Flavor-changing neutral currents involving b quarks and τ leptons

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We examine the experimental implications of flavor-changing neutral currents (FCNC's) involving b quarks and/or τ leptons. Several final-state configurations signaling the presence of FCNC's are discussed; we find that cascade decays by ordinary charged currents provide a substantial background when looking for FCNC decays of b quarks. Present limits on τ rare decay modes do not as yet rule out FCNC decays. We compare our results with those previously obtained by other authors.

I. INTRODUCTION

As is well known, the standard model of the weak interactions[1-3] provides a natural explanation[4] for the absence of strangeness-changing neutral currents at the level of G_F and $G_F\alpha$ and gives good agreement with the experimental results for the K_L-K_S mass difference and the rate for $K_L \to \mu^+\mu^-$.[5,6] The model in its three-doublet form, known as the Kobayashi-Maskawa (KM) model,[3] also predicts the absence of flavor-changing neutral currents (FCNC's) of any kind, including systems involving heavy quarks, at the level of G_F and $G_F\alpha$. [Within the $SU(2)\times U(1)$ model, the conditions for the natural absence of FCNC's were studied by Glashow and Weinberg.[4]]

So far, the standard model has been very successful; all of the present data on neutral currents[7] as well as charged currents can be accommodated within it. [This includes the decay modes of the D (Refs. 8 and 9) and the τ as well.] There is, however, a substantial portion of the model which has not yet been subject to detailed experimental study since the particles have either not been produced (such as b-carrying mesons) or the data are still in a preliminary form (as in the charm-meson and τ-lepton cases).

Recently, Buccella and Oliver[10] have made a thorough study of possible charm-changing neutral-current (CCNC) effects within the D-meson system and have obtained limits on the allowed range of possible couplings. (Their bound is strongest when the CCNC's are purely left-handed.)

In this paper we will make a parallel analysis for the system of b-carrying mesons; we will assume that the charged currents of the theory are those given by the standard KM model; we will also examine the possibility of e-τ or μ-τ FCNC's.

Section II contains an analysis of B^0-$\bar{B}^0$ transitions and compares the predictions of the standard model to one containing FCNC's for the B^0-$\bar{B}^0$ mass difference; we will also discuss the decay $B^0 \to \tau^-\tau^+$ (analogous to $K_L^0 \to \mu^+\mu^-$). In Sec. III we discuss the possible effects of b FCNC in ν interactions and the possible restrictions that can be obtained by looking for neutral-current b-quark decays.

In Sec. IV we discuss a possible e-τ or μ-τ FCNC and its effects on τ decay and τ production in deep-inelastic eN reactions. Section V contains a comparison of our results and procedures with those of Ali and Aydin.[11] Our conclusions can be found in Sec. VI.

II. THE B^0-$\bar{B}^0$ SYSTEM

In this section we will analyze B^0-$\bar{B}^0$ transitions[11] and compare the predictions of the standard model to one containing a b FCNC. Here B^0 will represent either the $b\bar{d}$ or $b\bar{s}$ meson ($B^0 = b\bar{q}$; $q = d$ or s). In our analysis we will follow the work of Ref. 10.

We will take our effective Lagrangians to be

$$\mathcal{L}^{|\Delta B|=2} = \sqrt{2}G_F\left|\sum_{q=d,s} g_L^q \bar{b}\gamma_\mu \tfrac{1}{2}(1-\gamma_5)q + g_R^q \bar{b}\gamma_\mu \tfrac{1}{2}(1+\gamma_5)q\right|^2 + \text{H.c.} \quad (2.1)$$

for $|\Delta B| = 2$ and

$$\mathcal{L}^{|\Delta B|=1} = \sqrt{2}G_F\left[\sum_{q=d,s} g_L^q \bar{b}\gamma_\mu \tfrac{1}{2}(1-\gamma_5)q + g_R^q \bar{b}\gamma_\mu \tfrac{1}{2}(1+\gamma_5)q\right] J_{\text{WS}}^\mu + \text{H.c.} \quad (2.2)$$

for $|\Delta B| = 1$. Here, we have taken (for any fermion f)

$$J_{\text{WS}}^\mu = \sum_{\text{fermions}} \bar{f}[(T_3^f - 2x_W Q^f)\gamma_\mu - T_3\gamma_\mu\gamma_5]f\,, \quad (2.3)$$

with T_3^f being the usual weak isospin, Q the charge of the fermion f, and $x_W \equiv \sin^2\theta_W \simeq 0.23$. (WS denotes Weinberg-Salam). Obviously the $|\Delta B| = 2$ piece contributes directly to the B^0-$\bar{B}^0$ mass difference while the $|\Delta B| = 1$ piece contributes to b-particle production and decay.

