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$SU_2 \otimes U_1$ gauge model of electroweak interaction with $(V+A)$ strangeness-changing charged current

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Abstract. We construct a model of renormalizable electroweak interaction with $(V+A)$ strangeness-changing charged current in the framework of the minimal spontaneously broken $SU_2 \otimes U_1$ gauge theory, taking our motivation from the recently reported measurement of the electron asymmetry in polarized Σ^--hyperon β-decay by Keller and co-workers. The model avoids strangeness-changing but admits charm-changing pieces in the neutral current. Several phenomenological consequences of the model are discussed together with a comparison with the standard model of electroweak interaction.

Keywords. Electroweak interaction; gauge theory; strangeness-changing charged current; charm-changing neutral current; quarks; leptons; intermediate bosons.

1. Introduction

A measurement of the electron asymmetry in the β-decay of polarized Σ^--hyperons has been reported recently by Keller *et al* (1982). This measurement has introduced a controversial issue of crucial importance for the theory of weak interactions, since according to it the strangeness-changing charged current should have a $(V+A)$ structure contrary to the results of earlier experiments on Λ decay in conformity with a $(V-A)$ structure (*cf.* Particle Data Group 1980). The $(V-A)$ structure for the charged strangeness-preserving hadronic, as well as for the charged electronic and muonic currents has been well established over the years* and so this structure has been carried over into the standard model of electroweak interaction arising in a renormalizable spontaneously broken $SU_2 \otimes U_1$ gauge theory (Weinberg 1967; Salam 1968; Glashow *et al* 1970; Kobayashi and Maskawa 1973). While the controversial issue raised by the latest experiment referred to above can only be settled by further experimentation, a question that naturally comes up is whether it is possible to construct a model of electroweak interaction, within the standard framework of $SU_2 \otimes U_1$ gauge theory, in such a way that the strangeness-changing piece of the charged current turns out to have a $(V+A)$ structure while agreement with established experiments is maintained in all the other respects.

The present paper describes such a model**. Two important additional features of the model are: (i) to meet the requirement of anomaly cancellations, essential for

*For a review, see the monograph by Marshak *et al* (1969). We shall follow this monograph for notations regarding the space-time metric, Dirac matrices, etc.

**A brief preliminary account was given in Pandit (1982).

renormalizability, we are forced to introduce at least one more pair of leptons and of quarks (this could have been avoided only if the tauonic charged current had also turned out experimentally to be of $(V + A)$ structure;) (ii) while there are no strangeness-changing pieces in the neutral current, there do appear charm-changing* pieces that are of considerable experimental interest.

In the next section we describe our modified scheme for electroweak interaction. Some features of the effective charged-current weak interactions implied by the model are discussed in § 3. The same is done for the neutral current phenomena in § 4. Comparisons with the results of the standard model are made in appropriate places. It will be seen that there are several features of experimental interest in the model presented here.

2. The model

We follow the, by now quite well known, procedure** of setting up the $SU_2 \otimes U_1$ gauge theory spontaneously broken by the introduction of one complex doublet of scalar fields. Conventional notation will be used, and we shall avoid repeating well-documented details.

We denote by Y the U_1 'charge' and by T_3 the diagonal generator of SU_2. The electric charge (in units of protonic charge) will be taken to be

$$Q = T_3 + Y. \tag{1}$$

Using the notation $u_{L,R} = \frac{1}{2}(1 \pm \gamma_5)u$, etc., we make (for reasons explained below) the following assignments of the quarks and leptons to $SU_2 \otimes U_1$ representations:

$$\text{Quark-doublets:} \quad \begin{bmatrix} u'_L \\ d_L \end{bmatrix}, \begin{bmatrix} c'_R \\ s_R \end{bmatrix}, \begin{bmatrix} t'_L \\ b_L \end{bmatrix}, \begin{bmatrix} g'_L \\ h_L \end{bmatrix}, \quad \text{with } Y = 1/6; \tag{2a}$$

