Weak interaction: Puzzle of the fourth force

T. D. Lee proposes that the weak interaction is a branch of electromagnetism. Accelerator experiments will test such theories

by Dietrick E. Thomsen

The weak interaction is one of the four forces by which the elementary particles of matter interact with each other, and it is probably the least understood of the quartet. The other three forces are gravitation, electromagnetism and the strong interaction. Nobody knows why there should be just four. Some physicists suspect the existence of a fifth; others would like to see the four reduced to aspects of a single one.

Three of the known four play important roles in the structure of matter: Gravitation governs the large-scale interactions of astronomical bodies. Electromagnetism determines chemistry and the structure of atoms and molecules. The strong interaction is the basis of the structure and behavior of atomic nuclei. By contrast, the role of the weak interaction in the over-all economy of the cosmos is rather obscure.

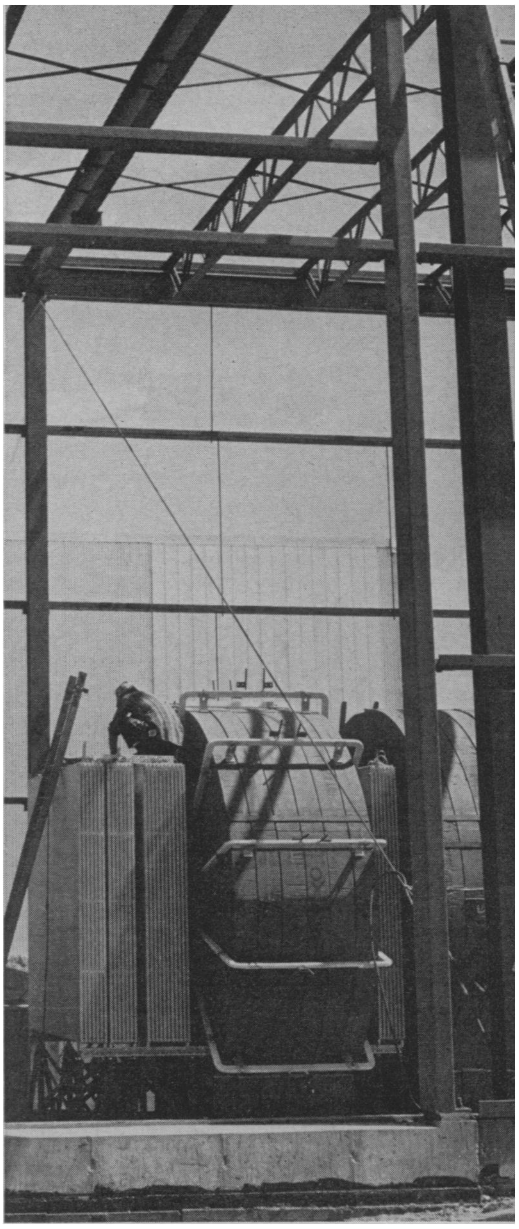
Historically and observationally the weak interaction appears to be a kind of afterthought. Certain nuclei and certain individual particles decay radioactively in ways that take too long to be attributed to the activity of the strong interaction. For various reasons these processes cannot be attributed to electromagnetism, and gravitation is much too weak. (The role of gravitation in particle physics up to now is limited to polite theoretical nods that acknowledge its existence; experimentally it is ignored.)

The weak interaction was postulated to explain these slow decays, and theorists set out to derive a universal theory that would explain them all as particular cases of its activity. There are many questions about the weak interaction and its role. One of the most important is whether it is truly a separate force or whether it is a special case of one of the others.

Some physicists suspect a close connection between the weak interaction and the strong. Most of the particles subject to weak decays belong to the class called hadrons, whose activities are generally governed by the strong interaction. Furthermore the developed theory of the weak interaction indicates that as the energy of the interacting particles rises, the weak interaction becomes stronger. Eventually it might become as strong as the strong interaction.

T. D. Lee of Columbia University suggests instead that the weak interaction may be a branch of electromagnetism. He outlined his latest thinking on this topic at the recent meeting of the American Physical Society in Seattle.

Lee sees a necessity for fundamental changes in the theories of electromagnetism and the weak interaction as experimental physicists approach the domain of really high energies. An important flaw in the current theory of the weak interaction is that peculiar property of getting stronger as the energy goes up. As the force gets stronger the probability that it will cause something to happen increases. By the time the energy gets to 300 billion electron-volts (GeV), Lee says, the probability passes beyond what the philosophical principles of particle physics will allow theoreticians to believe in.



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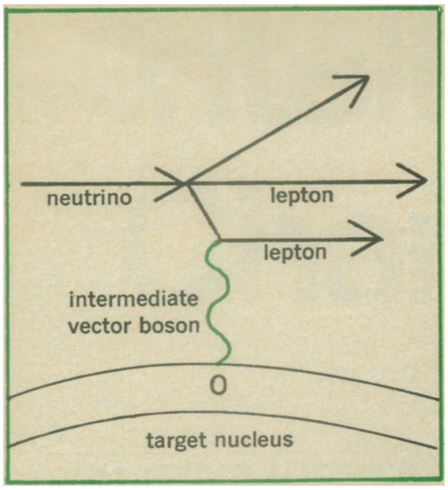
Equipment for NAL experiment.

In electromagnetism, theory predicts certain infinities that turn out to be finite in observation. An example is the so-called electromagnetic mass difference: a charged particle, say a pi-plus meson, is slightly more massive than its neutral counterpart, a pi-zero. The difference is attributed to energy generated by the charged particle's interaction with electromagnetic fields that surround it. Theory predicts that the difference should be infinite; in fact, it is very small.

