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WEAK MIXING AND *CP* VIOLATION INVOLVING HEAVY QUARKS AND POSSIBLE MEASUREMENTS IN e^+e^- EXPERIMENTS *

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We evaluate weak mass mixing among the neutral heavy mesons with a bottom ($Q = -\frac{1}{3}$) or top ($Q = +\frac{2}{3}$) quark and *CP* violation in the framework of six quark V − A models. It is argued that bottom and top mesons may distinguish the Higgs exchange mechanism of *CP* violation from a complex phase in the quark mass matrix, if bottom and top quark masses are sufficiently different. Estimates of weak mixing and *CP* violating effects for e^+e^- experiments at PETRA, PEP and CESR energies are presented.

1. Introduction

The states $\Upsilon(9.4)$, $\Upsilon'(10.0)$, ..., discovered by Herb et al. [1] are being generally interpreted as bound states of new heavy quarks with charge $Q = -\frac{1}{3}$ (generically called bottom, b) and/or with $Q = +\frac{2}{3}$ (called top, t). The state $\Upsilon(9.4)$ has also been confirmed by the DASP and PLUTO groups [1] at DESY. The tentative interpretation of the storage ring experiments seems to favour a bottomonium assignment for $\Upsilon(9.4)$. The states $\Upsilon'(10.0)$, ... may then either be radial excitations of $\Upsilon(9.4)$, as is favoured by the non-relativistic spectroscopic models, or else some of them might be associated with the top quark. With this interpretation one anticipates a rich spectroscopy of bottom mesons in the mass region 5 GeV $\leqslant m_B \leqslant$ 7 GeV. A somewhat unlikely circumstance may put the top mesons also in the same mass range. On the other hand there is a strong phenomenological basis for the (V − A) structure of charged weak currents [2]. The simplest and natural scheme to accomodate the top and bottom quarks is to extend the standard $SU(2)_L \otimes U(1)$ [3] model, as has been done by Kobayashi and Maskawa [4] (hereafter called KM).

The KM model was originally proposed to incorporate *CP* violation with the

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V – A charged weak currents. It was shown by a number of authors that such a scheme is consistent with the experimental data on *CP* violation [5]. Ellis et al. [6] argued that if *CP* violation is due entirely to the KM phase, then one anticipates rather large *CP* violation effects in the B^0-$\bar{B}^0$ or the T^0-$\bar{T}^0$ mesons. The possibility of observing large weak interaction mixing effects in the decays of neutral top and bottom mesons opens new vistas to study *CP* violation, which hitherto has not been observed outside the K^0-$\bar{K}^0$ complex.

Motivated by the observation of ref. [6], we study the weak mixing effects in all the possible neutral meson complexes having a top or bottom quark, namely B_d^0-$\bar{B}_d^0$, B_s^0-$\bar{B}_s^0$, T_u^0-$\bar{T}_u^0$ and T_c^0-$\bar{T}_c^0$ ★. *CP* violation due to mass mixings in all four neutral meson systems is calculated using the KM phase, as well as Higgs exchanges, which, as argued by Lee [7] and Weinberg [8], can also generate *CP* violating amplitudes. We also address ourselves to the question of experimentally observing weak mixing and *CP* violating effects in e^+e^- colliding beam experiments at PETRA, PEP and CESR. Our conclusions are summarised below.

(i) The weak mass mixings in the B_s^0-$\bar{B}_s^0$ and T_u^0-$\bar{T}_u^0$ mesons are large by at least $\cot^2\theta_C$ (θ_C = Cabibbo angle), as compared to the B_d^0-$\bar{B}_d^0$ and T_u^0-$\bar{T}_u^0$ mesons, respectively. We obtain ($s_i \equiv \sin\theta_i$)

$$(\Delta m)_{B_s^0\text{-}\bar{B}_s^0}/(\Delta m)_{B_d^0\text{-}\bar{B}_d^0} \simeq \cot^2\theta_C\left(\frac{s_2+s_3}{s_2}\right)^2 ,$$

$$(\Delta m)_{T_c^0\text{-}\bar{T}_c^0}/(\Delta m)_{T_u^0\text{-}\bar{T}_u^0} \simeq \cot^2\theta_C\left(\frac{s_2+s_3}{s_3}\right)^2 , \qquad (1.1)$$

where θ_2 and θ_3 are mixing angles in the KM mass matrix (for bounds on these angles see sect. 2). The enhancement ($\cot^2\theta_C$) is due to the standard four (GIM) quark couplings.

(ii) The *CP* violating ratios $\mathrm{Im}(m_{12})/\Delta m_{12}$ in the KM model are comparable for the B_d^0-$\bar{B}_d^0$ and T_u^0-$\bar{T}_u^0$ mesons, namely

$$(\mathrm{Im}\, m_{12}/\Delta m_{12})_{B_d^0\text{-}\bar{B}_d^0} \simeq (\mathrm{Im}\, m_{12}/\Delta m_{12})_{T_u^0\text{-}\bar{T}_u^0} \simeq \tan 2\delta ,$$

but differ for the B_s^0-$\bar{B}_s^0$ and T_c^0-$\bar{T}_c^0$ mesons:

$$(\mathrm{Im}\, m_{12}/\Delta m_{12})_{B_s^0\text{-}\bar{B}_s^0} \simeq \frac{s_2 \sin 2\delta}{s_3 + s_2 \cos\delta} ,$$

★ We use the following notation for the bottom and top mesons.

$$B_d^0 = b\bar{d} , \quad B_u^- = b\bar{u} , \quad B_s^0 = b\bar{s} , \quad B_c^- = b\bar{c} ,$$

$$T_u^0 = t\bar{u} , \quad T_d^+ = t\bar{d} , \quad T_s^+ = t\bar{s} , \quad T_c^0 = t\bar{c} ,$$

and similarly for antiparticles $\bar{B}^0$, B^+, etc.

$$(\mathrm{Im}\, m_{12}/\Delta m_{12})_{\mathrm{T_c^0}\text{-}\overline{\mathrm{T}}{}_c^0} \simeq \frac{s_3 \sin 2\delta}{s_2 + s_3 \cos\delta} \ .$$

Defining

$$\epsilon_m^{(\mathrm{B_d^0})} \equiv (\mathrm{Im}\, m_{12}/\Delta m_{12})_{\mathrm{B_d^0}\text{-}\overline{\mathrm{B}}{}_d^0} \,, \qquad \text{etc.,}$$

which coincide with the usual *CP* violating parameter $|\epsilon|$ defined through the relation

$$\epsilon = \frac{\frac{1}{2}\mathrm{Im}\,\Gamma_{12} + i\,\mathrm{Im}\, m_{12}}{\frac{1}{2} i \Delta\Gamma - \Delta m_{12}} \,,$$

in the limit

$$\mathrm{Im}\,\Gamma_{12}/\mathrm{Im}\, m_{12} \ll 1 \,, \qquad \Delta\Gamma/\Delta m_{12} \ll 1 \,,$$

one obtains the following relations *:

$$\epsilon_m^{(\mathrm{B_d^0})} = \epsilon_m^{(\mathrm{T_u^0})} = ((s_3 + s_2\cos\delta)/s_2)\, \epsilon_m^{(\mathrm{B_s^0})}$$

$$= ((s_2 + s_3\cos\delta)/s_3)\, \epsilon_m^{(\mathrm{T_c^0})} \simeq \frac{|\epsilon_\mathrm{K}|}{s_2 s_3 \left(-\ln\dfrac{m_c^2}{m_\mathrm{K}^2} - 1 + s_2^2 \dfrac{m_\mathrm{K}^2}{m_c^2}\right)} \ . \tag{1.2}$$

Here $|\epsilon_\mathrm{K}|$ refers to the $\mathrm{K^0}$-$\overline{\mathrm{K}}{}^0$ system.

(iii) If the KM phase $\delta = 0$ (or $<10^{-4}$) and *CP* is violated through the Higgs exchange mechanism, then the following relationships hold among the *CP* violating parameters:

$$\frac{\epsilon_m^{(\mathrm{B_d^0})}}{|\epsilon_\mathrm{K}|} \simeq \frac{\epsilon_m^{(\mathrm{B_s^0})}}{|\epsilon_\mathrm{K}|} \simeq \frac{m_t^2}{m_c^2} \,, \qquad \frac{\epsilon_m^{(\mathrm{T_u^0})}}{|\epsilon_\mathrm{K}|} \simeq \frac{\epsilon_m^{(\mathrm{T_c^0})}}{|\epsilon_\mathrm{K}|} \simeq \frac{m_b^2}{m_c^2} \,. \tag{1.3}$$

The scaling behaviour (1.3) stems from the fermion-fermion-Higgs couplings, which in a spontaneously broken gauge theory are proportional to the fermion mass. Thus, *CP* violation due to weak mass mixings in the top and bottom mesons are also predicted to be large from the Higgs exchange mechanism. Moreover, the KM phase δ and the Higgs induced *CP* violations can, in principle, be distinguished through the ratio $\epsilon_m^{\mathrm{B^0}}/\epsilon_m^{\mathrm{T^0}}$ which is 1 for the former case and m_b^2/m_t^2 for the latter **.

* The *CP* violation relations (1.2) and (1.3) are independent of the lifetime, τ of the bottom and top mesons.

** It is conceivable that the mass difference ($m_t - m_b$) is negligible as compared to either m_t or m_b, in which case the predictions of the KM phase δ and the Higgs exchange mechanism for $|\epsilon_\mathrm{B}^{(m)}|/|\epsilon_\mathrm{T}^{(m)}|$ would be practically the same. However, we would like to emphasize the growing strength of the Higgs induced *CP* violation with the quark mass, which could produce an effective *CP* violating interaction of order G_F in the decay of heavy mesons ($\mathrm{Q\bar{q}}$) with $m_\mathrm{Q} \sim m_\mathrm{H}$.

We advocate a precise measurement of the inclusive process:

$$\begin{aligned} e^+e^- &\to (B_d^0\bar{B}_d^0,\ B_s^0\bar{B}_s^0,\ T_u^0\bar{T}_u^0,\ T_c^0\bar{T}_c^0) \\ &\quad \to \ell^{\pm}\ell^{\pm} + \text{anything}\,, \end{aligned} \tag{1.4}$$

with $\ell = e, \mu$.

