Pramāṇa, Vol. 12, No. 4, April 1979, pp. 419–425, © printed in India

Neutral currents in alternative U_3 (W)–gauge models of weak and electromagnetic interactions

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MS received 26 December 1978

Abstract. Two alternative U_3(W)-gauge models are presented. Both agree with the recent Abbott-Barnett fits to the neutrino-nucleon neutral-current data, and with the SLAC measurement of the asymmetry parameter for longitudinally polarised electron-deuteron inelastic scattering. Results for $\sigma(\nu_\mu e)$, $\sigma(\bar{\nu}_\mu e)$ are also found in agreement with the latest measurements. The models differ in the parameter $Q_W(Z, N)$ characterising parity-violation in heavy atoms for which, however, the experimental situation is still unclear.

Keywords. Neutral currents; U_3(W)-gauge theory; neutrino interaction; polarised electron deuteron scattering asymmetry.

1. Introduction

In the present work, we discuss phenomena relating to weak neutral currents in the context of two new alternative models†, based on the framework of a spontaneously broken U_3(W)—gauge theory (Pandit 1976), unifying weak and electromagnetic interactions. In contrast to the earlier model, the new alternatives proposed here agree very well with (i) the recent stringent determinations of the neutrino-quark and neutrino-electron neutral-current interaction parameters from the analyses of relatively new data on neutrino interactions, and (ii) the more recent crucial measurement at SLAC of the asymmetry parameter (A_{eD}) for the inelastic scattering of longitudinally polarised electrons off deuteron.

The standard minimal $SU_2 \otimes U_1$ model (Weinberg 1967, Salam 1968, Glashow *et al* 1970) is already very well supported by the experimental determinations referred to above. Why then go into a more elaborate model, is a natural question to ask. Our answer is that these agreements are only sufficient, but not necessary, conditions for the validity of the model; hence, it is, at least, of some academic interest to present other models that work as well. Furthermore, in view of discoveries of a new heavy lepton (the τ) and of new heavy hadrons (the Υ's) it appears to us that it might turn out to be premature to foreclose all options other than that of the simplest standard model. In the U_3(W)-gauge theory we are forced to introduce in a critical manner new heavy quark flavours beyond the standard four (u, d, s, c), as well as new heavy leptons. As higher and higher energies become available in the future, more and

†A preliminary account was presented (contributed paper No. 1083) to the XIX International Conference on High Energy Physics, Tokyo (August, 1978).

more leptons and quarks might very well enter particle physics, and these might not enter in the simple sequential manner offered by the standard model.

We limit ourselves in this work to the common neutral current phenomena in order to establish a prima facie case for taking interest in the models proposed here.

2. General resumé of the U3(W)-gauge scheme

Following (Pandit 1976), we denote by G_a, $a=1, 2, \ldots, 8$, the hermitian generators of $SU_3(W)$, and by G_0 the generator of $U_1(W)$, where $U_3(W)=SU_3(W)\otimes U_1(W)$. The different models we speak of are obtained by choosing fermions (leptons and quarks) to belong to different suitable representations of this group. The electric charge operator is given by

$$Q=(G_3+\frac{1}{\sqrt{3}}G_8)+G_0. \tag{1}$$

$U_3(W)$-gauge invariant Lagrangian is constructed in the standard manner by the introduction of eight hermitian vector gauge fields coupled to the currents of G_a, $a=1,\ldots, 8$, with a single coupling constant f, and a ninth vector gauge field coupled to the current of G_0 with a coupling constant f'.

