CONTRIBUTION OF SCALAR DIQUARKS TO THE $\Delta I=1/2$ RULE

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One of the novel features of the superstring inspired models is the possible appearance of colour triplet particles with diquark couplings They can mediate hadronic decays of baryons and mesons We investigate their contribution to the $\Delta I=1/2$ rule through the operator product expansion

The superstring theory based on the $E_8 \times E_8'$ group in ten dimensions [1,2] seems to be the most promising candidate for a unified theory of all fundamental forces Compactification on a Kahler manifold with SU(3) holonomy leads to an $N=1$ supergravity theory, while an $E_6 \times SU(3)_H$ group emerges [3] Further breaking of E_6 by the Hosotani mechanism [4] implies a low-energy gauge group of rank five or six which contains the standard $SU(3)\times SU(2)\times U(1)$ group of electroweak and strong interactions [5,6] In the recent literature [7], much effort has been made in order to investigate all possible residual gauge groups containing $SU(3)\times SU(2)\times U(1)$ However, since there are a lot of phenomenological constraints, the construction of an acceptable low-energy model is not an easy task Several problems have already been discussed in the context of superstring-inspired models, i e , neutrino masses [8], flavour changing interactions [9], proton decay [10], additional neutral gauge bosons [11], etc

In this letter we are going to discuss the contribution to the $\Delta I=1/2$ rule in non-leptonic decays of mesons and baryons from interactions involving the new scalar quarks D and D^c which are found in the 27-dimensional representation of E_6 According to the conventional assignment we get

$$\{27\}=(u, d, u^c, e^c)+(d^c, \nu_e, e)+\nu^c$$
$$+(D^c, \bar{H}^0, \bar{H}^-)+(D, H^0, H^+)+N$$

If we restrict ourselves to the rank-five group, the D and D^c fields have the following quantum numbers under $SU(3)\times SU(2)\times U(1)\times U(1)$, which is the minimal group containing the standard group

$$D=(3, 1, -1/3, -2/3), \tag{1a}$$

$$D^c=(\bar{3}, 1, 1/3, -1/6) \tag{1b}$$

The most general superpotential coming from the trilinear couplings 27^3 is [9]

$$W=W_0+W_1+W_2+W_3\,, \tag{2}$$

where

$$W_0=\lambda_L \bar{H}L\ell^c+\lambda_u HQu^c+\lambda_d \bar{H}Qd^c$$
$$+\lambda_N H\bar{H}N+\lambda_\nu HL\nu^c+\lambda_D DD^c N, \tag{3a}$$

$$W_1=\lambda_1 DQQ+\lambda_1' D^c u^c d^c, \tag{3b}$$

$$W_2=\lambda_2 D^c LQ+\lambda_2' Du^c e^c, \tag{3c}$$

$$W_3=\lambda_3 Dd^c \nu^c \tag{3d}$$

A detailed analysis of the above superpotential has been done elsewhere [9] Here we just recall that in order to avoid several drawbacks, like fast proton decay, flavour-changing neutral currents, weak universality, W_1, W_2 and W_3 cannot coexist in the

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superpotential In fact, the above terms could be forbidden from the superpotential either by topological properties or by imposing discrete symmetries Here we are interested in the phenomenological implications of the W_1 term which gives rise to non-leptonic decays of mesons and baryons involving the D and D^c scalar quarks

Our approach to the $\Delta I=1/2$ rule will be through the operator product expansion (OPE) [12] Our aim is to check if the inclusion of D and D^c scalars can change the known picture [13] we get from the QCD corrections to the relevant operators The Penguin diagram has been discussed elsewhere [14] (though without inclusion of QCD corrections), therefore we restrict ourselves to the operators O_1 and O_2 appearing in the effective hamiltonian H_w

$$O_1=(\bar{u}_L\gamma^\mu s_L)(\bar{d}_L\gamma_\mu u_L), \tag{4a}$$

$$O_2=(\bar{u}_L\gamma^\mu t^a s_L)(\bar{d}_L\gamma_\mu t^a u_L), \tag{4b}$$

where the t^a are the SU(3) matrices ($a=1, \ldots, 8$) The above operators mix under renormalization, giving as eigenvectors, after diagonalization