Defining $N^{\pm\pm}$ as the number of events of the type $(X^{\mp}\ell^{\pm}\nu_{\ell})(X^{\mp}\ell^{\pm}\nu_{\ell})$, due to the semileptonic decay of a pair of neutral heavy mesons with $X^{\pm}$ any system of hadrons and photons, a measure of the weak mixing is the ratio

$$r_2 \equiv \frac{N^{++} + N^{--}}{N^{++} + N^{--} + N^{-+} + N^{+-}}\,.$$

The charge asymmetry,

$$a \equiv (N^{++} - N^{--})/(N^{++} + N^{--}) \simeq 4 \,\mathrm{Re}\, \epsilon\,,$$

measures *CP* violation. We estimate r_2 and a for all the four top and bottom neutral meson systems and investigate their sensitivity on the (as yet unknown) mixing angles and the mass of the t quark.

We emphasize that the states $\ell^{\pm}\ell^{\pm}$ + anything (and hence a contribution to r_2) can arise from the cascade decays of the bottom mesons as well. For example, the process

$$\begin{array}{l} e^+e^- \to B_d^0\bar{B}_d^0 \\ \qquad \hookrightarrow \bar{D}\ell^+\nu_{\ell},\ \rho\ell^+\nu_{\ell},\ \ldots \\ \quad \hookrightarrow D(n\pi),\ \ldots \\ \qquad\quad \hookrightarrow K\ell^+\nu_{\ell},\ K^*\ell^+\nu_{\ell},\ \ldots \end{array} \tag{1.5}$$

will give rise to final states like in (1.4). An experimentally useful handle to separate the genuine weak mixing effects (1.4) from the "background" (1.5) may be provided by the nature of the lepton energy spectra. It has been argued by one of us (A.A.) [11] that (i) the hierarchy of the kinematic mass differences involved in the B and D decays namely

$$(m_B - m_D)\,,\ (m_B - m_{D^*})\,,\ (m_B - m_{\rho}) >> (m_D - m_K)\,,\ (m_D - m_{K^*})\,, \text{etc.}$$

and (ii) the isoscalar nature of the dominant $\Delta B = -\Delta C = -\Delta Q$ transition in the KM model, which suppresses the multipionic emission in the semileptonic decay, will distinguish the lepton energy spectra from the B and D semileptonic decays. More precisely, (i) and (ii) are expected to give rise to very hard energy spectrum for the leptons from the decays

$$B \to D\ell\nu_{\ell}\,,\quad D\pi\ell\nu_{\ell}\,,\quad D^*\ell\nu_{\ell}\,.$$

On the other hand, the experimental lepton energy spectrum from the charm decay $D \to (K, K^*)\, \ell\nu_\ell$ is very soft [11,13]. A reasonable assumption about the nature of the charm quark $\to$ charm hadron fragmentation shows that the lepton energy spectrum from the chain

$$
\begin{aligned}
&B \to c(q\bar{q}) \\
&\quad \hookrightarrow D + \ldots \\
&\qquad \hookrightarrow (K, K^*)\, \ell^+\nu_\ell
\end{aligned}
$$

maintains this feature up to sufficiently high centre-of-mass energies. Consequently, a high enough lepton energy cut-off will suppress the final states $\ell^\pm \ell^\pm$ + anything from the cascade decay (1.5).

We also calculate the contribution of the top and bottom quarks to the electric dipole moment of the neutron, using Higgs exchange mechanism [8].

The paper is organised as follows. In sect. 2 we describe briefly the KM model and estimate weak mass mixing, Δm, the lifetime differences, $\Delta\Gamma$, and the ratios $\Delta m/\Gamma$, $\Delta\Gamma/\Gamma$ for all the four top and bottom neutral meson systems. Signatures of weak mass mixings are discussed in sect. 3. Sect. 4 contains estimates of the *CP* violating parameter $|\epsilon|$, using Higgs exchange mechanism as well as the KM phase δ, and the charge asymmetry, "a". Also contained in sect. 4 are the b- and t-quarks' contribution to the electric dipole moment of the neutron, using the Higgs exchange mechanism. In this section we also discuss the dependence of the various asymmetries on the mixing angles and on the mass of the t-quark. Sect. 5 contains a discussion of our results.

2. KM model and the weak mixings

For the purpose of this paper, the KM model is represented by the charged weak current

$$
J_\mu^- = (\bar{u}, \bar{c}, \bar{t})\, \gamma_\mu (1 - \gamma_5) \begin{pmatrix} c_1 & -s_1 c_3 & -s_1 s_3 \\ s_1 c_2 & c_1 c_2 c_3 - s_2 s_3\, e^{i\delta} & c_1 c_2 s_3 + s_2 c_3\, e^{i\delta} \\ s_1 s_2 & c_1 s_2 c_3 + c_2 s_3\, e^{i\delta} & c_1 s_2 s_3 - c_2 c_3\, e^{i\delta} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}, \tag{2.1}
$$

where $c_i\ (s_i) = \cos\theta_i\ (\sin\theta_i)$, $i = 1, 2, 3$, and we recall the bounds from Cabibbo universality and the observed $K_L - K_S$ mass difference [5]:

$$
\begin{aligned}
&s_3^2 < 0.06\,, \\
&s_1^2 \simeq \sin^2\theta_C = 0.05\,, \\
&s_2^2 < \eta \ln \eta + ((\eta \ln \eta)^2 + \eta)^{1/2}\,, \qquad \eta = m_c^2/m_t^2 \\
&\quad = 0.15 \qquad \text{for} \qquad m_t = 5\ \text{GeV} \\
&\quad = 0.06 \qquad \text{for} \qquad m_t = 15\ \text{GeV}\,.
\end{aligned} \tag{2.2}
$$

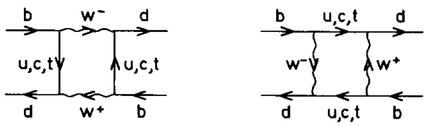

Fig. 1. Lowest-order quark diagram contributing to the B^0-$\bar{B}^0$ mass difference. The diagrams for the other neutral meson systems are similar with appropriate interchange of the quarks.

The weak interaction mass mixings among a pair of conjugate mesons are calculated in the standard way [10] through the $2W^{\pm}$ exchange box diagrams, shown in fig. 1. The results can be expressed in terms of an effective Lagrangian:

$$\mathcal{L}_{\text{eff}} = -\frac{G_F}{\sqrt{2}} \frac{\alpha}{4\pi} \frac{1}{m_W^2 \sin^2\theta_W} \tilde{m} \xi \tilde{O} , \tag{2.3}$$

where θ_W is the Weinberg angle. The mass mixing term Δm is now obtained by taking the matrix element of eq. (2.3) between single particle conjugate neutral meson states:

$$(\Delta m)_P = \frac{1}{m_P} \langle \bar{P} | -\mathcal{L}_{\text{eff}} | P \rangle , \tag{2.4}$$

with P = B_d^0, B_s^0 etc. In eq. (2.3) $\tilde{m}$, ξ and $\tilde{O}$ are the quark mass factor coming from the internal quark lines in fig. 1, the angle factor in the KM mass matrix, and the

Table 1
Weak mass mixing factors for the neutral bottom and top mesons

Meson system	$\tilde{m}$	ξ	$\tilde{O}$	$\langle \bar{P} \vert \tilde{O} \vert P \rangle$
B_d^0-$\bar{B}_d^0$	$m_t^2 + m_c^2 + \frac{2m_t^2 m_c^2}{m_t^2 - m_c^2} \ln \frac{m_c^2}{m_t^2}$	$s_1^2 s_2^2 \cos 2\delta$	$\{\bar{d}\gamma_\mu(1-\gamma_5)\, b\}^2$	$f_{B_d}^2 m_{B_d}^2$
B_s^0-$\bar{B}_s^0$	$m_t^2 + m_c^2 + \frac{2m_t^2 m_c^2}{m_t^2 - m_c^2} \ln \frac{m_c^2}{m_t^2}$	$(s_3 + s_2 \cos\delta)^2$	$\{\bar{s}\gamma_\mu(1-\gamma_5)\, b\}^2$	$f_{B_s}^2 m_{B_s}^2$
T_u^0-$\bar{T}_u^0$	m_b^2	$s_1^2 s_3^2 \cos 2\delta$ a)	$\{\bar{u}\gamma_\mu(1-\gamma_5)\, t\}^2$	$f_{T_u}^2 m_{T_u}^2$
T_c^0-$\bar{T}_c^0$	m_b^2	$(s_2 + s_3 \cos\delta)^2$	$\{\bar{c}\gamma_\mu(1-\gamma_5)\, t\}^2$	$f_{T_c}^2 m_{T_c}^2$

For the definition of $\tilde{m}$, ξ and $\tilde{O}$ see text (eq. (2.3)). The pseudoscalar coupling constants f_B etc., are defined as $\langle 0 | \bar{b}\gamma_\mu\gamma_5 d | B^0 \rangle = f_B (p_B)_\mu$.

a) Exact entry is:

$$s_1^2 s_3^2 \left[\cos 2\delta + \frac{4m_s^2}{m_b^2} \frac{s_2}{s_3} \cos\delta + \frac{m_s^2}{m_b^2} \frac{s_2}{s_3} \right] .$$

effective non-leptonic Hamiltonian, respectively. A summary of the old and new results for Δm, concerning the top and bottom neutral mesons, is given in table 1. Column 5 is obtained by saturating the matrix element in (2.4) by the intermediate vacuum state. This amounts to using a valence quark wave function for quark operators in $\mathcal{L}_{\mathrm{eff}}$ and might very well be an overestimation of the matrix element (2.4). From table 1 we obtain the following relations (it is tacitly assumed that both θ_2 and θ_3 are non-zero):

$$\frac{(\Delta m)_{\mathrm{B_s^0}\text{-}\overline{\mathrm{B}}_\mathrm{s}^0}}{(\Delta m)_{\mathrm{B_d^0}\text{-}\overline{\mathrm{B}}_\mathrm{d}^0}} = \cot^2\theta_\mathrm{C}\left(\frac{s_2+s_3}{s_2}\right)^2\left(\frac{f^2_{\mathrm{B_s^0}}m_{\mathrm{B_s}}}{f^2_{\mathrm{B_d^0}}m_{\mathrm{B_d}}}\right), \tag{2.5}$$

$$\frac{(\Delta m)_{\mathrm{T_c^0}\text{-}\overline{\mathrm{T}}_\mathrm{c}^0}}{(\Delta m)_{\mathrm{T_u^0}\text{-}\overline{\mathrm{T}}_\mathrm{u}^0}} = \cot^2\theta_\mathrm{C}\left(\frac{s_2+s_3}{s_3}\right)^2\left(\frac{f^2_{\mathrm{T_c^0}}m_{\mathrm{T_c^0}}}{f^2_{\mathrm{T_u^0}}m_{\mathrm{T_u^0}}}\right). \tag{2.6}$$

We estimate the last parenthesis in (2.5) and (2.6) to be O(1). The mass mixing effects in the $\mathrm{B_s^0}$-$\overline{\mathrm{B}}_\mathrm{s}^0$ and $\mathrm{T_c^0}$-$\overline{\mathrm{T}}_\mathrm{c}^0$ mesons are then enhanced by at least $\cot^2\theta_\mathrm{C}$ ($\simeq$20), and this enhancement is, within our estimates, independent of the assumption of vacuum (intermediate state) saturation.

