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Neutral current effects in the parity violating nuclear force

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Abstract. The measurements of the $\Delta I = 1$ part of the parity violating nuclear force when combined with information on neutral current couplings from neutrino scattering and pion production experiments allow an estimate of the isoscalar admixture in the neutral current if it has a vector axial-vector structure has been shown.

Keywords. Nuclear force; parity violation; weak interaction; Cabibbo theory; neutral current; enhancement; isoscalar-isovector interference.

1. Introduction

Since the discovery about two years ago of a new class of weak interactions arising from neutral currents, considerable effort has been directed towards elucidating the space time and isospin structure of the weak hadronic neutral currents. Data on neutral current events are now available (Aubert *et al* 1974, Benvenuti *et al* 1975, Barish *et al* 1975, 1976, Hasert *et al* 1974, Cline *et al* 1976) for such elastic and inelastic inclusive and exclusive reactions as

$$\bar{\nu} + e \rightarrow \bar{\nu} + e$$

$$\nu(\bar{\nu}) + p \rightarrow \nu(\bar{\nu}) + p$$

$$\nu + N \rightarrow \nu + N + \pi$$

$$\nu(\bar{\nu}) + N \rightarrow \nu(\bar{\nu}) + \text{hadrons.}$$

These investigations on the structure of the neutral currents may be divided broadly into two categories:

(i) Since neutral currents are necessarily predicted by all spontaneously broken gauge invariant unified theories of weak and electromagnetic interactions, it is of interest to estimate coupling parameters which appear in such theories (*e.g.*, θ_W in the Weinberg-Salam model) from experimental data (Paschos and Wolfenstein 1973, Sehgal 1973, 1974).

(ii) By making specific assumptions about the Lorentz and isospin structure of the neutral current without reference to any gauge theoretic model, attempts have been made to estimate the strengths of neutral current couplings directly from the data available. Rajasekaran and Sarma (Rajasekaran and Sarma 1975 and 1976) have obtained upper and lower bounds on these couplings from data on inclusive $\nu(\bar{\nu}) N$ processes; Ecker and Fischer (1976) have obtained lower bounds from data on weak and electromagnetic single pion production; Hung and Sakurai (1976) have shown that data on inclusive neutrino reactions on neutron and proton targets separately when combined with data on diffractive vector meson production may be used to determine all neutral current couplings if the current has isoscalar-isovector V, A structure.

In this paper, we investigate the effect of the neutral current on the $\triangle I = 1$ part of the parity violating nuclear force in a current algebra model. Our main result is that low energy experiments now in progress aimed at measuring the strength of this force may also be used to estimate the isoscalar-isovector admixture in the neutral current if it has a V, A structure. The strength of this force is purely that given by charged-current (Cabibbo) theory if the neutral current is purely isovector or isoscalar: the neutral current contribution arises purely from isoscalar-isovector interference. This result may be compared with that of Hung and Sakurai (1976) who show that this interference depends on the difference between neutral current contributions to νp and νn cross-section data in the quark valence model.

In section 2 we summarize the information presently available on the parity violating nuclear force and isolate the amplitude of interest. In section 3 we present the model, obtain the relevant neutral current contribution to the parity violating amplitude and show that it arises from isoscalar-isovector interference effects. In section 4 we present our conclusions and examine our result in relation to other analyses of neutral current coupling with and without reference to gauge theoretic models.

2. Parity violating nuclear force

Several detailed expositions of the theory of parity violating nuclear forces and their connection with weak interaction models exist in literature (Wilkinson 1958, Bailin 1972, Fischbach and Tadic 1973). We present those aspects of the theory relevant to the subsequent discussion.

