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RESTRICTIONS ON LEFT-RIGHT SYMMETRIC GAUGE THEORIES FROM THE NEUTRAL KAON SYSTEM AND B DECAYS*

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ABSTRACT

We investigate the constraints imposed on the weak mixing angles by the $K^0 - \bar{K}^0$ mass matrix and B meson decay in left-right symmetric gauge theories. In a class of such theories with manifest left-right symmetry the domain of Kobayashi-Maskawa angles allowed by the $K_L^0 - K_S^0$ mass difference has no overlap with that allowed by B meson decay.

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There is considerable theoretical attraction to left-right symmetric gauge theories of the weak and electromagnetic interactions where parity is conserved by the underlying theory and the observed parity violation is due to spontaneous symmetry breaking.[1,2] A number of such theories have been investigated, in particular $SU(2)_L \times SU(2)_R \times U(1)$, and it has been shown that they generally can mimic the successful predictions of the standard $SU(2) \times U(1)$ theory at low energies if the right-handed gauge bosons $W_R^{\pm}$ are made sufficiently heavy compared to $W_L^{\pm}$. At energy scales comparable to M_R, parity conservation is restored and much additional physics beyond the standard model is to be found, starting with the existence of the right-handed gauge bosons themselves.

A central question in such theories then is what is the mass of W_R? Low energy data on weak decays involving charged currents allow placing a lower bound on M_R in the 200 to 300 GeV range.[2] A considerable improvement in the lower bound on M_R in $SU(2)_L \times SU(2)_R \times U(1)$ was found by Beall *et al.* by considering the short-distance contribution to the $K^0 - \bar{K}^0$ mass matrix arising from the usual box diagrams involving quarks and W bosons, but with W_R present as well as W_L. The diagram with one W_R and one W_L, while giving an amplitude with an extra factor of M_L^2/M_R^2 compared to that in the standard model, gives a contribution with a large coefficient and matrix element such that in the four quark model it would dominate the purely left-handed contribution (and "ruin" agreement with experiment) unless[3] $M_R > 1.6\ TeV$.

This has led to more complete analyses[4,5] of the $K^0 - \bar{K}^0$ mass matrix constraints, in left-right symmetric theories. Mohapatra *et al.*[5] in particular have investigated $SU(2)_L \times SU(2)_R \times U(1)$ and extended the analysis to include both the top quark and the effects of Higgs bosons. The latter are potentially very important in that there is necessarily a $\Delta S = 2$ amplitude from neutral Higgs exchange at tree level. Indeed, working in the limit of vanishing $W_L - W_R$ mixing (known to be small from experiment[2]), they find that including the t quark and Higgs bosons in the calculation is very important and results in a much less stringent lower limit on M_R: values of several hundred GeV are allowed for reasonable top quark and Higgs' masses and particular values of the Kobayashi-Maskawa[6] (K-M) weak mixing angles.

In this paper we focus on the domain of allowed values of these mixing angles. We will show that this domain is ruled out by other restrictions on these angles coming from measurement of B meson decays. While we also work within the specific context of $SU(2)_L \times SU(2)_R \times U(1)$, the problem we find very likely is of a type which generalizes to a class of left-right symmetric theories.

First we consider the domain of allowed K-M angles emerging from the analysis of the $K^0 - \bar{K}^0$ mass matrix. In the simplest and most natural left-right symmetric theories, with so-called "manifest" left-right symmetry, the quark mass matrix is Hermitian and is diagonalizable by a single unitary matrix. The weak mixing angles are then the same on the left and right, so that with six quarks we need to deal with just a single 3×3 unitary matrix which can be parametrized[6] by three Cabibbo-like angles θ_i and a phase δ, as in the standard model. The solutions to the constraints imposed by the $K^0 - \bar{K}^0$ mass matrix found by Mohapatra *et al.*[5], involve values of $s_2 \equiv \sin\theta_2$ and $s_3 \equiv \sin\theta_3$ which, from the representative cases plotted in their paper, appear to be constrained to lie on hyperbolas in the $s_3 - s_2$ plane whose asymptotes are the lines $s_2 = s_3$ and $s_2 = 0$.