We emphasize that the enhanced mixings of $\mathrm{B_s^0}$-$\overline{\mathrm{B}}_\mathrm{s}^0$ and $\mathrm{T_c^0}$-$\overline{\mathrm{T}}_\mathrm{c}^0$ would have negligible phenomenological consequences if the strong decays $\mathrm{B_s^0} \to \mathrm{B^0}\overline{\mathrm{K}}^0$, $\mathrm{B^+K^-}$ and $\mathrm{T_c^0} \to \mathrm{T^0}\overline{\mathrm{D}}^0$, $\mathrm{T^+D^-}$ were allowed, since then both $\Delta m/\Gamma$ and $\Delta\Gamma/\Gamma$ are negligible. However guessing from the (D-$\mathrm{F^\pm}$) mass splitting for the charm mesons, we anticipate a similar pattern of mass differences among the bottom and top mesons. In discussing the phenomenological consequences we shall *assume* that none of the pseudoscalar mesons ($\mathrm{B_d^0}$, $\mathrm{B_s^0}$, $\mathrm{T_u^0}$, $\mathrm{T_c^0}$, ...) is allowed to decay strongly.

The states $\mathrm{B_d^0}$ and $\overline{\mathrm{B}}_\mathrm{d}^0$ (and similarly the other neutral mesons) are mixed by the weak interaction. Consequently the mass eigenstates are a linear combination of $\mathrm{B_d^0}$ and $\overline{\mathrm{B}}_\mathrm{d}^0$, which we denote by B_1, and B_2, having definite lifetimes Γ_1 and Γ_2. In the absence of *CP* violation, they are also definite eigenstates of the *CP* operator and are represented as

$$B_{1,2} \equiv \sqrt{\tfrac{1}{2}}(\mathrm{B^0} \pm \overline{\mathrm{B}}^0)\,.$$

We now evaluate the lifetime differences, $\Delta\Gamma = \Gamma_1 - \Gamma_2$. The contribution to $\Delta\Gamma$ comes from the final states with no net leptonic or flavour quantum numbers. The pure leptonic states, $\ell^\pm \ell^\mp$ will not contribute to $\Delta\Gamma$, to order $G_\mathrm{F}\alpha$ due to the generalised GIM mechanism. The two-quark final states give very small contribution to $\Delta\Gamma$ as well as to Γ, due to helicity argument. The main contribution to $\Delta\Gamma$ then comes from the diagrams shown in fig. 2 with 2a contributing to the $\mathrm{T_u^0}$-$\overline{\mathrm{T}}_\mathrm{u}^0$ and $\mathrm{B_d^0}$-$\overline{\mathrm{B}}_\mathrm{d}^0$ transitions, and 2b to the $\mathrm{T_c^0}$-$\overline{\mathrm{T}}_\mathrm{c}^0$ and $\mathrm{B_s^0}$-$\overline{\mathrm{B}}_\mathrm{s}^0$ transitions. We list the results for

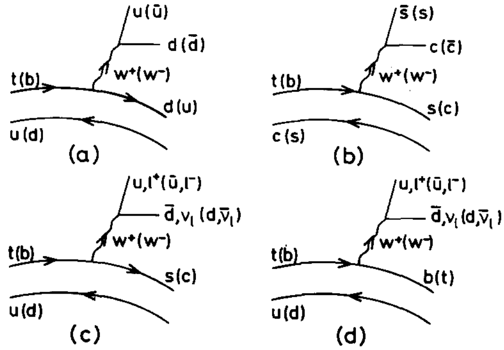

Fig. 2. Quark diagrams contributing to $\Delta\Gamma$, and the widths Γ of the neutral top and bottom mesons. (a) Leading contribution to $\Delta\Gamma$ for B_d^0-$\bar{B}_d^0$ and T_u^0-$\bar{T}_u^0$ mesons. (b) Leading contribution to $\Delta\Gamma$ for B_s^0-$\bar{B}_s^0$ and T_c^0-$\bar{T}_c^0$ mesons. (c) Leading diagram for the decay of the lowest lying top (or bottom) mesons below the threshold of bottom (top) quark. (d) Leading diagram for the decay of the lowest lying top (or bottom) mesons above the threshold of both the top and bottom mesons.

$\Delta\Gamma$:

$$(\Delta\Gamma)_{B_d^0\text{-}\bar{B}_d^0} = \frac{G_F^2}{64\pi^3} m_b^5 s_1^2 s_3^2 \,,$$

$$(\Delta\Gamma)_{B_s^0\text{-}\bar{B}_s^0} = \frac{G_F^2}{64\pi^3} m_b^5 (s_2^2 + s_3^2 + 2s_2 s_3 \cos\delta)\, \phi_b \,,$$

$$(\Delta\Gamma)_{T_u^0\text{-}\bar{T}_u^0} = \frac{G_F^2}{64\pi^3} m_t^5 s_1^2 s_2^2 \,,$$

$$(\Delta\Gamma)_{T_c^0\text{-}\bar{T}_c^0} = \frac{G_F^2}{64\pi^3} m_t^5 (s_2^2 + s_3^2 + 2s_2 s_3 \cos\delta)\, \phi_t \,, \tag{2.7}$$

where ϕ_b, ϕ_t are phase-space factors. We estimate $\phi_b = 0.2$ and $\phi_t = 0.5$ for $m_b = 5$ GeV, $m_t = 15$ GeV.

Note that both Δm and $\Delta\Gamma$ are independent of whether the transition $t \to b$ is real or virtual. However, Γ obviously depends on whether the transition $t \to b$ is allowed by the phase space. Identifying tentatively $\Upsilon(9.4)$ with the bottom quark, we shall use the following formulae, derived from the quark decay model *, to determine the widths.

$$\Gamma(B) = \frac{G_F^2 m_b^5}{32\pi^3} \left[s_1^2 s_3^2 + (s_2^2 + s_3^2 + 2s_2 s_3 \cos\delta)\, \phi(m_c^2/m_b^2)\right] ,$$

* See Ellis et al., ref. [6].

$$\Gamma(\mathrm{T}) = \frac{G_F^2 m_t^5}{32\pi^3}\left[s_1^2 s_2^2 + (s_2^2 + s_3^2 + 2s_2 s_3 \cos\delta)\,\phi\left(\frac{m_s^2}{m_t^2}\right)\right.$$

$$\left. + c_2 c_3 \cos\delta\,(c_2 c_3 \cos\delta - 2s_2 s_3)\,\phi(m_b^2/m_t^2)\right], \tag{2.8}$$

where

$$\phi(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \ln x\,.$$

The rates for $\Gamma(\mathrm{B_s^0})$ and $\Gamma(\mathrm{T_c^0})$ can be obtained from $\Gamma(\mathrm{B_d^0})$ and $\Gamma(\mathrm{T_u^0})$ respectively, if one takes into account the mass differences. In numerical calculation we have used

$$m_{\mathrm{B_d^0}} = m_b = 5.0\ \mathrm{GeV}\,,$$

$$m_{\mathrm{B_s^0}} = m_{\mathrm{B}} + 0.2\ \mathrm{GeV}\,,$$

$$m_{\mathrm{T_c^0}} = m_{\mathrm{T_u^0}} + 1.5\ \mathrm{GeV}\,.$$

3. Experimental consequences of weak mass mixing

In this section we discuss the experimental implications of weak mass mixing from the production and decay of top and bottom quarks. Our concern here is primarily the forthcoming experiments at PETRA, PEP and CESR. First, we note that barring the possibility of both s_2 and s_3 vanishingly small ($\ll 10^{-2}$), the lifetimes of the bottom mesons are expected to lie in a range 10^{-12}–10^{-13} sec.

A rough empirical formula is

$$\tau(\mathrm{B}) = [s_1^2 s_3^2 + \tfrac{1}{3}(s_2^2 + s_3^2 + 2s_2 s_3 \cos\delta)]^{-1} \times 10^{-13}\ \mathrm{sec.}$$

For the top mesons, the uncertainty in life times due to mixing angles is much less if the top mesons lie higher in mass than the bottom mesons, which is the attitude we have taken in this paper. Typical life times for top mesons are described by the approximate quark model relation

$$\tau(\mathrm{T}) = (15\ \mathrm{GeV}/m_{\mathrm{T}})^5 \times 10^{-17}\ \mathrm{sec.}$$

Thus, for both top and bottom mesons only time integrated information on mixing effects would be available. In this respect, all that has been said about the methods and measurements of weak mixing in $\mathrm{D^0}$-$\mathrm{\bar{D}^0}$ mesons * applies to the mixing among $\mathrm{B^0}$-$\mathrm{\bar{B}^0}$ and $\mathrm{T^0}$-$\mathrm{\bar{T}^0}$ mesons. However, apart from the differences in the magnitude of $\Delta m/\Gamma$ and $\Delta\Gamma/\Gamma$ for the charm mesons on one side, and the top and bottom mesons on the other, the expected selection rules for the top and bottom decays are differ-

* For mixing and *CP* violation in the $\mathrm{D^0}$-$\mathrm{\bar{D}^0}$ system, see ref. [9].

ent. This circumstance, by itself, justifies a reappraisal of the entire situation.