In Cabibbo theory, the weak Hamiltonian is

$$H_W = \frac{G}{\sqrt{2}} (J_\mu^+ J^\mu + \text{h.c.})$$

Here

$$J_\mu = J_\mu^{(l)} + J_\mu^{(h)}$$

$$J_\mu^{(l)} = \bar{l} \gamma_\mu (1 + \gamma_5) \nu_l$$

and

$$J_\mu^{\pm(h)} = J_\mu^\pm \cos \theta_c + S_\mu^\pm \sin \theta_c$$

$$J_\mu^\pm = V_\mu^1 \pm i V_\mu^2 + A_\mu^1 \pm i A_\mu^2$$

$$S_{\mu}^{\mp} = V_{\mu}^{4} \pm iV_{\mu}^{5} + A_{\mu}^{4} \pm iA_{\mu}^{5}$$

V_{μ}^{i}, A_{μ}^{i} are the octets of vector and axial-vector currents belonging to the octet representation of SU (3) and θ_c is the Cabibbo angle ($\sin\theta_c \simeq 0{\cdot}22$). In such a model, the parity violating nuclear force arises from both the semi-leptonic and non-leptonic parts of the Hamiltonian. The former, arising from lepton-neutrino pair exchanges, is $O(G^2)$ and may be neglected in comparison with those arising from single meson exchanges which is $O(Gf)$, f being the strong interaction coupling constant. In the latter, the weak hadronic current plays a role, only at one vertex, the parity conserving strong interaction accounting for the other. Parity violation in nuclear forces to $O(G)$ have been known to exist for a long time.

Since our interest is restricted to the nucleon-nucleon force, the relevant part of weak Hamiltonian is H_W^{NL} ($\triangle Y = 0$). From the isotopic properties of J_μ ($\triangle I = 1$) and S_μ ($\triangle I = 1/2$), we note that

$$H_W^{NL}(\triangle Y = 0) \sim \frac{G}{\sqrt{2}}\{\cos^2\theta_c\,[H_W^{NL}(2) + H_W^{NL}(0)] + \sin^2\theta_c\,[H_W^{NL}(1) + \tilde{H}_W^{NL}(0)]\}$$

in self-evident notation. $H(1)$ transforms as an isovector, etc.

For our purpose, the important feature of this isospin break-up is that the $I = 1$ piece of H_W^{NL} is proportional to $\sin^2\theta_c$. We shall be interested in the weak $NN\pi$ vertex, the pion having the lowest mass of the particles whose exchange give rise to the NN force. The nucleon-antinucleon system has $I = 0$, 1 and since the pion has $I = 1$ the most general πN vertex can have $I = 0$, 1, 2. Of the four possible parity violating vertices, only $N(\vec{\tau} \times \vec{\pi})\,N$ $(I = 1)$ has its $I_3 = 0$ component odd under charge conjugation. Since the Cabibbo Hamiltonian is CP invariant, its parity violating part must be odd under charge conjugation. The weak parity violating πN vertex can arise only from the $I = 1$ piece of H_W^{NL} which is proportional to $\sin^2\theta_c$. Thus in Cabibbo theory, the one pion exchange contribution to the parity violating nuclear force is much weaker than might have otherwise been expected (in comparison, *e.g.*, with $\triangle Y = 1$ vertices such as $\Lambda \to p\pi^-$ which are proportional to $\sin\theta_c\cos\theta_c$).

From this discussion it is apparent that the single pion exchange contribution arises entirely from the charged pion and the weak vertices of interest are

$$A(n_-^0):\quad n \to p\pi^-$$

$$A(p_+^+):\quad p \to n\pi^+.$$

It must be remembered that a model of weak interactions which alters this vertex in relation to Cabibbo theory prediction may be tested only against experiments which measure the $\triangle I = 1$ part of the parity violating nuclear force.

3. The parity violating $np\pi^-$ vertex

(i) *The model*

We assume that the weak Hamiltonian has, in addition to the Cabibbo part (H_c^W

a part arising out of the neutral currents of leptons and hadrons (H_N^W), which is also of the current-current form. Thus

$$H^W = H_c^W + H_N^W$$

$$H_c^W = \frac{G}{\sqrt{2}} (J_{\mu,c}^{(l)} + J_{\mu,c}^{(h)}) (J_c^{+(l)\mu} + J_c^{+(h)\mu})$$