$$\text{Lepton-doublets:} \quad \begin{bmatrix} \nu_{eL} \\ e_L \end{bmatrix}, \begin{bmatrix} \nu_{\mu L} \\ \mu_L \end{bmatrix}, \begin{bmatrix} \nu_{\tau L} \\ \tau_L \end{bmatrix}, \begin{bmatrix} \nu_{\sigma R} \\ \sigma_R \end{bmatrix}, \quad \text{with } Y = -1/2, \tag{2b}$$

the singlets:

$$u'_R, \quad c'_L, \quad t'_R, \quad g'_R, \quad \text{with } Y = +2/3; \tag{3a}$$

$$d_R, \quad s_L, \quad b_R, \quad h_R, \quad \text{with } Y = -1/3; \tag{3b}$$

$$\nu_{eR}, \quad \nu_{\mu R}, \quad \nu_{\tau R}, \quad \nu_{\sigma L}, \quad \text{with } Y = 0; \tag{3c}$$

$$e_R, \quad \mu_R, \quad \tau_R, \quad \sigma_L, \quad \text{with } Y = -1. \tag{3d}$$

*Charm-changing neutral current in the context of the WP-model have been considered in the past by Barger and Nanopoulos (1977).

**An excellent account may be found in Tulsi Dass (1973).

We have introduced additional quarks g and h ($Q = 2/3, \ -1/3$) and leptons ν_σ, σ($Q = 0, \ -1$) to achieve anomaly cancellations as explained below. By u', c', t' and g' we denote a general Kobayashi-Maskawa type mixture of the $Q = 2/3$ quarks u, c, t and g. For a first uncluttered survey of the dominant features of the model we shall, however, use here the following Cabibbo-angle mixture:

$$u' \simeq (\cos\theta)u + (\sin\theta)c, \; c' \simeq (-\sin\theta)u + (\cos\theta)\,c,$$
$$t' \simeq t, \; g' \simeq g \tag{4}$$

It will be understood, of course, that each quark comes in three colours which will, however, not be indicated explicitly in our expressions.

We have been led to make the assignments displayed in (2) and (3) for the following reasons: (i) we must put d_L and s_R in the respective doublets (equation (2a)), because we must have the well-established ($V - A$) structure for the strangeness-preserving piece of the charged current and we wish to have ($V + A$) structure for the strangeness-changing piece (in view of the result of Keller *et al* (1982)). (ii) We must also make sure that we do not end up having a strangeness-changing piece in the neutral current. To ensure this we must not allow mixing of the d and s quark fields (the GIM trick, Glashow *et al* 1970, will not work because of the opposite chiralities of the above two doublets). (iii) So, instead of mixing the d and s, as in the standard model, we must now appropriately mix the u and c (equation (4)) in order to introduce the Cabibbo angle effects in the hadronic pieces of the charged current. (iv) Since the ($V - A$) structures of the charged electronic and muonic currents are well established (*cf.* Marshak *et al* 1969) the electronic and muonic doublets must be left-handed (L) as in (2b). (v) Now, however, we must take care of anomaly cancellations*, essential for renormalizability. The anomaly from the (u'_L, d_L) doublet is cancelled by that arising from the (ν_{eL}, e_L) doublet; but, since the doublets (c'_R, s_R) and ($\nu_{\mu L}$, μ_L) have opposite chiralities, they cannot mutually cancel their respective anomalies. For cancellation we must have another right-handed (R) doublet of leptons and a left-handed (L) doublet of quarks. However, we cannot employ the leptons ν_τ and τ for this purpose since recent experiments** indicate that the charged tauonic current is most likely ($V - A$). Hence we are forced to introduce a new pair of leptons (ν_σ, σ) to form the desired R-doublet, and also a new pair of quarks (g, h) to go along with these. The assignments of (2) and (3) are thus mandatory for constructing a model of renormalisable electroweak interaction that keeps within the standard $SU_2 \otimes U_1$ gauge framework and realises our objective.