It is not difficult to show why this is the case and that it is a general feature of the restrictions imposed on the K-M angles in such a theory. The origin lies in neutral Higgs exchange which contributes a $\Delta S = 2$ amplitude at tree level. If there were no t quark and the neutral Higgs' masses were in the range of 100 GeV to 1 TeV considered by Mohapatra *et al.*,[5] this amplitude would make a contribution to the $K^0 - \bar{K}^0$ mass matrix of roughly 10^2 to 10^4 times that of the standard one[7] corresponding to the box diagram involving charm-quarks and left-handed W's. Inasmuch as the latter diagram, with plausible values for the corresponding $K^0 - \bar{K}^0$ matrix element and charm-quark mass, by itself yields a contribution of roughly the right magnitude to explain the $K_L^0 - K_S^0$ mass difference[7], the additional neutral Higgs contribution would be far too large to be acceptable, even with allowance for any reasonable long-distance contributions.

With the t quark included there is a way to obtain consistency with the $K_L^0 - K_S^0$ mass difference: make the coupling at the $H^0 \bar{d} s$ vertex,[8] which enters the $\Delta S = 2$ amplitude quadratically, very small by adjusting the K-M angles. This coupling is proportional to $\sum_{i=u,c,t} \lambda_i m_i$, where $\lambda_i = U_{is}^* U_{id}$ are products of elements of the K-M matrix. Thus, to an excellent approximation, the constraint from the real part of the $K^0 - \bar{K}^0$ mass matrix, i.e., the measured $K_L - K_S$ mass difference, will force

$$\begin{aligned} Re\{[\sum_i \lambda_i m_i]^2\} = Re\{[c_1 s_1 c_3 m_u + s_1 c_2 (c_1 c_2 c_3 - s_2 s_3 e^{-i\delta}) m_c \\ + s_1 s_2 (c_1 s_2 c_3 + c_2 s_3 e^{-i\delta}) m_t]^2\} = 0 , \end{aligned} \tag{1}$$

where $s_i = \sin\theta_i, c_i = \cos\theta_i$. We may safely neglect m_u compared to m_c and m_t. Then in the regime of small angles (i.e., we neglect terms quadratic in sines of angles compared to those of zeroth order), we have

$$Re\{[m_c + s_2(s_2 + s_3 e^{-i\delta}) m_t]^2\} = 0 . \tag{2}$$

The corresponding constraint due to the imaginary part of the $K^0 - \bar{K}^0$ mass matrix (which is related to ϵ, the CP violation parameter) demands that δ is close to 0^0 or 180^0. Inspection of eq. (2) shows that only the possibility $\delta \approx 180^0$ permits it to be satisfied. For $\cos\delta = -1$ it reads:[9]

$$\frac{m_c}{m_t} + s_2^2 - s_2 s_3 = 0 \; , \tag{3}$$

i.e., the equation of a hyperbola in the $s_3 - s_2$ plane whose asymptotes are the lines $s_2 = s_3$ and $s_2 = 0$, and with a minimum value of $s_3 = 2(m_c/m_t)^{1/2}$. Equation (3) agrees well with the specific cases for various m_t, M_H, and M_R actually plotted by Mohapatra *et al.*[5]

For the narrow purpose at hand of showing the contradiction with information on s_2 and s_3 from B meson decay, the analytic form in eq. (3) is unnecessary: for that we only need to know that $\cos\delta \approx -1$ and $s_2 < s_3$ hold for the solutions in ref. 5. But eq. (3) gives us insight into what is the key factor generating those specific solutions, and because of its origin in the $\Delta S = 2$ tree level amplitude induced by neutral Higgs exchange, indicates it has more generality than the specific theory at hand.

