LEARNING ABOUT NEUTRAL CURRENTS WITHOUT*

USING HIGH ENERGY NEUTRINOS OR NUCLEI

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ABSTRACT

Experiments which do not involve neutrinos are the only way to answer several basic questions about the neutral weak interactions, and can also be used to confirm what the neutrino experiments have shown. We raise some of the unsettled basic questions, briefly state what has been learned from the neutrino experiments, describe two types of non-neutrino experiments, and quantitatively explore the possibility of using them to confirm the neutrino results. We close with a discussion of electronic neutrino-electron scattering, where, as in the non-neutrino experiments. the interference between the neutral weak interactions and another force is studied.

INTRODUCTION

There are some very basic questions about the neutral weak interactions which can be answered only by non-neutrino experiments. To begin with, observations of the neutral weak interactions between neutrinos and other particles cannot tell us anything about the interactions in physical systems which do not involve neutrinos. Indeed, the interactions between, say, electrons and quarks, and those between neutrinos and quarks, could be mediated by entirely different neutral weak bosons and be completely unrelated. This possibility may not be very attractive, but it can never be ruled out by neutrino data.

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A second basic question is whether the neutral weak interactions, like the charged ones, violate parity. It is impossible in principle to study this question using neutrinos. The reason is, basically, that only left-handed neutrinos are available. If the neutral weak interactions conserve parity, then the cross section for a neutral weak process induced by left-handed neutrinos must equal that for the same process induced by right-handed neutrinos. But without right-handed neutrinos, we cannot test whether this is so.

The observation that corresponding neutrino and antineutrino cross sections are not equal does not imply parity-violation. To see this, assume that the neutral weak force between neutrinos and other matter is a local V,A interaction, so that the most general Hamiltonian density can be written in the form

$$\mathcal{H} = \bar{\nu}\gamma_\mu\nu\left(\mathcal{M}_\mu^{V,V} + \mathcal{M}_\mu^{V,A}\right) + \bar{\nu}\gamma_\mu\gamma_5\nu\left(\mathcal{M}_\mu^{A,V} + \mathcal{M}_\mu^{A,A}\right). \quad (1)$$

In the operators $\mathcal{M}$, which pertain to the matter with which the neutrinos interact, the first superscript indicates whether the operator multiplies the neutrino vector $\bar{\nu}\gamma_\mu\nu$ or axial vector $\bar{\nu}\gamma_\mu\gamma_5\nu$. The second superscript indicates whether $\mathcal{M}$ is itself a vector or axial vector. Now, for left-handed neutrino and right-handed antineutrino beams, the operators $\bar{\nu}\gamma_\mu\nu$ and $\bar{\nu}\gamma_\mu\gamma_5\nu$ are indistinguishable. Thus, experiments restricted to these beams cannot probe the full structure of (1). In particular any results consistent with that interaction are necessarily also consistent with

$$\mathcal{H} = \bar{\nu}\gamma_\mu\nu\left(\mathcal{M}_\mu^{V,V} + \mathcal{M}_\mu^{A,V}\right) + \bar{\nu}\gamma_\mu\gamma_5\nu\left(\mathcal{M}_\mu^{V,A} + \mathcal{M}_\mu^{A,A}\right). \quad (2)$$

This expression, being a product of two vectors plus a product of two axial vectors, is completely parity-conserving. Thus, neither unequal ν and $\bar{\nu}$ cross sections, nor any other neutrino results which are compatible with a V,A coupling, can possibly prove that the neutral weak force violates parity.[1]

A third basic question is whether the neutral weak interactions, like the charged ones, are V,A as opposed to S,P and T in character. The first generation neutrino experiments are unable to confirm this. In these experiments, anything V and A can do, S,P and T can do as well. In some of the reactions studied, S,P and T can reproduce the effects of V and A approximately. In other processes, there is actually a "confusion theorem" that states that anything V and A can do, S,P and T can do exactly. Thus, no matter how precise you make the neutrino measurements, you cannot distinguish between these two cases. This theorem[2] was discovered by E. Fischbach, G. Garvey, S.P. Rosen, and myself in the course of trying to prove the opposite.

In non-neutrino experiments, by contrast, one is typically looking for an interference between the neutral weak interaction and some other interaction whose properties are known, such as electromagnetism. Now, the interactions won't interfere unless they have certain characteristics in common. For example, they must contribute to the same helicity amplitudes. Thus, if an interference is seen, we can use our knowledge of the other interaction to make inferences about the properties of the neutral weak interaction.