First, note the following selection rules which are built in the KM model [4] (M is the approximate matrix element).

$$|M(\Delta T = -\Delta B = \Delta Q,\ \Delta C = \Delta S = \Delta I = 0)|^2 \propto c_2^2\ , \tag{3.1}$$

$$|M(\Delta T = \Delta S = \Delta Q,\ \Delta B = \Delta C = \Delta I = 0)|^2 \propto (s_2 + s_3)^2\ , \tag{3.2}$$

$$|M(\Delta T = \Delta Q,\ \Delta B = \Delta C = \Delta S = 0,\ \Delta I = \tfrac{1}{2})|^2 \propto s_1^2 s_3^2\ , \tag{3.3}$$

$$|M(\Delta B = -\Delta C = -\Delta S = -\Delta Q,\ \Delta I = 0)|^2 \propto (s_2 + s_3)^2\ , \tag{3.4}$$

$$|M(\Delta B = -\Delta Q,\ \Delta C = \Delta S = 0,\ \Delta I = \tfrac{1}{2})|^2 \propto s_1^2 s_3^2\ , \tag{3.5}$$

If $s_3 < s_2$, then (3.3) and (3.5) would be very small as compared to the rest. The selection rules (3.1)–(3.5) lead to very definite predictions about the composition of final states in the bottom and top decays. Next, we discuss the signatures of weak mass mixings, bearing in mind that (3.4) is a $b\bar{b}$ state, and $m_t > m_b$.

Consider the decay of B^0 meson first. On the basis of (3.4), one anticipates the dominance of charm final states *. However, without mixing the final states in e^+e^- collision have total $C = 0$. With weak mixings, one will have final states with $C = \pm 2$. Since the mixing in the D^0-$\bar{D}^0$ sector is negligible, the final states with (D^0D^0) and $(\bar{D}^0\bar{D}^0)$ are as good signals as (D^+D^+) and (D^-D^-) for B^0-$\bar{B}^0$ mixing. Consequently, transitions like $D^{*0} \to D^0\pi^0$, $D^+\pi^-$ will not blur the signatures of B^0-$\bar{B}^0$ mixing. B^0-$\bar{B}^0$ mixing will give rise to processes of the type:

$$\begin{aligned} e^+e^- \to B_d^0\bar{B}_d^0 \xrightarrow[\text{mixing}]{} & 2((d\bar{c})\,\ell^+\nu_\ell)\ ,\quad 2((c\bar{d})\,\ell^-\bar{\nu}_\ell)\ ,\\ & 2((d\bar{c})(u\bar{d}))\ ,\quad 2((c\bar{d})(\bar{u}d))\ ,\\ & 2((c\bar{u})(d\bar{d}))\ ,\quad 2((u\bar{c})(d\bar{d}))\ , \end{aligned} \tag{3.6}$$

where $d\bar{c}$ means D, D*, D**, etc. The signatures of B^0-$\bar{B}^0$ mixing are then (i) $2(D^0, \bar{D}^0, D^\pm)$ with the accompanying hadrons non-strange (π, ρ etc.); (ii) two like-sign leptons (μ, e) with hard momentum spectra and accompanying kaons **.

The B_s^0-$\bar{B}_s^0$ production and mixing will involve processes of the type:

$$\begin{aligned} e^+e^- \to B_s^0\bar{B}_s^0 \xrightarrow[\text{mixing}]{} & 2((s\bar{c})\,\ell^+\nu_\ell)\ ,\quad 2((c\bar{s})\,\ell^-\bar{\nu}_\ell)\ ,\\ & 2((s\bar{c})(u\bar{d}))\ ,\quad 2((c\bar{s})(\bar{u}d))\ ,\\ & 2((c\bar{u})(\bar{s}d))\ ,\quad 2((u\bar{c})(s\bar{d}))\ , \end{aligned} \tag{3.7}$$

* The explicit form of the selection rules is due to Ellis et al. [6]. For earlier speculations, see also ref. [12].

** For explicit lepton momentum spectrum calculations see Ali, ref. [11]. See also, Walsh [12].

where again $c\bar{u}$ and $c\bar{s}$ mean D, D*, D**, ... and F, F*, F**, ..., respectively. The signatures of B_s^0-$\bar{B}_s^0$ mixing are then

(i) $2F^{\pm}$ with the accompanying hadrons non-strange (π, ρ);

(ii) $2(D^0, \bar{D}^0, D^{\pm})$ with accompanying kaons;

(iii) two like-sign leptons (μ, e) with hard momentum spectra and accompanying η, η', ϕ [13] ⋆.

Above the threshold of the t-quark, the dominant transition is expected to be (3.1), though under special circumstances the transition (3.2) may also compete ⋆⋆. The T^0-$\bar{T}^0$ production and mixing will lead to the mixed modes of the type:

$$\begin{aligned} e^+e^- \to T^0\bar{T}^0 \xrightarrow[\text{mixing}]{} & 2((b\bar{u})\, \ell^+\nu_\ell)\,, \quad 2((u\bar{b})\, \ell^-\nu_\ell)\,, \\ & 2((b\bar{u})(u\bar{d}))\,, \quad 2((u\bar{b})(\bar{u}d))\,, \\ & 2((b\bar{d})(u\bar{u}))\,, \quad 2((d\bar{b})(u\bar{u}))\,. \end{aligned} \tag{3.8}$$

The signatures of T^0-$\bar{T}^0$ mixing are:

(i) $2(B^{\pm}, B^0, \bar{B}^0)$ with the accompanying hadrons non-strange (B^+ can be identified through $B \to \bar{D}^0\pi^+$ and $\bar{B}$ through $D^0\pi^-$ or $D^+\pi^-\pi^-$ modes etc. ...);

(ii) two like-sign leptons (μ, e) and the accompanying hadrons identified as $2B^-$ or $2B^+$. The shape of the lepton spectrum now depends on the mass difference $m_t - m_b$.

The T_c^0-$\bar{T}_c^0$ mixing leads to final states involving $2(J/\psi)$ or 4D mesons:

$$\begin{aligned} e^+e^- \to T_c^0\bar{T}_c^0 \xrightarrow[\text{mixing}]{} & 2[(c\bar{c})\, \ell^+\nu_\ell\, \ell^-\bar{\nu}_\ell]\,, \\ & 2[(c\bar{c})\, \ell^-\nu_\ell(u\bar{d})]\,, \\ & 2[(c\bar{c})\, \ell^+\nu_\ell(\bar{u}d)]\,, \\ & 2[(c\bar{c})(u\bar{d})(\bar{u}d)]\,, \\ & 2[(c\bar{u})(\bar{c}d)(u\bar{d})]\,. \end{aligned} \tag{3.9}$$

⋆ For the semileptonic decays of $F^{\pm}$ mesons, see ref. [13].

⋆⋆ The relative rate of $t \to s + ...$ and $t \to b + ...$ transitions is determined by the expression (derived from quark decay model):

$$\frac{\Gamma(t \to s + (u\bar{d} \text{ or } \ell^+\nu_\ell)}{\Gamma(t \to b + (u\bar{d} \text{ or } \ell^+\nu_\ell)} \simeq \frac{(s_2 + s_3)^2}{c_2^2}\, \frac{\phi_t(m_s/m_t)}{\phi_t(m_b/m_t)}\,,$$

where

$$\phi_t(x) = 1 - 8x^2 + 8x^6 - x^8 - 12x^4 \ln x^2\,.$$

For $m_t \geqslant 5$ GeV, $\phi(m_s/m_t) \simeq 1$, but if $(m_t - m_b)$ is not large ($\leqslant 1$ GeV), there can be substantial suppression of the $t \to b$ transition due to phase space. It has been argued [14] that $s_2 \sim 0.5$ and $s_3 \leqslant \sin\theta_C$. The two circumstances together may make $t \to s + ...$ transition comparable to $t \to b$.

However, all these states can also be reached without T_c^0-$\overline{T}_c^0$ mixing. One could advocate six-lepton final states $\ell^\pm \ell^\pm 2(\ell^+ \ell^-)$ as definite evidence of T_c^0-$\overline{T}_c^0$ mixing, but the branching ratio is expected to be very small.

On the other hand, the nature of the lepton momentum spectrum may provide a handle on distinguishing the primary leptons in the decay $t \to b\ell^+\nu_\ell$ from the ones coming from the secondary process $b \to c\ell^-\bar{\nu}_\ell$. This will be the case if $(m_t - m_b) >$ 5 GeV, since then one anticipates a very hard lepton momentum spectrum for the primary leptons from top decay, $t \to b\ell^+\nu_\ell$. So, a high enough momentum cut-off (for example, $E_{\ell^\pm} > 5$ GeV for $m_t \geqslant 10$ GeV and $E_{\text{c.m.}} = 20$–25 GeV) may be used to remove the secondary leptons. The final states $2(J/\psi, \psi')\,\ell^+\ell^+$ and $2(J/\psi, \psi')\,\ell^-\ell^-$ with both the leptons very energetic is evidence of T_c^0-$\overline{T}_c^0$ mixing. In the absence of a clear hierarchy in the masses of the heavy quarks, which translates itself in the hadron and lepton energy spectra of the decay products, it would be difficult to detect T_c^0-$\overline{T}_c^0$ mixing experimentally.