$$O_-=O_1-3O_2, \quad O_+=O_1+\tfrac{3}{2}O_2 \tag{5a,b}$$

The first one has $\Delta I=1/2$ while the second has $\Delta I=1/2$ and 3/2 The leading logarithmic approximation gives an enhancement factor to the first

$$a_-=[\alpha_s(\mu)/\alpha_s(M_W)]^{4/b}, \tag{6}$$

where α_s is the running coupling constant of QCD

$$\alpha_s(Q)=2\pi/b\ln(Q/\Lambda),$$

μ is the characteristic hadronic scale, M_W is the W-boson mass and $b=11-\frac{2}{3}\cdot$(# flavours) is the $O(g^3)$ term in the QCD β-function The second operator gets a suppression factor

$$a_+=[\alpha_s(\mu)/\alpha_s(M_W)]^{-2/b} \tag{7}$$

Therefore the enhancement of O_- relative to O_+ is

$$F_W\equiv a_-/a_+=[\alpha_s(\mu)/\alpha_s(M_W)]^{6/b}\simeq 5$$

$$(\mu=140\text{ MeV}, N_f=4 \text{ and } \Lambda=70\text{ MeV}), \tag{8}$$

not enough to explain the experimental value (~ 20)

Now, how is this picture modified with the inclusion of D-scalars? These new particles can mediate only $\Delta I=1/2$ decays Therefore we expect no new

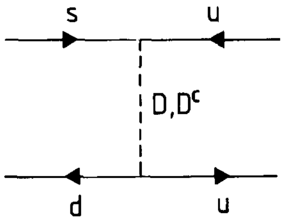

Fig 1 $D(D^c)$ mediated $\Delta S=1$ transition

operators to appear in the effective hamiltonian The only thing we have to calculate is the zeroth order coefficient of the new contribution to the O_- operator

Let us assume for the moment that there is no mixing between D and D^c The coefficient to the operator O_- is evaluated through the diagram of fig 1 This diagram, with the D-scalar gives

$$A_D=(\bar{u}^c_{Li}s_{Lj})(\bar{u}_{Ll}d^c_{Lk})$$

$$\times\epsilon^{ijm}\epsilon^{lkm}(-\lambda_1^2/M_D^2)=(\lambda_1^2/M_D^2)\tfrac{1}{2}\ \tfrac{2}{3}(O_1-3O_2)$$

$$=(\lambda_1^2/M_D^2)\tfrac{1}{3}O_-, \tag{9}$$

where i, j, k and l are colour indices and we have used Fierz rearrangements and identities of conjugate spinors Eq (9) shows also explicitly that the D's contribute only to $\Delta I=1/2$ transition A factor of 2 must be included in A_D due to the two terms we get from the antisymmetry with respect to SU(2) indices of the DQQ term,

$$A_D=\tfrac{2}{3}(\lambda_1^2/M_D^2)O_- \tag{10}$$

The enhancement factor F becomes

$$F_D=F_W$$

$$+\frac{\frac{2}{3}\ (\lambda_1^2/M_D^2)[\alpha_s(\mu)/\alpha_s(M_D)]^{4/b}}{\sqrt{2}\,G[\alpha_s(\mu)/\alpha_s(M_W)]^{-2/b}}, \tag{11}$$

where we have imposed the strong assumption that the D's couple to the usual quarks through the usual linear combination (KM angles) [14]

The D^c scalar induces the same operator but with right-handed currents,

$$O_-^R=O_1^R-3O_2^R$$

This operator induces $\Delta I=1/2$ transitions and we know that, under renormalization, it has the same

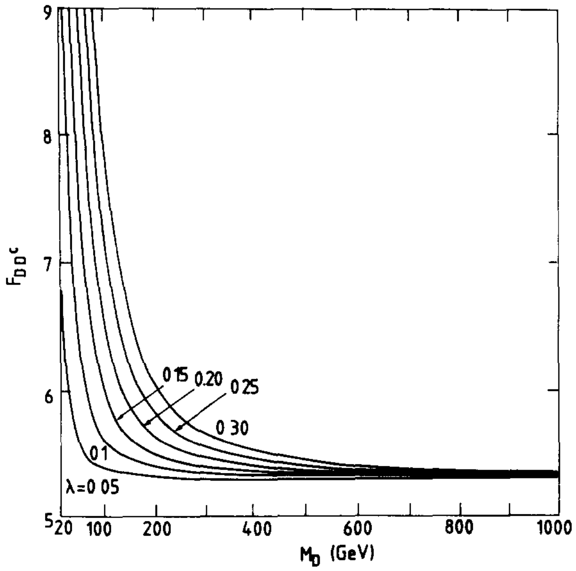

Fig 2 The enhancement factor $F_{D\,D^c}$ as a function of the mass M_D ($M_D = M_{D^c}$), for different values of λ ($\equiv \lambda_1 = \lambda_1'$)

