

PARITY VIOLATION IN ELECTRON SCATTERING*

CHARLES Y. PRESCOTT
Stanford Linear Accelerator Center
Stanford University
Stanford, California 94305

CONTENTS

- I. The Gauge Theory Motivation - Introduction and Brief History
- II. Parity Violation in the Quark-Parton Model
- III. Experimental Techniques and Results
- IV. Connections to Neutrino Scattering, Medium Energies, and Atomic Physics

I. INTRODUCTION AND BRIEF HISTORY OF GAUGE THEORIES

Parity violation has been well established in particle physics for many years, since the 1950's where it was first seen in beta decay processes. The strong and electromagnetic forces are parity conserving, and the experimental evidence that parity was violated in the weak processes came somewhat as a surprise. Beta decay of radioactive nuclei occurred through emission of both e^+ and e^- , requiring charged weak forces of both signs. Even though neutral weak forces had not been observed it was conjectured that a neutral component of weak decays could also exist, and Zel'dovich⁽¹⁾ in 1957, suggested that parity violating effects may be observable in electron scattering processes and in atomic spectra. These early conjectures were the beginnings of what we now see as development of the unified gauge theories of the weak and electromagnetic interactions. The history of gauge theories begins with electromagnetism, where the force between charged particles is

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CHARLES Y. PRESCOTT

understood in quantum field theory to be carried by a massless vector particle we call the photon. The long range of the electromagnetic force makes it plainly visible in our every day experience. The weak interactions exhibited both "weakness" of strength and short range. Feynman and Gell-Mann first proposed the V-A form of the weak interactions,⁽²⁾ and the possible similarity in structure to electromagnetism stirred ideas that these two forces could be unified. The short range of the weak force required that particles which mediate it be massive. The massiveness of these particles, called W^+ and W^- , solved some, but not all, of the divergencies arising in calculations of some processes. The possibility that weak and electromagnetic forces could be explained by a simple triplet of particles (W^+ , γ , W^-), had serious problems as a theory. The strength of the couplings and the masses of the γ and the W 's were quite different. Problems in the quantum field theory existed where certain processes were not renormalizable. Perhaps more importantly the photon exhibited only vector couplings, but lacked the axial vector piece seen for the W 's. Parity violation, or lack of it for the photon, was evidence that a simple triplet structure was insufficient to explain both weak and electromagnetic forces.

Progress in quantum field theory was accompanied by early attempts at model building. The extension to four vector bosons, two of which were neutral, was discussed in 1961 by Glashow.⁽³⁾ He suggested that mixing between the two neutral bosons might be arranged to give a massless physical state (the photon) and a massive neutral particle. Glashow's model lacked a mass relationship or a mechanism to obtain heavy mass. Salam and Ward in 1964 introduced $SU(2) \times U(1)$ as the underlying group structure.⁽⁴⁾ It contained mixing of the photon-neutral vector boson, but still had no means for generating

PARITY VIOLATION IN ELECTRON SCATTERING

mass. In 1967, through the mechanism of spontaneous symmetry breaking, Weinberg introduced mass generation. He wrote down a "theory of leptons"⁽⁵⁾ that achieved the needed theoretical objectives. In the quantum field theory, a local gauge invariance leads to massless vector bosons as the carriers of the force. A scalar doublet of particles was introduced which coupled to these particles and led to large masses desired. Although these scalar particles represented an ad hoc assumption, the resulting theory was constructed with a most economical structure, avoiding problems of earlier attempts. That the theory was renormalizable was assumed by Weinberg, but soon shown to be so by t'Hooft in 1971.⁽⁶⁾ Also in 1971 the theory of leptons was extended to include the quarks by Glashow, Iliopoulos, and Miani.⁽⁷⁾ The resulting form is referred to as the "Weinberg-Salam", the "Salam-Weinberg", or just the "standard" model of weak and electromagnetic interactions.

The model contains four massive vector bosons which couple to the constituents of matter, leptons and quarks. Three of the vector bosons are in a SU(2) triplet (W^+ , W^0 , W^-) and the fourth is a singlet, B^0 . The group structure is SU(2) x U(1). The W's couple to "weak isospin" of particles (a weak charge analogous to electromagnetic charge) and the B^0 couples to weak isospin and electric charge. The W^0 and B^0 are not the physical particles. Certain linear combinations are identified as the physical particles. One combination

$$\gamma = \cos\theta_W B^0 - \sin\theta_W W^0 \quad (1)$$

can be arranged to be massless and have vector couplings. It is identified as the photon. The orthogonal combination

$$Z^0 = \sin\theta_W B^0 + \cos\theta_W W^0 \quad (2)$$

CHARLES Y. PRESCOTT

is massive and is the mediator of a new force, the weak neutral current. This latter combination led to the gauge theory prediction of neutral currents. The mixing parameter, $\sin\theta_W$, is not specified, but mass relations in terms of it do exist:

$$m_W = 37.4 \text{ GeV}/\sin\theta_W \quad (3)$$

$$m_{Z^0} = m_W/\cos\theta_W = 75 \text{ GeV}/\sin 2\theta_W \quad (4)$$

The standard model also specifies the weak isospin assignment of the fundamental fermions:

| leptons | | | | quarks | | | |
|--|--|--|--|---|---|--|----------|
| $\begin{pmatrix} \nu_e \\ e^- \end{pmatrix}_L$ | $\begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}_L$ | $\begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}_L$ | | $\begin{pmatrix} u \\ d' \end{pmatrix}_L$ | $\begin{pmatrix} c \\ s' \end{pmatrix}_L$ | $\begin{pmatrix} t \\ b \end{pmatrix}_L$ | doublets |
| e^-_R | μ^-_R | τ^-_R | | $u_R, d'_R, c_R, s'_R, t_R, b_R$ | | | singlets |

The neutral currents in $SU(2) \times U(1)$ couple according to

$$T_3 - Q \sin^2\theta_W \quad (6)$$

where $T_3 = \pm\frac{1}{2}$ for the doublets and 0 for the singlets. The "L" or "R" refer to left-handed or right-handed components of the particles. The asymmetry between left and right-handed particle assignments is disturbing, but appears to describe the structure of the weak interactions. The construction of the theory does not explain this asymmetry, but simply makes this choice, apparently on the grounds that this is the simplest possibility. Nevertheless, equation 6 tells us that left and right-handed neutral current couplings will be different, and with this choice parity violation in the neutral currents is introduced.