Following the pattern of the standard theory we obtain the electroweak interaction expressed in conventional notation as:

$$-L_{\text{int}} = e\left(A_\mu j_\mu^{\text{em}} + \frac{2}{\sin(2\theta_W)} Z_\mu\,(J_\mu^3 - \sin^2\theta_W j_\mu^{\text{em}}) + \frac{1}{\sqrt{2}\sin\theta_W}\,(W_\mu^+ J_\mu^{1+i2} + \text{h.c.})\right). \tag{5}$$

*For a general discussion on the treatment of anomalies, see Georgi and Glashow (1972).
**For a review and references see Perl (1980).

Here j_μ^{em} is the current of the electric charge Q and J_μ^a, $a = 1, 2, 3$, is the current of the generator T_a of SU_2. As in the standard model, we have

$$m_W \simeq 37{\cdot}3 \text{ GeV}/\sin\theta_W, \; m_Z = m_W/\cos\theta_W. \tag{6}$$

Assuming (4) as expressing the dominant approximation to the possible mixings, and employing the notation L_ρ for $\gamma_\rho(1+\gamma_5)$ and R_ρ for $\gamma_\rho(1-\gamma_5)$ we have for the fermionic parts of the various currents:

$$\begin{aligned}(-i)\,j_\rho^{\text{em}} = &-[\bar{e}\,\gamma_\rho\,e + \bar{\mu}\,\gamma_\rho\,\mu + \bar{\tau}\,\gamma_\rho\,\tau + \bar{\sigma}\,\gamma_\rho\,\sigma]\\ &+\tfrac{2}{3}\,[\bar{u}\,\gamma_\rho\,u + \bar{c}\,\gamma_\rho\,c + \bar{t}\,\gamma_\rho\,t + \bar{g}\,\gamma_\rho\,g]\\ &-\tfrac{1}{3}\,[\bar{d}\,\gamma_\rho\,d + \bar{s}\,\gamma_\rho\,s + \bar{b}\,\gamma_\rho\,b + \bar{h}\,\gamma_\rho\,h],\end{aligned} \tag{7}$$

$$\begin{aligned}(-2i)\,J_\rho^{1+i2} \simeq\; &\bar{\nu}_e\,L_\rho\,e + \bar{\nu}_\mu\,L_\rho\,\mu + \bar{\nu}_\tau\,L_\rho\,\tau + \bar{\nu}_\sigma\,R_\rho\,\sigma\\ &+\bar{t}\,L_\rho\,b + \bar{g}\,L_\rho\,h + \cos\theta\,[\bar{u}\,L_\rho\,d + \bar{c}\,R_\rho\,s]\\ &-\sin\theta\,[\bar{u}\,R_\rho\,s - \bar{c}\,L_\rho\,d],\end{aligned} \tag{8}$$

$$\begin{aligned}(-4i)\,J_\rho^3 \simeq\; &[\bar{\nu}_e\,L_\rho\,\nu_e + \bar{\nu}_\mu\,L_\rho\,\nu_\mu + \bar{\nu}_\tau\,L_\rho\,\nu_\tau + \bar{\nu}_\sigma\,R_\rho\,\nu_\sigma]\\ &-[\bar{e}\,L_\rho\,e + \bar{\mu}\,L_\rho\,\mu + \bar{\tau}\,L_\rho\,\tau + \bar{\sigma}\,R_\rho\,\sigma]\\ &-[\bar{d}\,L_\rho\,d + \bar{s}\,R_\rho\,s + \bar{b}\,L_\rho\,b + \bar{h}\,L_\rho\,h]\\ &+\bar{t}\,L_\rho\,t + \bar{g}\,L_\rho\,g + \cos^2\theta\,[\bar{u}\,L_\rho\,u + \bar{c}\,R_\rho\,c]\\ &+\sin^2\theta\,[\bar{u}\,R_\rho\,u + \bar{c}\,L_\rho\,c] + \sin 2\theta\,[\bar{u}\,\gamma_\rho\,\gamma_5\,c + \bar{c}\,\gamma_\rho\,\gamma_5\,u].\end{aligned} \tag{9}$$

Note that the neutral current has no strangeness-changing piece, but does have a substantial pure axial-vector charm-changing piece (the last term of (9)) proportional to $\sin 2\theta$.