After discussing the possible signatures of the various neutral meson mixing, we reproduce the formula for the mixing effects. (This formula first discussed for D^0-$\overline{D}^0$ mixing is due to Pais and Treiman in ref. [9].) In particular, one has for the $B_d^0 \leftrightarrow \overline{B}_d^0$ transition:

$$r_1 \equiv \frac{\Gamma(B^0 \to X^- \ell^+ \nu_\ell)}{\Gamma(B^0 \to X^+ \ell^- \bar{\nu}_\ell)} = \frac{(\Delta\Gamma/2\Gamma)^2 + (\Delta m/\Gamma)^2}{2 - (\Delta\Gamma/2\Gamma)^2 + (\Delta m/\Gamma)^2} \,. \tag{3.10}$$

Similar expressions are valid for $B_s^0 \leftrightarrow \overline{B}_s^0$, $T_u^0 \leftrightarrow \overline{T}_u^0$ and $T_c^0 \leftrightarrow \overline{T}_c^0$ transitions. The mixing effects associated with the semileptonic decay could be measured in an inclusive process in e^+e^- annihilation experiments of the type:

$$e^+e^- \to \ell^\pm \ell^\pm + \text{anything}\,, \qquad (\ell = e, \mu)\,. \tag{3.11}$$

Denoting by $N^{\pm\pm}$ the number of events of the type $(X^\mp \ell^\pm \nu_\ell)(X^\mp \ell^\pm \nu_\ell)$, which come from $B^0\overline{B}^0$ etc. production and mixing, one has (see Okun et al. in ref. [9]):

$$\begin{aligned} r_2 &= \frac{N^{++} + N^{--}}{N^{++} + N^{--} + N^{+-} + N^{-+}} \\ &= \frac{(4(\Delta m)^2 + (\Delta\Gamma)^2)(8\Gamma^2 + 4(\Delta m)^2 - (\Delta\Gamma)^2)}{32(\Gamma^2 + (\Delta m)^2)^2} \,. \end{aligned} \tag{3.12}$$

The ratios r_1 and r_2 for the bottom mesons depend on the mass of the top quark through Δm and on the angles θ_2 and θ_3 through Γ, $\Delta\Gamma$ and Δm. However, note that both $\Delta m/\Gamma$ and $\Delta\Gamma/\Gamma$ for the B_s^0-$\overline{B}_s^0$ system are rather insensitive to θ_2 and θ_3, and are large. Consequently, the predictions for the B_s^0-$\overline{B}_s^0$ system are much more reliable. Numerical estimates for $\Delta m/\Gamma$ and $\Delta\Gamma/\Gamma$, which are valid if $m_t > m_b$ are given for convenience in table 2 as well as an estimate of r_1, and r_2 for all the four top and bottom neutral meson systems. For these estimates, we have assumed $m_b =$

Table 2
Estimates of τ, $\Delta m/\Gamma$, $\Delta\Gamma/\Gamma$, r_1, r_2 and "a" for the various neutral bottom and top mesons, mixed by weak interactions

Meson system		B_d^0-$\bar{B}_d^0$	B_s^0-$\bar{B}_s^0$	T_u^0-$\bar{T}_u^0$	T_c^0-$\bar{T}_c^0$
$\tau(\times 10^{-14}$ sec.)		1.8	1.5	1.2×10^{-3}	7.6×10^{-4}
$\Delta\Gamma/\Gamma$		1.8×10^{-2}	9×10^{-2}	3.5×10^{-3}	6.5×10^{-2}
$\Delta m/\Gamma$	(i)	0.1	3.1	1.7×10^{-4}	5.5×10^{-3}
	(ii)	3.5×10^{-2}	1.1	2×10^{-5}	7×10^{-4}
r_1	(i)	5×10^{-3}	0.82	1.5×10^{-6}	5×10^{-4}
	(ii)	6×10^{-4}	0.4	1.5×10^{-6}	5×10^{-4}
r_2	(i)	1×10^{-2}	0.5	3×10^{-6}	1×10^{-3}
	(ii)	1.2×10^{-3}	0.4	3×10^{-6}	1×10^{-3}
"a" KM	(i)	5×10^{-4}	4×10^{-5}	5×10^{-6}	1×10^{-5}
	(ii)	1×10^{-3}	1×10^{-4}	1×10^{-8}	2×10^{-8}
"a" Higgs	(i)	3×10^{-2}	5×10^{-3}	4×10^{-5}	1.5×10^{-4}
	(ii)	7×10^{-2}	1×10^{-3}	7×10^{-8}	3×10^{-7}

(i) and (ii) correspond to assuming $f_B = 500$ MeV, $f_T/f_B = m_t/m_b$ and $f_B = 300$ MeV, $f_T/f_B = \sqrt{m_t/m_b}$ respectively. We have assumed $m_b = 5.0$ GeV, $m_t = 15.0$ GeV, $\theta_2 = \theta_3 = \theta_C$ and $\sin\delta = 2.6 \times 10^{-3}$.

5.0 GeV, $m_t = 15.0$ GeV, $\theta_3 = \theta$ (Cabibbo) and $\theta_2 = \theta_2^{max}(m_t = 15$ GeV). For a fixed value of $m_t = 15$ GeV, variation in r_1 and r_2 with respect to θ_2 and θ_3 for the bottom meson system are shown in figs. 3, 4, respectively. In fig. 5, the dependence of r_1 and r_2 on the mass of the top quark are shown for fixed value of $\theta_3 = \theta_C$ and $\theta_2 = \theta_2^{max}(m_t)$. Note that the estimates of r_1 and r_2 for the top meson systems are typically $<10^{-3}$ for a large range of m_t, θ_2 and θ_3 and are not shown in the figures. Note also that while the mixing effects in B_s^0-$\bar{B}_s^0$ are large and rather uniform, the measurement of r_1 and r_2 for the B^0-$\bar{B}^0$ system would require a rather fortutions situation with respect to θ_2, θ_3 and m_t.

Concluding this section we remark that in an experimental setup N^{+-} receives contribution from the $C\bar{C}$ production and decay, as well as from states like B^+B^- etc., which are not mixed. In order to use eq. (3.12), it is necessary to identify the parent particles as $B^0\bar{B}^0$ etc. One could, by using the signature listed above, demand definite hadrons to eliminate this background. We also remind that the cascade decays

$$\begin{array}{l} e^+e^- \to b\bar{b} \\ \quad \hookrightarrow \bar{c} + \ldots \\ \quad \hookrightarrow c\ell^-\bar{\nu}_\ell \quad \hookrightarrow \bar{s}\ell^-\bar{\nu}_\ell \end{array}$$

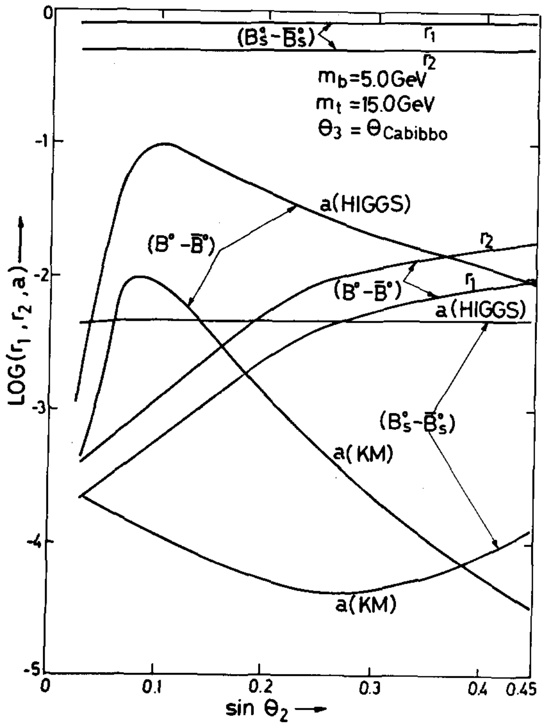

Fig. 3. Asymmetries r_1, r_2 and "a" for the neutral bottom meson systems as a function of the weak angle θ_2.

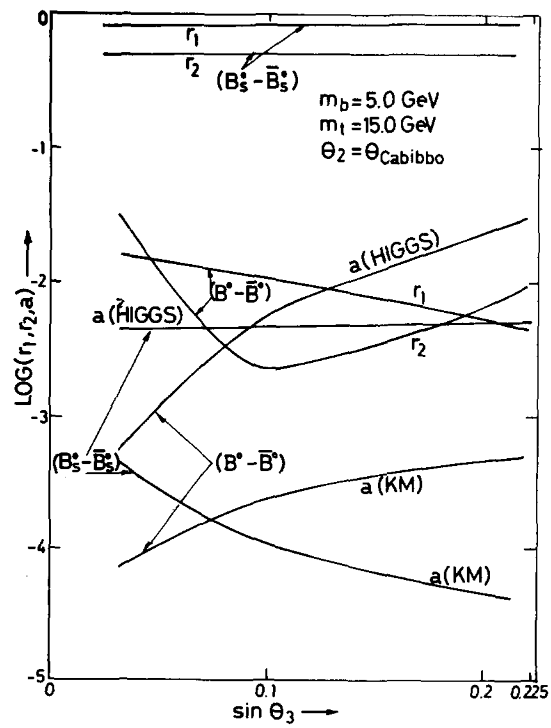

Fig. 4. Asymmetries r_1, r_2 and "a" for the neutral bottom meson systems as a function of the weak angle θ_3.

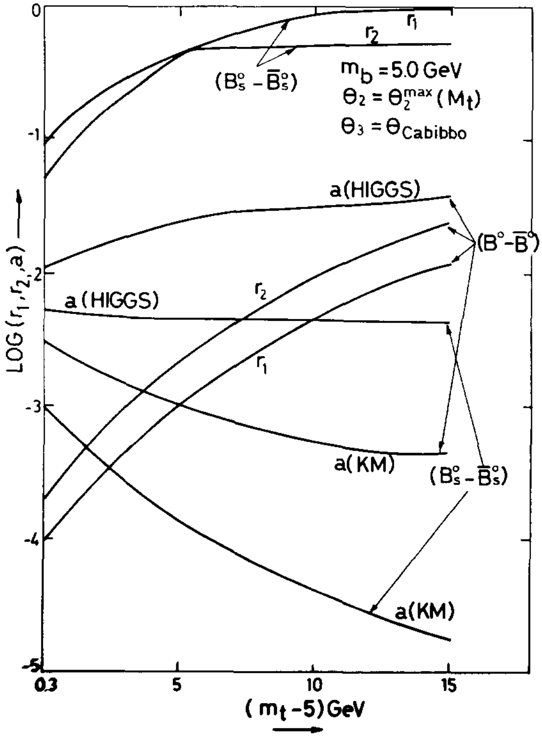

Fig. 5. The dependence of the asymmetries r_1, r_2 and "a" for the neutral bottom meson systems on the mass of the top quark.

contribute to N^{--} (and similarly to N^{++}) and this background would have to be eliminated by using a high lepton momentum cut-off. Of course, the identification of definite hadronic states in the reaction like (3.11) or the high lepton momentum cut-off necessarily compromise statistics, but such are the pains in the search of weak mixing effects in any case!