Let me conclude the introduction with a list of the physical implications of the standard model. First, and most

PARITY VIOLATION IN ELECTRON SCATTERING

importantly, there is the existence of neutral currents. They were first seen in 1973 in Gargamelle at CERN.⁽⁸⁾ (The discovery of neutral currents, coupled with the theoretical proof by t'Hooft in 1971 that the theory was renormalizable, popularized gauge theories in general, and other models quickly sprang up. But by late 1978 most of those had been discredited by experiment.) A second prediction of the standard model is the interference between weak and electromagnetic forces, and this should be observed as parity violation in electron scattering or atomic spectra, for example, and as parity violation and charge asymmetries in e^+e^- annihilation. The interference effects are typically small, but grow with increasing energy. Finally, I mention briefly the prediction of the existence of one or more scalar particles. The mass is not specified in the model, and no scalar particles are yet known to exist. Discovery of such particle or particles, however, would be strong support for the mechanism of spontaneous symmetry breaking, an essential part in the theory.

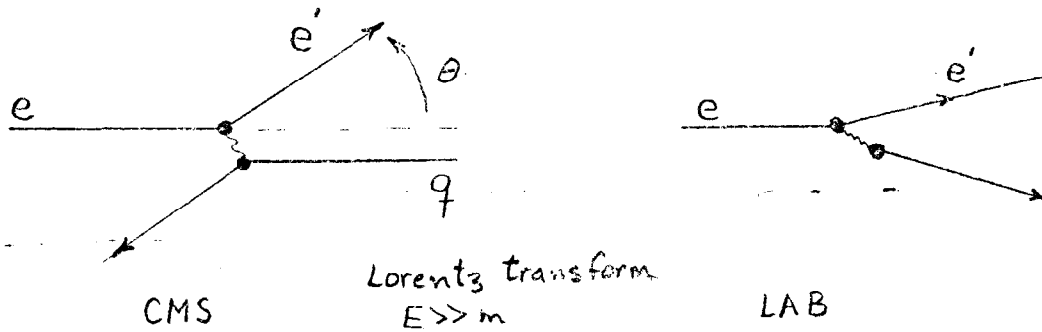
II. PARITY VIOLATION IN THE QUARK-PARTON MODEL

Let me now turn to inelastic electron scattering, a process we understand well, at least at the phenomenological level. Although parity violation effects can have a number of physical manifestations, we consider here only one case, the cross-section asymmetry for

$$e(\text{polarized}) + d(\text{unpolarized}) \rightarrow e' + X. \quad (7)$$

We will make the usual quark-parton model assumption that scattering occurs from spin $\frac{1}{2}$ constituents, and that we can neglect the mass of the electron and quarks.⁽⁹⁾ Consider the simplest hypothetical case where the electron scatters from a free stationary quark, at a CMS angle θ to the initial direction.

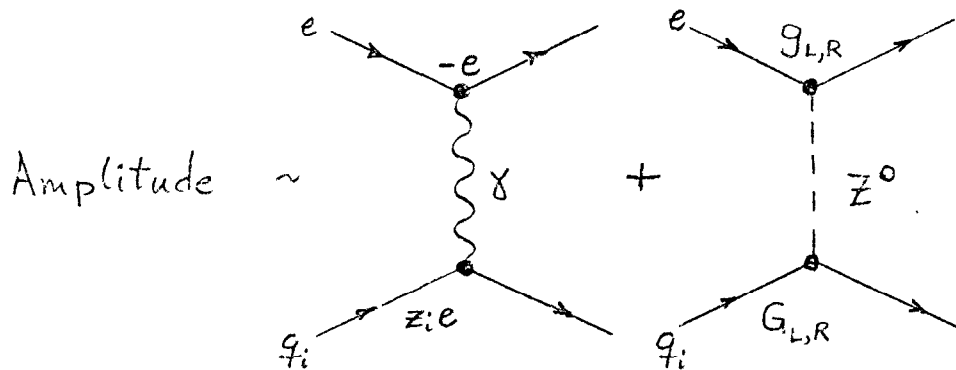
CHARLES Y. PRESCOTT



Lorentz transforming to the lab frame gives $E' = E_0/2 (1 + \cos\theta)$. Define a kinematic variable $y = (E_0 - E')/E_0$, which is the fraction of the beam energy transferred to the quark, and in terms of y

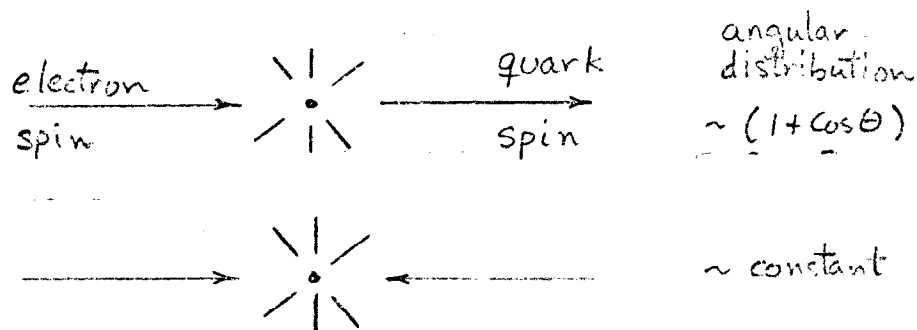
$$\frac{1}{2}(1 + \cos\theta) = 1 - y. \quad (8)$$

The scattering amplitude consists of two parts, an electromagnetic part and a weak part:



where the sign of the electric charge is shown explicitly, $z_i = \pm 1/3$ or $\pm 2/3$ depending on the quark or antiquark considered, and $g_{L,R}$ ($G_{L,R}$) are neutral current couplings for left and right-handed electrons (or quarks). Since unpolarized targets are used, we sum over two terms in the cross section corresponding to opposite spin projections for the incoming quark.