The gauge symmetry is spontaneously broken through the introduction (cf. Pandit 1976 and 1977) of three $SU_3(W)$ triplets of complex Higgs scalar fields

$$\phi^{(i)}\equiv(\phi_1^{(i)}, \phi_2^{(i)}, \phi_3^{(i)}),\ i=1, 2, 3, \text{ with } G_0=-2/3 \text{ for } \phi^{(1)}$$

$$\text{and } G_0=+\tfrac{1}{3} \text{ for } \phi^{(2)} \text{ and } \phi^{(3)}.$$

The 'vacuum' is then arranged to be such (by a suitable choice of the potential function) that $\phi_1^{(1)}$, $\phi_2^{(2)}$ and $\phi_3^{(3)}$ attain non-zero vacuum expectation values:

$$\langle\phi_2^{(2)}\rangle_0=\langle\phi_3^{(3)}\rangle_0=\eta\neq 0 \text{ and } \langle\phi_1^{(1)}\rangle_0=\eta'\neq 0.$$

This choice, allowing $\eta\neq\eta'$ in general, is made to meet the stringent requirement (necessary in any gauge theory seeking to unify weak and electromagnetic interactions) that only the gauge vector boson coupled to the electromagnetic current remains massless, while all the other eight (weak interaction) vector bosons become massive.

The vector boson fields diagonalising the mechanical mass-matrix generated by the above spontaneous breaking of the gauge symmetry, and their interactions are specified as follows: coupled with strength $f/\sqrt{2}$ are $W_\mu^\pm$ to the currents of $(G_1\pm iG_2)$, $R_\mu^\pm$ to the currents of $(G_4\pm iG_5)$, H_μ to the current of (G_6+iG_7) and $H_\mu^\dagger$ to the current of (G_6-iG_7). Besides these non-hermitian fields, we have three hermitian neutral vector boson fields A_μ, $Z_{1\mu}$ and $Z_{2\mu}$. A_μ couples to the electromagnetic current of Q with strength e. $Z_{1\mu}$ couples to the

$$(\mathscr{G}_1-\sin^2\chi\, Q)\text{—current, with strength } \frac{e}{\sin\chi\cos\chi}, \tag{2}$$

and $Z_{2\mu}$ couples to the

$$\mathscr{G}_2\text{—current, with strength } \frac{e}{\sqrt{3}\sin\chi}, \tag{3}$$

where we have employed the notation:

$$\mathscr{G}_1 \equiv G_3 + \frac{1}{\sqrt{3}} G_8;\ \ \mathscr{G}_2 \equiv -G_3 + \sqrt{3}\, G_8; \tag{4}$$

$$\tan\chi \equiv (2f'/\sqrt{3}f). \tag{5}$$

The non-zero masses of the vector bosons are:

$$m^2(W^\pm) = m^2(R^\pm) = f^2\,\eta^2(1+\tfrac{1}{2}\,\delta);$$

$$m^2(Z_2) = f^2\eta^2;\ m^2(Z_1) = \frac{1}{\cos^2\chi}\, f^2\,\eta^2(1+\tfrac{2}{3}\,\delta); \tag{6}$$

where the parameter δ is defined by

$$(\eta'/\eta)^2 \equiv 1+\delta,\ (\delta>-1). \tag{7}$$

The limiting value $\delta=-1$ will *not* be allowed as we must have both η and $\eta'\neq 0$ to generate all the fermion mechanical masses. In terms of the conventional four-fermion Fermi coupling constant G we have the normalisation:

$$G = \frac{f^2}{4\sqrt{2}\, m^2\,(W^\pm)}. \tag{8}$$

Weak (diagonal) neutral current phenomena will thus be described by the Z_1 and Z_2 mediated interactions in terms of the two parameters $\sin^2\chi$ and δ of the present theory. In this connection, it will be useful to note the relations:

$$\frac{e^2}{6m^2(Z_1)\sin^2\chi\,\cos^2\chi} = \delta_1\,\frac{G}{\sqrt{2}};\ \ \frac{e^2}{6m^2(Z_2)\sin^2\chi} = \delta_2\,\frac{G}{\sqrt{2}}; \tag{9}$$

where we define:

$$\delta_1 \equiv 1 - \frac{\delta}{6+4\delta},\ \ \delta_2 \equiv 1 + \frac{1}{2}\,\delta. \tag{10}$$

3. Model A

In this model we take, for *leptons*, $(e_L,\ \nu_e\ E_L^0)$ and $(\mu_L,\ \nu_\mu,\ M_L^0)$ to belong to the $\underline{3}^*$ representation of $SU_3(W)$ with $G_0 = -\frac{1}{3}$, where subscript L means left-handed components ($e_L \equiv \frac{1}{2}(1+\gamma_5)e$, etc.) and E^0 and M^0 are neutral heavy leptons of electronic and muonic type, respectively.

