D^0–$\overline{D^0}$ MIXING IN SUPERSTRING-INSPIRED E_6 MODELS

Biswarup MUKHOPADHYAYA, Amitava RAYCHAUDHURI and Aditi RAY-MUKHOPADHYAYA
Department of Pure Physics, Calcutta University, 92 Acharya Prafulla Chandra Road, Calcutta-700 009, India

Received 17 February 1987

In E_6 models emerging at low energies from the superstring there are exotic charge-$\frac{1}{3}$ h-quarks. When h–b mixing is taken into account, SUSY contribution to D^0–$\overline{D^0}$ mixing is enhanced several orders beyond that in the standard model and is close to the experimental upper limit.

Superstring theories after compactification on a Calabi–Yau manifold lead to supersymmetric (SUSY) E_6 grand unified models [‡1]. Such models contain exotic fermions in addition to the usual ones, and they survive to low energies when no intermediate mass scales are present, as is suggested on cosmological grounds [2]. Among these fermions the charge-$\frac{1}{3}$ colour triplet h-quarks have recently attracted some attention. When the electroweak gauge symmetry is broken, the $SU(2)_L$ singlet h-quark can mix with the d-type quarks and such mixing leads to interesting phenomenological consequences. An independent motivation for this kind of mixing is provided by the observed small deviation from unitarity of the (3×3) Kobayashi–Maskawa (KM) matrix V [3,4]. h–d mixing has been studied [5] in the context of neutral currents, h-quark decay, top-quark mass and sneutrino VEV. The precision to which V_{ud} is known restricts h–d mixing to be very small and it does not have any significant effect on *CP*-violation and heavy meson mixing [6]. The same reasoning applies for h–s mixing as well. The remaining possibility is that of h–b mixing which can be comparatively large [3]. This mixing has dramatic implications on *CP*-violation – the lower bound on the t-quark mass is removed and ϵ'/ϵ is consistent with experiment even for the most unfavourable situation for the standard model [6]. B^0–$\overline{B^0}$ mixing is found to remain unaffected. In this note we investigate the D^0–$\overline{D^0}$ system in the light of h–b mixing.

In the standard model D^0–$\overline{D^0}$ mixing is generated through W-exchange box diagrams with d-type quarks in the internal lines. It has been shown [7] that since $m_c \gg m_s$, m_d it is important to retain the momenta in the external lines of the box diagram – this suppresses Δm_D by 2 orders of magnitude and it is found to be $O(10^{-17}$–10^{-18} GeV), which is several orders smaller than the current experimental bound, viz. 6.5×10^{-13} GeV [8].

Incorporating the h-quark we now have a generalised (3×4) KM matrix V:

$$V=\begin{pmatrix} C_1 & -S_1C_3 & -S_1S_3C_\alpha & S_1S_3S_\alpha \\ S_1C_2 & C_1C_2C_3-S_2S_3e^{i\delta} & (C_1C_2S_3+S_2C_3e^{i\delta})C_\alpha & -(C_1C_2S_3+S_2C_3e^{i\delta})S_\alpha \\ S_1S_2 & C_1S_2C_3+C_2S_3e^{i\delta} & (C_1S_2S_3-C_2C_3e^{i\delta})C_\alpha & -(C_1S_2S_3-C_2C_3e^{i\delta})S_\alpha \end{pmatrix}, \tag{1}$$

where $C_i=\cos\theta_i$, $S_i=\sin\theta_i$, and we have assumed that h mixes with b alone. From the experimental constraints on the KM elements, $\cot\alpha\leqslant0.11$ [3]. From now on we will set $\cot\alpha=0.11$.

‡1 See ref. [1] for reviews.

The angles θ_2 and θ_3 are usually determined from the bottom lifetime τ_B and the ratio $\bar{R}=\Gamma(b\to u\ell\nu)/\Gamma(b\to c\ell\nu)$. With the extra h-quark, θ_2 and θ_3 are given by

$$S_3=(S_3)_{std.}/C_\alpha, \quad \theta_2=[\cos^{-1}(c/\sqrt{a^2+b^2C_\delta^2})+\sin^{-1}(bC_\delta/\sqrt{a^2+b^2C_\delta^2})]/2\,, \tag{2,3}$$

with $a=C_3^2-C_1^2S_3^2$, $b=-2C_1S_3C_3$ and $c=C_3^2+S_3^2(C_1^2-5.78)$. The presence of C_α in eq. (2) enhances S_2 and S_3 – this is at the root of the dramatic effects on CP-violation [6]. There it has been shown that when one requires consistency with the experimental value of ϵ, for realistic top quark masses (30–60 GeV) $C_\delta\simeq\pm1$. However, the solutions corresponding to $C_\delta\simeq-1$ can be ruled out from the constraints [4] on V_{cd} from charm production by neutrinos.