PARITY VIOLATION IN ELECTRON SCATTERING



$$\sigma_R = \left| \frac{-z_i e^2}{Q^2} + \frac{g_R G_L^i}{Q^2 + M_Z^2} \right|^2 (1-y)^2 + \left| \frac{-z_i e^2}{Q^2} + \frac{g_R G_R^i}{Q^2 + M_Z^2} \right|^2 \quad (9)$$

A similar expression exists for σ_L . The parity non-conserving asymmetry, defined as

$$A_{\text{PNC}} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

is found to be

$$A_{\text{PNC}} = -\frac{2Q^2}{M_Z^2} \frac{\left[g_A(z_i G_V^i) + g_V(z_i G_A^i) h(y) \right]}{z_i^2 e^2} \quad (10)$$

where

$$g_{V(A)} = \frac{1}{2} (g_R^{(+)} g_L^{(-)})$$

$$G_{V(A)}^i = \frac{1}{2} (G_R^i g_L^i) \quad (11)$$

$$h(y) = \frac{1 - (1-y)^2}{1 + (1-y)^2}$$

$$\frac{2Q^2}{M_Z^2 e^2} = 1.79 \times 10^{-4} Q^2, \quad Q^2 \text{ in } (\text{GeV}/c)^2$$

CHARLES Y. PRESCOTT

In the standard model, the neutral current couplings are given by

$$G_{L(R)}^i = T_{3L(R)}^i - z_i \sin^2 \theta_W \quad (\text{quarks}) \quad (12)$$

$$g_L = -\frac{1}{2} + \sin^2 \theta_W \quad (\text{left-handed electron})$$

$$g_R = 0 + \sin^2 \theta_W \quad (\text{right-handed electron})$$

Real targets, like deuterons or protons, consist of a mix of quarks, each with a momentum distribution function $f_i(x)$, where x is the usual scaling variable $Q^2/2Mv$. In the spirit of deep inelastic scattering, each quark contributes incoherently to the cross section by an amount $f_i(x)$. For the parity violating asymmetry the factor $\sum_i f_i(x)$ must be inserted in both the numerator and denominator of equation 10. However, for isoscalar targets such as deuterium, $f_u(x) = f_d(x)$, and only \sum_i must be inserted in the numerator and denominator in equation 10 (the x dependence drops out).

Taking free quarks for targets we get the following predictions for asymmetries, shown in Figure 1. Here we set $\sin^2 \theta_W = \frac{1}{4}$, which simplifies the expressions. (Experimentally measured values are near $\frac{1}{4}$.) For the anti-quark target asymmetries, relative to its quark, z_i and G_V^i change sign, while G_A^i does not. This means that asymmetries for u and \bar{u} targets are equal, and likewise for d and \bar{d} targets.

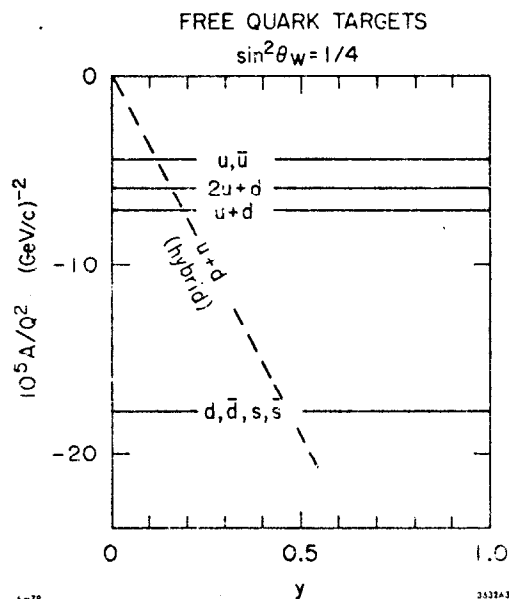


Figure 1

PARITY VIOLATION IN ELECTRON SCATTERING

In the parton model the deuteron consists of 3 u quarks, 3 d quarks, and a "core" or "sea" of $u\bar{u} + d\bar{d} + s\bar{s}$ quark pairs. The amount of $q\bar{q}$ sea contribution does not significantly modify predicted asymmetries; only the $s\bar{s}$ part of the quark sea affects the values, and that part is expected to be small.

Based on the standard model and the simple quark-parton model of inelastic scattering, the conclusions are

- (i) For isoscalar targets such as deuterons, A_{PNC}/Q^2 is independent of x ($f_u(x) \equiv f_d(x)$)
- (ii) We expect A_{PNC}/Q^2 to be nearly independent of y , since $\sin^2\theta_W \approx 1/4$ experimentally, and y -dependence vanishes at that value.
- (iii) We expect A_{PNC}/Q^2 to be insensitive to $q\bar{q}$ sea terms.

Let me take a brief look at another $SU(2) \times U(1)$ gauge theory model. Suppose there exists a heavy neutral particle, call it E^0 , which sits in a right-handed doublet with the electron, $\begin{pmatrix} E^0 \\ e^- \end{pmatrix}_R$. This model, called the "hybrid" model, changes the neutral current couplings of the electron, according to equation 12. This model is also shown in Figure 1. Because of the relation equation 12, measured asymmetries are sensitive to the existence or non-existence of other particles not involved in the process! Our recent results strongly disfavor the hybrid model.