A theorist might be tempted to try

	Positive charge	Neutral	Negative charge	Rest mass of each
A field particles represent traditional electromagnetic field)		γ (Photon)		0
B field particles (represent weak interaction)	W^+ (intermediate vector boson)	B^0 (Massive photon)	W^- (intermediate vector boson)	37.29 GeV

LEE'S PROPOSED FAMILY OF INTERMEDIATE PARTICLES



Neutrino-nucleus interaction.

to solve these difficulties by mixing the strong interaction with either or both of the others. Lee says it won't work: It can make things worse but not better.

What does make them better, he says, is to mix together the weak interaction and electromagnetism as if they were two aspects of the same thing. Formally this is an attractive route to take since the mathematical expressions of the two interactions are similar and go together well. Lee replaces the separate formulations of the electromagnetic field and the weak interaction field with a joint formulation in which the traditional electromagnetic field, called the A field, appears along with a new field, the B field, that represents the weak interaction.

One of the most important predictions of this new formulation, which may be susceptible to experimental test, concerns the field quanta or intermediate particles of the two fields. Each kind of force field should have a quantum, a particle that embodies the force concerned and serves as an intermediary to carry the force from place to place. The photon or light particle is the quantum of traditional electromagnetism, the A field. The present theory of the weak interaction predicts that its quantum should be a so-called intermediate vector boson, which can come in two varieties, positively or negatively charged, designated W-plus or W-minus. To these Lee adds what he calls a massive photon or B particle. The B particle is the electrically neutral counterpart of the W particles and with them it forms a triplet of the same mass. This triplet and the traditional massless, chargeless photon of the A field form part of a family or multiplet of related particles.

Lee's theory predicts that the mass of the triplet particles is 37.29 GeV. Recently evidence for the existence of a possible intermediate vector boson of about this mass was reported from cosmic-ray observations conducted in a mine in Utah (SN: 8/21/71, p. 121). Lee comments that while cosmic-ray evidence is welcome, final confirmation of the existence of such particles must come from accelerator experiments where all the experimental conditions can be more closely controlled.

Accelerator experiments to test these and other questions regarding the weak interaction are being undertaken. Two current ones were described at the Seattle meeting by Alfred K. Mann of the University of Pennsylvania.

One of the experiments, now in progress at the Stanford Linear Accelerator Center, attempts to discover whether physicists are acquainted with the whole family of neutrinos. Neutrinos (SN: 9/25/71, p. 212) are the only known particles that are subject to the weak interaction and to no other force (except gravity). To understand the weak interaction, physicists must understand neutrinos. Two forms of neutrinos are now known, one that associates with electrons and one that associates with mu mesons. The experiment is looking for any new kinds of neutrinos and any unknown short-lived particles that might decay radioactively into neutrinos.

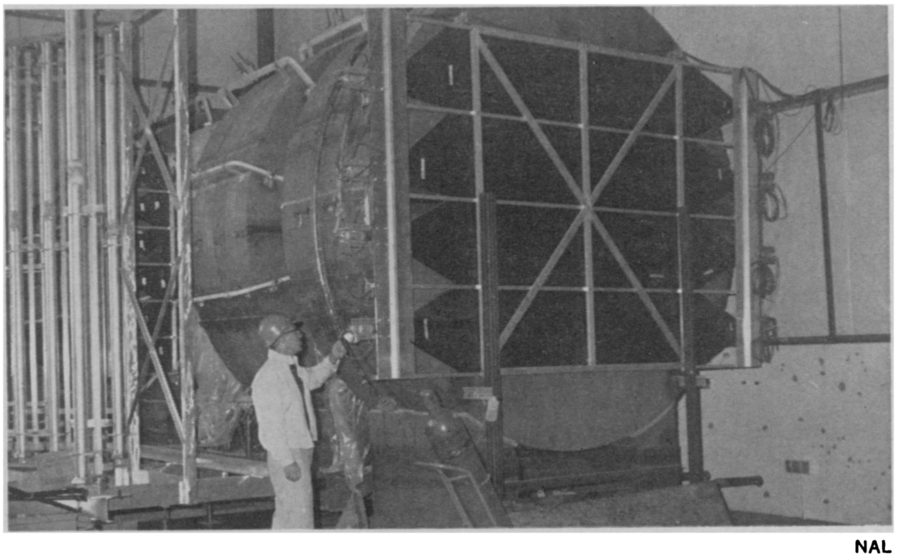
In the experiment, the accelerator beam is struck against two targets, one of them several dozen feet upstream from the other. The numbers of neutrinos from the two targets are compared. If unknown short-lived neutrino parents (lifetimes less than 10^{-10} second) are produced, then the ratio of upstream to downstream counts should be different from what current theory predicts. So far, says Mann, the data seem to be consistent with experiments done at lower energies, which would tend to indicate that no short-lived parents are being produced. But all the results are not in yet, and the statistics are not complete enough for a judgment. The experimenters are David Fryberger, Alan Rothenberg, Melvin Schwartz and Theodore Zipf of SLAC; David Kreinick of the University of Pennsylvania; David Dorfan of the University of California at Santa Cruz; J. M. Gaillard of the CERN laboratory in Geneva and Mann.

Columbia Univ.

Lee: A theory that unites two forces.

The second experiment is being set up at the National Accelerator Laboratory and is expected to run as soon as that accelerator is ready to go. Physicists involved are James E. Pilcher and Carlo Rubbia of Harvard; David Cline, Richard L. Imlay and Don D. Reeder of the University of Wisconsin and Mann.

The NAL experiment will bring a beam of high-energy neutrinos into a bubble chamber to see how they interact with atomic nuclei. Mu mesons should result from the interaction, and the numbers and momenta of the mu mesons should give information about the existence of the intermediate vector boson, its characteristics and the manner of its participation in the interaction. ☐



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Mann inspects detection equipment for neutrino-nucleus experiment at NAL.