$$J_{\mu,c}^{(l)} = \bar{l}\gamma_\mu (1 + \gamma_5)\, \nu_l$$

$$J_{\mu,c}^{(h)} = \cos\theta_c (V_\mu^1 + iV_\mu^2) + \sin\theta_c (V_\mu^4 + iV_\mu^5) + \cos\theta_c (A_\mu^1 + iA_\mu^2) + \sin\theta_c (A_\mu^4 + iA_\mu^5)$$

$$H_N^W = \frac{G}{\sqrt{2}} (J_{\mu,N}^{(l)} + J_{\mu,N}^{(h)}) (J_N^{(l)\mu} + J_N^{(h)\mu})$$

$$J_{\mu,N}^{(l)} = \bar{\nu}\gamma_\mu (1 + \gamma_5)\, \nu + \bar{l}\gamma_\mu (1 + \gamma_5)\, l$$

$$J_{\mu,N}^{(h)} = (\alpha V_\mu^3 + \gamma V_\mu^8 + \beta A_\mu^3 + \delta A_\mu^8).$$

The superscripts 1, 2, ..., 8 refer, as usual, to SU (3) transformation properties. We have assumed, in consonance with most neutral current studies (Sehgal 1974, Rajasekaran and Sarma 1975, 1976, Ecker and Fischer 1976, Hung and Sakurai 1976), that the weak hadronic neutral current is vector-axial vector in Lorentz structure, is strangeness conserving and has isospin $\leqslant 1$. We also assume that its isovector component is the neutral counterpart of the isovector currents which appear in the Cabibbo Hamiltonian and that its isoscalar component transforms like λ_8. The appearance of four independent coupling parameters α, β, γ, δ implies that relative strength of the neutral current piece of the Hamiltonian relative to the charge current piece is left free, as are the relative strengths between the various parts of the neutral current.

The phenomenological Hamiltonian thus obtained is not chiral invariant. In calculating the weak parity violating $np\pi^-$ vertex, we shall, however, assume in the usual fashion that charge-current commutators of the vector and axial charges with the currents are those which follow from the chiral algebra. If therefore $H_{\rm pv}$ is the parity violating part of the weak Hamiltonian which contributes to the weak parity violating $np\pi^-$ vertex, we have:

$$H_{\rm pv} = \frac{G}{\sqrt{2}} [\sin^2\theta_c (V_\mu^{(4+i5)} A^{\mu\,(4-i5)} + A_\mu^{(4+i5)} V^{\mu\,(4-i5)}) + (\alpha V_\mu^3 + \gamma V_\mu^{(8)}) (\beta A^{\mu(3)} + \delta A^{\mu(8)}) + (\beta A_\mu^{(3)} + \delta A_\mu^{(8)}) (\alpha V^{\mu\,(3)} + \gamma V^{\mu\,(8)})].$$

Contracting the pion using the standard LSZ reduction techniques and using PCAC, we have

$$\langle \pi^-(q)\, p\,(p) \mid H_{\rm pv}^W (0) \mid n\,(n)\rangle = -\frac{1}{f_\pi} \frac{1}{\sqrt{2q_0 V}} \langle p\,(p) \mid [F_5^{1-i2} (0),\, H_{\rm pv}^W (0)] \mid n\,(n)\rangle.$$

We evaluate these commutators using the SU (3) charge-current commutation relations

$$[F_5^i(x_0),\ V_\lambda^j(x)] = if^{ijk} A_\lambda^k(x)$$

$$[F_5^i(x_0),\ A_\lambda^j(x)] = if^{ijk} V_\lambda^k(x)$$

to obtain

$$[F_5^{1-i2}(0),\ H_{pv}^W(0)]$$

$$= -\frac{1}{\sqrt{6}} \sin^2\theta_c\, \tilde{H}_{pc}^{k^- k^0}(0) - \frac{1}{\sqrt{3}}\, a\gamma\, \tilde{H}_{pc}^{\pi^-\pi^0}(0)$$

$$-\frac{1}{2\sqrt{3}}(a\delta + \beta\gamma)\, \tilde{H}_{pc}^{\pi^-\eta_0}(0).$$

We have used the notation

$$\tilde{H}_{pc}^{k^- k^0} = V_\mu^{k^-}(0)\, V^{\mu k^0}(0) + A_\mu^{k^-}(0)\, A^{\mu k^0}(0), \text{ etc.}$$