III. EXPERIMENTAL TECHNIQUES AND RESULTS

I will describe here only the more important techniques and the major results obtained at SLAC in 1978 for polarized e-d scattering. Many of the details will be omitted.

First and most important, we needed a polarized electron

CHARLES Y. PRESCOTT

source for injection into the linear accelerator which had the following properties:

- (i) High beam intensity (up to 5×10^{11} \bar{e} 's/pulse, 120 pulses per second)
- (ii) Good polarization ($\sim 40\%$)
- (iii) Reversal of polarization, rapid and randomized from one pulse to next
- (iv) All other beam parameters not effected by reversal of polarization

The principle of operation, photoemission from gallium arsenide surfaces, was proposed by Ed Garwin (SLAC), Dan Pierce (NBS) and H.C. Seigmann (ETH Zurich) in 1974. Development of a suitable source at SLAC took about 3 years. Cross section measurements were made by scattering accelerated beams of polarized electrons in a 30 cm liquid deuterium target, and detecting them in a magnetic spectrometer. The spectrometer contained two electron counters, a gas Cerenkov counter and a lead glass shower counter. Figure 2 shows a schematic of the experiment. Counting rates in the counters were very high (typically 1000 electrons per 1.5 usec pulse) so that fluxes of electrons, rather than individual counters, were measured. We took the anode current from the photo multiplier tubes in each counter

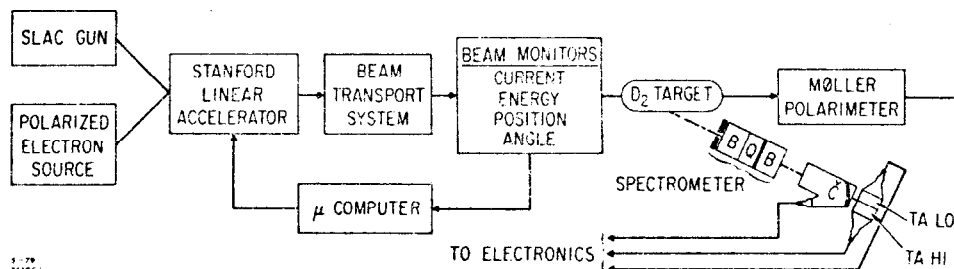
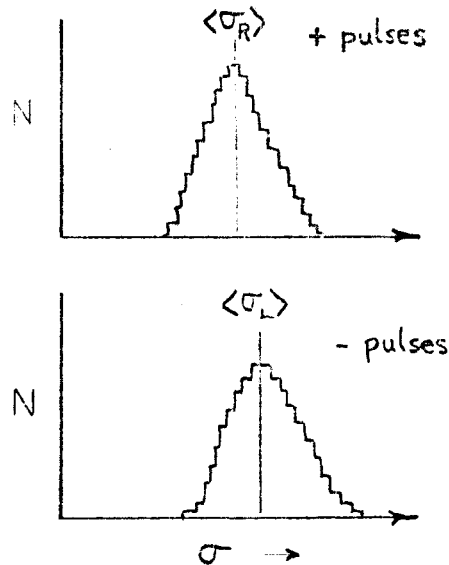


Figure 2

PARITY VIOLATION IN ELECTRON SCATTERING

as a measure of electron flux. Each beam pulse provided a cross section measurement when fluxes were normalized to incident beam charge obtained from beam toroid monitors.⁽¹⁰⁾ A run consisted of a large number of pulses of randomly mixed + and - polarizations. In our computer two distributions of the cross sections, one for beam pulses of right-handed electrons and one for pulses of left-handed electrons. The experiment consists in looking for a small relative shift in the means of these two distributions. The asymmetry is independent of the normalization used, so arbitrary cross section units work well. Absolute calibration of the apparatus is unnecessary. The method is essentially a difference measurement of two nearly equal quantities. By averaging over sufficiently long runs, the errors on the means

can be reduced to a level small enough to see weak interference effects. The widths of the histograms reflected the statistical counting, and these were monitored carefully during the experiment.



An important factor in the experimental work lies in the control of systematic effects as demonstrated by consistency of data and null measurements contained in the data. Systematic effects most likely arise from influence that reversals at the polarized source have on other beam parameters. The important parameters (position and angle at the

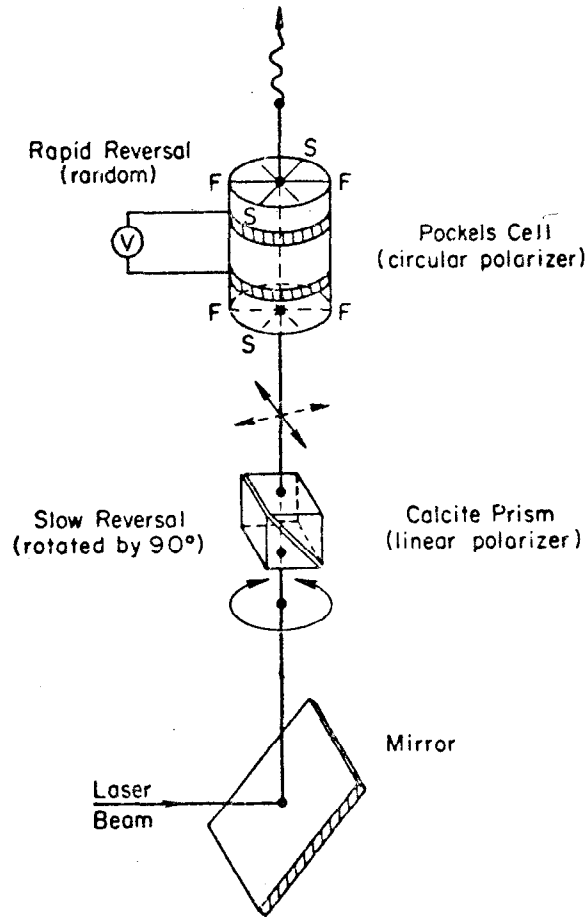
CHARLES Y. PRESCOTT

target, beam energy, intensity) were monitored with a set of devices positioned along the beam line to look for problems. The monitoring system was based on resonant microwave cavities which had a node placed on the beam axis. Displacements transverse to the beam line induced signals proportional to the current times the displacement. The high resolution obtained (typically 10 μm accuracy for a single pulse) resulted in position, angle and energy changes monitored to great sensitivity. These beam monitoring measurements ruled out systematic problems related to beam parameter changes when polarization was reversed.