For *quarks* we assume six flavours: u, d, s, c, t and g. The charges of t and g are $+\frac{2}{3}$, just as of u and c, while d and s carry charge $-\frac{1}{3}$. From these we form two $\underline{3}^*$-representations of $SU_3(W)$: (d'_L, u_L, t'_L) and (s'_L, c_L, g'_L) with $G_0 = +\frac{1}{3}$. The primes on d' and s' represent the standard Cabibbo rotated combinations of d and s. Similarly, t' and g' represent some suitable mixtures of t and g.

The right-handed (R—) components of all the fermions will be taken to be singlets of $SU_3(W)$ with G_0 values equal to the respective electric charges.

Additional quarks and leptons may also be suitably included, but they are not relevant for the phenomenology discussed here. The leptons ν_τ, τ along with another heavy τ-type lepton T may thus be included. Anomaly cancellation using this device can be arranged along the lines already spelled out in detail in Pandit (1976).

We now discuss the standard weak current phenomena of current experimental interest. For this we employ the relevant Z_1 and Z_2 mediated effective interactions using the results listed in §2. We note, for this purpose, that $\mathscr{G}_1=(-\frac{2}{3}, +\frac{1}{3}, +\frac{1}{3})$ and $\mathscr{G}_2=(0, -1, +1)$ for the $\underline{3}^*$-triplets of the L-components. The R-components being all singlets of $SU_3(W)$ have $\mathscr{G}_1=\mathscr{G}_2=0$.

(i) The *ν-nucleon* neutral current processes are described (using parton picture) by the effective interaction Lagrangian in the notation of Abbott and Barnett (1978):

$$L_{\text{eff}}(N) = -\frac{G}{\sqrt{2}}\,\bar{\nu}\,\gamma_\rho\,(1+\gamma_5)\,\nu\;[u_L\,\bar{u}\,\gamma_\rho\,(1+\gamma_5)\,u + u_R\,\bar{u}\,\gamma_\rho\,(1-\gamma_5)\,u$$

$$+\, d_L\,\bar{d}\,\gamma_\rho\,(1+\gamma_5)\,d + d_R\,\bar{d}\,\gamma_\rho\,(1-\gamma_5)\,d], \tag{11}$$

where u_L, u_R, d_L, d_R are coupling parameters (not to be confused with spinor symbols used above) given in this model as follows:

$$u_L = \tfrac{1}{6}\,(\delta_1+3\delta_2) - \tfrac{1}{3}\,\delta_1 \sin^2\chi,\; d_L = \delta_1\,(-\tfrac{1}{3}+\tfrac{1}{6}\sin^2\chi),$$

$$u_R = -\tfrac{1}{3}\,\delta_1 \sin^2\chi,\; d_R = \tfrac{1}{6}\,\delta_1\sin^2\chi. \tag{12}$$

(ii) For the asymmetry parameter characterising the inelastic scattering of longitudinally polarised electrons off unpolarised deuteron, we have, following the considerations and notations of Cahn and Gilman (1978),

$$A_{eD} = -\frac{G\,q^2}{2\sqrt{2}\pi\alpha}\left[\left(\frac{4}{5} - 2\sin^2\chi\right) + \frac{1-(1-y)^2}{1+(1-y)^2}\left(\frac{4}{5} - \frac{12}{5}\sin^2\chi\right)\right]\delta_1. \tag{13}$$