FINDINGS FROM NEUTRINO SCATTERING

What have we learned so far from neutrino scattering? As discussed by several speakers at this Conference, we have learned a great deal about the neutral weak interactions between neutrinos and hadrons, which is to say between neutrinos and quarks. For a given quark q. the νq interactions can be characterized by the two constants $V_{\nu q}$ and $A_{\nu q}$ defined pictorially by Figure 1.

The quantity $V_{\nu q}$ is the coupling constant for the interaction between a left-handed neutrino (the only kind we have) and the vector current of the quark. As indicated by the figure, if there are several neutral weak bosons, this interaction is a sum over the contributions of all of them. Analogously, $A_{\nu q}$ measures the neutral weak interaction between a neutrino and the axial vector current of the quark. For normal nuclear matter, which consists to a good approximation of up quarks and down quarks, we have two vector constants V_ν up and V_ν down, or equivalently the isovector and isoscalar constants $V_{\nu q}^{I=1}$ and $V_{\nu q}^{I=0}$, and analogously

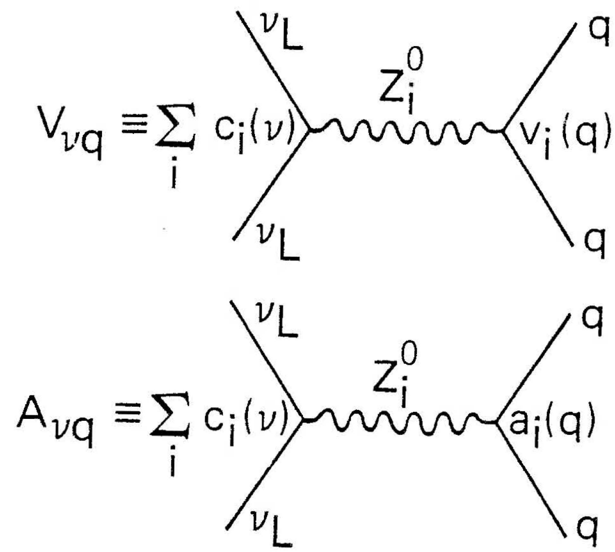

FIG. 1
Neutrino-quark interactions. The parameters $V_{\nu q}$ and $A_{\nu q}$ are the coupling constants for the interactions described by the corresponding diagrams. The constant $c_i(\nu)$ is the coupling of a left-handed neutrino to the i'th boson, Z_i^0, while $v_i(q)$ and $a_i(q)$ are, respectively, the couplings of Z_i^0 to the vector and axial vector currents of the quark q.

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$A_{\nu q}^{I=1}$ and $A_{\nu q}^{I=0}$.

A quark-model analysis by Sehgal,[3] followed by work of Hung and Sakurai,[4] and Ecker,[5] with confirmation by Langacker and Sidhu,[6] has yielded intriguing evidence that the four νq couplings are given either by the values called Solution A, or by those called Solution B, in Table I.[4]

TABLE I

Solution	$V_{\nu q}^{I=1}$	$A_{\nu q}^{I=1}$	$V_{\nu q}^{I=0}$	$A_{\nu q}^{I=0}$
A	$.45 \pm .14$	$-.92 \pm .14$	$-.35 \pm .15$	$-.12 \pm .15$
B	$.92 \pm .14$	$-.45 \pm .14$	$.12 \pm .15$	$.35 \pm .15$

Future neutrino experiments which could single out the correct solution have been discussed by Hung and Sakurai,[4] and by Kim, Langacker, and Sarkar.[7] However, recently Abbott and Barnett[3] have found that existing data on the process $\nu(\bar{\nu})$ + nucleon $\rightarrow$ $\nu(\bar{\nu})$ + nucleon + pion already favor Solution A. It is of great interest that this solution agrees closely with the prediction of the original Weinberg-Salam gauge model.

Now, it would be very nice to confirm, via non-neutrino experiments, that the νq couplings inferred from the neutrino data are indeed correct. Furthermore, there are gauge models more complicated than the Salam-Weinberg model which predict exactly the same νq couplings. Thus, it is necessary to go beyond neutrino physics to distinguish between the various theoretical possibilities.

I will not say anything about the neutrino-electron interactions because, as we have heard at this Conference, the situation there is experimentally uncertain. Let me just mention that these interactions are characterized by two constants, $V_{\nu e}$ and $A_{\nu e}$, which are the analogues of $V_{\nu q}$ and $A_{\nu q}$.

THE HYDROGEN-DEUTERIUM EXPERIMENTS

The first non-neutrino experiments I would like to talk about are the searches for parity-violation in atomic hydrogen and deuterium. Experiments with hydrogen are in progress at Michigan, the University of Washington, and Yale. The parity-violating effects sought by such experiments can come, in general, from either of the odd-parity electron-proton interactions shown in Figure 2.