The proof that parity violation exists lies in control of electron spin. Polarized electrons are photoemitted when one illuminates gallium arsenide surfaces with circularly polarized light. Monochromatic light ($\lambda = 710 \text{ nm}$) from a pulsed dye laser is linearly polarized in a Glan-Thompson calcite prism and circularly polarized in a Pockels cell quarter wave plate. Voltage, approximately $\pm 2 \text{ kV}$, applied to the ring electrodes drives the Pockels cell into $\pm \lambda/4$ retardation. By reversing the applied voltage, reversal of polarization is accomplished rapidly and easily within the 8.3 msec spacing between beam pulses. The pattern of + or - is randomized, and each beam pulse is tagged for the computer by the + or - Pockels cell voltage.

Normally + or - 100% circular polarization gives + or - longitudinal polarization. However, if the prism is rotated by 90° about the laser beam axis, the fast and slow axes of the Pockels cell are interchanged relative to the plane of linear polarization. In this orientation + voltage on the Pockels cell gives - longitudinal polarization for the electron beams. The experimental asymmetries are formed in our computer

PARITY VIOLATION IN ELECTRON SCATTERING



4-76 OPTICAL REVERSAL SCHEME 1288A3

Figure 3

according to the sign of Pockels cell voltage

$$A_{\text{exp}} = \frac{\sigma(v=+) - \sigma(v=-)}{\sigma(v=+) + \sigma(v=-)} \quad (13)$$

and we would expect this asymmetry to change sign when the prism is rotated to 90° . More generally, we expect

$$A_{\text{exp}} = P_e A_{\text{PNC}} \cos(2\phi_p) \quad (14)$$

where P_e is the magnitude of the electron beam polarization and A_{PNC} is the parity non-conserving asymmetry the theorist calculates.

CHARLES Y. PRESCOTT

Figure 4 shows the results for each of the counters, the gas Čerenkov and the lead-glass shower counter, superimposed.

The two counters serve as a consistency check. They have different responses to backgrounds, different physical processes producing signals, and different electronics monitoring the fluxes. The only thing common to these counters is the electron signal, monitored simultaneously in both. That is, they count the same electrons and are, therefore, statistically highly correlated.

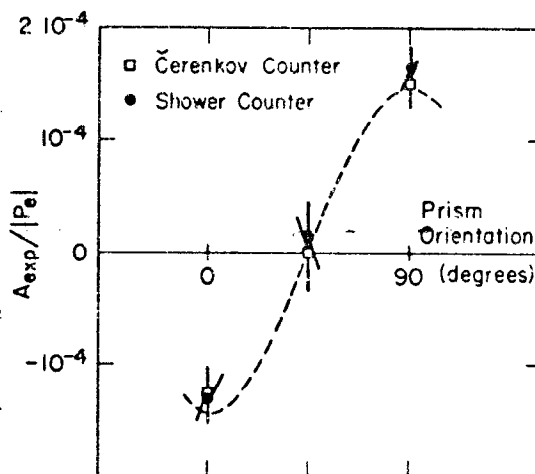


Figure 4

The point at 45° is particularly important, since in this configuration the source is producing unpolarized electrons. Parity violating asymmetries must vanish, but systematic problems which mask or fake parity violation would still be present. The 45° measurements are consistent with 0 as expected. The agreement between gas Čerenkov and lead-glass shower counters strengthen the belief observed asymmetries arise from parity violation.

Additional control of electron spin can occur because of spin precession in the beam transport system. Due to the electron's anomalous magnetic moment, at relativistic energies the spin will precess faster than momentum in the uniform magnetic field by

$$\theta_{\text{prec}} = \frac{E_0}{m_e} \left(\frac{g-2}{2} \right) \theta_{\text{bend}} = \frac{E_0}{3.237 \text{ GeV}} \pi \text{ radians} \quad (15)$$

PARITY VIOLATION IN ELECTRON SCATTERING

By varying the beam energy, the spin of the electron at the target changes relative to the spin at the source, and we expect experimental asymmetries to vary according to

$$A_{\text{exp}} = P_e A_{\text{PNC}} \cos \left(\frac{E_{0\pi}}{3.237 \text{ GeV}} \right) \quad (16)$$

where for these measurements the prism orientation is taken into account. The results shown in Figure 5 are in good agreement with this form. The point at 17.8 GeV is consistent with zero as expected. This point has additional significance. The spin orientation is transverse here, normal to the plane of scatters and therefore transverse spin components as a possible source of asymmetries is ruled out.

The $g-2$ precession of the experimental asymmetries constitutes the proof that the interaction has a helicity dependent part, which is equivalent to parity violation in this reaction. The statement that this arises from weak-electromagnetic interference is inferred, because these measurements are in good agreement with models of weak-electromagnetic interactions, as we will see.