Among the possible b-quark decay modes are the following (we treat the antiquark in the initial state as a spectator):

$$b \to c\bar{u}d \sim V_{11}V_{23}^*, \tag{2.4a}$$

$$b \to c\bar{u}s \sim V_{12}V_{23}^*, \tag{2.4b}$$

$$b \to c\bar{c}d \sim V_{21}V_{23}^*, \tag{2.4c}$$

$$b \to c\bar{c}s \sim V_{22}V_{23}^*, \tag{2.4d}$$

$$b \to u\bar{u}d \sim V_{11}V_{13}^*, \tag{2.4e}$$

$$b \to u\bar{u}s \sim V_{12}V_{13}^*, \tag{2.4f}$$

$$b \to u\bar{c}d \sim V_{21}V_{13}^*, \tag{2.4g}$$

$$b \to u\bar{c}s \sim V_{22}V_{13}^*. \tag{2.4h}$$

Here the V_{ij} are the complex elements of the KM charged-current mixing matrix:

$$J_\mu^{cc} = \mathcal{P}\gamma_\mu(1-\gamma_5)V\mathfrak{N} \tag{2.5}$$

with

$$\mathcal{P} = \begin{bmatrix} u \\ c \\ t \end{bmatrix}, \quad \mathfrak{N} = \begin{bmatrix} d \\ s \\ b \end{bmatrix}. \tag{2.6}$$

In our analysis we will always *assume* that

$$|V_{23}|^2 \gg |V_{13}|^2 \tag{2.7}$$

(consistent with the bounds of Ref. 6) such that b decays mainly into charm. This implies that from a single B_d^0 decay we expect a single (anti) charmed particle with amplitude $V_{11}V_{23}^*$ ($V_{21}V_{13}^*$), with no accompanying K's, as well as a negatively charged lepton if the decay is semileptonic. The B_s^0 decay will yield a single (anti) charmed particle with amplitude $V_{12}V_{23}^*$ ($V_{22}V_{13}^*$), with an accompanying $s\bar{s}$ pair.

Mixing must be taken into account, however, since the B_d^0 and $\bar{B}_d^0$ share common final states, e.g.,

$$\begin{aligned} B_d^0 &\to c\bar{u}d\bar{d} \sim V_{11}V_{23}^*, \\ \bar{B}_d^0 &\to \bar{u}cd\bar{d} \sim V_{21}^*V_{13}. \end{aligned} \tag{2.8}$$

Similarly, for the B_s^0 and $\bar{B}_s^0$ states,

$$\begin{aligned} B_s^0 &\to c\bar{u}s\bar{s} \sim V_{12}V_{23}^*, \\ \bar{B}_s^0 &\to \bar{u}cs\bar{s} \sim V_{22}^*V_{13}. \end{aligned} \tag{2.9}$$

Here, we have shown the initial spectator quark explicitly.

Neglecting CP violation, we form the CP eigenstates $(B^0 \pm \bar{B}^0)/\sqrt{2}$, with definite masses ($m_\pm$) and inverse lifetimes ($\lambda_\pm$). Following Ref. 10, we find the probabilities of getting a negative or a positive lepton from an initially pure B^0 state:

$$\frac{N(B^0 \to l^+ + x)}{N(B^0 \to l^- + x)} = \frac{\delta m^2 + \delta\lambda^2/4}{2\lambda^2 + \delta m^2 - \delta\lambda^2/4}, \tag{2.10}$$

with

$$\lambda = \tfrac{1}{2}(\lambda_+ + \lambda_-), \quad \delta\lambda = \lambda_+ - \lambda_-, \quad \delta m = m_+ - m_-. \tag{2.11}$$