In the E_6 model we are interested in, box diagram contributions to Δm_D with the h-quark in the inner lines will dominate because of the large h-mass ($m_h>25$ GeV) – similar to the b-quark dominance in the standard case [7]. Using the same formalism we find an enhancement of O ($\tan^2\alpha$) from the KM factors at the vertices and a further factor of O(10) from the momentum integrals. Thus Δm_D is now of the order of 10^{-14}–10^{-15} GeV and is still well below the stipulated limit.

In the SUSY standard model, there exists the further possibility of gluino induced diagrams contributing to D^0–$\overline{D^0}$ mixing. Such contributions – flavour violation through the gluino – have non-trivial effects on CP-violation in the neutral kaon system [9]. In that case the gluino exchange box diagrams have d-type squarks ($\tilde{D}$) in the inner lines. Flavour violation occurs predominantly in the left-handed sector. The (3×3) $\tilde{D}_L$ mass matrix at low energies is of the form

$$M^2(\tilde{D}_L)=\mu_L^2I+M_dM_d^+ +cM_uM_u^+\,, \tag{4}$$

where the last term ($c\sim1$) arises from the renormalisation due to the top-quark Yukawa coupling and is responsible for flavour non-conservation; μ_L^2 is a flavour-blind SUSY breaking parameter.

The SUSY graphs in the D^0–$\overline{D^0}$ case have $\tilde{U}$ inner lines. The mass matrix relevant to this case is

$$M^2(\tilde{U}_L)=\mu_L^2I+M_uM_u^+ +c'M_dM_d^+\,. \tag{5}$$

Since the d-type quarks are lighter than the u-type quarks the gluino mediated flavour violation is less pronounced in this case and the SUSY contribution to Δm_D is rather small (10^{-18}–10^{-21} GeV) [10].

Turning now to the E_6 model under discussion, the third term in eq. (5) will include m_h^2 which, due to the large m_h, makes a marked difference in the context of D^0–$\overline{D^0}$ mixing. The exact form of Δm_D in terms of the SUSY parameters and the KM mixing angles can be obtained from the corresponding expression for Δm_K in ref. [9] (see eq. (23)).

In our calculations we have used $f_D=0.2$ GeV, $c'=0.5$ and have chosen the gluino mass m_g to be 40, 70 and 100 GeV and $\mu_L=50$, 70 and 100 GeV [‡2]. We find that Δm_D is significantly enhanced and can be as large as O(10^{-13} GeV) for $m_g=40$ GeV, $\mu_L=50$ GeV and sufficiently large m_h (50 GeV). In fig. 1 we have plotted $P(D^0\to\overline{D^0})$ which is related to Δm_D through

$$P(D^0\to\overline{D^0})=\tfrac{1}{2}(\Delta m_D/\Gamma)^2\,, \tag{6}$$

where Γ (1.53×10^{-12} GeV) is the D^0 decay width. $P(D^0\to\overline{D^0})$ can be extracted from the experimental data on like-sign dileptons and has been measured in proton–Fe collisions [12], neutrino production [13] and muon scattering [14]. The last mentioned experiment gives the most stringent upper bound, viz. $P(D^0\to\overline{D^0})\lesssim0.012$ which is also shown in the figure.

It should be pointed out that in this calculation we have taken only the short-distance contribution to Δm_D and in the estimation of the hadronic matrix element we have used the so called "bag factor" $B=0.33$. Left–right mixing in the squark sector, which is anyway small, has been dropped. In the SUSY box diagrams we have not retained the momenta in the external lines since the internal lines are now heavy SUSY particles.

‡2 These masses are consistent with the most recent experimental findings [11].