behaviour as the left-handed O_- operator Therefore we get

$$F_{D\,D^c} = F_W + F_D + \frac{\frac{1}{3}\,(\lambda_1'^2/M_{D^c}^2)[\alpha_s(\mu)/\alpha_s(M_{D^c})]^{4/b}}{\sqrt{2}\,G[\alpha_s(\mu)/\alpha_s(M_W)]^{-2/b}} \tag{12}$$

To have a feeling of the above quantity $F_{D\,D^c}$, it is natural to put $\lambda_1 = \lambda_1'$ and $M_D = M_{D^c}$ In fig 2 we plot this quantity as a function of M_D, for different values of λ We see that even with $\lambda = 0\,3$ we must have $M_D \leqslant 150$ GeV in order to gain 25% in enhancement, relative to F_W

We know that L–R currents [13], under renormalization, get an enhancement significantly bigger than L–L and R–R currents The corresponding exponent is $10/b$ instead of $4/b$ If we assume D–D^c mixing, then an operator with the desired L–R structure will appear in the effective hamiltonian If ϕ is the mixing angle, D_1 and D_2 the physical states after diagonalization and $\bar\lambda = \sqrt{\lambda_1 \lambda_1'}$ a mean coupling, the enhancement factor from the L–R operator is

$$F_{LR} = |\bar\lambda^2 \sin\phi\cos\phi \times\{[\alpha_s(\mu)/\alpha_s(M_{D_1})]^{10/b}/M_{D_1}^2 - [\alpha_s(\mu)/\alpha_s(M_{D_2})]^{10/b}/M_{D_2}^2\} \times\{\sqrt{2}\,G[\alpha_s(\mu)/\alpha_s(M_W)]^{-2/b}\}^{-1}| \tag{13}$$