We may thus separately group the charged-current and neutral current contributions to the parity violating vertex:

$$\langle \pi^- p \mid H_{pv,\,c}^W \mid n\rangle = -\frac{N}{\sqrt{6}} \sin^2\theta_c \langle p \mid \tilde{H}_{pc}^{k^- k^0} \mid n\rangle$$

$$\langle \pi^- p \mid H_{pv,\,N}^W \mid n\rangle = -\frac{N}{\sqrt{3}} \langle p \mid a\gamma\, \tilde{H}_{pc}^{\pi^-\pi^0} + \tfrac{1}{2}(a\delta + \beta\gamma)\, \tilde{H}_{pc}^{\pi^-\eta_0} \mid n\rangle$$

$(N = 1/(f_\pi \sqrt{2} q_0 V))$ is a normalization constant common to both contributions.

(ii) *The neutral current contribution*

To evaluate the neutral current contribution

$$\langle \pi^- p \mid H_{pv,\,N}^W \mid n\rangle = -\frac{N}{\sqrt{3}} \langle p \mid a\gamma\, \tilde{H}_{pc}^{\pi^-\pi^0} + \tfrac{1}{2}(a\delta + \beta\gamma)\, \tilde{H}_{pc}^{\pi^-\eta_0} \mid n\rangle$$

we first note that $H_{pc}^{\pi^-\pi_0}$ does not contribute to the amplitude. We have already argued on the basis of CP invariance that a product of currents transforming as $j^{\pi^-} j^{\pi^0}$ does not contribute to the weak parity violating $np\pi$ vertex. This was the reason for dropping the parity violating term proportional to $\cos^2\theta_c$. Thus

$$\langle \pi^- p \mid H_{pv,\,N}^W \mid n\rangle = -\frac{N}{2\sqrt{3}}(a\delta + \beta\gamma) \langle p \mid \tilde{H}_{pc}^{\pi^-\eta_0} \mid n\rangle$$

and the neutral current contribution to the parity violating $(np\pi)$ vertex arises entirely from the interference between the isoscalar and isovector parts of the neutral current. This is a consequence of the assumption that the neutral current Hamiltonian is also of the current-current form, and that the neutral currents have specific transformation porperties under SU (3).

(iii) *Relative magnitude of charged-current and neutral current contributions*

Since

$$\langle \pi^- p \mid H_{\text{pv}, c} \mid n \rangle = -\frac{N}{\sqrt{6}} \sin^2 \theta_c \langle p \mid \tilde{H}_{\text{pc}}^{k^- k^0} \mid n \rangle$$

$$\langle \pi^- p \mid H_{\text{pv}, N} \mid n \rangle = -\frac{N}{2\sqrt{3}} (\alpha\delta + \beta\gamma) \langle p \mid \tilde{H}_{\text{pc}}^{\pi^- \eta_0} \mid n \rangle$$

a direct comparison of this particular combination of neutral current couplings with experiments sensitive to the $\Delta I = 1$ part of the parity violating nuclear force requires an estimate of the relevant matrix elements. We obtain this estimate by saturating the product of currents by a set of baryon octet intermediate states. It is well known that in such approximation schemes, the decuplet contribution adds a small correction (5–10%) to that from the octet. We are not interested in numerical estimates of such accuracy. We use only an F-type coupling for the charge form factor of the vector current and relate the vector form factors to the electromagnetic form factors for which we use the conventional dipole fit. Thus, *e.g.*,

$$\langle p(p) \| V_\mu^{\pi^-} \| n(p_i) \rangle \langle n(p_i) \| V^{\mu,\eta_0} \| n(n) \rangle$$

$$= \int d^3p_i \left(\frac{m_i}{E_i}\right) \bar{u}(p) \left[F_1^{\text{I.V.}}(q_1^2)\gamma_\mu + \frac{i\sigma_{\mu\nu} q^\nu}{2m_p} F_2^{\text{I.V.}}(q_1^2)\right]$$