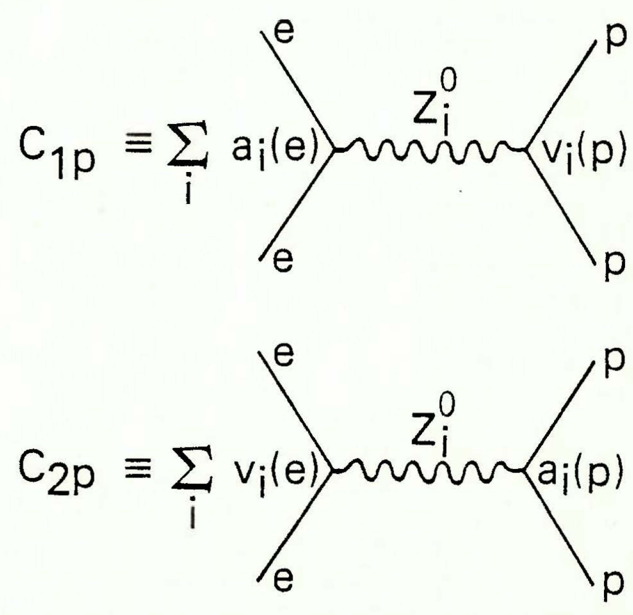

FIG. 2
Odd-parity interactions between an electron and a proton. The notation is analogous to that in Figure 1.

As indicated by the figure, the coupling constant for the interaction between the axial current of the electron and the vector current of the proton is called C_{1p}. That for the interaction between the vector current of the electron and the axial current of the proton is called C_{2p}. For electron-neutron interactions, there are two analogous constants C_{1n} and C_{2n}. Naturally, every interaction is a sum over the contributions of all the neutral weak bosons, in case there are more than one.

The idea of the hydrogen experiments is due, as far as I know, to Lewis and Williams[9] at Michigan, and I would like to take a minute to describe it. What one looks for is a parity-violating mixing between the $2s_{\frac{1}{2}}$ and the $2p_{\frac{1}{2}}$ atomic levels. These are the levels which normally are separated by the Lamb shift, a separation which is much too big for weak mixing to produce measurable effects. So one eliminates the Lamb shift by applying an external magnetic field whose strength is so adjusted that the Zeeman effect will just make the two levels cross. That is not enough, however, and so in addition one deliberately induces a <u>large</u> Stark mixing between the s and p levels by applying an external electric field. Then one looks for an interference between the s-p mixing induced by the weak interactions and that induced by the Stark effect.

To illustrate how this is done, let us consider the experiment in progress at Michigan. There, as pictured in Figure 3(a), one starts with a beam of neutral hydrogen atoms in the $2s_{\frac{1}{2}}$ state with the total angular momentum of the electrons, J_e, pointing up along the beam direction. These atoms enter a region in which there is a static magnetic field, $\vec{B}$, to induce the required Zeeman effect, and a static electric field, $\vec{E}$, to produce Stark mixing. In addition, there is an rf electric field, $\vec{\varepsilon}_{rf}$, at a frequency which will cause transitions from the initial state to the $2s_{\frac{1}{2}}$ level with J_e pointing <u>down</u> along the beam direction. One then looks for atoms in the latter final state downstream of the region containing the fields $\vec{B}$, $\vec{E}$, and $\vec{\varepsilon}_{rf}$, by looking for their decays. Figure 3(b) shows the $2s_{\frac{1}{2}}$ and $2p_{\frac{1}{2}}$ levels, for each value of J_e, as a function of magnetic field strength. The experiment is done at the value of $|\vec{B}|$ where the $|2s_{\frac{1}{2}}, \downarrow\rangle$ and $|2p_{\frac{1}{2}}, \uparrow\rangle$ levels cross. The hydrogen atoms start out in the state labelled ① in the figure, and then make the transition ② to the final state ③. Notice, however, that since both the initial and final states are spherically-symmetric s-waves, the rf field, which points in some specific direction, would not induce transitions between them at all were it not for the fact that some p-wave is mixed into the final s-state. Thus, the transition rate is proportional to the square of the p-wave admixture. Since this admixture is produced both by Stark and by weak effects, the transition rate will contain a term which is <u>first-order</u> in the

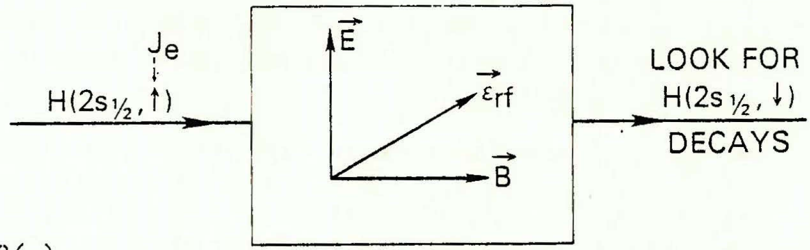

FIG. 3(a)
The hydrogen experiment. The arrows for J_e, the total angular momentum of the electron, indicate whether it points up or down along the beam axis. Other symbols are discussed in the text.

