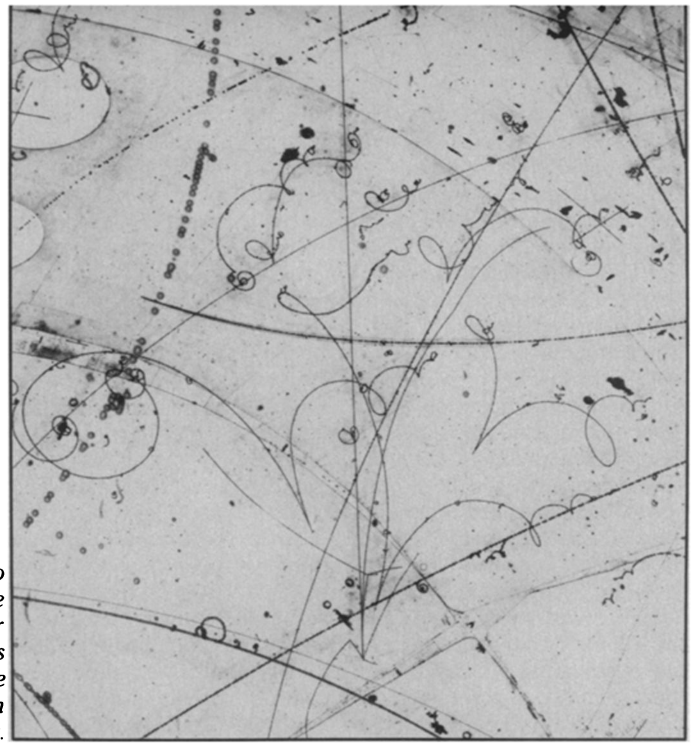
Ups & Downs of Neutrino Oscillation

If neutrinos change flavor back and forth, it could be a sweet and sour result for particle physics



Fermilab

A meon neutrino enters the bubble chamber at center bottom. It interacts with a nucleus at the point toward which all the curly "vees" point.

BY DIETRICK E. THOMSEN

In 1964 the physicist Bruno Pontecorvo (who in spite of his Italian name lives and works in Moscow) suggested that neutrinos might "oscillate," that is, cyclically change their identities. Two varieties of neutrino were then known, one produced in association with the electron and one produced in association with the particle called the muon. Pontecorvo proposed that a given neutrino, instead of maintaining either the electron or the muon identity, could switch back and forth as it flew along.

The idea was considered and dismissed for lack of evidence. In the past few months it has come crashing back into the attention of physicists. There is one out-and-out claim of having observed neutrino oscillations. On June 23, at the Neutrinos 80 meeting in Erice, Sicily, a negative will be reported from a similar experiment. New experiments are being set up in different places, particularly one and maybe two at the Fermi National Accelerator Laboratory in Batavia, Ill. Theorists are busy reassessing the consequences of neutrino oscillation, which could be alterations in important processes in particle physics, nuclear physics, astrophysics and cosmology. In one view, oscillating neutrinos could someday come to crush the universe.

The change that made the difference was the arrival of a third kind of neutrino. A few years ago the tau lepton, a third member of the related (lepton) family, electron, muon, tau, was found. A rule of theoretical physics then required the existence of a third variety of neutrino, the tau neutrino. Evidence had shown no reason to think that electron neutrinos oscillated to muon neutrinos. However, theorists, particularly Vernon Barger and David Cline of the University of Wisconsin, went to work to see whether electron neutrinos could oscillate to tau neutrinos and found it theoretically possible.

Although there has not yet been positive evidence for the existence of tau neutrinos, experimenters went to work too. The first direct claim for oscillations was made in April by Frederick Reines and co-workers of the University of California at Irvine (SN: 5/10/80, p. 292). Using the Savannah River Nuclear Reactor in South Carolina they determined that the flux of antineutrinos that the reactor gives off as a result of its nuclear processes was seriously deficient in electron antineutrinos. They attribute this deficiency to oscillations of some electron antineutrinos to tau antineutrinos.

Now there comes the result of a similar experiment done at a reactor in Grenoble, France, which sees no serious discrepancy in the number of electron antineutrinos. This is the one that will be presented at Erice. It was done by a dozen physicists from the California Institute of Technology, the University of Munich and the Institute for Nuclear Science at Grenoble (Felix H. Boehm of Caltech et al.). Their observations were finished at the end of April.

Nuclear processes in the reactor yield a stream of antineutrinos, which are recorded by a detector at some distance from the reactor. These should be all electron antineutrinos. Some of them may oscillate to tau antineutrinos before reaching the detector. If the detector finds significantly fewer electron antineutrinos than are supposed to start out from the reactor there is a presumption that some of them have oscillated even though the detectors in these cases cannot certify the presence of tau antineutrinos.