Similarly, one can consider such ratios as

$$\frac{N(B_d^0 \to c^- + \text{pions})}{N(B_d^0 \to c^+ + \text{pions})}, \tag{2.12}$$

with a similar expression for the B_s^0 decay. (In what follows, we will not discuss the hadronic final states for B_s^0 decay since they are quite complicated in signature, e.g., $c + s\bar{s}$.) The expression (2.12) can be evaluated using Eq. (7) of Ref. 10; we denote by α_i the amplitude for $B_d^0 \to c^+ +$ pions ($\sim V_{11}V_{23}^*$) and by β_i the amplitude for $B_d^0 \to c^- +$ pions ($\sim V_{21}V_{13}^*$).

To go further we must say something about the relative sizes of λ, $\delta\lambda$, and δm. Here we employ the quark model; the calculation of λ is straightforward in terms of the V_{ij} and any possible nonleptonic enhancement factors.[12] In this calculation we take the quark masses as given by their current algebra values and we assume that the V_{ij} are given by the central values[13] obtained by Shrock, Trieman, and Wang[6] (STW). To calculate $\delta\lambda$, we consider the matrix

$$\Gamma_{ij} = \sum_n \langle B_i | H_W | n\rangle\langle n | H_W | B_j\rangle \rho_n, \quad i,j = 1,2, \tag{2.13}$$

where B_i is B^0 or $\bar{B}^0$. ρ_n is the appropriate phase-space factor for the final state $|n\rangle$. Note that for B_d^0 the only possible intermediate states are (2.4c) and (2.4e); for B_s^0 the only states are (2.4d) and (2.4f). For Γ_{11} and Γ_{22} we find, trivially,

$$\Gamma_{11} = \Gamma_{22} = \lambda \tag{2.14}$$

and, in the CP-conserving limit,

$$\Gamma_{12} = \Gamma_{21} = \tfrac{1}{2}\delta\lambda. \tag{2.15}$$

Tables I and II show the values for λ and $\delta\lambda/\lambda$ for the B_d^0-$\bar{B}_d^0$ and B_s^0-$\bar{B}_s^0$ systems, respectively, under various assumptions. The values of $\delta\lambda/\lambda$ obtained

TABLE I. Average inverse lifetime, lifetime difference, and δm for the B_d^0 ($\equiv b\bar{d}$) meson system for four different models. A: STW solution (b) without nonleptonic enhancement factors. B: STW solution (a) without nonleptonic enhancement factors. C: Same as A with $f_1^2 + 2f_2^2 = 4$. D: Same as B with $f_1^2 + 2f_2^2 = 4$. For δm we have taken $B(f_B/f_\pi)^2$ equal to unity.

	λ (10^{-2} eV)	$\delta\lambda/\lambda$	δm (eV)
A	1.61	1.30×10^{-1}	1.9×10^{-3}
B	6.54	5.04×10^{-2}	5.4×10^{-4}
C	1.97	1.42×10^{-1}	1.9×10^{-3}
D	7.95	5.54×10^{-2}	5.4×10^{-4}

TABLE II. Same as Table I for the B_s^0 ($\equiv b\bar{s}$) meson system.

	λ (10^{-2} eV)	$\delta\lambda/\lambda$	δm (eV)
A	1.61	3.58×10^{-1}	8.0×10^{-3}
B	6.54	3.32×10^{-1}	4.1×10^{-2}
C	1.97	3.90×10^{-1}	8.0×10^{-3}
D	7.95	3.64×10^{-1}	4.1×10^{-2}

here are comparable to those obtained for the D^0-$\bar{D}^0$ system[10] ($\sim5\times10^{-2}$).