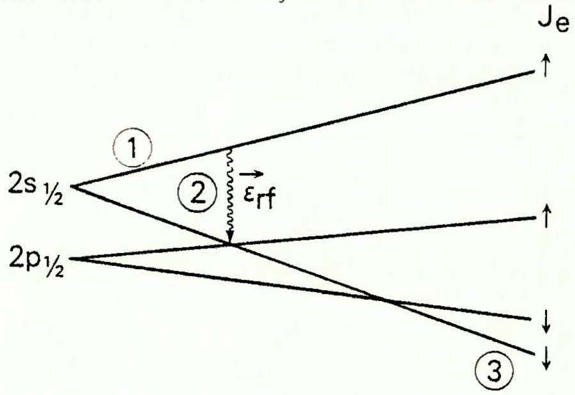

FIG. 3(b)
The $2s_{1/2}$ and $2p_{1/2}$ levels in an external magnetic field, with field strength increasing to the right. Symbols are discussed in the text.

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weak interactions. To isolate this term experimentally, one varies the directions of $\vec{E}$, $\vec{B}$, and $\vec{\varepsilon}_{rf}$, and looks for a term which behaves as $(\vec{\varepsilon}_{rf}\cdot\vec{E})(\vec{\varepsilon}_{rf}\cdot\vec{B})$.

In the current experiment, it happens that the hyperfine structure of the weakly-mixed levels is such that only C_{2p} can contribute. However, future experiments will be sensitive to C_{1p} as well, and will also be done with deuterium.

HIGH ENERGY POLARIZED ELECTRON SCATTERING

The other kind of non-neutrino experiment I would like to talk about is the high energy scattering of longitudinally polarized electrons by unpolarized targets. This experiment probes essentially the same couplings, of course, as do the hydrogen-deuterium measurements. What one studies here is the asymmetry

$$A = \frac{d\sigma(e_R) - d\sigma(e_L)}{d\sigma(e_R) + d\sigma(e_L)}\ , \qquad (3)$$

where $d\sigma(e_R)$ and $d\sigma(e_L)$ are corresponding differential cross sections for right-handed and left-handed incident electrons, respectively. A non-vanishing asymmetry would be an unambiguous parity-violating effect.

At SLAC, an experiment is currently being carried out by a SLAC-Yale collaboration that hopes to study the asymmetry A in the deep inelastic scattering of electrons by deuterons and by protons, and in the elastic scattering of electrons by protons.

CONFIRMING NEUTRINO RESULTS BY NON-NEUTRINO EXPERIMENTS

Now, how can one confirm, via non-neutrino experiments, the νq couplings which have been inferred from the neutrino data? The idea is illustrated in Figure 4.

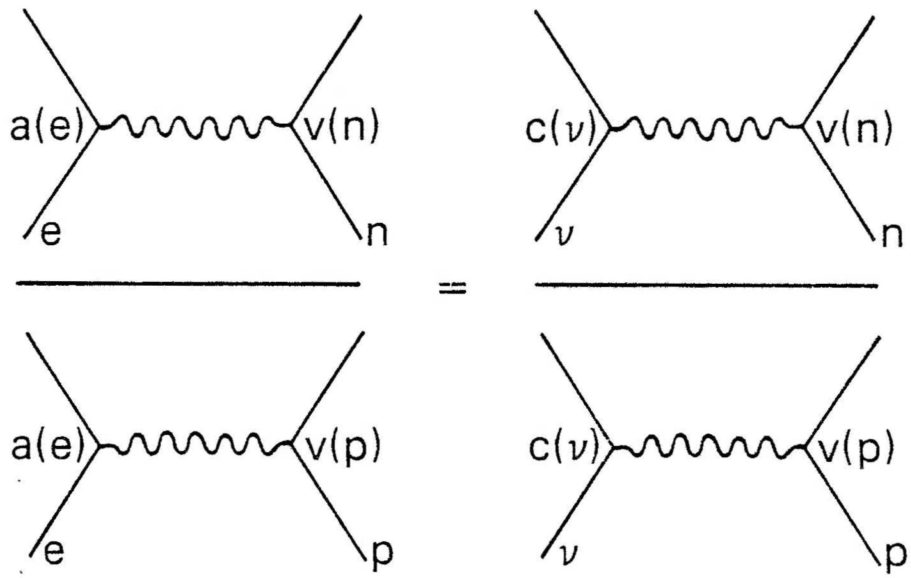

FIG. 4
Related ratios of electron-nucleon and neutrino-nucleon neutral weak couplings, assuming there is only one Z^0, whose exchange is represented by the wavy line.

