponding representations) which lead to NFC has recently been done.[8] The interest in this classification was in great part motivated by the question of calculability of Cabibbo-like angles. In fact, it has been shown that if one imposes NFC in the Higgs couplings, then the mixing angles are either unrealistic (i.e., 0 or $\pi/2$) or arbitrary (i.e., noncalculable). I will not be concerned here with the question of calculability and will therefore assume that the mixing angles are arbitrary. After spontaneous symmetry breaking, the fermion mass terms can be written

$$\sum_{i,j,\alpha,\beta}\{\bar{n}_{iL}(\Gamma_\alpha^d)_{ij}v_\alpha\exp(i\theta_\alpha)n_{jR}+\bar{p}_{iL}(\Gamma_\beta^u)_{ij}v_\beta'\exp(-i\theta_\beta')p_{jR}\}, \tag{10}$$

where $\langle\varphi_\alpha^0\rangle = v_\alpha\exp(i\theta_\alpha)$, $\langle\chi_\beta^0\rangle = v_\beta'\exp(i\theta_\beta')$. Using (9), (10) it is simple to verify that the mass matrices for the up and down quarks can be made real and diagonal through the following transformations:

$$n_{iL} = (O_L^d)_{ij}d_{jL};\quad n_{jR} = (O_R^dK^d)_{jl}d_{lR};$$
$$p_{iL} = (O_L^u)_{ij}u_{jL};\quad p_{jR} = (O_R^uK^d)_{jl}u_{lR}. \tag{11}$$

Where K^u, K^d are diagonal matrices

$$(K^d)_{ii} = \exp(-i\gamma_i),\quad (K^u)_{ii} = \exp(-i\delta_i) \tag{12}$$

with phases γ_i, δ_i satisfying

$$\textstyle\sum_\alpha(M_\alpha^d)_{ii}v_\alpha\exp(i\theta_\alpha) = m_{d_i}\exp(i\gamma_i),$$
$$\textstyle\sum_\beta(M_\beta^u)_{ii}v_\beta'\exp(i\theta_\beta') = m_{u_i}\exp(i\delta_i). \tag{13}$$

Note that u_i, d_i are the physical quark states, with masses m_{u_i}, m_{d_i}. From (11) it follows that the left-handed charged current is still given by (7), and the generalized Cabibbo matrix is real. This completes the proof that, even in this general case, the vector gauge interactions are *CP* conserving. In this class of theories with NFC the *CP*-invariance violation in $K^0\to 2\pi$ decay is entirely due to Higgs-boson exchange and one expects to have relatively light Higgs particles[4] (~15 GeV). As has been emphasized by Weinberg,[4] another clear signature of this class of theories is the prediction of a relatively large neutron electric dipole moment (of the order of 10^{-24} $e\cdot$cm).

Finally, I would like to analyze the implications of abandoning the constraint of NFC but still requiring a spontaneous *CP* nonconservation. In this case, it is possible to obtain spontaneous *CP* nonconservation with just two Higgs doublets, as has been shown by Lee.[3] The *CP* nonconservation results essentially from a relative phase between the vacuum expectation values of the neutral Higgs fields. It is straightforward to verify that in this case, the complex phase coming from the vacuum expectation values will in general also generate a physically meaningful complex phase in the Cabibbo-like matrix (I am, of course, assuming the existence of six quarks) leading to *CP* violation *à la* Kobayashi-Maskawa.[9] One would therefore have two mechanisms[10] for *CP*-invariance violation (KM and Higgs exchange), their relative strength depending on the details of the model. Since in this class of theories the neutral Higgs bosons mediate flavor-changing interactions, one expects them to be very heavy. It may then happen that the KM mechanism provides most of the *CP* nonconservation in *K* decays. However, even if that is the case, Higgs-boson exchange could still play a dominant role in the neutron dipole moment.

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Search for Possible Signatures of Bottom-Meson Production in p-Fe Interactions at 400 GeV/c

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Evidence of bottom-quark–state production has been searched for in p-Fe interactions at 400 GeV/c by looking for multimuon final states. Muons in such final states could come from $B\rightarrow\psi\rightarrow 2\mu$ decay accompanied by a muonic decay of $\overline{B}$ (or $\overline{B}\rightarrow\overline{D}\rightarrow\mu$ chain) or from a combination of B and D muonic decays. With the assumption of a 10% branching ratio for $B\rightarrow\mu X$, a search for several specific decay modes yields an upper limit for the B production cross section of $\lesssim$ 50 nb/nucleon.

Recently there has been reported evidence[1] for the production of a new heavy state in $\pi^- N$ interactions at 150 and 175 GeV/c. The mass of this state, 5.3 GeV, and the observed decay mode,[2] $\psi K\pi$, make it very tempting to associate this new possible state with the predicted B meson, i.e., a postulated bound state of a b and $\overline{d}$ quark. Furthermore, the size of the cross section, about 200 nb based on reasonable assumptions about the branching ratio, appears to be very close to recent theoretical estimates.[3] These same theoretical estimates predict an even larger cross section for 400-GeV p-p interactions.

We report here on the search for multimuon final states in p-Fe interactions at 400 GeV/c which could be possible signatures of $B\overline{B}$ production and decay. The apparatus used in this work has been described in detail previously.[4] Its principal elements are a variable density target calorimeter which measures the total hadronic and electromagnetic energy to ± 3.5% at 400 GeV, an instrumented muon identifier, and a large-solid-angle iron toroidal muon spectrometer. The important characteristics of the apparatus are the large muon acceptance, the ability to determine missing neutrino energy, and the high density of the target calorimeter which strongly suppresses background muons from π and K decays.

We have looked for three specific signatures of $B\overline{B}$ production and decay:

(1) $pN\rightarrow\psi\mu X$, i.e., a final state containing three muons, two of which reconstruct to a ψ mass (2.6 GeV $< M <$ 3.6 GeV) and arise from