The values of u_L, u_R, d_L, d_R determined by Abbott and Barnett (1978), and the SLAC measurement (Prescott *et al* 1978) of A_{eD} may now be used to determine the parameters δ and $\sin^2\chi$ for our model. Values of δ between $-0{\cdot}9$ and -1 and $\sin^2\chi \simeq 0{\cdot}25$ give very good agreements. Thus, merely as an example, for $\delta=-0{\cdot}95$, and $\sin^2\chi$ $=0{\cdot}25$, we obtain

$$u_L \simeq +0{\cdot}38,\quad d_L \simeq -0{\cdot}42,\quad U_R \simeq -0{\cdot}12,\quad d_R \simeq +0{\cdot}06, \tag{14}$$

to be compared with the fits of Abbott and Barnett (1978): u_L=0·33+0·07, d_L= − 0·40 ± 0·07, u_R=—0·18 ± 0·06 and d_R =0·0 ± 0·11. For the same values of the parameters and y=0·21, we find

$$A_{eD} \simeq -8{\cdot}8 \times 10^{-5}\, q^2/\mathrm{GeV}^2, \tag{15}$$

in very good agreement with the value (—9·5 ± 1·6)×10^{-5} q^2/GeV^2 measured at SLAC [Prescott *et al* 1978).

(iii) *For (ν–e)–scattering* we have the effective interaction

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

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

where $$C_V = (-\tfrac{1}{3} + \sin^2\chi)\delta_1,\ C_A = -\tfrac{1}{3}\delta_1,\ C'_V = C_V + 1,\ C'_A = C_A + 1. \tag{17}$$

Again, as an example, with $\sin^2\chi \simeq 0{\cdot}25$ and $\delta \simeq -0{\cdot}95$, we obtain

$$\sigma(\nu_\mu e) \simeq 0{\cdot}17 \times 10^{-41}\ \mathrm{cm}^2\ (E_\nu/\mathrm{GeV}),\ \sigma(\bar{\nu}_\mu e) \simeq 0{\cdot}11 \times 10^{-41}\ \mathrm{cm}^2\ (E_\nu/\mathrm{GeV}). \tag{18}$$

The value of $\sigma(\nu_\mu e)$ agreeswell with the latest result,(0·18±0·08)×10^{-41} cm^2 E_ν/GeV, from BNL-Columbia (Cnops *et al* 1978. See also Faissner *et al* 1978).

(iv) For the *atomic physics parity violation* in heavy atoms arising from the neutral axial vector current of the electron coupled to the neutral vector currents of the u and d quarks, we have the characteristic parameter

$$Q_W(Z, N) = \delta_1\ [-4\,(\sin^2\chi)\, Z - 2N]. \tag{19}$$

For atomic bismuth (Z=83, N=126) we find for $\delta \simeq -0{\cdot}95$ and $\sin^2\chi \simeq 0{\cdot}25$:

$$Q_W(\mathrm{Bi}) \simeq -480. \tag{20}$$

Here the earlier results from Oxford (Baird *et al* 1977) and Seattle (Lewis *et al* 1977) do not agree with the latest result from Novosibirsk (Barkov and Zolotorev 1978). We must thus reserve judgment for future. For comparison, in the standard W--S model with $\sin^2\theta_w \simeq 1/4$, Q_w (Bi) ≃ 130.

4. Model B

In this model the choice of leptons and their representations is identical with that in model A. The difference comes in the quark sector. Again we assume six quarks u, d, s, c, b and h, where b and h are now different heavy quarks both carrying electric charge $-\tfrac{1}{3}$. From these we form two 3-representations of SU$_3$(W): (u_L, d'_L, b'_L)

and (c_L, s'_L, h'_L), both having $G_0=0$. The meanings of the primes and subscript L are as before. The R-components of all the fermions are again taken to be $SU_3(W)$ singlets with G_0 equal to their respective electric charges. Again additions of further heavy quarks and leptons, and anomaly cancellation, will follow the lines of Pandit (1976).