Namely, if there is only one Z^0, then one can consider the ratio between a pair of non-neutrino measurements, involving, say, the axial vector current of the electron, and the vector currents of two different combinations of quarks, such as the neutron and proton. The unknown electron vertex will cancel out of this ratio, leaving a quantity which depends only on quark couplings. This quantity must equal the ratio between the coupling of the vector current of a neutron to a neutrino and that of a proton to a neutrino, since now the unknown neutrino vertex cancels out. In experiments with light atoms, then, one needs to look both at hydrogen and deuterium, and consider ratios of the results. In polarized electron scattering, one needs to use both proton and deuteron targets. (Relations such as that in Fig. 4 are of the same sort as those which have been discussed by Hung and Sakurai as tests of the single-Z^0 hypothesis.[10])

I would like to present the predictions of the νq solutions A and B for various ratios of non-neutrino measurements. In order to discuss the polarized electron experiment, let us introduce parameters $\bar{C}_{1p}$, etc., which will be analogues of the constants C_{1p}, etc., in the hydrogen-deuterium experiment. In particular, let $\bar{C}_{1p}$ measure the contribution to the asymmetry A of the interaction between the axial current of the electron, and the vector current of the quarks, in the deep inelastic scattering of polarized electrons from protons. (The specific combination of quarks sampled in this scattering depends on the kinematical point at which the experiment is done. Thus, $\bar{C}_{1p}$ is not a constant. It depends on parton structure functions, and has been evaluated for the kinematical point which corresponds to the present SLAC - Yale experiment.[11] This has been done using the general analysis of polarized electron scattering by Cahn and Gilman.[12]) In a similar way, let $\bar{C}_{2p}$ measure the contribution of the interaction between the vector current of the electron and the axial current of the quarks in the same reaction. Let $\bar{C}_{1d}$ and $\bar{C}_{2d}$ be the analogues of $\bar{C}_{1p}$ and $\bar{C}_{2p}$ for the case where the target is a deuteron. Finally, let $\bar{C}_{1el}$ be the analogue in the elastic scattering from protons of $\bar{C}_{1p}$ in the deep inelastic scattering. (In the elastic collision, only one of the two odd-parity interactions contributes.[12])

In calculating the uncertainties in the various non-neutrino predictions, I did not use the errors quoted for the νq couplings in Table I, because these are not uncorrelated. Rather, I expressed the νq couplings back in terms of the neutrino data from which they came,[13] and assumed the errors in those data to be uncorrelated.

The predictions of Solutions A and B for the ratios of non-neutrino measurements are given in Table II. In the hydrogen-deuterium experiment, the constants C_2 depend on the "isoscalar axial vector renormalization constant for the proton." This quantity is unknown, so I have used the two popular estimates for it,[4,14] and calculated the predictions involving the C_2's for both. As can be seen, the choice of estimate does not make very much difference.

We see from the hydrogen-deuterium part of Table II that the pre-

TABLE II. Predictions of the νq coupling solutions for ratios of quantities to be measured in the hydrogen-deuterium experiment (H - D), and in polarized electron scattering.

Ratio	Prediction of Solution A	Prediction of Solution B
H-D		
C_{1n}/C_{1p}	2.53 ± 1.44	$-.55 \pm .79$
C_{2n}/C_{2p}	$\left\{ \begin{array}{l} -.89 \pm .24 \\ -.93 \pm .15 \end{array} \right.$	$\left. \begin{array}{l} -2.71 \pm 1.71 \\ -1.76 \pm .57 \end{array} \right\}$
$\dfrac{C_{1p}/C_{2p}}{A_{\nu e}/V_{\nu e}}$	$\left\{ \begin{array}{l} .42 \pm .50 \\ .43 \pm .53 \end{array} \right.$	$\left. \begin{array}{l} -4.44 \pm 3.45 \\ -3.31 \pm 1.97 \end{array} \right\}$
Polarized e		
$\overline{C}_{1d}/\overline{C}_{1p}$	$1.21 \pm .15$	$1.03 \pm .03$
$\overline{C}_{2d}/\overline{C}_{2p}$	$1.00 \pm .04$	$1.28 \pm .24$
$\dfrac{\overline{C}_{1d}/\overline{C}_{2d}}{A_{\nu e}/V_{\nu e}}$	$-.38 \pm .33$	-3.93 ± 3.37
$\overline{C}_{1d}/\overline{C}_{1el}$	-2.69 ± 5.62	$1.27 \pm .34$

