A new day for the weak interaction

The two biggest new particle accelerators may initiate a new era in the study of the puzzling weak force

by Dietrick E. Thomsen

The weak interaction is one of the least understood topics in particle physics. It is one of the four kinds of force that physicists recognize in nature, and, as its name indicates, it is much weaker than two of the others, the strong (nuclear) interaction and electromagnetism. It has therefore been difficult to study because its effects are usually masked by the two stronger forces.

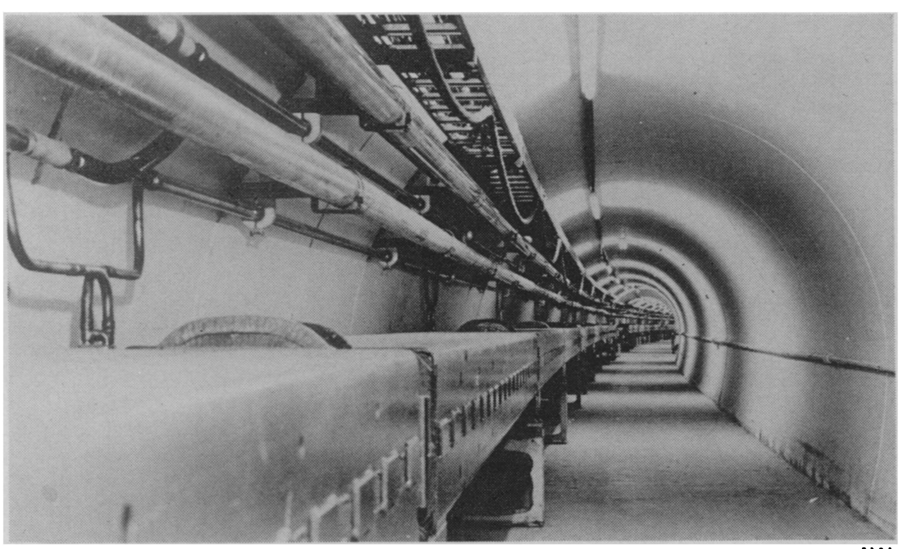
In a few years the world will have at least two particle accelerators with capacities of hundreds of billions of electron-volts energy, and physicists hope that these machines may allow the beginning of a new era of systematic and vigorous investigation of the weak force. "There is a finite chance that in our lifetime we'll see something interesting in the weak interaction," David B. Cline of the University of Wisconsin told the recent Coral Gables Conference on Fundamental Interactions at High Energy at the University of Miami.

The first manifestation of the weak interaction that physicists noticed was nuclear beta decay. In beta decay a neutron inside an atomic nucleus turns into a proton, emitting by the way an electron (called in the old days a beta ray) and an antineutrino. In recent years many other particles have been found that decay radioactively under the influence of the weak interaction.

From these decay activities alone it is hard to arrive at a good mathematical description of the weak force or to test rival theories. That can be better done by investigating how the force acts in particle collisions in accelerator experiments. But the two stronger forces blot out the effect of the weak force unless one party to the collision is a neutrino. (Neutrinos are the only known kind of particle that responds to the weak force but to neither of the two stronger ones.)

To do experiments with neutrinos requires a copious and energetic beam of them. The world's two new accelerators (the National Accelerator Laboratory now in operation at Batavia, Ill., and CERN II beginning construction near Geneva) will provide such beams. They may be used to study the weak force itself and to use it as a means of probing the structure of other particles. "The new accelerators may very well provide a new era in neutrino spectroscopy," A. K. Mann of NAL told the Coral Gables Conference. "It may be the new optics of the remainder of this century."

One of the most important questions to be decided by forthcoming experiments is whether the weak force is a local interaction or a nonlocal one. A local interaction is one in which the two interacting particles affect each other directly, rather like two billiard balls colliding. In a nonlocal interaction, the interacting particles exchange an intermediarly particle, and this particle mediates the effect of one to the other. In the strong interaction, the intermediary particle is a virtual meson; in electromagnetism it is a virtual photon.



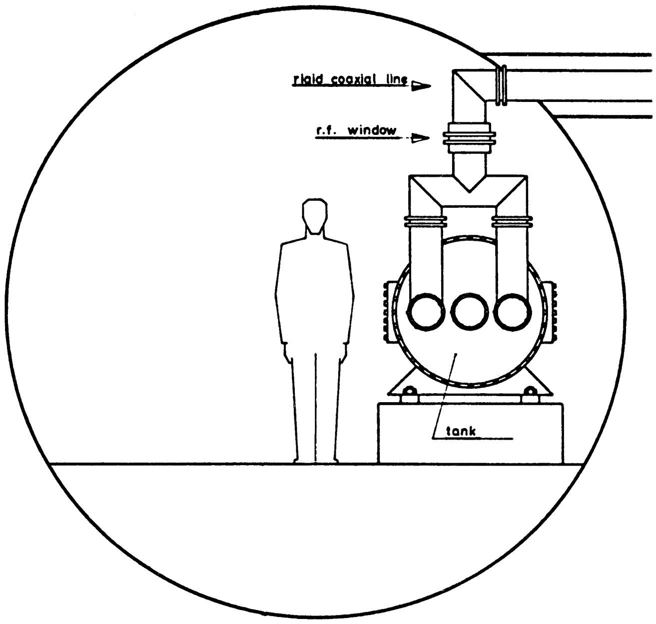
NAL

National Accelerator Laboratory: Opening a new regime in neutrino physics.