4. *CP* violation

CP violation in the K^0-$\bar{K}^0$ system, with the KM phase δ, has been calculated by a number of authors [5], and that in the B_d^0-$\bar{B}_d^0$ system by Ellis et al. [6]. The *CP* impurity parameter ϵ is defined, for the B_d^0-$\bar{B}_d^0$ system, for example, by

$$B_{1,2} = N[(1 + \epsilon_B)\, B^0 \pm (1 - \epsilon_B)\, \bar{B}^0] , \qquad (4.1)$$

with

$$N = [2(1 + |\epsilon_B|^2)]^{-1/2} ,$$

$$\epsilon_{\rm B} = \frac{\frac{1}{2}{\rm Im}\,\Gamma_{12}^{\rm B} + i\,{\rm Im}\,m_{12}^{\rm B}}{\frac{1}{2}i\Delta\Gamma^{\rm B} - \Delta m^{\rm B}}\,. \tag{4.2}$$

Ignoring Im Γ_{12} one obtains

$$|\epsilon_{\rm B}| = \epsilon_m^{(\rm B)}/(1 + \tfrac{1}{4}(\Delta\Gamma^{\rm B}/\Delta m^{\rm B})^2)^{1/2}\,, \tag{4.3}$$

$$\mathrm{Re}\,\epsilon_{\rm B} = \frac{1}{2}\frac{\Delta\Gamma^{\rm B}}{\Delta m^{\rm B}}|\epsilon_{\rm B}|\,, \tag{4.4}$$

where

$$\epsilon_m^{(\rm B)} \equiv {\rm Im}\,m_{12}^{\rm B}/\Delta m_{12}^{\rm B}\,. \tag{4.5}$$

The CP violating parameter $\epsilon_m^{\rm B}$ (which reduces to $|\epsilon_{\rm B}|$ if $(\Delta\Gamma)^2 \ll \Delta m^2$) for the $\rm B^0$-$\rm \overline{B}^0$ and $\rm T^0$-$\rm \overline{T}^0$ system are given by [6]

$$\epsilon_m^{(\rm B_d^0)} = \tan 2\delta \simeq \epsilon_m^{(\rm T_u^0)}\,. \tag{4.6}$$

We remark that while $\epsilon_m^{(\rm B_d^0)}$ and $\epsilon_m^{(\rm T_u^0)}$ are comparable in the KM model, $|\epsilon^{\rm B}|$ and $|\epsilon^{\rm T}|$ are in general not, since *a priori* $\Delta\Gamma/\Delta m$ are in general very different for the $\rm B^0$-$\rm \overline{B}^0$ and $\rm T^0$-$\rm \overline{T}^0$ systems. CP violation in the $\rm B_s^0$-$\rm \overline{B}_s^0$ and $\rm T_c^0$-$\rm \overline{T}_c^0$ system can be readily evaluated and we find

$$\epsilon_m^{(\rm B_s^0)} \simeq \frac{s_2 \sin 2\delta}{s_3 + s_2\cos\delta}\,, \qquad \epsilon_m^{(\rm T_c^0)} \simeq \frac{s_3 \sin 2\delta}{s_2 + s_3\cos\delta}\,. \tag{4.7}$$

Thus, one obtains

$$\begin{aligned}\epsilon_m^{(\rm B_d^0)} = \epsilon_m^{(\rm T_u^0)} &= \frac{s_3 + s_2\cos\delta}{s_2}\,\epsilon_m^{(\rm B_s^0)} = \frac{s_2 + s_3\cos\delta}{s_3}\,\epsilon_m^{(\rm T_c^0)} \\ &= |\epsilon_{\rm K}|/s_2 s_3\left(-\ln\frac{m_c^2}{m_t^2} - 1 + s_2^2\frac{m_t^2}{m_c^2}\right).\end{aligned} \tag{4.8}$$

So, $\epsilon_m^{(\rm B_s^0)}$ and $\epsilon_m^{(\rm T_c^0)}$ may differ considerably from $\epsilon_m^{(\rm B_d^0)}$ and $\epsilon_m^{(\rm T_u^0)}$ depending on the angles θ_2 and θ_3.

It has been argued [5,6] that if the entire CP violation in the $\rm K^0$-$\rm \overline{K}^0$ sector comes from δ, then $s_2 s_3 \sin\delta = 10^{-3}$. Using the upper bounds on s_2 and s_3, one estimates that $\epsilon_m^{(\rm B_d^0)}, \epsilon_m^{(\rm T_u^0)}$ are bigger as compared to $|\epsilon_{\rm K}|$ by at least an order of magnitude. However, it is conceivable that the CP violation observed in the $\rm K^0$-$\rm \overline{K}^0$ system may not be attributed to small mixings in the six-quark mass matrix. The conditions under which the KM phase δ can (but may not) vanish are investigated by Fritzsch in the context of an $\rm SU(2)_L \otimes SU(2)_R \otimes U(1)$ model [14]. The resulting $(V - A)$ charged current is then identical to (2.1) but with $\delta = 0$ and hence no CP violation. One is then forced to try other mechanisms of CP violation. Within the context of the standard $\rm SU(2)_L \otimes U(1)$ model [3], it has been suggested that Higgs exchange can be used to implement *CP* violation in a natural way [7,8].

To recapitulate, one now has to extend the minimal Higgs structure of the standard model [3] by adding at least two extra Higgs doublets. In order to restrict the proliferation of the various Higgs couplings to the quarks and vector bosons, and to avoid $\Delta S \neq 0$ (and $\Delta C \neq 0$), $\Delta Q = 0$ transitions to order $G_F\alpha$, some discrete symmetry transformations are necessary [8] which allow only two of the Higgs doublets to be coupled; one to the right-handed quarks with $Q = +\frac{2}{3}$ and the other to the right-handed quarks with $Q = -\frac{1}{3}$. The Yukawa (Higgs-quark-quark) interaction is then of the form

$$\mathcal{L}_Y = \sum_{i,j=1}^{3} \Gamma_{ij}^{(1)} n_{iR}(\varphi_1^{+*} P_{jL} + \varphi_1^{0*} n_{jL})$$

$$+ \sum_{i,j=1}^{3} \Gamma_{ij}^{(2)} P_{iR}(\varphi_2^0 P_{jL} - \varphi_2^+ n_{jL}) + \text{h.c.}\,, \tag{4.9}$$

where $P_i(n_i)$ are quarks with charge $+\frac{2}{3}\,(-\frac{1}{3})$ and $P_{jL,R} \equiv (1 \mp \gamma_5) P_j$. The symmetry is now broken spontaneously by giving non-zero vacuum expectation values to φ_1^0, and φ_2^0. One then chooses a basis in which the quark mass matrix is diagonal. The charge current matrix can be made identical to the KM matrix and we assume $\delta = 0$. The Lagrangian (4.9) in this basis now becomes (u, d, s, etc. are mass eigenstates):

$$\mathcal{L}_Y = (\lambda_1^*)^{-1} \varphi_1^{0*} [m_d \bar{d}_R d_L + m_s \bar{s}_R s_L + m_b \bar{b}_R b_L]$$

$$+ (\lambda_2)^{-1} \varphi_2^0 [m_u \bar{u}_R u_L + m_c \bar{c}_R c_L + m_t \bar{t}_R t_L]$$

$$+ (\lambda_1^*)^{-1} \varphi_1^{+*} [m_d c_1 \bar{d}_R u_L + m_d c_2 s_1 \bar{d}_R s_L - m_s s_1 c_3 \bar{s}_R u_L$$

$$+ m_s(c_1 c_2 c_3 - s_2 s_3) \bar{s}_R c_L - m_b s_1 s_3 \bar{b}_R u_L + m_b(c_1 c_2 s_3 + s_2 c_3) \bar{b}_R c_L]$$

$$- (\lambda_2)^{-1} \varphi_2^+ [m_u c_1 \bar{u}_R d_L - m_u s_1 c_3 \bar{u}_R s_L + m_c c_2 s_1 \bar{c}_R d_L$$

$$+ m_c(c_1 c_2 c_3 - s_2 s_3) \bar{c}_R s_L + m_t s_1 s_2 \bar{t}_R d_L + m_t(c_1 s_2 c_3 + c_2 s_3) \bar{t}_R s_L]$$

$$+ \text{h.c.}$$

The interaction conserves *CP* by appropriately defining the phases of the scalar fields, but *CP* may not be conserved by the scalar propagators [8]. The exchange of a single Higgs boson now leads to the effective Fermi interaction:

$$-A [m_d c_1 \bar{d}_R u_L + m_d c_2 s_1 \bar{d}_R s_L - m_s s_1 c_3 \bar{s}_R u_L + m_s(c_1 c_2 c_3 - s_2 s_3) \bar{s}_R c_L$$

$$- m_b s_1 s_3 \bar{b}_R u_L + m_b(c_1 c_2 s_3 + s_2 s_3) \bar{b}_R c_L] [m_u c_1 \bar{u}_R d_L - m_u s_1 c_3 \bar{u}_R s_L$$

$$+ m_c c_2 s_1 \bar{c}_R d_L + m_c(c_1 c_2 c_3 - s_2 s_3)\bar{c}_R s_L + m_t s_1 s_2 \bar{t}_R d_L$$

$$+ m_t(c_1 s_2 c_3 + c_2 s_3)\bar{t}_R s_L] + \text{h.c.}\,, \tag{4.9}$$

where

$$A \equiv \langle T(\varphi_1^{+*}\varphi_2^{+})\rangle_{0,q=0}/\lambda_1^*\lambda_2\,.$$