We now turn our attention to δm; in the KM model with no flavor-changing neutral currents we have[5,6]

$$\delta m = \mathrm{Re}\,\frac{-2Bf_B^{\,2}m_B(G_F/\sqrt{2})(\alpha/4\pi)}{3x_W}\sum_{i,j=u,c,t}\lambda_i\lambda_j A_{ij}\,, \tag{2.16}$$

where $\lambda_i = V_{ib}V^*_{id,s}$, x_W is $\sin^2\theta_W$ ($\simeq 0.23$), f_B is the B-meson decay constant, and

$$A_{ij} = (1-x_i)^{-1}(1-x_j)^{-1} + (x_i-x_j)^{-1}\left[\frac{x_i^{\,2}}{(1-x_i)^2}\ln x_i - \frac{x_j^{\,2}}{(1-x_j)^2}\ln x_j\right], \tag{2.17}$$

with $x_i \equiv m_i^{\,2}/m_W^{\,2}$. ($m_W$ is the mass of the W in the WS model.) This results from calculating the diagrams of Fig. 1. The factor B is used to take into account corrections to the vacuum-insertion approximation and is less than unity; for the K^0-$\bar{K}^0$ system, $B\simeq 0.4$.[6] We find ($m_t \simeq 20$ GeV)

$$\delta m_{B_d} \sim 10^{-3}B(f_B/f_\pi)^2 \text{ eV}\,,\qquad \delta m_{B_s} \sim 10\,\delta m_{B_d}\,, \tag{2.18}$$

which, together with Tables I and II, imply [for $B(f_B/f_\pi)^2 = 1$]

$$\left(\frac{\delta m}{\lambda}\right)_B^2 \sim \begin{cases}10^{-7} & \text{for } B_d\\ 10^{-5} & \text{for } B_s\,.\end{cases} \tag{2.19}$$

As a comparison, for the K^0-$\bar{K}^0$ system we find

$$(\delta m/\lambda)_K^{\,2} \approx 0.9\,, \tag{2.20}$$

whereas for the D^0-$\bar{D}^0$ system we expect (assuming no FCNC)

$$(\delta m/\lambda)_D^{\,2} \sim 10^{-6}\,. \tag{2.21}$$

Exact values can be obtained from Tables I and II; we remind the reader that the factor $B(f_B/f_\pi)^2$ may be quite large ($\gg 1$).

If only a $|\Delta B| = 2$ neutral-current piece were present, there would be a contribution to δm of order G_F; since this does not affect $\delta\lambda$ we may write (2.10) as

$$\frac{N(B^0\to l^+ + x)}{N(B^0\to l^- + x)} \simeq \frac{\delta m^2}{2\lambda^2+\delta m^2}\,, \tag{2.10$'$}$$

since we than expect $\delta m^2 \gg \delta\lambda^2$ and, as before, $\lambda^2 \gg \delta\lambda^2/8$. If, however, both $|\Delta B| = 2$ *and* $|\Delta B| = 1$ pieces were present, $\delta\lambda$ could be modified significantly, since B^0 and $\bar{B}^0$ would share more common final states:

$$b\bar{d} \to d\bar{d} + \bar{q}q(l^+l^-, \bar{\nu}\nu)\,,\qquad b\bar{s} \to s\bar{s} + \bar{q}q(l^+l^-, \bar{\nu}\nu)\,. \tag{2.22}$$

A clear signal then, for $|\Delta B| = 1$ couplings of substantial size, is values of λ and $\delta\lambda/\lambda$ much larger than expected.

In the former case, we can calculate δm and use (2.10′) to put bounds on the coupling constants; following Ref. 10 we find, from Fig. 2,

$$\delta m_{\rm FC} = \frac{G_F}{\sqrt{2}} f_B^{\,2} m_B \times\left\{\frac{4}{3}(g_L^{\,2}+g_R^{\,2})f_1 + 2g_Lg_R\left[-\tfrac{1}{9}(8f_2+f_3) + \frac{2}{3}\frac{m_B}{m_b+m_q}\right]\right\}, \tag{2.23}$$

where

$$f_1 = f\,,\quad f_2 = f^{1/2}\,,\quad f_3 = f^{-4}\,, \tag{2.24}$$

and

$$f = \left[1 + \frac{23}{3}\frac{\alpha_S(m_b^{\,2})}{4\pi}\ln\left(\frac{m_W^{\,2}}{m_b^{\,2}}\right)\right]^{-6/23}\,, \tag{2.25}$$

where strong-interaction corrections have been taken into account. Assuming $m_B \simeq m_b + m_q$, we

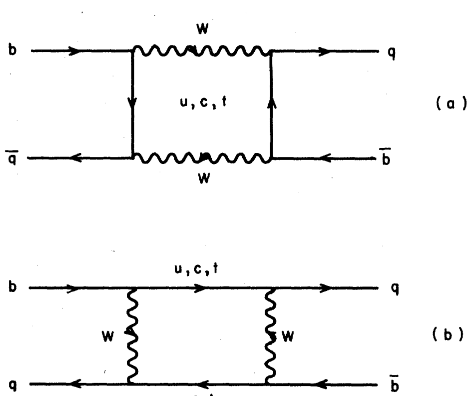

FIG. 1. Graphs contributing to the B^0-$\bar{B}^0$ mass difference in the KM model.