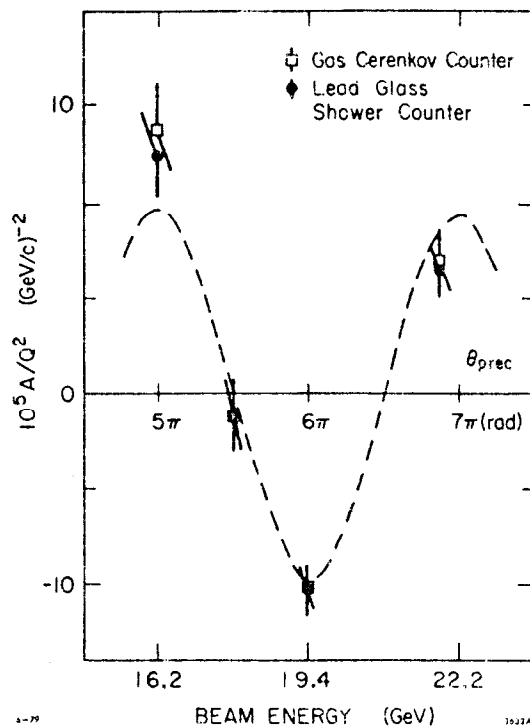


Figure 5

CHARLES Y. PRESCOTT

Data were also taken at different E' values for the electron, corresponding to different y values, defined earlier. The standard model predicts no y variation in A/Q^2 for $\sin^2\theta_W = \frac{1}{4}$. Our results are close to this value; the best fit for the data, using the standard model and the simple quark-parton picture, is $\sin^2\theta_W = 0.224 \pm 0.020$. Figure 6 shows the data plotted against y values, and three different "fits". The first, marked W-S, is the standard model for $\sin^2\theta_W = 0.224$. A second fit, marked "Model Independent" corresponds to the two-parameter form

$$A/Q^2 = a_1 + a_2 \frac{1 - (1 - y)^2}{1 + (1 - y)^2} \quad (17)$$

which comes from the parton model independent of gauge theory assumptions. The fit

parameters are $a_1 = (-9.7 \pm 2.6) \times 10^{-5} (\text{GeV}/c)^2$ and $a_2 = (4.9 \pm 8.1) \times 10^{-5} (\text{GeV}/c)^2$, which agree with standard model predictions. The best fit for the hybrid model is also shown. It has a poor χ^2 and is strongly disfavored.

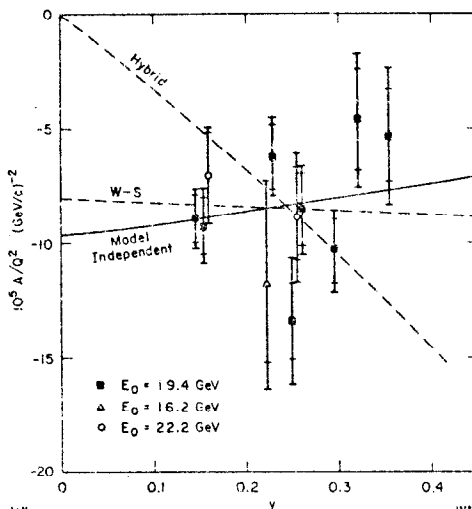


Figure 6

IV. CONNECTIONS TO NEUTRINO SCATTERING, MEDIUM ENERGIES, AND ATOMIC PHYSICS

Our results clearly show evidence for neutral currents in electron scattering, but information on neutral current phenomena also come from other processes.

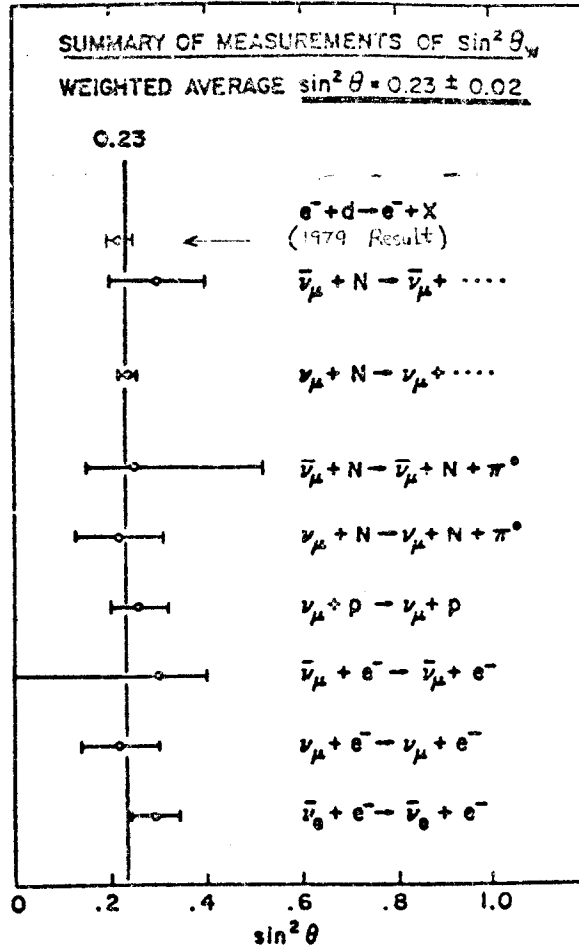
PARITY VIOLATION IN ELECTRON SCATTERING

Figure 7 is a compilation of measurements on $\sin^2 \theta_W$ taken from C. Baltay's talk at Tokyo last year. (11)

It shows values of $\sin^2 \theta_W$ from a variety of different reactions, mostly neutrino scattering experiments. Only one experiment, the one from SLAC, is not with neutrino beams, and of the eight neutrino measurements only one comes from low energies. (12) The experiments are all consistent with the world average $\sin^2 \theta_W = 0.23 \pm 0.02$. The conclusion

is that the original gauge theory of weak and electromagnetic interactions works well!

Figure 7



Although our results taken together with neutrino neutral current results constitute a great success for the standard model, experiments must continue to challenge these basic ideas. At SLAC we are searching for a source of nearly 100% polarization, which will open up new experimental possibilities, but so far have not succeeded in that search. In the near future I understand gallium arsenide sources will exist at Mainz and at the Bates lab at MIT. This opens up possibilities at medium energies for neutral current work with nuclei, and I want to

CHARLES Y. PRESCOTT

comment on a few points about connections between our work, medium energies, and atomic physics.