dictions for C_{1n}/C_{1p} and C_{2n}/C_{2p} are fairly definite, both for Solution A and for Solution B. The errors are not outlandish, and the two sets of predictions, A and B, are distinct. We note also that it may not be absolutely necessary to make measurements in both hydrogen and deuterium. Namely, if one can measure both C_{1p} and C_{2p} in hydrogen, one will still have a test. Here the quantity that depends only on quark couplings is not C_{1p}/C_{2p}, of course, but this ratio divided by the ratio $A_{\nu e}/V_{\nu e}$ between the axial vector and vector couplings of the electron. The latter ratio can in principle be determined from νe scattering; in fact, M. Baldo-Ceolin reported at this Conference that a combined analysis of the Aachen-Padova νe data and the reactor $\bar{\nu}_e$-e data[15] already suggests a value for it. Notice that a precise value isn't needed; the predictions of Solutions A and B for $(C_{1p}/C_{2p})/(A_{\nu e}/V_{\nu e})$ differ in sign, and the sign of $A_{\nu e}/V_{\nu e}$ will be fixed once we know which cross section, that for ν_μ-e scattering or that for $\bar{\nu}_\mu$-e scattering, is the bigger.

From the polarized electron part of Table II, we see that, by contrast with hydrogen-deuterium, this experiment does not look so hopeful. The ratios C_{1d}/C_{1p} and C_{2d}/C_{2p} have a tendency to be unity, regardless of the details of the weak interaction. (This is true not only for Solutions A and B but also for various gauge models that one might like to test.[12]) The ratio $(\bar{C}_{1d}/\bar{C}_{2d})$ / $(A_{\nu e}/V_{\nu e})$, which can be studied using only the experimentally-preferred deuteron target, has the same sign for both Solutions A and B. For the ratio $\bar{C}_{1d}/\bar{C}_{1el}$, the prediction of Solution A has a very large error. Polarized electron scattering is, of course, a very important experiment; we are saying only that it does not look useful for verifying the νq couplings.

The conclusion I would draw from these results is that the hydrogen-deuterium experiments do look promising as a way of confirming that Solution A is right, or else distinguishing between Solutions A and B.[16]

Now, the non-neutrino experiments could surprise us. Perhaps they will find that there are parity-violating effects, but that these effects grossly contradict the predictions of both Solutions A and B. If we accept the neutrino analysis that produced these solutions, such a finding would suggest that the hypothesis that there is only one Z^0, which led to our non-neutrino predictions, is wrong! Or, it could be that we will find that all parity-violating effects vanish, at least in lowest order. However, such a result would also be evidence for more than one Z^0, or else evidence for something bizarre, such as S,P, and T couplings.

ELECTRONIC NEUTRINOS

I would like to discuss now a class of neutrino reactions which, like the non-neutrino processes, involve an interference between the neutral weak interaction and another force. I refer to the scattering of electronic neutrinos and antineutrinos from electrons, where the other force is the charged weak interaction. (Since the nuclear and heavy atom neutral current experiments have been well-treated elsewhere in this Conference, I will not discuss them.)

In spite of the present uncertainty, let us assume that the ν_μ-e and $\bar{\nu}_\mu$-e cross sections will be known within the fairly near future. Thus, while the ν_e-e and $\bar{\nu}_e$-e cross sections can provide some of the same information, let us think of them more as results that can tell us something new.[15] At present, there is a reactor $\bar{\nu}_e$-e experiment[15] that has already been completed, and there are plans by Chen and Reines for a LAMPF experiment on ν_e-e.

The presence of both charged and neutral current contributions to ν_e-e and $\bar{\nu}_e$-e scattering is illustrated for the ν_e-e case by Figure 5. Corresponding to the figure, the

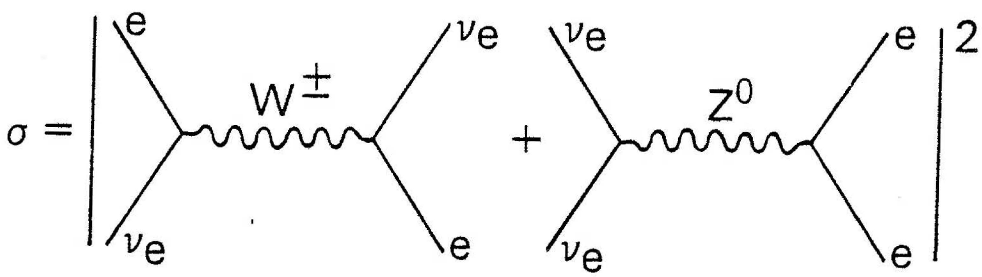

FIG. 5
The cross section σ for ν_e-e scattering.

