

# search & discovery

## Parity nonconservation in neutral-current interactions

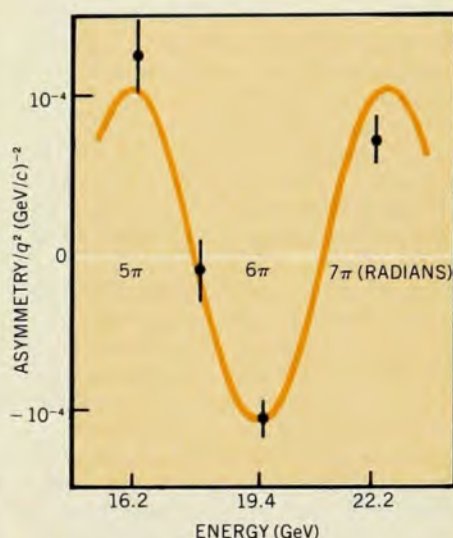
An experiment with polarized electrons at SLAC has found evidence for parity nonconservation in a neutral-current interaction. The observation offers strong support for the Weinberg-Salam gauge theory of the weak and electromagnetic interactions and removes the need for the more complicated gauge theories that have been developed since the original model by Steven Weinberg (Harvard University) and Abdus Salam (International Centre for Theoretical Physics) more than ten years ago.

Since particle physicists started taking the Weinberg-Salam model seriously, the model has had its ups and downs. Although its prediction of neutral currents was verified in 1973, since then various flies have appeared in the ointment, such as the so-called high- $\gamma$  anomaly and the failure to observe nonconservation of parity in atomic bismuth. More complicated gauge theories were developed to account for the experimental results. But the recent SLAC observation of nonconservation of parity in the inelastic scattering of polarized electrons from deuterium and hydrogen makes many particle physicists feel Nature is simple after all. As a noted theorist said, "The game isn't over, but it looks like the Weinberg-Salam model is a good approximation to the ultimate gauge theory."

The SLAC-Yale experiment was an extremely difficult one—looking for an interference between the weak and electromagnetic forces. Gauge theories predicted that the parity nonconserving asymmetry would be observable at the level of roughly one part in  $10^4$ . And to see this effect, the experimenters had to measure the difference between the counting rate of electrons with one helicity and the counting rate of electrons with opposite helicity.

Results from the experiment have been eagerly awaited. They were announced by Charles Prescott at a regular Monday colloquium at SLAC on 12 June and at the Sixth Trieste Conference on Particle Physics later that month, and by Charles Sinclair at the Oxford Conference on Neutrino Physics early in July. A paper has been submitted<sup>1</sup> to *Physics Letters* by the 20-person team from SLAC, Yale University, CERN, Aachen and the University of Hamburg, which is led by Prescott, Sinclair, Richard Taylor (SLAC) and Vernon Hughes (Yale University).

The group used longitudinally polarized electrons from SLAC with energies between 16.2 and 22.2 GeV. Just as in the old inelastic-scattering experiments done at SLAC that provided support for the parton model, the experiment looked at



**Observed asymmetry in SLAC experiment** shows the expected cosine variation (colored curve) as the beam helicity changes as a function of beam energy owing to the  $g - 2$  precession in the beam transport system. The cosine behavior is taken as strong evidence that observed effects are caused by electron spin.

inelastically scattered electrons coming from an unpolarized deuterium target (and later an unpolarized hydrogen tar-

*continued on page 19*

## Three groups see diamagnetic anomaly in copper chloride

A group of experimenters in Moscow has reported seeing very large diamagnetic signals from samples of copper chloride subjected to pressures of kilobars. The effect occurs at transition temperatures as high as 150 K. Two groups in the United States have seen related effects.

The Soviet group speculates that they have observed the Meissner effect or exclusion of magnetic flux characteristic of superconductivity. But they do not see perfect diamagnetism, and they do not see infinite conductivity. They do see an increase in conductivity four to six orders of magnitude, still small compared to that of ordinary metals.

Interest in the copper-chloride anomaly is reminiscent of that displayed five years

ago when a group at the University of Pennsylvania reported seeing "superconducting fluctuations" in TTF-TCNQ at 60 K. Subsequent experiments failed to reproduce the magnitude of the effect originally measured.