The connection between high energy, medium energy, and atomic spectra parity violation lies in the fundamental neutral current couplings. Following the work of Bjorken, Sakurai, Feinberg and others ⁽¹³⁾ an effective parity violating coupling can be defined (in Bjorken's notation)

$$\begin{aligned} \mathcal{L} = & -G/\sqrt{2} \left[\bar{e} \gamma_{\mu} \gamma_5 e \left\{ \epsilon_{AV}^{eu} \bar{u} \gamma_{\mu} u + \epsilon_{AV}^{ed} \bar{d} \gamma_{\mu} d \right\} \right. \\ & \left. + \bar{e} \gamma_{\mu} e \left\{ \epsilon_{VA}^{eu} \bar{u} \gamma_{\mu} \gamma_5 u + \epsilon_{VA}^{ed} \bar{u} \gamma_{\mu} \gamma_5 d \right\} \right] \end{aligned} \quad (18)$$

where the coefficients ϵ_{AV}^{eu} , ϵ_{AV}^{ed} , ϵ_{VA}^{eu} , ϵ_{VA}^{ed} are low energy phenomenological parity violating couplings and u,d refer to up and down quarks. This choice is a complete set of parity violating couplings provided only vector and axial-vector forms are allowed. This assumption stems from a strong theoretical bias that pervades almost all discussions of neutral currents. Our experimental results lend strong support to the V,A structure of neutral currents, since S,P and T forms do not lead to parity violation. ⁽¹⁴⁾

These phenomenological couplings are the meeting grounds for experiment and theory. Experiments measure these couplings (usually linear combinations of them); theory predicts their values. An equivalent set are defined by Sakurai ⁽¹⁵⁾ and are perhaps more appropriate to experiments. They are the isovector and isoscalar combinations, and correspond to linear combinations of Bjorken's couplings. Using Bjorken's notation and the parton model assumptions

$$\frac{A/Q^2}{\text{(intercept)}} = - \frac{3G}{10\pi\alpha\sqrt{2}} \left[(2 \epsilon_{AV}^{eu} - \epsilon_{AV}^{ed}) + (2 \epsilon_{VA}^{eu} - \epsilon_{VA}^{ed}) \left\{ \frac{1-(1-y)^2}{1+(1-y)^2} \right\} \right] \quad (19)$$

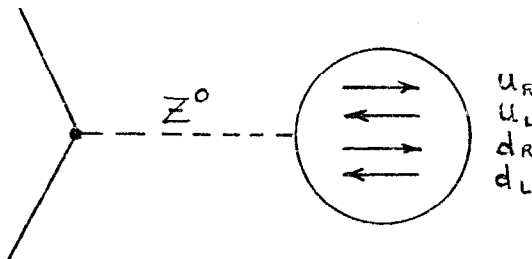
(intercept) (slope)

PARITY VIOLATION IN ELECTRON SCATTERING

Only linear combinations are determined from our data, and a complete separation of the fundamental couplings requires new and different experimental measurements. SLAC e d data cannot separate these coefficients, and possible further data would not help much. But at medium energies and in atomic physics, parity violation is sensitive to different linear combinations of the ϵ 's, and results from these other processes could serve to make the separations. This is the new information that medium energies and atomic physics can provide.

A basic difference between high energy scattering and medium energy and low energy neutral current phenomena is that amplitudes add incoherently in deep inelastic scattering, but are coherent at the lower energies. A simplification of form in the deep inelastic occurs where scattering is calculated as a simple sum over constituent quark targets. For elastic scattering or low energies, final states are indistinguishable and the fundamental processes must be added within the amplitude.

In the nuclei, nucleons tend to form closed shells. Constituent quarks will be paired, spins opposed. Using equations 11 and 12, one can easily show that for a coherent sum over u and d quarks whose spins are opposed the hadronic axial vector neutral current couplings G_A will vanish, while the corresponding vector current coupling G_V does not. To the extent that nuclear shells are closed, the hadronic term G_A will be zero or small (compared to G_V). One usually sees that for elastic scattering or in



CHARLES Y. PRESCOTT

atomic physics parity violation only G_V contributes. The hydrogen nucleus is an exception where not all quarks are paired. In deep inelastic scattering both G_V and G_A contribute, and enter into the intercept and slope terms, respectively.

Sakurai's choice of parameters $\tilde{\alpha}$, $\tilde{\beta}$, $\tilde{\gamma}$, $\tilde{\delta}$ correspond to vector-isovector, axialvector-isovector, vector-isoscalar, and axialvector-isoscalar couplings, respectively. Transitions between nucleon states, which are eigenstates of spin, parity and isospin, can act as filters to preferentially select currents of the $\tilde{\alpha}$, $\tilde{\beta}$, $\tilde{\gamma}$, $\tilde{\delta}$ forms. Possible examples are discussed by G. Feinberg.⁽¹⁶⁾ Measurement of a polarization asymmetry in a $\Delta I = 0$, 0^+ to 0^- nuclear transition would isolate the $\tilde{\delta}$ contribution in weak neutral currents. It is predicted to be 0 in the standard model. Candidate levels in O^{16} exist, which may make such a test possible. Elastic scattering from C^{12} (selects $\tilde{\alpha}$) and a $T = 1$ state at 12.8 MeV in O^{16} (selects $\tilde{\beta}$) are other possibilities. Whether these measurements are experimentally feasible depends on details only the experimenters can determine. Intensity and polarization of the electron beam, cross section magnitude, backgrounds, signal to noise, and systematic effects all must be considered and understood.

Parity violation in atomic physics can answer some of these questions. The parity violation is observed through circular dichroism effects, or rotation of linear polarization in passing through metal vapors. As in electron scattering from nuclei, the coherence of amplitudes suppresses the hadronic axial-vector contributions, and atomic physics parity violation is related only to the "intercept" term in the elastic $e d$ parity violation.