$$\times \frac{p_i + m_i}{2m_i} \left[F_1^{\text{I.S.}}(q_2^2)\gamma^\mu + \frac{i\sigma^{\mu\nu} q_\nu}{2m_i} F_2^{\text{I.S.}}(q_2^2)\right] u(n)$$

with $q_1 = p - p_i$, $q_2 = p_i - n$. $F_{1,2}^{\text{I.S.}}$, $F_{1,2}^{\text{I.V.}}$ are the isoscalar and isovector charge and magnetic form factors, for which we use the following parametrization:

$$F_1^{\text{I.V.}}(q^2) = \frac{1}{2}\left[1 - (\mu_p - \mu_n)\frac{q^2}{4m^2}\right]\left(1 - \frac{q^2}{4m^2}\right)^{-1}\left(1 - \frac{q^2}{b}\right)^{-2}$$

$$F_1^{\text{I.S.}}(q^2) = \frac{1}{2}\left[1 - (\mu_p + \mu_n)\frac{q^2}{4m^2}\right]\left(1 - \frac{q^2}{4m^2}\right)^{-1}\left(1 - \frac{q^2}{b}\right)^{-2}$$

$$F_2^{\text{I.V.}}(q^2) = \tfrac{1}{2}[(\mu_p - \mu_n) - 1]\left(1 - \frac{q^2}{4m^2}\right)^{-1}\left(1 - \frac{q^2}{b}\right)^{-2}$$

$$F_2^{\text{I.S.}}(q^2) = \tfrac{1}{2}[(\mu_p + \mu_n) - 1]\left(1 - \frac{q^2}{4m^2}\right)^{-1}\left(1 - \frac{q^2}{b}\right)^{-2}$$

$$b = 0{\cdot}71\,(\text{GeV})^2, \qquad \mu_p = 2{\cdot}79, \qquad \mu_n = -1{\cdot}91.$$

For the matrix elements of the axial vector currents, we use symmetric and antisymmetric SU(3) couplings for both electric and magnetic form factors, D/F ratio of 1·5 and $g_A(0)/g_V(0) = 1{\cdot}18$. Thus, for the reduced matrix elements, *e.g.*,

$$\langle p(p) \| A_\mu^\pi \| n(n)\rangle = \bar{u}(p)\left[\gamma_\mu \gamma_5 f_1(q_1^2) + \frac{q_{1\mu}\gamma_5}{2m} f_2(q_1^2)\right] u(n)$$

$$q_1 = p - n,\ f_1(q^2) = (1 - q^2/b)^{-2},\ f_2(q^2) = \frac{4m^2}{m_\pi^2 - q^2} f_1(q^2).$$

We have evaluated the integrals setting $p = n$ ($q_1 = -q_2$) and with degenerate baryon octet masses. Kinematic mass breaking and a small finite pion 4-momentum may easily be taken into account. However, they only add small corrections to the result. Since we are at present more interested in the qualitative changes in the parity violating $np\pi$ vertex due to the presence of neutral currents and experimental results on the $\Delta I = 1$ part of the parity-violating force are not yet available, we have ignored finer corrections arising from such features of the theory as kinematic mass splitting, etc.

4. Results, status of experiments and conclusions

(i) *Results*

We write the parity violating $np\pi^-$ vertex as a sum of contributions arising from charged and neutral currents respectively:

$$\langle p\pi^- | H_{pv}^W | n\rangle = N\bar{u}(p)\, u(n)\, [T_C + T_N]$$

$$N = -\frac{1}{f_\pi}\frac{1}{\sqrt{2q_0V}} \to -\frac{1}{f_\pi}\frac{1}{(2\pi)^{3/2}}\frac{1}{(2m_\pi)^{1/2}}$$

We obtain $T_C = 2{\cdot}5251 \sin^2\theta_C$; $T_N = 1{\cdot}3542\,(\alpha\delta + \beta\gamma)/2$.

The charged and neutral current contributions have been evaluated retaining only octet intermediate states. The contributions of the other multiplets in the intermediate state are known to be small due to their larger masses. The charged-current contribution to the $BB\pi$ vertex has been evaluated earlier in various contexts by several authors (Chiu and Schechter 1966, Biswas *et al* 1966, Tadic 1968, Fischbach and Trabert 1968, McKeller 1967). We have recalculated this contribution as a check on the numerical results for the analogous contribution from the neutral current.