In the next two sections we shall discuss some of the main immediate consequences of our model of relevance to present day experiments.

3. Effective charged-current weak interactions

3.1 μ-decay

For purposes of normalisation we put down the effective four-fermion interaction responsible for muon decay which is, as it must be, the same as in the standard theory:

$$L_{\text{eff}} = -\frac{G}{\sqrt{2}}(\bar{\nu}_\mu\,\gamma_\rho\,(1+\gamma_5)\,\mu)\,(\bar{e}\,\gamma_\rho\,(1+\gamma_5)\,\nu_e) + \text{h.c.} \tag{10}$$

The Fermi coupling constant G is given by

$$\frac{G}{\sqrt{2}} = \frac{e^2}{8m_W^2 \sin^2 \theta_W}. \tag{11}$$

3.2 τ-*decays*

The τ-decays will continue to be described as in the standard model.

3.3 *Semi-leptonic decays of ordinary hadrons*

Using the old SU_3 notation of Cabibbo theory (*cf.* Marshak *et al* 1969) the semi-leptonic decays of the old strange and non-strange hadrons will be described by the effective interaction

$$L_{\text{eff}} = i\frac{G}{\sqrt{2}}[\bar{\mu} L_\rho \nu_\mu + \bar{e} L_\rho \nu_e] [\cos \theta (V_\rho^{1+i2} + A_\rho^{1+i2})$$
$$+ \sin \theta (- V_\rho^{4+i5} + A_\rho^{4+i5})] + \text{h.c.} \tag{12}$$

Note the change in sign in front of V_ρ^{4+i5} in comparison with the standard theory. The strangeness-changing hadronic current is thus $(V + A)$ instead of $(V - A)$.

Of the semi-leptonic decays of mesons only the K_{l4} decays involve both the V as well as the A currents. However, the relevant experimental as also the theoretical analyses are too intricate to yield still an unambiguous decision on the $(V - A)$ versus $(V + A)$ nature of the strangeness-changing charged current (see Marshak *et al* 1969).

For the Σ^- -hyperon β-decay, in particular, we thus have $g_V = \sin\theta$, $g_A = \sin \theta (- F + D)$, (see Marshak *et al* 1969). Thus with $F \approx 0{\cdot}43$ and $D \approx 0{\cdot}79$, we find $(g_A/g_V) \approx + 0{\cdot}36$. This sign agrees with the result of Keller *et al* (1982) who favour the value $(g_A/g_V) = + 0{\cdot}44 \pm 0{\cdot}03$. To obtain this agreement of sign was, of course, the starting motivation of our work. So, apart from the sign of (g_A/g_V) for the Λ hyperon (*cf.* Particle Data Group 1980), our model agrees with data on semi-leptonic hadronic decays as well as the standard model. Further experimentation will be needed to settle the present controversial situation regarding the $(V - A)$ versus the $(V + A)$ structure of the strangeness-changing charged current.

3.4 *Leptonic processes involving charmed hadrons*

The effective interaction operative is

$$L_{\text{eff}} = -\frac{G}{\sqrt{2}}[(\bar{\nu}_\mu L_\rho \mu) + (\bar{\nu}_e L_\rho e) + \dots]$$
$$[(\cos \theta)\, \bar{s} R_\rho c + (\sin \theta)\, \bar{d} L_\rho c] + \text{h. c.} \tag{13}$$

The only differences from the standard model come in the change of sign of the sin θ term and in the cos θ term having $(V+A)$ instead of the usual $(V-A)$ structure for the hadronic current. Measurements of semi-leptonic decay rates of charmed hadrons are not sensitive to these changes and so for this purpose our model is not distinguished from the standard model.

