Neutral Lepton Currents

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The question is raised whether there is a self-coupled neutral lepton current in weak interactions.

IT is our purpose to raise the question whether there is a term of the form

$$J_0 J_0 \tag{1}$$

in the weak-interaction Hamiltonian. By J_0, we mean a neutral lepton current of the form

$$J_0 = g_\mu(\bar{\mu}\mu) + g_e(\bar{e}e) + g_\nu(\bar{\nu}_\mu\nu_\mu) + g_\nu'(\bar{\nu}_e\nu_e), \tag{2}$$

where, for example, $(\bar{e}e) = i\bar{\psi}_e\gamma_\lambda(1+\gamma_5)\psi_e$. The term (1) may represent either a direct interaction, or an effective interaction through a neutral intermediate boson W_l^0. The four g's are, of course, real.

The usual argument for the absence of neutral lepton currents is based on the following six experimental observations:

$$K^+ \not\rightarrow \pi^+ + e^+ + e^-,$$
$$K^+ \not\rightarrow \pi^+ + \text{neutrinos},$$
$$K_2^0 \not\rightarrow \mu^+ + \mu^-,$$
$$K^+ \not\rightarrow \pi^+ + \mu^+ + \mu^-,$$
$$\nu_\mu + Z \not\rightarrow \nu_\mu + Z,$$

and

$$\bar{\nu}_\mu + Z \not\rightarrow \bar{\nu}_\mu + Z.$$

Of these six, the first four have been discussed by Lee and Yang,[1] who draw the conclusion that the neutral lepton current (2) is not coupled to the strangeness-changing hadron current. The last two were reported by Benardini *et al.*,[2] and hence (1) is not coupled to the strangeness-conserving hadron current. The third decay has been discussed in detail recently by Coury.[3]

These six reactions are of course not relevant to the question whether (1) is present. In order to answer this question, we must study the lepton system. Two types of experiments immediately come to mind.

(*a*) *Experiments where the electron is used as the target.* Of the four elastic reactions

$$\nu_e + e^- \rightarrow \nu_e + e^-,$$
$$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-,$$
$$\nu_\mu + e^- \rightarrow \nu_\mu + e^-,$$

and

$$\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-,$$

the first one seems experimentally hopeful. This reaction goes through both the usual lepton current and (1). We can use the neutrino from K capture, as discussed by Lee and Sirlin.[4] Note that the accuracy required for the present purpose is only about 10^{-3} or 10^{-4} of that required by Lee and Sirlin, who are interested in radiative corrections.

The last two of these four elastic reactions, namely those involving the μ neutrinos, can perhaps be looked for in high-energy neutrino experiments. This, however, seems very difficult because of the small electron mass.

(*b*) *Experiments using a high-energy neutrino beam.* The coupling (1) gives rise to the processes, among others,

$$\nu_\mu + Z \rightarrow \nu_\mu + Z + e^- + e^+,$$

and

$$\bar{\nu}_\mu + Z \rightarrow \bar{\nu}_\mu + Z + e^- + e^+.$$

If the electrons and positrons can be identified unambiguously, and if the energy is not so high as to produce real intermediate bosons, then there is virtually no background for these two reactions. Except for the difference in coupling constants, the cross sections for these reactions are identical to, within the approximation of a four-fermion point interaction, that of

$$\nu_e(\bar{\nu}_e) + Z \rightarrow \nu_e(\bar{\nu}_e) + Z + e^- + e^+,$$

which has been studied by Czyz, Sheppey, and Walecka.[5]

Next we speculate briefly about the magnitude of the interaction (1), if present. From the point of view of universality, it is very tempting to think that the four g's of (2) are equal at least in magnitude. Depending on the relative sign of g_e and g_ν', the cross section for the elastic scattering of e^- and ν_e may be either increased or decreased from the value in the absence of (1). If we further deny the existence of any intermediate boson and postulate that the interaction (1) is characterized by the usual Fermi constant G, then the rate for $\nu_e + e^- \rightarrow \nu_e + e^-$ is either increased four times or greatly reduced. This possibility does not seem very attractive; one alternative is that the coupling constant between the neutral lepton current and W_l^0 is identical to that between the usual lepton current and the charged

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[3] F. M. Coury, doctoral dissertation, University of Vienna, 1965 (unpublished).
[4] T. D. Lee and A. Sirlin, Rev. Modern Physics **36**, 666 (1964).
[5] W. Czyz, G. D. Sheppey, and J. D. Walecka, Nuovo Cimento **34**, 404 (1964).

intermediate boson. In this case, the effect of (1) on $\nu_e+e^- \rightarrow \nu_e+e^-$ depends on the ratio of the mass of W_l^0 to that of the charged intermediate boson.