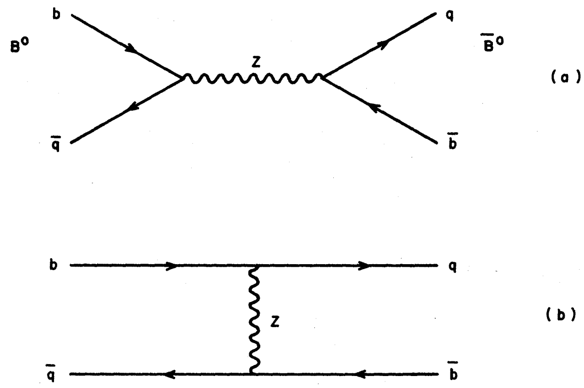

FIG. 2. Additional graphs contributing to the B^0-$\bar{B}^0$ mass difference if FCNC's are present.

can write δm_{FC} as

$$\delta m_{FC}=\frac{G_F}{\sqrt{2}}f_B{}^2 m_B[A(g_L{}^2+g_R{}^2)+Bg_Lg_R]\ , \quad (2.26)$$

with

$$A=\tfrac{4}{3}f_1\ , \quad B=\tfrac{2}{9}(5f_3-8f_2)\ .$$

Given some knowledge of f and f_B and B^0 decay properties, this can provide the same kind of bounds as found in Ref. 10 for the D^0 case.

The values of δm^2 provides the best bounds on $|\Delta B|=2$ couplings; if $|\Delta B|=1$ couplings are present, various bounds can be arrived at by measuring $\delta\lambda$, looking for unexpected final states in b decay, or looking for unexpected production rates of hadrons containing b quarks in ν and $\bar{\nu}$ interactions. Let us examine some of the decay modes for b quarks if FCNC's are present.

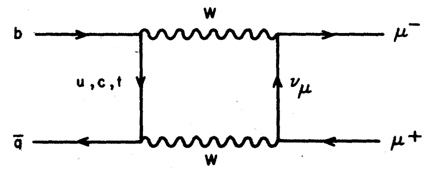

FIG. 3. Graph for $B^0\to\tau^+\tau^-$ in the KM model.

One of the best final states to look for if $|\Delta B|=1$ transitions are present is the decay $B^0\to\tau^+\tau^-$, since τ's are readily identified. As in the case of $K_L\to\mu^+\mu^-$, this decay mode is expected due to one-loop graphs (shown in Fig. 3) as well as other contributions.[14]

Following Shrock and Voloshin[14] we find the "short-distance" contribution to the branching ratio for this mode to be

$$B(B^0\to\tau^+\tau^-)=\frac{G_F{}^2}{2\pi^4}\frac{(1-4m_\tau{}^2/m_B{}^2)^{1/2}}{(1-m_\tau{}^2/m_B{}^2)^2}\frac{\left(\sum_{i=u,c,t}\mathrm{Re}(V_{ib}^*V_{iq})m_i{}^2\right)^2}{|V_{qb}|^2}B(B^+\to\tau^+\nu_\tau)\frac{\tau(B^0)}{\tau(B^+)}\ , \quad (2.27)$$

where $q=d$ or s, depending on the meson. The dominant contribution to the sum is from the t quark and we find

$$B(B^0\to\tau^+\tau^-)\simeq 6.0\times10^{-14}(\mathrm{Re}V_{tq})^2(f_B/f_\pi)^2m_t{}^4$$
$$\sim 2\times10^{-15}(f_B/f_\pi)^2m_t{}^4\ , \quad (2.28)$$

which for $f_B/f_\pi\sim3$, $m_t=25$ GeV is $\sim10^{-8}$.