Optical rotation effects in atoms can be enhanced through

PARITY VIOLATION IN ELECTRON SCATTERING

- (i) Use of heavy atoms; parity violating effects grow as Z^3
- (ii) Selection of transitions where parity conserving amplitudes are suppressed
- (iii) Working with nearly degenerate levels

Experiments with atomic bismuth levels (17-19) and with thallium (20) have been reported. The experimental results are contradictory at present, with two groups reporting null (or nearly so) results, compatible with parity conservation, and two groups reporting visible parity violation effects at the level needed for the weak neutral currents. The experimental situation is confused. Further complicating matters, the theory is not very well understood. Small effects can have large perturbations to parity violation calculations. We must await further work in the atomic physics sector of parity violation before these contradictions are going to be resolved. Figures 8 and 9 summarize SLAC e d results in terms of the four neutral current couplings. Both Bjorken's coefficients and Sakurai's coefficients are shown. The intercept term a_1 leads to a band on Figure 8. The slope parameter a_2 gives the stripe in Figure 9. Hypothetical e-nucleus results are shown for illustration purposes only. The slope of these stripes is given by neutral current phenomenology; the widths are from experimental error, here only hypothetical.

Atomic spectra parity violation measurements also contribute bands that fall on Figure 8 (but not on Figure 9), but have not been shown. The present status of four reporting groups is summarized in Table I.

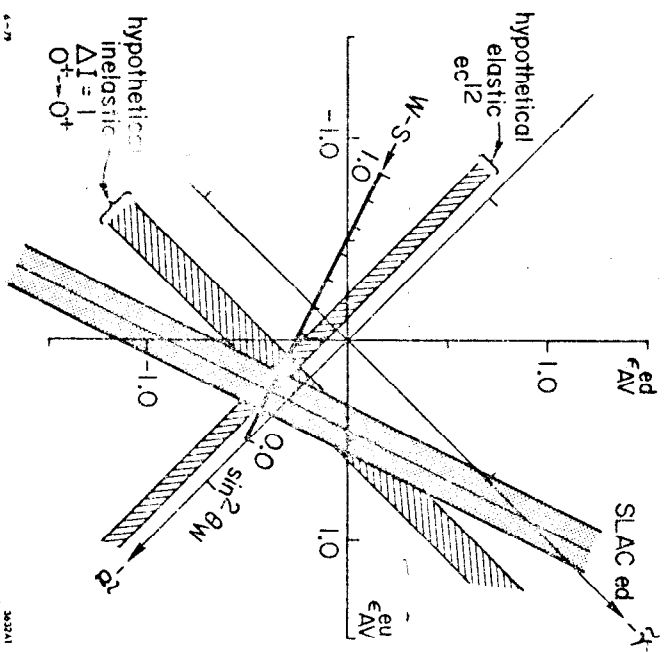


Figure 8

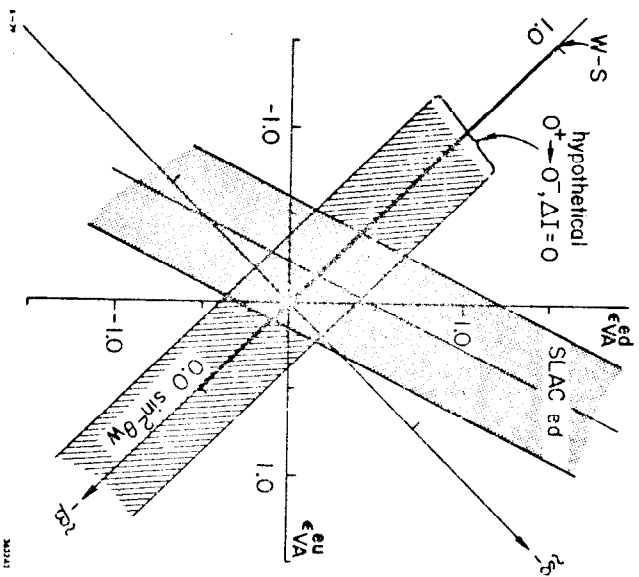


Figure 9

PARITY VIOLATION IN ELECTRON SCATTERING

TABLE I. PARITY VIOLATION IN ATOMIC SPECTRA

| Experiment | Atom | Transition (nm) | $R = \text{Im} \left(\frac{E1}{M1} \right)$ | W-S Prediction |
|-----------------------------|------|--------------------|--|--|
| Seattle ⁽¹⁷⁾ | Bi | 875.7 | $(-2.5 \pm 2.7) \times 10^{-8}$ | $(-10 \text{ to } -18) \times 10^{-8}$ |
| Oxford ⁽¹⁸⁾ | Bi | 648 | $(+2.7 \pm 4.7) \times 10^{-8}$ | $(-13 \text{ to } -23) \times 10^{-8}$ |
| Novosibirsk ⁽¹⁹⁾ | Bi | 648 | $(-19 \pm 5) \times 10^{-8}$ | $(-13 \text{ to } -23) \times 10^{-8}$ |
| Berkeley ⁽²⁰⁾ | Th | 292.7 | $(2.6 \pm 1.2) \times 10^{-3}$ | $(0.7 \text{ to } 1.6) \times 10^{-3}$ |

The future for neutral current phenomenology is brightest at the new storage rings, PETRA and PEP now, and for the future the $p\bar{p}$ collider at CERN and LEP. The prospects for measuring indirect effects of the Z^0 is good at high energies where the effects are (relatively) large, and in the future the ultimate prospect is the direct production of the Z^0 and observation through its many decay modes. However, there are ways in our present laboratories to test for effects of the neutral currents. The effects are typically quite small, but we are limited only by our ingenuity. We have not yet observed the Z^0 , and until that day comes we should continue to apply our experimental skills with the tools available to test these fundamental concepts.

CHARLES Y. PRESCOTT

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