Weinberg [8] has shown that A is in general complex for more than two Higgs doublets thus violating CP *. The CP violation parameter, $\mathrm{Im}\,A$, can be determined from the K^0-$\bar{K}^0$ system:

$$\mathrm{Im}\,A = 3.2 \times 10^{-3}\,\frac{G_F}{m_s m_c}\,. \tag{4.10}$$

One could also parametrise it in terms of the Higgs masses:

$$\mathrm{Im}\,A = x|A| = x\frac{G_F}{m_H^2}\,,$$

assuming $x = \pm 1$ will lead to maximal CP violation. Now, evaluating $\mathrm{Im}\,m_{12}$ through the appropriate $W^{\pm}H^{\mp}$ exchange box diagrams (which are similar to those in fig. 1 with one $W^{\pm}$ replaced by the Higgs boson, $H^{\pm}$) and Δm determined through the $2W^{\pm}$ exchange diagrams (with $\delta = 0$) we get,

$$\frac{\mathrm{Im}\,m_{12}^B}{\Delta m_{12}^B} \simeq x\,\frac{m_t^2}{m_W^2/m_H^2 - 1}\left[\frac{1}{m_H^2}\left(\ln\frac{m_H^2}{m_t^2} - 2\right) - \frac{1}{m_W^2}\left(\ln\frac{m_W^2}{m_t^2} - 2\right)\right]\,, \tag{4.11}$$

$$\frac{\mathrm{Im}\,m_{12}^T}{\Delta m_{12}^T} \simeq x\,\frac{m_b^2}{m_W^2/m_H^2 - 1}\left[\frac{1}{m_H^2}\left(\ln\frac{m_H^2}{m_b^2} - 2\right) - \frac{1}{m_W^2}\left(\ln\frac{m_W^2}{m_b^2} - 2\right)\right]\,. \tag{4.12}$$

Eqs. (4.11) and (4.12) also hold for B_s^0-$\bar{B}_s^0$ and T_c^0-$\bar{T}_c^0$ transitions, respectively. Comparing the result with that for the K^0-$\bar{K}^0$ system in the same approach:

$$\frac{\mathrm{Im}\,m_{12}^K}{\Delta m_{12}^K} = \frac{x m_c^2}{m_W^2/m_H^2 - 1}\left[\frac{1}{m_H^2}\left(\ln\frac{m_H^2}{m_c^2} - 2\right) - \frac{1}{m_W^2}\left(\ln\frac{m_W^2}{m_c^2} - 2\right)\right]\,, \tag{4.13}$$

it is easy to see from (4.11)–(4.13) that the CP violating parameter $\mathrm{Im}\,m_{12}/\Delta m_{12}$ scales with the (mass)^2 of the appropriate fermion (up to logarithmic terms). Hence, the Higgs mechanism leads to the relations:

$$\frac{\epsilon_m^{(B_d^0)}}{|\epsilon_K|} \simeq \frac{m_t^2}{m_c^2}\,, \qquad \frac{\epsilon_m^{(T_u^0)}}{|\epsilon_K|} \simeq \frac{m_b^2}{m_c^2}\,. \tag{4.14}$$

* In the presence of pseudoparticles, which might be needed so as to have P and CP invariance in strong interactions, the program of implementing the CP violation in weak interactions by Higgs exchange needs at least four Higgs doublets otherwise $A \equiv \langle T(\varphi_1^{+*}\varphi_2^{+})\rangle_0/\lambda_1^*\lambda_2$ becomes real. For a detailed discussion of this point see ref. [15].

$\epsilon_m^{(B_d^0)}$ and $\epsilon_m^{(T_u^0)}$ are at least an order of magnitude bigger than $|\epsilon_K|$. We remark that the ratios (4.14) are independent of the ambiguities of Higgs masses, the assumption of maximal *CP* violation, and the assumption of vacuum (intermediate state) dominance of the matrix element (2.4). Moreover, there are no contributions from the neutral Higgs bosons since $B_d^0 \leftrightarrow \overline{B}_d^0$, $T_u^0 \leftrightarrow \overline{T}_u^0$ etc. involve, respectively $\Delta B = \pm 2$, $\Delta T = \pm 2$ neutral current transitions, which are absent in the KM type models. Eqs. (4.14) may constitute one of the cleanest tests of the hypothesis of *CP* violation through Higgs exchange.

CP violation can be measured in e^+e^- experiments through the charge asymmetry of the lepton pairs coming from the production of a neutral meson pair, subsequent weak mixing and semileptonic decays. For example, one has to look at processes of the type,

$$e^+e^- \to B^0\overline{B}^0 \xrightarrow[\text{mixing}]{} \ell^\pm \ell^\pm + \text{anything}\,.$$

CP violation is now related to the charge asymmetry through the relation (see Okun et al., in ref. [9]),

$$a \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = \frac{4\,\mathrm{Re}\,\epsilon_B(1 + |\epsilon_B|^2)}{(1 + |\epsilon_B|^2) + 4(\mathrm{Re}\,\epsilon_B)^2}\,. \tag{4.15}$$

Ignoring $\mathrm{Im}\,\Gamma_{12}^B$ in eq. (4.2), we have

$$\mathrm{Re}\,\epsilon_B = \frac{1}{2}\frac{\Delta\Gamma_B}{\Delta m_B}|\epsilon_B|\,. \tag{4.16}$$

We have evaluated the *CP* violating charge asymmetry in the lepton pairs, (4.15)*, using both the KM phase δ as well as the Higgs mechanism. The precise value of the asymmetry "a" depends on the KM parameters θ_2, θ_3 and m_t, the top quark mass. In addition it also depends on the values of the pseudoscalar constants f_B and f_T, through Δm. Since none of these quantities are known at present, it is more appropriate to study the asymmetry "a" for a plausible range of these parameters. In fig. 3 we have plotted the dependence of "a", r_1 and r_2 on θ_2, assuming $\theta_3 = \theta_c$, $m_t = 15$ GeV and $f_B = 500$ MeV. For the KM phase δ, we have used the relation $s_2 s_3 \sin\delta = 10^{-3}$. The dependence of these asymmetries on θ_3 is presented in fig. 4, assuming $\theta_2 = \theta_c$. The dependence on the top quark mass is plotted in fig. 5, with $\theta_2 = \theta_2^{\max}(m_t)$, as determined from the $K_L - K_S$ mass-difference constraint (6),

* In the process

$$e^+e^- \to (B^{*+}B^- + B^+B^{*-})$$
$$\quad\; \hookrightarrow \overline{B}^0\pi^+ \qquad \hookrightarrow B^0\pi^-,\ B^-\pi^0 \text{ etc.},$$

the relation for the charge asymmetry, "a" (4.15) is to be divided by 2.

and $\theta_3 = \theta_c$. In table 2, we present some representative values for the quantities of interest, namely life time, τ, $\Delta\Gamma/\Gamma$, $\Delta m/\Gamma$, r_1, r_2 and "a". The entries are calculated by assuming $m_b = 5$ GeV, $m_t = 15$ GeV, $\theta_3 = \theta_2 = \theta_c$, $\sin\delta = 2.5 \times 10^{-3}$, with cases (i) and (ii) referring to the values $f_B = 500$ MeV, $f_T/f_B = m_t/m_b$ and $f_B = 300$ MeV, $f_T/f_B = \sqrt{m_t/m_b}$, respectively.

There are various comments that we would like to make at this stage. First, note that the Higgs mechanism gives at least an order of magnitude larger charge asymmetry "a" for the bottom mesons as compared to the KM phase δ.

Next, the major dependence of "a" on the various angles comes through the factor $\Delta\Gamma/\Delta m$, as can be seen by looking at eqs. (4.3), (4.4) and (4.15). For the bottom meson sector, $\Delta\Gamma/\Delta m \ll 1$ for a plausible range of θ_2 and θ_3. So, the expression for Re ϵ_B can be well-approximated by

$$\mathrm{Re}\,\epsilon_B = \frac{1}{2}\frac{\Delta\Gamma}{\Delta m}\left(\frac{\mathrm{Im}\,m_{12}}{\Delta m_{12}}\right) .$$

It is easy to see that the charge asymmetry "a" becomes smaller with the mass difference, Δm, increasing or the life time difference, $\Delta\Gamma$, decreasing. This is the familiar pattern from the K^0-$\bar{K}^0$ system. For the bottom mesons, one anticipates a bigger value of "a" for the B^0-$\bar{B}^0$ complex as compared to the B_s^0-$\bar{B}_s^0$. This can be seen through table 1 and figs. 3–5, where barring $\theta_3 \ll \theta_c$ the charge asymmetry "a" is much bigger for the B^0-$\bar{B}^0$ sector.

Table 1 also shows that $\Delta\Gamma/\Gamma$ and $\Delta m/\Gamma$ for the B_s^0-B_s^0 sector do not depend on θ_2 and θ_3. The asymmetries r_1, r_2 and "a" (Higgs) for the B_s^0-B_s^0 system are then independent of θ_2 and θ_3, whereas "a" (KM) reflects the dependence of Im $m_{12}/\Delta m_{12}$ on θ_2 and θ_3. This is corroborated by figs. 3 and 4.

For the charge asymmetry "a" in the top meson sectors, both the KM and the Higgs models give rather small values. We have given these numbers for a representative values of the various parameters in table 2. Perhaps, it is interesting to point out that when $\Delta\Gamma/\Delta m \gg 1$, as is the case for the neutral top mesons in our model (see table 2), Re ϵ_T is well-approximated by the expression:

$$\mathrm{Re}\,\epsilon_T = 2\left(\frac{\Delta m}{\Delta\Gamma}\right)\left(\frac{\mathrm{Im}\,m_{12}^T}{\Delta m_{12}^T}\right) .$$

One now expects bigger CP violating effects when Δm is large and $\Delta\Gamma$ small, in contrast to the B mesons. This is the reason why the charge asymmetry is larger for the T_c^0-$\bar{T}_c^0$ system as compared to the T_u^0-$\bar{T}_u^0$ system. Again, the Higgs mechanism gives roughly an order of magnitude bigger estimates of "a" for the top mesons as compared to the KM model, though the absolute values are hopelessly small.