If $|\Delta B|=1$ FCNC's are present, the above decay can go directly via the diagram in Fig. 4. The rate for this process would be simply

$$\Gamma_{FCNC}=\frac{G_F{}^2f_B{}^2M_B{}^3}{8\pi}\left(\frac{m_\tau}{M_B}\right)^2(1-4m_\tau{}^2/m_B{}^2)^{1/2}(g_L-g_R)^2$$
$$\simeq 8.88\times10^{11}(g_L-g_R)^2f_B{}^2/f_\pi{}^2\ \mathrm{sec}^{-1} \quad (2.29)$$

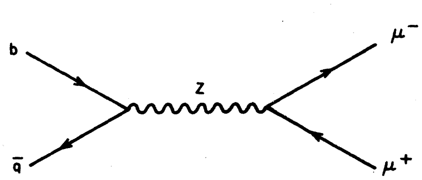

FIG. 4. Additional graph for $B^0\to\tau^+\tau^-$ if FCNC's are present.

or, with a branching ratio,

$$B\sim3\times10^{-2}(g_L-g_R)^2(f_B{}^2/f_\pi{}^2)\ . \quad (2.30)$$

If we knew that B was less than ten times the value given by (2.28), we would find the bound

$$|g_L-g_R|\lesssim3\times10^{-4} \quad (2.31)$$

which is comparable to the charm bound on g_L.[10]

III. FURTHER CONSTRAINTS

In addition to pure leptonic decays, we would also have semileptonic decays as well if $|\Delta B|=1$ FCNC's existed; these data would not give bounds as good as (2.31). Such modes as $b\to dl^+l^-$ and $b\to sl^+l^-$ would be the simplest to detect; apart from phase-space factors these widths would be

$$\Gamma_{SL}=\frac{G_F{}^2M_b{}^5}{768\pi^3}(g_L{}^2+g_R{}^2)(1-4x_W+8x_W{}^2)$$
$$\approx1.6\times10^{-2}(g_L{}^2+g_R{}^2)\ \mathrm{eV}\quad(x_W=0.23)\ . \quad (3.1)$$

Note that this is comparable to the lifetimes found above, apart from the factor $(g_L{}^2+g_R{}^2)$. If Γ_{SL}/Γ_{tot} was $\lesssim10^{-2}$ we could conclude only that

$$(g_L{}^2+g_R{}^2)\lesssim10^{-2}\ , \quad (3.2)$$

which is not as good as (2.31). Similar bounds can be obtained by looking for b-quark production by ν or $\bar{\nu}$ reactions. In the valence-quark limit we find (as in Ref. 10) for an isoscalar target

$$R^{\nu}\equiv\frac{\sigma(\nu N\to\nu B)}{\sigma(\nu N\to\nu X)}\simeq\frac{\frac{1}{4}(g_L{}^2+g_R{}^2/3)}{\frac{1}{2}-x_W+\frac{20}{27}x_W{}^2}\,, \tag{3.3}$$

$$R^{\bar{\nu}}\equiv\frac{\sigma(\bar{\nu}N\to\bar{\nu}B)}{\sigma(\bar{\nu}N\to\bar{\nu}X)}\simeq\frac{\frac{1}{4}(g_L{}^2+3g_R{}^2)}{\frac{1}{2}-x_W+\frac{20}{9}x_W{}^2} \tag{3.4}$$

for a large b-d coupling. If the b-s coupling were large instead, the above ratios would need to be multiplied by the sea (s) to valence ratio which is $\lesssim 0.1$.

Looking at other possible b-quark final states may not provide such clean signals, with a few exceptions; one possibility is $b\to s\bar{s}s$ leading to a three-kaon final state. Apart from possible nonleptonic enhancement effects this should occur with a rate

$$\Gamma_{3K}=\frac{G_F{}^2M_b{}^5}{64\pi^3}(g_L{}^2+g_R{}^2)(\tfrac{1}{4}-\tfrac{1}{3}x_W+\tfrac{2}{9}x_W{}^2)$$
$$\simeq 3.9\times10^{-2}\times(g_L{}^2+g_R{}^2)\text{ eV}\quad(x_W\simeq0.23)\,. \tag{3.5}$$

Again, apart from the factor of $(g_L{}^2+g_R{}^2)$, this rate is comparable to the lifetimes found in Tables I and II.