Even though superconductivity close to room temperature in copper chloride is far from being demonstrated, many solid-state workers are wondering what could account for the observations. So far, except for superconductors, no substance has been observed with such a large diamagnetic susceptibility. And the highest superconducting transition temperature known is about 23 K. If copper chloride is not a superconductor, what is it?

The Moscow experiment, done by N. B.

Brandt, S. V. Kuvshinnikov, A. P. Rusakov and V. M. Semenov of Moscow State University and the Moscow Institute of Steel and Alloys, was reported<sup>1</sup> in the Russian version of *JETP Letters* in January.

Earlier, in 1977, Rusakov collaborated on an experiment at Cleveland State University with C. W. Chu and S. Z. Huang (now at the University of Houston), Steven Early and Theodore Geballe (Stanford University) and C. Y. Huang (Los Alamos). The group observed similar anomalies but on a smaller scale; their results are reported<sup>2</sup> this month in *Physical Review B*.

And very recently, Issai Lefkowitz (Army Research Office and University of

Labs) that if one had an intrinsic semi-metal in which electron mass and hole mass were sufficiently different and in which their concentrations were sufficiently low, there might appear a "Wigner lattice" of holes, permeated by the electron gas. Abrikosov then speculated that Cooper pairing of the electrons could be caused by their coupling to oscillations of the lattice of holes, with resultant superconductivity.

Very recently A. K. Rajagopal (IBM on leave from Louisiana State University) has argued that Abrikosov's calculations are in error because he fails to consider the effect of Coulomb repulsion of the electrons. Marvin Cohen and his collaborators at the University of California, Berkeley, have done a band-structure calculation that disagrees with the Rusakov model.

Several years ago David Allender, James Bray and John Bardeen (then all at the University of Illinois) developed a theory for excitonic superconductivity for a nonuniform medium consisting of layers or filaments of metal in a semiconductor matrix. Such a medium, they said, might show superconductivity. Geballe told us the copper-chloride anomaly might be due to a microscopic structural rearrangement and charge transfer resulting in fine-scaled conducting domains. This could allow, he believes, for some variant of the Allender-Bray-Bardeen mechanism to become operative. However, Bardeen himself told us he does not think the anomaly is due to the Allender, Bray and Bardeen mechanism. If the effect is real, he told us, he favors a mechanism involving electron-hole pairs, such as that advocated by Rusakov and Abrikosov. In any case, Bardeen thinks that the suggested explanation requires that the proposed "electron-hole" droplets in copper chloride have a much higher concentration of electrons and holes than those in silicon and germanium. The hole lattice, he said, would have to be incommensurate with a copper-chloride lattice and the holes not be self-trapped.

Lefkowitz told us that the mode instabilities (which depend on exciton density) are associated with high transition temperature superconductors. In some earlier experiments, in 1964-65, he had shown that a dielectric anomaly was only observable if one populated the solid (thallium chloride and thallium bromide) with excitons.

James C. Phillips and Eugene Blount (Bell Labs) are skeptical of excitonic superconductivity in copper chloride, noting that it requires a very small band gap between valence and conduction bands, inconsistent with the transparency of the material. They believe that the high electrical conductivity at high pressures may be the result of the reversible chemical reaction:  $2 \text{CuCl} \rightleftharpoons \text{Cu} + \text{CuCl}_2$ . They do not offer an explanation of the high diamagnetism, but feel that the ir-

reproducibility and peculiar temporal and temperature oscillations suggest that the ultimate explanation may lie in experimental artifacts.

Other explanations offered to us included piezoelectric charges, caused by squeezing the sample, hence leading to false pyroelectricity, or magnetic transformations.

Chu and Geballe stressed to us that the most important direction at present is to get the experiments under control. "We need better methods of sample preparation and characterization. Once definitive experiments have been done, the appropriate models are bound to follow."

—GBL

## References

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## Parity nonconservation

*continued from page 17*

get). The experiment looks at electrons scattered at 4 deg from the beam and with secondary energy of 80% of the primary energy; the momentum transfer,  $q^2$ , varies from 1 to 1.8 (GeV/c)<sup>2</sup>.

Between beam pulses the polarity of the next beam pulse is chosen in a completely random fashion. As Prescott explained to us, by randomizing the reversal one averages out effects produced by periodic fluctuations in the beam.