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cross section $\sigma(\nu_e\text{-}e)$ is given schematically by

$$\sigma \sim |C|^2 + |N|^2 + I \quad , \qquad (4)$$

where $|C|^2$ is the square of the charged-current amplitude and is known from muon decay. $|N|^2$ is the square of the neutral-current amplitude and will soon be known from ν_μ and $\bar{\nu}_\mu$ measurements, and I is a possible interference term. If it can be demonstrated experimentally that the interference term is present, then we will learn a great deal about neutral weak interactions. First, we will learn that (at least in this process) the outgoing neutrino produced by these interactions is the same as the incoming one, and not some new particle. It is the same because the charged current diagram in Fig. 5 does not change neutrino identity, and if the neutral current one did, the two could not interfere.[17] Secondly, we will learn that neutrino helicity does not flip in neutral weak interactions, which means that the neutral couplings are of V, A structure. Again, the point is that the charged weak interactions preserve neutrino helicity, so, to interfere with them, the neutral interactions must do the same (at least sometimes).[2] Finally, we will learn that, in particular, the left-handed electron participates in neutral weak interactions. This is so because it is the left-handed electron that participates in the charged interactions; that is what it means to say the charged weak current is V - A. The only part of the neutral interaction which can interfere with the charged one is that involving the V - A neutral current of the electron.

We see from this last remark that $I \propto (V_{\nu e} - A_{\nu e})$, where $V_{\nu e}$, $A_{\nu e}$ are the νe neutral couplings defined earlier.[18] In SU(2) x U(1) gauge models, with the usual treatment of the left-handed electron, $(V_{\nu e} - A_{\nu e}) \propto (\sin^2\theta_W - \frac{1}{2})$, where θ_W is the Weinberg angle. Thus, $I < 0$ as long as $\sin^2\theta_W$ is less than $\frac{1}{2}$, as it is, for example, if we assume the Weinberg-Salam model and appeal to the data.

Now the existing reactor results do not establish that the interference term is there. On the other hand, if we assume that $I \neq 0$, then these data provide evidence that $I < 0$. This is shown in Figure 6,

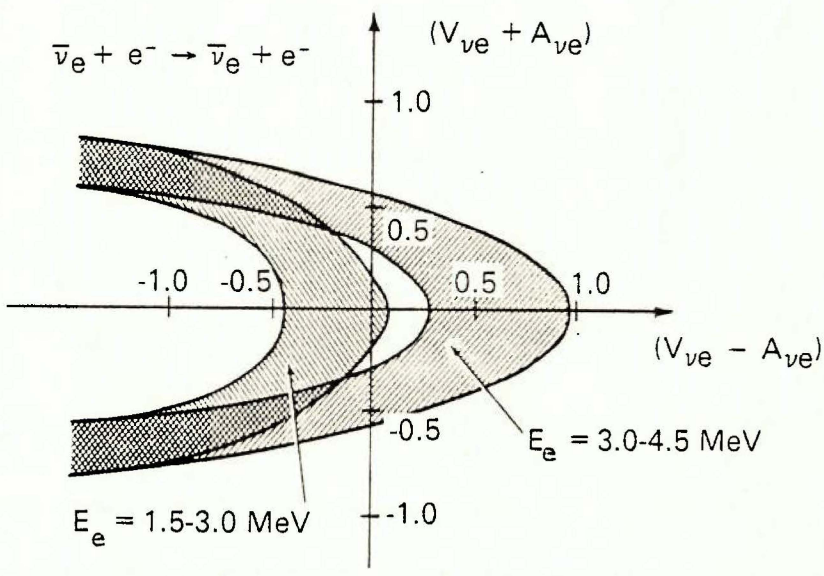

FIG. 6
The regions in νe coupling space allowed by reactor data[15] for electron recoil energies E_e in each of two bins.

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where we see that the only regions allowed by the two energy bins together correspond to negative values of $(V_{\nu e} - A_{\nu e})$.