There are several important backgrounds to consider when looking for FCNC decays of b quarks; these result mainly from the decay chain

$$b\to c\to s\,, \tag{3.6}$$

Consider the FCNC decay $b\to se^+e^-$; a substantial background will come from the decay chain

$$b\to ce^-\nu_e \quad \searrow se^+\nu_e\,, \tag{3.7}$$

which will have a branching ratio of ~1%. Similarly the decay $b\to s\bar{s}s$ may be simulated by the process

$$b\to c\bar{c}s \quad \searrow \bar{s}+x \quad \searrow s+x\,. \tag{3.8}$$

We expect this branching ratio to be quite substantial (~15%). Obviously, a good understanding of these backgrounds is necessary to observe a clean signal for the FCNC modes. Perhaps the best signal, if the b-d FCNC is present, is to look for $b\to dl^+l^-$. Here there will be no accompanying K's and the backgrounds are dominated by electromagnetic effects only.

IV. CONSTRAINTS ON FCNC'S OF THE τ

The present existing data on the τ lepton is completely consistent with the expectations of the standard model.[15] One set of specific final-state modes which would signal τ FCNC's is

$$\tau^-\to e^-\mu^+\mu^-,\quad \tau^-\to e^-e^+e^-,$$
$$\tau^-\to\mu^-\mu^+\mu^-,\quad \tau^-\to\mu^-e^+e^-. \tag{4.1}$$

For these modes we would find the branching ratio

$$\frac{\Gamma(\tau\to3l)}{\Gamma(\tau^-\to\nu_\tau e^-\bar{\nu}_e)}=\tfrac{1}{4}(g_L{}^2+g_R{}^2)(1-4x_W+8x_W{}^2)$$
$$=0.13(g_L{}^2+g_R{}^2)\quad\text{for } x_W\simeq0.23. \tag{4.2}$$

Here g_L and g_R are the left- and right-handed coupling constants for the τ FCNC. Given the present data,[16]

$$B(\tau\to3l)<0.04\,. \tag{4.3}$$

We find only the weak bound

$$\sum(g_L{}^2+g_R{}^2)<1.7\,, \tag{4.4}$$

which clearly does not rule out possible FCNC's involving the τ. Here, the sum extends over the couplings for the processes (4.1).

As another measure of the possible lepton-number-violating FCNC's, we consider the deep-inelastic process $(e,\mu)N\to\tau^-X$. If we normalize this reaction to the charged-current reaction $\nu_\mu N\to\mu^-X$ in the limit that only valence quarks contribute and neglect the phase-space suppression from the heavy τ^- final state,[17] we find (assuming scaling as well)

$$T=\frac{\sigma(e^-N\to\tau^-X)}{\sigma(\nu N\to\mu^-X)}$$
$$\simeq(g_L{}^2+\tfrac{1}{3}g_R{}^2)(u_L{}^2+d_L{}^2)+(\tfrac{1}{3}g_L{}^2+g_R{}^2)(u_R{}^2+d_R{}^2)\,, \tag{4.5}$$

where

$$u_L=\tfrac{1}{2}-\tfrac{2}{3}x_W,\quad u_R=-\tfrac{2}{3}x_W\,,$$
$$d_L=-\tfrac{1}{2}+\tfrac{1}{3}x_W,\quad d_R=\tfrac{1}{3}x_W\,. \tag{4.6}$$

For $x_W\simeq0.23$ this yields

$$T\simeq0.31g_L{}^2+0.13g_R{}^2. \tag{4.7}$$

Hence,

$$\sigma(e^-N\to\tau^-X)$$
$$\simeq(0.31g_L{}^2+0.13g_R{}^2)\times0.74\times10^{-38}\times E^e\text{ cm}^2, \tag{4.8}$$

with E^e being the incident electron energy in GeV. A similar result would hold if the initial lepton were a μ^-. There have been many discussions of heavy-lepton production in ν reactions[18]; the signals for τ^- production by e^- (μ^-) would be similar to those discussed for ν's. Assuming an initially pure pure e^- (μ^-) beam, one would look for an outgoing μ^- (e^-) in the direction opposite to the hadronic jet with a large fraction of the total energy. This results from the leptonic decay of the τ^- after it is produced at the leptonic vertex.