The relevant restriction on the K-M angles from B decay comes from the present upper limit[10] on $\Gamma(b \to ue\nu)$ compared to $\Gamma(b \to ce\nu)$:

$$\frac{\Gamma(b \to ue\nu)}{\Gamma(b \to ce\nu)} < 0.05 \; . \tag{4}$$

When converted into a statement on K-M angles this reads

$$\frac{s_1^2 s_3^2}{0.41(s_2^2 + 2 s_2 s_3 c_\delta + s_3^2)} < 0.05 \; , \tag{5}$$

where the factor of 0.41 takes account of the smaller phase space available in $b \rightarrow ce\nu$, because of the charm quark mass.[11] Using the experimental value of s_1, we rewrite eq. (5) as

$$s_2^2 + 2c_\delta s_2 s_3 - 1.44\, s_3^2 > 0\ . \tag{6}$$

Clearly $s_2 = 0$ is forbidden, so we may rewrite eq. (6) in the case of interest as

$$1 + 2c_\delta(s_3/s_2) - 1.44\,(s_3/s_2)^2 > 0\ . \tag{7}$$

The quadratic form in s_3/s_2 on the left-hand side is positive for values of s_3/s_2 ranging up to $[c_\delta + (1.44 + c_\delta^2)^{1/2}]/1.44$. For $c_\delta \approx -1$, as found above from the $K^0 - \bar{K}^0$ mass matrix constraints, $s_3/s_2 < 0.39$ or

$$s_2 > 2.56\, s_3\ . \tag{8}$$

Even if we relax the constraint on δ to be just that $\cos\delta < 0$, we still obtain $s_2 > 1.2\ s_3$. Thus s_2 and s_3 are restricted to a region which does not overlap at all with that where $s_2 < s_3$, as demanded by eq. (3) which expresses the constraint following from imposing consistency with the observed $K_L^0 - K_S^0$ mass difference.

We conclude that the imposition of the constraint of being consistent with the observed $K_L^0 - K_S^0$ mass difference upon the manifest left-right symmetric theory $SU(2)_L \times SU(2)_R \times U(1)$ results in values for the K-M angles which are inconsistent with our knowledge of B meson decays. The critical factor in forcing the K-M angles into such a domain is the potentially enormous $\Delta S = 2$ amplitude from neutral Higgs boson exchange which makes one choose K-M angles so as to make the $d - s$ flavor changing coupling essentially vanish. One could get around the problem we have pointed out by giving up the "manifest" portion of manifest left-right symmetry and thereby allowing different weak mixing angles on the left and right.[12] Presumably nothing prevents this except the decidedly less aesthetic theory that results. Alternatively one could make the Higgs mass larger so as to suppress the $\Delta S = 2$ Higgs exchange amplitude. Higgs masses of order 10 TeV would be required. With a negligible Higgs contribution, we will have come full circle back to the work of Beall *et al.*[3]: the scale of M_R and the restoration of parity invariance are pushed upward into the multi-TeV region.

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[8] In the minimal $SU(2)_L \times SU(2)_R \times U(1)$ gauge theory there are two neutral Higgs bosons with flavor changing couplings. While the form of the interaction of one is scalar and the other pseudoscalar, both couplings are proportional to $\sum_i \lambda_i m_i$. As in ref. 5 we have taken a common mass and lumped their effects together.

[9] While the exact condition $\cos\delta = -1$ and therefore $\sin\delta = 0$ is not

allowed (it corresponds to no CP violation arising from the K-M matrix), the actual values of δ obtained by fitting to ϵ make $\cos\delta = -1$ an excellent approximation in eq. (2). The use of the actual values of δ acts in any case to strengthen the key condition for our argument that $s_2 < s_3$ for the solutions of eq. (2).

[10] E. Thorndike, CLEO collaboration results presented at Rencontre de Moriond, La Plagne, France, March 14-19, 1983.

[11] M. K. Gaillard and L. Maiani in Quarks and Leptons, Cargese 1979, edited by M. Levy; J. L. Basdevant, D. Speiser, J. Weyers, R. Gastmans, and M. Jacob (Plenum Press, New York, 1980), p. 433. Changing the effective b and c quark masses within a reasonable range could make this factor as large as about 0.5, but this does not change our conclusion.

[12] The flavor changing Higgs couplings are still present and are a potentially serious problem, but their connection solely to the K-M matrix measured in low energy weak processes (in particular, to B decay), is severed.