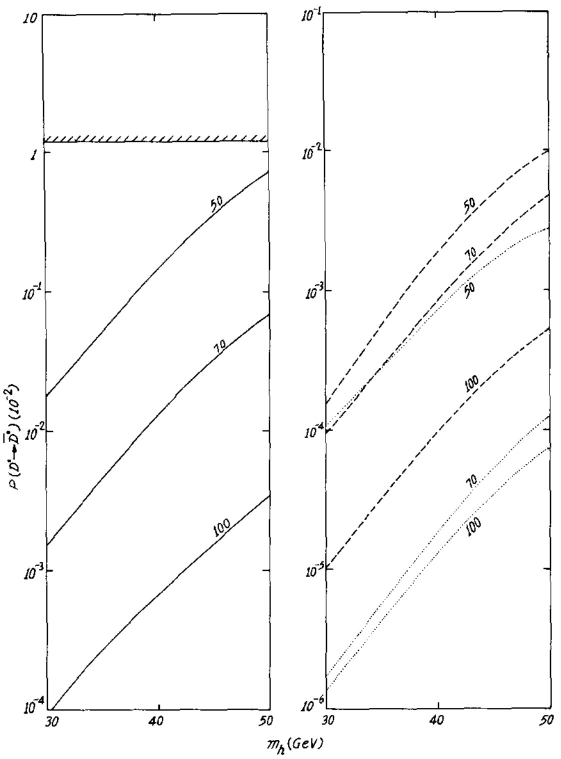

Fig. 1. $P(D^0 \to \overline{D^0})$ as a function of m_h. $\tau_B = 1.0$ ps, $B = 0.33$, $\bar{R} = 0.04$. The solid, broken and dotted lines correspond to $m_g = 40$, 70 and 100 GeV, respectively. Curves for $\mu_L = 50$, 70 and 100 GeV are shown. The experimental bound is also indicated.

In conclusion, we have found that in the superstring-inspired E_6 model with h–b mixing the contribution to Δm_D from SUSY box diagrams is increased by several orders and, in some cases, is strikingly close to the experimental upper bound. Thus if future experiments indicate a Δm_D much larger than the standard model prediction, then it will provide indirect support to h–b mixing in superstring-inspired E_6 models.

This research has been supported by a Council of Scientific and Industrial Research, India fellowship (B.M.) and research grants from the University Grants Commission, India (A.R.) and Indian National Science Academy (A.R. and A.R.-M.).

References

[1] M.B. Green, Surv. High En. Phys. 3 (1983) 127;
J.H. Schwarz, Phys. Rep. 89 (1982) 323;
J. Ellis, Invited talk Second Nobel Symp. on Elementary particle physics, CERN preprint CERN-TH 4474/86.

[2] K. Enqvist, D.V. Nanopoulos and M. Quiros, Phys. Lett. B 169 (1986) 343.

[3] K. Enqvist, J. Maalampi and M. Roos, Phys. Lett. B 176 (1986) 396.

[4] G. Barbiellini and C. Santoni, Riv. Nuovo Cimento 9 (1986) 1;
W.I. Marciano and A. Sirlin, Phys. Rev. Lett. 56 (1986) 22.

[5] V. Barger et al., Phys. Rev. D 33 (1986) 1912;
R.W. Robinett, Phys. Rev. D 33 (1986) 1908;
S.M. Barr, Phys. Rev. Lett. 55 (1985) 2778;
F. Cornet et al., Phys. Lett. B 174 (1986) 224;
J. Pulido, CERN preprint CERN-TH 4501/86;
B. Campbell et al., CERN preprint CERN-TH 4469/86.

[6] B. Mukhopadhyaya, A. Ray and A. Raychaudhuri, Phys. Lett. B 186 (1987) 147.
[7] A. Datta and D. Kumbhakar, Z. Phys. C 27 (1985) 515;
see also G. Ecker and W. Grimus, Z. Phys. C 30 (1986) 293.
[8] Particle Data Group, Review of particle properties, Phys. Lett. B 170 (1986) 1.
[9] J.-M. Gérard, W. Grimus, A. Masiero, D.V. Nanopoulos and A. Raychaudhuri, Nucl. Phys. B 253 (1985) 93.
[10] A. Datta, Phys. Lett. B 154 (1985) 287.
[11] A. Honma, talk presented XIII Intern. Conf. on High energy physics (Berkeley, CA, 1986).
[12] A. Bodek et al., Phys. Lett. B 113 (1982) 82.
[13] H. Burkhardt et al., Z. Phys. C 31 (1986) 39.
[14] A.C. Benvenuti et al., Phys. Lett. B 158 (1985) 531.