Another possible final state is back-to-back jets, one of which comes from the leptonic vertex; this results from the hadronic decay of the τ. Such a signal, however, can have substantial background from other mechanisms such as associated production.

If FCNC's are present there are several τ final states which would indicate their presence in addition to the pure leptonic decay discussed above; all of these final states would have to contain an e^- (μ^-). For example,

$$\begin{aligned} &\tau^- \to e^-\eta\,, \\ &\tau^- \to e^-\phi\,, \\ &\tau^- \to e^-\rho\,, \\ &\tau^- \to e^-\pi^0\,, \end{aligned} \tag{4.9}$$

and similarly for $\tau^- \to \mu^-$.

Limits on processes such as these have not been presented at this time and may be important in locating possible FCNC's of τ leptons.

V. COMPARISON WITH PREVIOUS WORK

In order to look for FCNC's in heavy-quark systems we have had to examine the predictions of the KM model for the quantities λ, $\delta\lambda$, and δm in both the B_d^0-$\bar{B}_d^0$ and B_s^0-$\bar{B}_s^0$ systems. In earlier work on the KM predictions for these same quantities, rough estimates were made by Ali and Aydin.[11] We have improved upon these calculations in the following ways.

First, we have made use of the newly obtained bounds on the KM mixing angles[6] (we have used the central values obtained by STW). Second, in calculating δm, we have kept the exact formula for A_{ij} [Eq. (2.17)] whereas only the lowest-order terms were kept by the above authors. Thirdly, in calculating both λ and $\delta\lambda$ we have used a detailed calculation of the phase space for the various final states. Lastly, we have used a value of m_t ($\simeq$20 GeV), since $m_t \leq 15$ GeV seems to be ruled out by recent data from PETRA. [Furthermore, we have left $B(f_B/f_\pi)^2$ as a free parameter.]

Our results for the KM predictions can be found in Tables I and II; these are to be compared with the predictions of Ali and Aydin (AA) found in their Table II. Note first that the values obtained here for $\delta\lambda/\lambda$ are ~5–10 times larger than those of AA; most of this can be traced to our value of λ, which is 10–20 times smaller than that found by AA. This results from our different choice for mixing angles and our detailed phase-space considerations.

In calculating δm, AA have assumed $B = 1$ and $(f_B/f_\pi) = 3.85$ or 2.31; using these values we find our results for $\delta m/\lambda$ in the B_d^0-B_d^0 system are larger roughly by a factor of 10. This results, essentially, from the smaller value of λ obtained here. For the B_s^0-B_s^0 system, our results are again larger by a factor of 5–10, most of which is again traceable to our smaller λ value and to mixing-angle differences.

In conclusion, we find our results for these quantities to be in rough agreement with those of AA, except for the λ value by which we differ by roughly a factor of ~10, even though we have made the above improvements in the calculation.

We would like to point out that AA also consider CP-violation effects in the heavy-meson system; such a discussion is outside the scope of this paper.

VI. CONCLUSION

In this paper we have considered the possibility of the existence of flavor-changing neutral currents involving b quarks and τ leptons. We have analyzed the B^0-$\bar{B}^0$ system with and without these currents to see what kind of bounds future experiments can put on any FCNC couplings. We have examined several final states such as $b \to se^+e^-$ which would signal b FCNC's although there is background of a substantial amound due to the ordinary charged-current decay chain

$$b \to c e^- \bar{\nu}_e, \quad c \to s e^+ \nu_e\,.$$

Similarly, we examined the possible limits on couplings which can be arrived at from ν, $\bar{\nu}$ production of b-flavored particles.

For τ leptons, some limits already exist on possible FCNC's although they are quite weak [see Eq. (4.4)], and their existence is certainly not ruled out. One important mode is τ decay into three charged leptons. We can also look for τ production in $e(\mu)N$ deep-inelastic interactions.

We conclude that the Glashow-Iliopoulos-Maiani mechanism has not been tested sufficiently to conclude that quarks (and leptons) heavier than u, d, s, and c (e, μ) do not participate in FCNC's. Much more experimental work is needed in this area.

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