Where differences, although rather subtle, do occur from the standard model is in the phenomena of dimuon* production (signalling charm production) in the collisions of high energy ν_μ and $\bar{\nu}_\mu$ with nucleons. In this connection it should be noted that in the ν_μ collision the production is off the valence d-quark with the standard factor sin θ and the standard $(V-A)$ interaction, whereas it is off the sea s-quark with the standard factor cos θ but modified $(V+A)$ interaction. In $\bar{\nu}_\mu$ collision the production is off sea quarks $\bar{d}$ and $\bar{s}$ — the dominant cos θ factor occurring for $\bar{s}$ quark with the modified $(V+A)$ interaction. It will thus be very interesting to look for these subtle differences in experimental studies through the so called y-distribution studies, specially in $\bar{\nu}_\mu$ collisions.

3.5 *Nonleptonic decays*

The effective interactions for $|\Delta S| = 1$ parity-conserving (pc) and parity-violating (pv) processes are, respectively,

$$L_{\text{eff}}\,(|\Delta S| = 1,\ \text{pc}) = \frac{G}{\sqrt{2}} \sin\theta \cos\theta\, (\tfrac{1}{2})$$

$$[\{\bar{u}\,\gamma_\mu\, d,\ \bar{s}\,\gamma_\mu\, u\} - \{\bar{u}\,\gamma_\mu\,\gamma_5\, d,\ \bar{s}\,\gamma_\mu\,\gamma_5\, u\}] + \text{h. c.}, \tag{14}$$

$$L_{\text{eff}} = (|\Delta S| = 1,\ \text{pv}) = \frac{G}{\sqrt{2}} \sin\theta \cos\theta\, (\tfrac{1}{2})\, [\{\bar{u}\gamma_\mu\,\gamma_5\, d,\ \bar{s}\gamma_\mu\, u\} -$$

$$\{\bar{u}\gamma_\mu\, d,\ \bar{s}\gamma_\mu\,\gamma_5\, u\} + \text{h.c.}, \tag{15}$$

where we have used the notation $\{A, B\} = AB + BA$. The expressions (14) and (15) differ from those in the standard model in the crucial (—) sign present in their right hand sides. While the isospin properties are not changed, the SU_3 properties in the limit of exact SU_3 symmetry are now crucially altered as a result. Also, as a result, the short-distance QCD enhancement and suppression behaviours of the different effective operators will get modified (see in this connection, *e. g.* the review by Lee (1975)). Nonleptonic decays are well-known for their having remained largely intractable on account of the complications arising due to the hadronic strong interactions. We propose to go into all related questions elsewhere.

Interesting modifications will appear also in the description of the nonleptonic decays of charmed hadrons. The dominant interaction proportional to $\cos^2\theta$ again arises from the current $\times$ current interaction using charged currents (with the same strangeness and charm selection rules as in the standard model), whereas the subdominant part proportional to cos θ sin θ will now receive a contribution also from

*For a recent review see Fisk (1981).

the charm-changing piece in the neutral current. We relegate a discussion of charmed hadron decays also to a separate occasion since strong interaction complications are present here too and will require detailed problematic considerations typical of nonleptonic processes.

4. Effective neutral-current weak interactions

We now discuss some typical weak neutral current effects. For a review of experiments and references see, *e.g.* Winter (1979).

4.1 *Neutrino-electron scattering*

$$L_{\text{eff}} = -\frac{G}{\sqrt{2}}\,[\bar{\nu}_\mu \gamma_\lambda (1+\gamma_5)\nu_\mu \cdot \bar{e}\gamma_\lambda (C_V + C_A\gamma_5)\,e$$

$$+\,\bar{\nu}_e \gamma_\lambda (1+\gamma_5)\nu_e \cdot \bar{e}\gamma_\lambda (C'_V + C'_A\gamma_5)\,e], \tag{16}$$

where $C_V = -\frac{1}{2} + 2\sin^2\theta_W,\ C_A = -\frac{1}{2},\ C'_V = C_V + 1,\ C'_A = C_A + 1.$ (17)

The effective interaction is the same as in the standard model.