A new polarized-electron source was developed at SLAC for this experiment based on an approach suggested in 1974 by Edward Garwin (SLAC), Daniel Pierce and Hans-Christian Siegmann (ETH, Zurich). The new source differs in several respects from the atomic-beam source pioneered by the Yale group for use at SLAC in experiments using polarized

beams and polarized targets at the same time. With this source, a Yale-SLAC group in 1976 achieved a sensitivity in the measurement of asymmetry of about one part in 10<sup>3</sup>.

The new source consisted of a crystal of gallium arsenide that emits polarized electrons when bombarded with circularly polarized light. Large instantaneous currents are available from the source, up to  $4 \times 10^{11}$  electrons per pulse on target. (On occasion, the source produced more polarized electrons than could be accepted by the accelerator.) The average polarization was about 40%. By changing the circular polarization of the light hitting the gallium arsenide, the electron polarization can be reversed, and this change can be made easily and rapidly, with very little change in the properties of the electron beam.

Although the experiment requires an accuracy of 1 in 10<sup>5</sup> to see the predicted asymmetry, A. Prescott explained that the cross sections  $\sigma_+$  for positive-helicity electrons and  $\sigma_-$  for negative-helicity electrons need not be measured that accurately. Because

$$A = (\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-)$$

lots of quantities cancel out.

The asymmetry the group finds for deuterium is  $(-9.5 \pm 1.6) \times 10^{-5}q^2$  with statistical and systematic uncertainties each about 10%. For hydrogen, with fewer statistics, they find  $A = (-9.7 \pm 2.7) \times 10^{-5}q^2$ . With deuterium, Prescott noted, one would visualize scattering off six quarks, with equal numbers of up and down. With hydrogen, on the other hand, one has two up and one down quark. Although the asymmetry would be expected to be slightly different for hydrogen in the Weinberg-Salam model, the expected difference is much smaller than the experimental uncertainties.

Several consistency checks were made by the experimenters. For example, they made three different kinds of null measurements.



**PETRA stored its first beam on 15 July**, 6 months ahead of schedule. Gustav-Adolf Voss, project leader, is surrounded by team members celebrating in traditional fashion. Shortly after, a 3-mA beam of electrons was accumulated for two hours and 5-GeV electron-positron collisions were produced at low intensity. By mid-September, the PLUTO detector from DORIS is to be moved into the PETRA beam, and experiments with some luminosity are to begin at 5 GeV in each beam.

► Using an unpolarized electron beam, they arbitrarily assigned positive or negative helicity to the pulses and looked for an asymmetry. The result was consistent with zero.

► They used linearly polarized photons striking the gallium arsenide, which should give unpolarized electrons from the source. The result was consistent with zero.

► Using polarized electrons from the source, the experimenters ran at an energy at which the electrons would strike the target with their spin perpendicular to the beam direction. The expected null effect was observed. The direction of electron spin at the target depends on energy because of its precession in the magnetic field that transports the electrons from the accelerator to the target. The precession arises from the anomalous magnetic moment,  $g - 2$ , of the electron and is given by

$$\frac{(g - 2)}{2} \times (\text{beam-deflection angle})$$

At 19.4 GeV, the precession is equivalent to three full revolutions of the electron spin. If the energy is decreased (or increased) by 3.27 GeV, the spin will make 2.5 (3.5) revolutions and the observed asymmetry should change sign. That the experimental results follow the expected cosine behavior can be seen in the figure, and this data is taken as very strong evidence that the observed effects are due to electron spin.

The size of the asymmetry agrees with predictions of the Weinberg-Salam model, with the one free parameter of this model, the Weinberg or mixing angle,  $\theta_w$  (related to the mass ratio of the charged and neutral intermediate vector bosons) taken to have the value indicated by the more recent neutrino experiments. The value obtained from the SLAC experiment is  $\sin^2 \theta = 0.20 \pm 0.03$ .

Although the Weinberg-Salam model had been introduced more than a decade ago, the model did not have much impact until it was shown to be renormalizable, in 1971, by Gerhard 't Hooft (University of Utrecht) and by the late Benjamin Lee. In 1973, neutral currents were actually observed in neutrino-nucleon inelastic scattering. A neutral current occurs in a process where a lepton scatters off another particle, does not change its charge, and a neutral particle is exchanged between the lepton and the particle it scatters from. Finding neutral currents was of course encouraging for supporters of gauge theories. The Weinberg-Salam model further required that neutrinos and antineutrinos have different neutral-current cross sections on nuclear matter. Over the years, that prediction has been borne out.