The original motivation for raising the present question is as follows: Since the neutral lepton currents are not coupled to the schizons of Lee and Yang,[1] is it possible that these currents are coupled to some other intermediate boson? It must be emphasized that we have no cogent reason at all to believe in the existence of the interaction (1); we are rather asking how we can find out experimentally about the existence of this interaction. If (1) is found to be present, then it becomes tempting to speculate in numerous directions. For example, if we think that all weak interactions are mediated by bosons, then we may ask whether there is a strong trilinear coupling involving W_l^0 and the charged intermediate bosons. Such a coupling may be used to account for the large masses of the bosons, and may have other desirable properties. In particular, this can be fitted into the schizon scheme of Lee and Yang[1] if we assign W_l^0 to be a singlet under isotopic spin rotation and require this trilinear coupling to conserve isotopic spin with the schizons treated as two doublets.

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Sum Rules in Nuclear Beta Decay*

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The previously developed "elementary-particle" treatment of nuclear beta decay, $N_i \rightarrow N_f+e^{\mp}+\nu_e$, is combined with the Adler-Weisberger procedure, to obtain sum rules relating axial-vector coupling constants for *nuclear* beta decays, $G_A(N_i \rightarrow N_f)$, to integrals over pion energy of pion–final-nucleus total cross sections, $\mathcal{I}(\pi^\pm,N_f)$. It is shown that the ratio $[\mathcal{I}(\pi^\pm,N_f)/\mathcal{I}(\pi^\pm,p)]=-[\mathcal{I}(\pi^\pm,N_f)/\mathcal{I}(\pi^\pm,n)]$ is just equal to the difference between the number of protons and the number of neutrons in N_f, $[Z-(A\text{-}Z)]$, multiplied by a factor which becomes unity in the approximation of neglect of meson-exchange corrections to $G_A(N_i \rightarrow N_f)$.

I. INTRODUCTION

In the present work the previously developed "elementary-particle" ("E-P") treatment of nuclear beta decay, $N_i \rightarrow N_f+e^{\mp}+\nu_e$,[1] is combined with the Adler-Weisberger (A-W) procedure,[2,3] to obtain sum rules relating axial-vector coupling constants for *nuclear* beta decays, $G_A(N_i \rightarrow N_f)$, to integrals over pion energy of pion-final nucleus total cross sections, $\mathcal{I}(\pi^\pm,N_f)$. It is shown that the ratio

$$[\mathcal{I}(\pi^\pm,N_f)/\mathcal{I}(\pi^\pm,p)]=-[\mathcal{I}(\pi^\pm,N_f)/\mathcal{I}(\pi^\pm,n)]$$

is just equal to the difference between the number of protons and the number of neutrons in N_f, $[Z-(A-Z)]$, multiplied by a factor which becomes unity in the approximation of neglect of meson-exchange corrections to $G_A(N_i \rightarrow N_f)$. Experimental verification of this relationship between "purely strong-interaction type" nuclear properties will provide further confirmation of the basic assumptions underlying the "E-P" treatment and the A-W procedure.

II. CALCULATIONS

We start by writing down the equal-time commutation (ETC) relation[4]

$$Q_A^{(+)}(t)Q_A^{(-)}(t)-Q_A^{(-)}(t)Q_A^{(+)}(t)=2I^{(3)},$$

$$Q_A^{(\pm)}(t)\equiv -i\int \{J_{A;4}^{(1)}(\mathbf{x},t)\pm iJ_{A;4}^{(2)}(\mathbf{x},t)\}d\mathbf{x}, \quad (1)$$

where $J_{A;\mu}^{(i)}$ and $I^{(3)}$ are, respectively, the axial-vector strangeness-preserving weak current and the third component of isospin; the assumption of the validity of this ETC relation and also of the partially conserved-axial-vector-current (PCAC) relation,[5] i.e. of the pion-pole-dominated unsubtracted dispersion relation for the form factor associated with any hadron $\rightarrow$ hadron matrix element of $(\partial/\partial x_\mu)\{J_{A;\mu}^{(1)}(x)\pm iJ_{A;\mu}^{(2)}(x)\}$, constitutes the basis of the A-W procedure.[6] Equation (1) immedi-

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[6] See Refs. 2 and 3 and also B. Renner, Phys. Letters **20**, 72 (1965).