4.2 *The process $e\bar{e} \to \mu\bar{\mu}$*

From (9) it is clear that for the Z^0 contribution for this process also our model does not differ from the standard model.

4.3 *Parity violation in atomic physics*

This arises, as is well-known, from the coupling of the neutral axial-vector current of the electron with the vector parts of the neutral currents of the u and d quarks. In these parts our model does not differ from the standard model and so we obtain the same result.

4.4 *Asymmetry in deep inelastic polarized e-deuteron scattering*

In the notation of Cahn and Gilman (1978), the asymmetry parameter according to our model is given by

$$A_{eD} = -\frac{Gg^2}{2(\sqrt{2})\pi\alpha}\left(\frac{9}{10}\right)\left[\left(1 - \frac{20}{9}\sin^2\theta_W\right)\right.$$

$$\left. + (1 - 4\sin^2\theta_W)\left(1 - \frac{4}{3}\sin^2\theta\right)\frac{1-(1-y)^2}{1+(1-y)^2}\right] \tag{18}$$

The difference from the standard model appears here through the occurrence of the additional factor $[1 - (4/3)\sin^2\theta]$ in the second term. For $\sin\theta \approx 0{\cdot}2$, this factor is

$\approx 0{\cdot}95$, so that the difference is hardly distinguishable by the present experiments (Prescott *et al* 1978, 1979)

4.5 *Parameters characterising flavour-preserving neutral current ($\nu_\mu - N$) interactions*

Using the currently standard notation, the relevant effective interaction can be written as

$$L_{\rm eff} = -\frac{G}{\sqrt{2}}(\bar{\nu}_\mu L_\lambda \nu_\mu)[u_L(\bar{u}L_\lambda u)+u_R(\bar{u}R_\lambda u)+d_L(\bar{d}L_\lambda d)+d_R(\bar{d}R_\lambda d)], \quad (19)$$

where

$$u_L = \tfrac{1}{2}(1-\sin^2\theta) - \tfrac{2}{3}\sin^2\theta_W,\ u_R = \tfrac{1}{2}\sin^2\theta - \tfrac{2}{3}\sin^2\theta_W; \quad (20)$$

$$d_L = -\tfrac{1}{2} + \tfrac{1}{3}\sin^2\theta_W,\ d_R = \tfrac{1}{3}\sin^2\theta_W \quad (21)$$

The expressions for d_L and d_R are the same as in the standard model, whereas the expressions for u_L and u_R differ by the small correction terms $-\frac{1}{2}\sin^2\theta$ and $\frac{1}{2}\sin^2\theta$, respectively. So these parameters do not significantly differ from those in the standard model.

4.6. *Processes involving charm-changing neutral current*

According to (9), there is a pure axial-vector charm-changing piece in the neutral current. This will lead to $|\Delta C|=1$ as well as $|\Delta C|=2$ current $\times$ current effective interactions with interesting consequences (totally absent in the standard model). We write the charm-changing neutral current as

$$g_L\bar{u}\gamma_\lambda \tfrac{1}{2}(1+\gamma_5)c + g_R\bar{u}\gamma_\lambda \tfrac{1}{2}(1-\gamma_5)c + \text{h.c.} \quad (22)$$

where

$$g_L = -g_R = \sin\theta\cos\theta. \quad (23)$$

For normalization purposes it should be noted that this current leads to the $|\Delta C|=1$ effective interaction

$$L_{\rm eff}(|\Delta C|=1) = -\frac{G}{\sqrt{2}}[\bar{\nu}_\mu\gamma_\lambda(1+\gamma_5)\nu_\mu + \ldots][g_L\bar{u}\gamma_\lambda \tfrac{1}{2}(1+\gamma_5)c$$
$$+ g_R\bar{u}\gamma_\lambda\tfrac{1}{2}(1-\gamma_5)c] + \text{h.c.} \quad (24)$$

Recently a detailed theoretical analysis of the effects of a charm-changing neutral current for arbitrary g_L and g_R has been carried out by Buccella and Oliver (1980) and we shall use their results in the following discussion.