Formulations of both kinds have been suggested for the weak interaction. In the traditional nonlocal formulation, the intermediary is called the intermediate vector boson. Lately some theorists, most prominently T. D. Lee of Columbia University (SN: 10/9/71, p. 252) and Steven Weinberg of Massachusetts Institute of Technology, have been trying to work out a combined theory of the weak interaction plus electromagnetism. In this case there is a family of intermediaries among which both the vector boson and the photon find a place.

The local formulations arouse dismay because in them the particles most concerned with the weak interaction, the class called leptons (the electron, the muon, the two kinds of neutrino and their respective antiparticles), are point particles; like a formal geometric point, they have zero dimensions. It is difficult to visualize a body with mass that does not occupy space, and, when one tries, all sorts of disturbing paradoxes come forth: The particles have infinite mass densities, infinite self-energies, infinite electric charge densities and other infinities, some of which appear to be at variance with known properties of the particles.

A nonlocal weak interaction allows the particles to occupy space. It also does away with the troublesome infinities. Besides its esthetic qualities, what evidence is now in hand tends to incline some people toward the nonlocal theory. "The point theory of the weak interaction cannot be exact," says Mann. He and others expect that the inexactness will become clear in the new range of energies about to be opened up. At energies near 300 billion electron-volts (GeV) something new may happen, he suggests. Some structure may appear in the interaction: maybe a vector boson propagator, maybe new kinds of leptons, maybe new neutrinos, maybe higher-



CERN II: With the new accelerators neutrino spectroscopy may become the optics of the next generation.

CERN

order weak processes, rare events that nature forbids at low energies but are barely possible at high energies.

These things, especially the vector boson, have repeatedly been searched for, but never found. In spite of many years of experiments there is just one claim to possible observation of the vector boson. It is by a group at the University of Utah (SN: 8/21/71, p. 121). It is not likely to gain widespread acceptance until it is confirmed by independent investigators.

Physicists generally believe that the elusiveness of the vector boson is due to its mass: It is too massive to be generated by the energy available in current accelerator experiments. (The Utah observation tends to support this idea: The particle the Utah group found in the cosmic rays had a mass of about 37 GeV, well above the production capabilities of present accelerators.)

If the boson is very massive, that would explain at the same time why other deviations from locality have not been found. A characteristic length—the range of the interaction, in effect—is associated with the mass of the intermediary particle. The greater the mass, the shorter the range. The range of electromagnetic forces, whose intermediary particle, the photon, has zero rest mass, is infinite; the range of the strong interaction, whose characteristic intermediary, the pi meson, has a mass of 135 million electron-volts, is restricted to about the dimensions of an atomic nucleus. If the vector boson has a mass around 40 GeV, its range would be fantastically short, and it would take very-high-energy probes to examine such short distances to find deviations from locality.

The new accelerators may be able to do this. Meanwhile other experiments are continuing. Mann is involved in one now running at the Stanford Linear Accelerator Center attempting to find out particularly if there are unknown leptons, short-lived particles that decay into neutrinos (SN: 10/9/71, p. 252). So far, he says, the experiment hasn't found any, but he adds that the investigation is only in its first stages. Later, more precise experiments may find something.

Other questions being asked include whether neutrinos can produce leptons and their antileptons by the process known as pair production and whether neutrinos are stable against radioactive decay. Recent experiments that try to record the flux of neutrinos supposedly coming from nuclear reactions on the sun have recorded far fewer than theory had anticipated (SN: 2/26/72, p. 138). John N. Bahcall of the Institute for Advanced Study in Princeton, N.J., and others have suggested that if neutrinos decay before they can complete their 8-minute journey from the sun to the earth, the discrepancy may be resolved. (That length of time is enormous from a particle physics point of view, but very short astronomically.)

As the weak interaction becomes better known, its use to probe structures of interest to physicists is likely to increase, and such work may yield information not available to probes that interact by other forces. The new accelerators will be able to provide neutrino beams with enough energy and enough neutrinos to be practical for use as probes. NAL will be able to supply a billion neutrinos per square centimeter per second at energies between 20 and 100 GeV. Mann calls this a new regime in neutrino physics. □