The neutral current phenomena may be discussed again as in the last section. We only have to note that (in distinction with model A) for the quark triplets we must now take

$$\mathscr{G}_1 = (+\tfrac{2}{3}, -\tfrac{1}{3}, -\tfrac{1}{3}),\ \mathscr{G}_2 = (0, +1, -1).$$

Then using the notations introduced in §3, we note below the relevant results.

(i) Concerning *ν-nucleon* neutral current processes we now have:

$$u_L = \delta_1 (\tfrac{1}{3} - \tfrac{1}{3}\sin^2\chi),\ d_L = -\tfrac{1}{6}(\delta_1+3\delta_2)+\tfrac{1}{6}\delta_1\sin^2\chi,$$
$$u_R = -\tfrac{1}{3}\delta_1\sin^2\chi,\ d_R = \tfrac{1}{6}\delta_1\sin^2\chi. \tag{21}$$

(ii) For the asymmetry parameter for longitudinally polarised *e-deuteron* inelastic scattering we have

$$A_{eD} = -\frac{G q^2}{2\sqrt{2}\pi\alpha}\left[(1-2\sin^2\chi)\,\delta_1 + \frac{1-(1-y)^2}{1+(1-y)^2}(1-3\sin^2\chi)\,\delta_1\right]. \tag{22}$$

Again we can obtain good agreement with the fits of Abbott and Barnett (1978) for ν-N data and with the measured value (Prescott *et al* 1978) of A_{eD}, this time with δ ranging from $\simeq -1$ to $-0{\cdot}75$ and $\sin^2\chi \simeq 0{\cdot}3$. Merely as an example, we take $\delta \simeq -0{\cdot}8$ and $\sin^2\chi \simeq 0{\cdot}3$ and obtain:

$$u_L \simeq 0{\cdot}30,\ d_L \simeq -0{\cdot}45,\ u_R \simeq -0{\cdot}13,\ d_R \simeq 0{\cdot}07; \tag{23}$$

and, with $y = 0{\cdot}21$,

$$A_{eD} \simeq -9{\cdot}9\times 10^{-5}\,(q^2/\mathrm{GeV}^2), \tag{24}$$

in excellent agreement with Abbott and Barnett (1978) and Prescott *et al* (1978), respectively.

(iii) For *(ν-e)-scattering*, the coupling parameters are formally the same as for model A (since the lepton representations are the same in both the models) and are given by equation (17). The difference would arise from the different values of $\sin^2\chi$ and δ needed in the two models for processes (i) and (ii). For $\delta \simeq -0{\cdot}8$ and $\sin^2\chi \simeq 0{\cdot}3$, we have in this model:

$$\sigma(\nu_\mu e) \simeq 0{\cdot}12\times 10^{-41}\ \mathrm{cm}^2\,(E_\nu/\mathrm{GeV});\ \sigma(\bar{\nu}_\mu e) \simeq 0{\cdot}10\times 10^{-41}\ \mathrm{cm}^2\,(E_\nu/\mathrm{GeV}). \tag{25}$$

These are to be compared with the values of equation (18) for model A. The value of $\sigma(\nu_\mu e)$ is again consistent with the experimental result of Cnops *et al* (1978).

(iv) For the *atomic physics parity-violation* in heavy atoms we now have

$$Q_W(Z, N) = 2Z(1-2\sin^2\chi)\,\delta_1, \tag{26}$$

independent of N. Taking, for illustration, $\delta \simeq -0{\cdot}8$ and $\sin^2\chi \simeq 0{\cdot}3$ we obtain for bismuth

$$Q_W(\mathrm{Bi}) \simeq +86. \tag{27}$$

Thus the two models differ drastically in predicting this parameter. However, in view of the already noted unsettled experimental situation, we have to reserve judgment for future.

In view of the results displayed above, we feel that the models presented here deserve further attention and study.

Acknowledgement

The author thanks Dr K V L Sarma for numerous helpful discussions on the phenomenology of neutral currents.

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