Since*

$$T_N/T_C = 11{\cdot}06 \times \tfrac{1}{2}(\alpha\delta + \beta\gamma),$$

an enhancement in the $\Delta I = 1$ part of the parity violating nuclear force [as, it has been suggested, is required for the $\Delta I = 0, 2$ pieces of the force (Hadjimichael and Fischbach 1971, Danilov 1972)] due to the presence of neutral currents will result only if the neutral current has a substantial isoscalar part, comparable to the isovector part (if $\alpha, \beta, \gamma, \delta \sim 1$ for reasons we discuss below). In any case, if the neutral current is purely isovector [as in the Adler-Tuan model (Adler and Tuan 1975)], it does not contribute to this parity violating vertex.

* The sign of this ratio is not known. This may lead to important cancellations if T_N and T_C are of the same order of magnitude.

(ii) *Status of experiments*

Two experiments are in progress (Fischbach and Tadic 1973, Henley 1976) for the measurement of the $\triangle I = 1$ part of the parity violating nuclear force. These are: (*a*) angular asymmetry of the emitted photon in the capture of polarized slow neutrons in hydrogen, *viz.*, angular asymmetry $n+p \rightarrow d+\gamma$; (*b*) Rate of α capture in deuterium $\alpha + d \rightarrow Li^6 + \gamma$.

The circular polarization of the emitted photon in experiment (*a*) which is sensitive to the $\triangle I = 0$ part of the parity violating force was measured by Lobashov and his group (Lobashov *et al* 1972) who found a value $P = (1\cdot3 \pm 0\cdot45) \times 10^{-6}$. This is generally believed to be at least an order of magnitude larger than what may be expected from Cabibbo theory (Henley 1976). It has been pointed out by Craver *et al* (1976) that estimates from theory are subject to considerable uncertainties due to inexact knowledge of the deuteron wavefunction at pion Compton wavelengths. While the angular asymmetry prediction for a given weak interaction Hamiltonian will be subject to the same uncertainties, order of magnitude deviations from the prediction of Cabibbo theory would indicate a large isoscalar-isovector contribution from neutral currents.

(iii) *Estimates of neutral current couplings and an upper limit on the magnitude of the neutral current contribution*

Any estimate of the magnitude of the neutral current contribution to the parity violating $np\pi^-$ vertex requires a knowledge of all four couplings, $\alpha, \cdots, \delta$. No estimates of the magnitudes of all four couplings based on the analysis of experimental data alone are available. In particular, no estimates whatsoever of δ, the axial vector isoscalar coupling, are available possibly because the neutral current in the one-parameter Weinberg-Salam theory without charmed or strange hadrons has no axial vector isoscalar component. We summarise briefly the available estimates from which our conclusions are drawn.

(*a*) Rajasekaran and Sarma (1976) have obtained upper and lower bounds on α and β independent of the magnitudes of the isoscalar couplings. From the data on total cross-sections for ν and $\bar{\nu}$ scattering on isospin averaged nucleon targets and from electron scattering data, they obtain an octagonal region in the $\alpha\beta$ plane around the origin within which α, β must lie. Maximum allowed values are $\alpha \simeq \beta \approx 0\cdot6$. Larger values of α (β) are compatible only with smaller values of β (α). Their lower bounds require data on νp and νn scattering separately which are just becoming available (Cline *et al* 1976). In an earlier paper Rajasekaran and Sarma (1975) showed that these values are relatively stable with respect to arbitrary admixtures of a vector isoscalar component ($\gamma \neq 0$, $\delta = 0$).

(*b*) Ecker and Fischer (1976) use data on weak and electromagnetic single pion production to obtain bounds on the isovector coupling which allow arbitrary isoscalar admixtures. If their lower bounds are combined with the upper bounds of Rajasekaran and Sarma, the maximum allowed values are

$$\alpha \sim 0\cdot6, \qquad \beta \sim 0\cdot8.$$

A purely isoscalar current ($\alpha = \beta = 0$) is disfavoured as is the Adler-Tuan *V–A* isovector model ($\alpha = \beta$, $\gamma = \delta = 0$).