Hopefully, the planned LAMPF experiment can confirm that I is negative, assuming it to be present, and perhaps this experiment can even prove that I is present in the first place. The experiment will use a beam dump, in which positive pions come to rest and then decay according to the usual chain:

$$\pi^+ \to \mu^+ + \nu_\mu$$
$$\quad\quad \hookrightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

This means that three different species of neutrinos will be streaming out of the beam dump and entering the detector. The neutrino spectra will be as shown in Figure 7,[19] where E_{top} is the top of

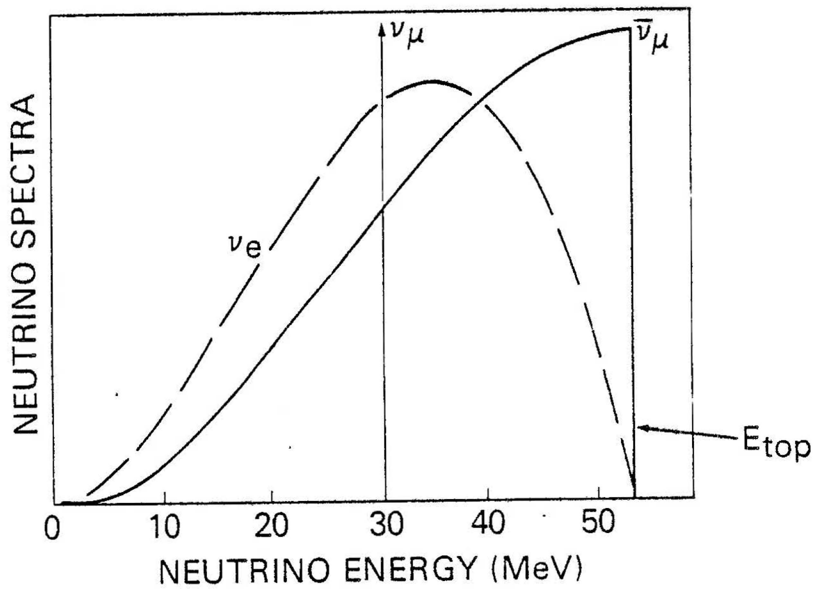

FIG. 7
The spectra of the neutrinos emitted from a beam dump.

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the spectrum, and the spectrum for ν_μ is a spike because these neutrinos come from a two-body decay.

Needless to say, the detector cannot tell which kind of neutrino initiated any given event. Well then, you ask, can one learn anything in such a complicated situation? E. Fischbach, S.P. Rosen, H. Spivack, and I have tried to see. What one expects in ν_e-e scattering, at least if we believe the smaller of the existing ν_μ-e cross section results, is that $|C|^2 > |I| > |N|^2$. Thus, roughly speaking, what one would like to find out in the LAMPF experiment is whether the ν_e-e cross section is bigger or smaller than what one would get from the charged-current piece alone.

What the experiment will measure is the event rate as a function of the energy E_e of the recoil electron. We have made some theoretical estimates of this event rate for values of E_e above the ν_μ spike, which cannot correspond to ν_μ-initiated events. In this E_e range, only ν_e and $\bar{\nu}_\mu$ contribute, and we have taken both contributions into account.

If one assumes, for example, the Aachen-Padova values[20] for the ν_μ-e and $\bar{\nu}_\mu$-e cross sections in order to determine N, then one finds the event rates given in Table III. The rates are quoted for two recoil energy bins, and we have taken the lower bin to begin at $\frac{1}{2}E_{top}$, which is approximately where the ν_μ spike is.

TABLE III. Expected event rates, in arbitrary units, in two recoil energy bins. The various rows correspond, as indicated, to negative, positive, and non-existent interference between the neutral and charged weak contributions to ν_e-e scattering.

Interference	$1/2E_{top} < E_e < 3/4E_{top}$	$3/4E_{top} < E_e < E_{top}$
$I = -2\|N\|\|C\|$	52	12
$I = +2\|N\|\|C\|$	90	20
$I = 0$	70	16

From Table III, we see that to distinguish between destructive and constructive interference, the experiment will have to determine the event rate and the overall flux normalization accurately enough to tell the difference between 52 and 90. To establish that the interference term is present in the first place, it will have to determine these things with enough added precision to distinguish between 52 and 70. We shall leave it to our experimental colleagues to say how easily they can do that.

SUMMARY

In summary, neutral weak interaction experiments which do not involve neutrinos are the only means of answering some very basic questions about this interaction. In addition, they are a way to confirm some of the things which we think we have learned from neutrino physics. Every one of these non-neutrino experiments is difficult, but, hopefully, in the next few years they will play a significant role in our discovery of the true nature of the neutral weak force.

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