Experimental searches for a charm-changing neutral current in neutrino-nucleon reactions look for the 'wrong sign' lepton in the reaction products. In the approximation of the valence quark parton model the relevant quantities are

$$R = \frac{\sigma(\nu_\mu N \to \nu_\mu C)}{\sigma(\nu_\mu N \to \nu_\mu X)} = \left(\frac{1}{2}\right) \frac{g_L^2 + \frac{1}{3} g_R^2}{4\left(\frac{1}{2} - x + \frac{20}{27} x^2\right)}, \tag{25}$$

$$\bar{R} = \frac{\sigma(\bar{\nu}_\mu N \to \bar{\nu}_\mu C)}{\sigma(\bar{\nu}_\mu N \to \bar{\nu}_\mu X)} = \left(\frac{1}{2}\right) \frac{g_L^2 + 3g_R^2}{4\left(\frac{1}{2} - x + \frac{20}{9} x^2\right)}, \tag{26}$$

where x stands for $\sin^2 \theta_W$, N is an 'isoscalar' target and $C(X)$ denote final states with (without) charm. In the expressions given by Buccella and Oliver the factors (1/2) in (25) and (26) are missing. Since the charm-changing interaction involves only the u quark, whereas the charm-preserving interactions involves both the u and the d quarks, and since in an 'isoscalar' target the number of valence u quarks is one-half of the total number of valence u and d quarks, the above factors (1/2) are necessary.

(a) Holder *et al* (1978) obtained a 90% C.L. limit

$$R < 0{\cdot}026, \tag{27}$$

which implies that (using $x \simeq 0{\cdot}23$)

$$(g_L^2 + \tfrac{1}{3} g_R^2) < 0{\cdot}064 \tag{28}$$

For $\sin \theta \simeq 0{\cdot}2$, we obtain for our model, equation (23), the value

$$(g_L^2 + \tfrac{1}{3} g_R^2) \approx 0{\cdot}053, \tag{29}$$

within the above limit.

(b) Efremenko *et al* (1979) obtained a 90% C.L. limit

$$\bar{R} < 0{\cdot}04, \tag{30}$$

which implies that (using $x \simeq 0{\cdot}23$)

$$(g_L^2 + 3\, g_R^2) < 0{\cdot}124, \tag{31}$$

whereas in our model

$$(g_L^2 + 3\, g_R^2) \approx 0{\cdot}16 \tag{32}$$

in disagreement, however not in a flagrant manner, with the above limit. Confirmations of the above experimental limits at a higher confidence level should thus be looked for.

(c) Experiments of the Columbia-BNL group reported by Baltay (1978) extract another interesting limit:

$$\frac{\Gamma\,(c \to e^+ e^- X)}{\Gamma\,(c \to e^+ \nu_e\, X)} < 0{\cdot}02, \tag{33}$$

which again leads in the valence parton model (see Buccella and Oliver 1980) to

$$g_L^2 + g_R^2 < 0{\cdot}16, \tag{34}$$

whereas in our model

$$g_L^2 + g_R^2 \approx 0{\cdot}08. \tag{35}$$

(d) $|\Delta C| = 2$, $(D^0 - \bar{D}^0)$ —mixing of sizable amount is expected in our model. A detailed analysis, including QCD corrections that are critical, in the general case has been carried out by Buccella and Oliver (1980). These authors arrive at the conclusion: 'Strictly speaking, large g_L, g_R couplings are not excluded....D^0—$\bar{D}^0$ mixing cannot exclude large (dominantly axial-vector) couplings.' In our model the coupling *is* pure axial-vector.

The considerations presented in §§ 3 and 4 above indicate that the model has several interesting consequences of experimental interest. Severe tests of the model, both for the strangeness-changing charged current as well as for the charm-changing neutral current, are expected from the study of charm production in high energy $\bar{\nu}_\mu$ reactions.

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