We conclude that the CP violating charge asymmetry "a" may be a measurable effect in e^+e^- experiments involving the production of bottom mesons.

4.1. Electric dipole moment of the neutron

The electric dipole moment of the neutron *, D_E (neutron), in the KM model has been recently calculated by Shabalin [18]. It was argued earlier in refs. [5] and [6] that in the KM model D_E (neutron) receives contribution from 2W$^\pm$ exchange diagrams and consequently lies in the range of a prediction of superweak theory (D_E (neutron) $\sim 10^{-29}$ e • cm.). However, when one calculates all the diagrams then to this order D_E (neutron) vanishes [18]. Thus, in the KM type models, D_E (neutron) receives contribution only through 3W$^\pm$ exchange diagrams and consequently has a value much below 10^{-29} e • cm.

Weinberg [8] calculated the electric dipole moment of the neutron, using Higgs exchange mechanism with four quarks. His estimates of D_E (neutron) are of the order 10^{-24} e • cm., though there is considerable uncertainty due to the quark masses. Thus, measurement of D_E (neutron) is a good measure of testing Higgs mechanism. We add the contribution of the top and bottom quarks to D_E (neutron). The dipole moment now reads as (with maximal CP violation, i.e. $x = 1$) (see fig. 6) **:

$$D_E(\mathrm{u}) = -\tfrac{1}{3}e\frac{G_F}{\sqrt{2}}\frac{1}{8\pi^2}\frac{m_u}{m_H^2}\left\{m_d^2 c_1^2\left(\ln\frac{m_H^2}{m_d^2}-1\right)\right.$$

$$\left. + m_s^2 s_1^2 c_3^2\left(\ln\frac{m_H^2}{m_s^2}-1\right) + m_b^2 s_1^2 s_3^2\left(\ln\frac{m_H^2}{m_b^2}-1\right)\right\} ,$$

$$D_E(\mathrm{d}) = \tfrac{2}{3}e\frac{G_F}{\sqrt{2}}\frac{1}{8\pi^2}\frac{m_d}{m_H^2}\left\{m_u^2 c_1^2 \ln\left(\frac{m_H^2}{m_u^2}-1\right)\right.$$

$$\left. + m_c^2 s_1^2 c_3^2\left(\ln\frac{m_H^2}{m_c^2}-1\right) + m_t^2 s_1^2 s_3^2 \ln\left(\frac{m_H^2}{m_t^2}-1\right)\right\} .$$

Defining the relative contribution of the b and t quarks (as compared to the u, d, s

* For a summary of the experimental results on the electric dipole moment of the neutron, see ref. [17]. This article also contains references of earlier theoretical attempts.

** In higher-order weak interactions involving no net flavour change, like the electric dipole moment of the neutron, there is, in general, a contribution from the neutral Higgs meson. *A priori*, this contribution is arbitrary since the mass of the neutral Higgs meson is not constrained either by theory or present experiments. However, one could derive a bound on m_{H^0}, otherwise the contribution of the neutral Higgs to the dipole moment by itself will be in conflict with the experimental result on D_E (neutron), see ref. [16]. We assume $m_{H^0} > m_{W^\pm}$ and neglect the contribution of neutral Higgs mesons. Note that there is no such contribution to flavour changing transitions like $B^0 \leftrightarrow \bar{B}^0$, $T^0 \leftrightarrow \bar{T}^0$ etc., due to the absence of non-diagonal neutral current transitions involving Higgs bosons, in the KM type models.

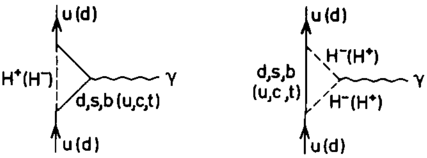

Fig. 6. Lowest order contribution to the electric dipole moment of the neutron with Higgs exchanges.

and c quarks) to D_E (neutron):

$$y \equiv \frac{\sum\limits_{i=t,b} (4D_E^i(d) - D_E^i(n))}{\sum\limits_{i=u,d,s,c} (4D_E^i(d) - D_E^i(n))} ,$$

we find (assuming $m_u = m_d = 300$ MeV, $m_s = 500$ MeV, $m_c = 1.5$ GeV, $m_b = 5$ GeV, $m_H = 70$ GeV and $\theta_3 = \theta_c$)

$$y = 0.18 \quad \text{for } m_t = 5 \text{ GeV} ,$$
$$= 0.5 \quad \text{for } m_t = 15 \text{ GeV} .$$

Thus, the contribution of the top and bottom quarks is not negligible if θ_3 is of the order of the Cabibbo angle. It is conceivable that b and t quarks by themselves give a contribution of O (10^{-24}) to D_E (neutron), irrespective of the uncertainty of the u, d and s quark masses.

5. Discussion and conclusions

Motivated by the discovery of $\Upsilon(9.4)$, $\Upsilon'(10.0)$ and the observation of Ellis et al. [6] that the weak mass mixing effects are expected to be large among the B^0-$\bar{B}^0$ mesons, we have studied the entire neutral meson sector of the left-handed six-quark models. A clear pattern in weak mass mixings seems to emerge among the known neutral meson systems (K^0-$\bar{K}^0$ and D^0-$\bar{D}^0$) and the yet to be discovered heavy neutral top and bottom meson systems (B_d^0-$\bar{B}_d^0$, B_s^0-$\bar{B}_s^0$, T_u^0-$\bar{T}_u^0$, and T_c^0-$\bar{T}_c^0$). Characterising these effects through $\Delta m/\Gamma$ and $\Delta\Gamma/\Gamma$, it is obvious that weak mixing is expected to be important when Γ is suppressed due to weak angles (the suppression of Γ in K^0-$\bar{K}^0$ system comes *via* $\sin^2\theta_C$ whereas for the bottom mesons it is characterised by $((s_2 + s_3 \cos\delta)^2$ or $s_1^2 s_3^2)$.

There is an additional enhancement factor in favour of the K^0-$\bar{K}^0$ (over the D^0-$\bar{D}^0$ system) and neutral bottom meson systems (over the neutral top mesons) from the quark masses in the box diagram of fig. 1 (see $\tilde{m}$ in table 1). Mixing in the K^0-$\bar{K}^0$ and neutral bottom meson sectors (B^0-$\bar{B}^0$ and B_s^0-$\bar{B}_s^0$) is expected to be large, whereas it should be suppressed for the D^0-$\bar{D}^0$ and the neutral top meson sectors.

Thus, there is a natural mechanism in the KM type models to understand why mixing is important in the K^0-$\bar{K}^0$ sector and small in the D^0-$\bar{D}^0$. In addition, we find the weak mass mixing effects in the B_s^0-$\bar{B}_s^0$ sector larger as compared to the B^0-$\bar{B}^0$. It is conceivable that mixing in the B_s^0-$\bar{B}_s^0$ sector may even be complete (as in the K^0-$\bar{K}^0$ system). This can be traced directly to the underlying GIM structure of the left-handed six-quark models. We have then addressed ourselves to the question of distinguishing these mixings, their possible signatures and measurement in e^+e^- annihilation experiments at PETRA, PEP and CESR energies.

We have also studied the question of *CP* violation due to the mass mixings among the neutral top and bottom mesons. This is done both in the context of the KM model with a complex phase δ, and using the alternative approach to incorporate *CP* violation through Higgs exchange [7,8]. We find that the predictions of the Higgs exchange mechanism for *CP* violation in the top and bottom meson sectors are also large. Moreover, one could relate the *CP* violating parameter $\mathrm{Im}\, m_{12}^{\mathrm{B}}/\Delta m_{12}^{\mathrm{B}}$ and $\mathrm{Im}\, m_{12}^{\mathrm{T}}/\Delta m_{12}^{\mathrm{T}}$ for the B^0-$\bar{B}^0$ and T^0-$\bar{T}^0$ mesons with their counterpart in the K^0-K^0 system. The ratios

$$\frac{\mathrm{Im}\, m_{12}^{\mathrm{B}}/\Delta m_{12}^{\mathrm{B}}}{\mathrm{Im}\, m_{12}^{\mathrm{K}}/\Delta m_{12}^{\mathrm{K}}} \quad \text{and} \quad \frac{\mathrm{Im}\, m_{12}^{\mathrm{T}}/\Delta m_{12}^{\mathrm{T}}}{\mathrm{Im}\, m_{12}^{\mathrm{K}}/\Delta m_{12}^{\mathrm{K}}}$$

then obey a scaling relation (eq. (4.14)). These relations are free of theoretical ambiguities due to uncertainties in the Higgs mass, dominance assumption about the matrix element of the effective non-leptonic Hamiltonian, and the assumption of maximality of the *CP*-violating interactions, i.e., the value of x. This circumstance then provides a rather clean and sensitive test of the hypothesis of *CP* violation through Higgs exchange, more so if m_{b} and m_{t} are not very close to each other.

We then discuss the measurement of lepton pair charge asymmetry, (4.15), coming from the production, subsequent mixing and semileptonic decay of top and bottom meson pairs in e^+e^- experiments, as a measure of *CP* violation. We have calculated the charge asymmetry "a" for both the mechanisms and studied the effect of varying the various parameters, θ_2, θ_3, m_{t} and the pseudoscalar coupling constants f_{B} and f_{T}. We find that the charge asymmetry "a" in the production of bottom mesons should be a measurable effect in a high statistics lepton pair experiment. The corresponding asymmetry for the top mesons is expected to be smaller, reflecting perhaps the same sequence of *CP* violation as in the K^0-$\bar{K}^0$ and D^0-$\bar{D}^0$ systems. The predictions of the Higgs model for the charge asymmetry are uniformally larger over those of the KM model.

We conclude by emphasizing the importance of studying high statistics lepton pair production, in e^+e^- experiments at PETRA, PEP and CESR, coming from the decay of a pair of heavy top and bottom mesons, as a powerful tool to reveal the nature of (as yet) poorly understood mechanism of *CP* violation.

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