In 1976, two kinds of experiments caused doubt about the Weinberg-Salam model. One was the observation of the

high- $\gamma$  anomaly in a charged-current neutrino interaction. Subsequent experiments have not confirmed the observation. The other kind of experiment, however, is still in disagreement with the model. E. N. Fortson and his collaborators at the University of Washington and P. G. H. Sandars and his collaborators at Oxford University have looked for parity nonconservation in atomic bismuth. Their most recently reported results see no parity violation at a level of accuracy ten times lower than the prediction of theory. However, some theorists question the reliability of the atomic-physics calculations for bismuth, the results of which have varied from calculation to calculation. Recently, L. Barkov and M. S. Zolotarev at the Nuclear-Physics Institute in Novosibirsk have studied the same bismuth line as the Oxford group. They report that the ratio of the measured change in polarization to the theoretically expected change (as calculated by I. B. Khriplovich of Novosibirsk) is  $1.1 \pm 0.3$ . That is, the Soviet experiment is in agreement with the Weinberg-Salam model.

Although two out of three of the atomic-physics experiments are not observing parity violation, the violation might still be there but be lower than present calculations indicate, one prominent gauge theorist pointed out to us. Although there might similarly be uncertainties and possible systematic effects in the SLAC experiment, there appears to be no doubt that nonconservation of parity has been observed.

Other groups are working on atomic-physics searches for parity violation in hydrogen or in thallium. But so far, no results from these searches have been published. Although the SLAC and Oxford-Washington experiments apparently contradict each other, the SLAC experiment is sensitive to the presence of two terms in the interaction and the Oxford-Washington experiments sensitive to only one. To separate the effects of each of the two interaction terms, a forthcoming experiment at SLAC will attempt to measure the asymmetry as a function of electron energy loss.

Earlier this year, another disagreement with the Weinberg-Salam model appeared, this time in neutrino-electron scattering measurements. Using the Gargamelle bubble chamber at CERN, P. Alibrand and his collaborators reported<sup>2</sup> finding 10 neutral-current events (out of 25 000 charged-current events). In the framework of the standard  $SU(2) \times U(1)$  model (such as that of Weinberg and Salam), at 90% confidence level,  $\sin^2 \theta$  was greater than 0.74, they said. With the currently accepted value for  $\sin^2 \theta$  about 0.25,  $1.7 \pm 0.2$  events are expected. More recently, the group has analyzed another 80% of their data and found the number of events more consistent with the Weinberg-Salam model.

Very recently Charles Baltay (Columbia University), Robert Palmer and Nicholas Samios (Brookhaven) and their collaborators have done a similar experiment at Fermilab and report<sup>3</sup> 11 events in a sample of 106 000 charged-current events. Their data restrict the value of  $\sin^2 \theta$  to be 0.20 with error bars of  $+0.16$  and  $-0.08$ , in good agreement with several previous neutral-current measurements and with the Weinberg-Salam model.

**Nonconservation of parity** is inherent in the original form of the Weinberg-Salam model. The theory starts with four intermediate vector mesons—one charged, one oppositely charged and two neutrals that get mixed together, the photon and the  $Z$ . Before the mixing takes place, the two charged mesons and one of the neutrals form a triplet; the other neutral forms a singlet. The triplet of gauge bosons only interacts with left-handed quarks and leptons. That is, the  $SU(2)$  part of  $SU(2) \times U(1)$  only acts on left-handed quark and lepton states. Parity violation is built in from the beginning for the charged currents, which govern the ordinary weak interaction (as in beta decay), and arises automatically in the neutral currents in their theory.

Later some theorists developed theories in which right-handed quarks and leptons are in doublets, so that one had complete symmetry. But then it was difficult to explain why one does not observe right-handed quarks in beta decay. In such theories, parity-conserving neutral currents are required and neutrino and antineutrino cross sections are equal. Such theories looked less promising as experimenters found the cross sections to be unequal.

In response to the early atomic-bismuth experiments, some theorists developed more complicated gauge theories, which contained more than four intermediate vector mesons (including the photon). In those models, one could have parity conservation in neutral currents and unequal neutral-current cross sections for neutrino and antineutrino.

Assuming that the SLAC workers have indeed found parity violation in neutral currents, and that the atomic-physics experiments will eventually find parity violation at some level, much of the motivation for more complicated gauge theories disappears. —GBL

## References

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