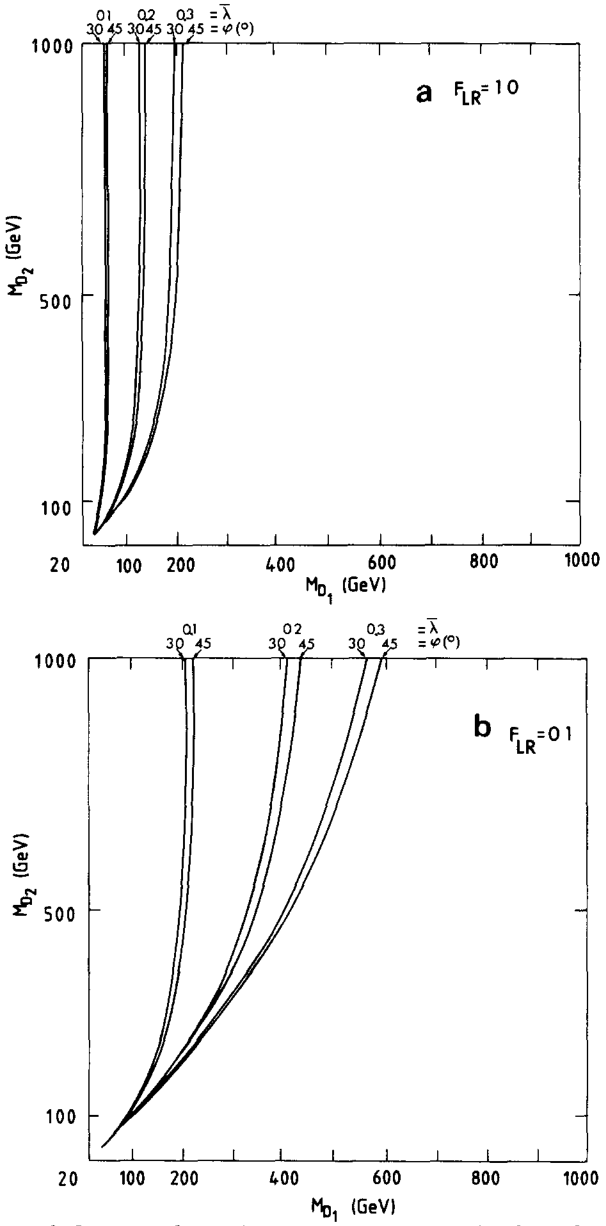

Fig 3 Contours of the enhancement factor F_{LR} in the plane of (M_{D_1}, M_{D_2}) for different values of the mixing angle ϕ (= 30°, 45°) and $\bar\lambda$ (= 0 1, 0 2, 0 3) (a) F_{LR} = 1 0, (b) F_{LR} = 0 1

In fig 3 we show the contour of F_{LR} in the (M_{D_1}, M_{D_2}) plane, and for $\phi = 30°$ and 45° Again here we notice that even with $\bar\lambda = 0\,3$ and maximal mixing ($\phi = 45°$), one of the $D_{1\,2}$ must be below 200 GeV in order to have $F_{LR} \sim 1\,0$ or $F_{LR}/F_W \sim 20\%$

In conclusion, treating the D-mediated hadronic decays of mesons and baryons as a short-distance effect, we calculated the contribution of the above D-scalar to the $\Delta I = 1/2$ rule [#1] We see that we cannot expect any sizeable contribution, which, even in the most favourable case ($\bar{\lambda}=0\ 3$, maximal mixing $\phi=45°$) does not exceed the (first-order) result from the weak effective hamiltonian by 20% if $M_D=200$ GeV

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[#1] No standard method can be applied to the matrix elements, since D-mediated decays are not of the so-called external type quark graphs

References

[1] J H Schwarz, Phys Rep 89 (1982) 223,
M B Green, Surv High En Phys 3 (1983) 127
[2] D J Gross, J A Harvey, E Martinec and R Rohm, Phys Rev Lett 54 (1985) 502, Nucl Phys B 256 (1985) 253,
M Green and J H Schwarz, Phys Lett B 149 (1984) 117, B 151 (1985) 21
[3] P Candelas, G T Horowitz, A Strominger and E Witten, Nucl Phys B 258 (1985) 46,
E Witten, Nucl Phys B 258 (1985) 75, B 268 (1986) 79
[4] Y Hosotani, Phys Lett B 126 (1983) 309, B 129 (1983) 193
[5] M Dine, V Kaplunovsky, M Mangano, C Nappi and N Seiberg, Nucl Phys B 259 (1985) 549,
J D Breit, B A Ovrut and G Segre, Phys Lett B 158 (1985) 33,
B R Greene, K H Kirklin, P Miron and G G Ross, Nucl Phys B 278 (1986) 667
[6] J Ellis, CERN-preprints TH 4439/86 and TH 4474/86 (1986), in preparation
[7] J Ellis, K Enqvist, D V Nanopoulos, K Olive, M Quiros and F Zwirner, Phys Lett B 176 (1986) 403,
B A Campbell, J Ellis, M K Gaillard, D V Nanopoulos and K Olive, Phys Lett B 180 (1986) 77,
B A Campbell, J Ellis and D V Nanopoulos, Phys Lett B 181 (1986) 283
[8] C H Albright, Phys Lett B 178 (1986) 219,
A Masiero, D V Nanopoulos and I Sanda, Phys Rev Lett 57 (1986) 663
[9] B A Campbell, J Ellis, K Enqvist, M K Gaillard and D V Nanopoulos, CERN-preprint TH 4479/86 (1986)
[10] G Lazarides, G Panagiotakopoulos and Q Shafi, Phys Rev Lett 56 (1986) 432, 56 (1986) 557, Nucl Phys B 278 (1986) 657
[11] V D Angelopoulos, J Ellis, D V Nanopoulos and N D Tracas, Phys Lett B 176 (1986) 203
[12] K Wilson, Phys Rev 179 (1969) 1499
[13] M K Gaillard and B W Lee, Phys Rev Lett 33 (1974) 108,
G Altarelli and L Maiani, Phys Lett B 52 (1974) 351
[14] E Papantonopoulos, N D Tracas and G Zoupanos, Phys Lett B 188 (1987) 493