Thus, if we do not make the assumption that the isoscalar couplings are an order of magnitude larger than the isovector ones, we are forced to conclude that, *at best*, α, β, γ, $\delta \lesssim 1$ and neutral currents provide an enhancement $\lesssim 10$ over Cabibbo theory in the parity violating $np\pi^-$ vertex. We note that this estimate of $\alpha, \ldots, \delta$ is consistent with improved data on inclusive reactions presented at the Aachen conference reported in Hung and Sakurai (1976).*†

(iv) *Gauge models, charmed currents, etc.*

Any specific gauge model for a weak Hamiltonian will relate the couplings $\alpha, \cdots, \delta$ to one or more mixing parameters of the theory. If we take the charmed quark version of the Weinberg-Salam model (Salam 1968, Weinberg 1967) due to Glashow *et al* (1970) as an example, we have

$$J_{\mu, N} = J_\mu^{(3)} + J_\mu^{(c)} + J_\mu^{(s)} - 2 \sin^2 \theta_W J_\mu^{\text{e.m.}}$$

i$J_\mu^{(3)}$ is the isovector part (vector and axial vector) apart from that which appears n $J_\mu^{\text{e.m.}}$; $J_\mu^{(c)}$ and $J_\mu^{(s)}$ are isoscalar pieces containing charm and strangeness changing parts of the neutral current which may be neglected when low energy nucleon couplings are considered since nucleons contain charmed or strange quarks in excited states only. Then, in our notation,

$$\alpha = 1 - 2 \sin^2 \theta_W \qquad \gamma = -\frac{2}{\sqrt{3}} \sin^2 \theta_W$$

$$\beta = 1 \qquad \delta = 0$$

so that this model when coupled to ours leads to an enhancement ratio

$$\left| \frac{T_N}{T_c} \right| = \frac{1 \cdot 3542}{2 \cdot 5251} \; \frac{\frac{2}{\sqrt{3}} \sin^2 {}_W\theta}{\sin^2 \theta_c} \cdot \frac{1}{2}.$$

This is to be compared with the enhancement factor of $(8/3)[(\sin^2 \theta_W)/(\sin^2 \theta_c)]$ obtained by Gari and Reid (1974) on the basis of quark model and current algebra alone.

(v) *Conclusion***

We thus conclude that measurements of the $\Delta I = 1$ piece of the parity violating

* In a recent analysis of neutrino and antineutrino cross-section data (Benvenuti *et al* 1976) it is suggested that *V-A* structure for the neutral current provides the best fit obtainable if the choice is restricted to $V - A$, $V + A$ and either V or A. This would require $\alpha = \beta$, $\gamma = \delta$ which, when combined with the conclusion drawn by Hung and Sakurai (1976) from inclusive data reported at the Aachen conference, suggests that $\alpha = \beta \sim 0 \cdot 6$, $\gamma = \delta \sim 0 \cdot 5$.

† A recent analysis of the pion counting experiment at Gargamelle (Coremans *et al* 1976) suggests that the hadronic neutral current is dominantly isovector. If such is indeed the case, our analysis shows that the neutral current does not contribute to the parity violating force under consideration. We thank the referee for drawing this result to our attention.

** After the work was completed, we came across the paper of Desplanques and Hadjimichael (Desplanques and Hadjimichael 1976) which deals with this problem in the same framework. They use octet dominance and obtain the relevant reduced matrix element from nonleptonic hyperon decays. Thus they do not obtain the dynamical suppression factor $1 \cdot 3542/2 \cdot 5251$ arising from our use of phenomenological fits to vector and axial vector form factors in evaluating the reduced matrix elements. In other respects their results are analogous to ours. We thank S. Rai Choudhury for drawing our attention to this paper.

nuclear force when combined with data on neutrino scattering and pion production experiments will permit an estimate of the isoscalar admixture in the weak hadronic neutral current.

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