The detector at Grenoble was placed 8.7 meters away from the reactor core. This is more or less comparable to Reines's 11.5 meters. One important question, to which the answer is not known, is how far a neutrino flies before it oscillates. Although Reines sees oscillations at around 10 meters, the Caltech-Munich-Grenoble group do not. Both groups intend to go back and measure at different distances. To extend their distances to 38 and even 65 meters the Caltech-Munich-Grenoble group will need a more powerful source of antineutrinos than the 57-megawatt reactor they have been using so they will move their observations to the 2,700-megawatt power reactor at Gösgen, Switzerland. The Reines group intend to continue with the 2,000-megawatt Savannah River Reactor.

Another good source of neutrinos is what physicists call a beam dump. A beam dump is the end of the line for most particles in an accelerator laboratory. When the primary particles (protons or electrons) have been accelerated, the secondary particles have been made, and all have been experimented with, those that are still flying are slammed against a block of dense material (usually a heavy metal) to absorb them. That is the beam dump.

Nothing comes for nothing in this world. The reactions by which other particles are absorbed and put out of the way produce neutrinos (and also muons). Since neither of these is likely to be very damaging to anything, they are usually left alone. However, people who *want* to experiment with neutrinos find beam dumps a good place.

An experiment has been running in a beam dump at the CERN laboratory in Geneva. This finds a deficiency in the number of electron neutrinos arriving at a detector 1.5 kilometers from the absorber. It finds only half as many as it ought.

But the results are sketchy and on the borderline of statistics, Don Reeder of the University of Wisconsin said in an interview at Fermilab. And he adds that the CERN experiment suffers from a bias: At 1.5

kilometers a detector of a reasonable size will receive only particles emitted at a very narrow angle to the axis of the beam.

Reeder speaks for a group of physicists from the University of Wisconsin, the University of Michigan and Ohio State University. They are setting up an experiment in a Fermilab beam dump that is designed to have improved statistics and take neutrinos at a much wider angle to the beam axis. To do this they are bringing the detector up close. A detector with a 20-foot-square surface facing the beam is set up 60 meters from the tungsten block where the beam dumps. To get rid of muons, which could be a serious interference, large magnets have been designed to bend them upward and downward away from the detectors. In the CERN experiment, 1.5 kilometers of earth effectively absorbed the muons. Installation is about finished, but observation will not begin until autumn because of a summer shutdown of the accelerator necessitated by budget cuts.

"It's one thing to observe the disappearance of electron neutrinos," says Reeder. "We would like to see positive instead of negative evidence." So three months ago a Wisconsin group proposed to the laboratory management that the laboratory's 15-foot bubble chamber be used to look specifically for evidence of tau neutrinos produced by oscillations of neutrinos in the beam of neutrinos regularly provided for experiment at Fermilab.

The proposal takes advantage of a limitation on research at Fermilab that the laboratory is momentarily working hard to remove: the upper limit of 400 billion electron-volts on the energy of the accelerated protons on which everything else depends. When these protons strike a target to produce neutrinos for the "neutrino line," they don't have the energy to produce the newly discovered ultraheavy particles, which could be the source of tau neutrinos. Thus tau neutrinos found in the beam line should all or nearly all come from oscillation of electron neutrinos. Tau neutrinos can be identified when they interact with an atomic nucleus in the liquid of the bubble chamber. The interaction products should always include at least one tau particle.

Positive evidence from an experiment of this sort would not only certify that oscillation was taking place, it would rule out another possibility that is being discussed: oscillation of neutrinos to antineutrinos. The introduction of tau neutrinos reopened the question of neutrino oscillations after evidence had shown that electron neutrinos do not oscillate to muon neutrinos. Discussion has usually assumed that electron neutrinos would oscillate to tau neutrinos and electron antineutrinos to tau antineutrinos.

There is also the possibility that neutrinos may oscillate into antineutrinos. This would be detectable only by the disappearance of neutrinos, because this kind of oscillation produces not ordinary antineutrinos but antineutrinos with their spins in the wrong direction. These "couple" to nothing, that is, they are unable to make their presence known by any kind of interaction. This would be the interpretation of the CERN beam dump result, says Reeder, if the Fermilab bubble chamber experiment is done (it is yet to be approved) but finds no evidence of tau neutrinos and if the Fermilab beam dump detector close to the neutrino source finds equal numbers of electron and muon neutrinos.

If neutrinos oscillate, their shakiness will result in serious problems for particle physics, nuclear physics, astrophysics and cosmology. This business of being an electron neutrino or a tau neutrino is what is called "flavor." In their unending search

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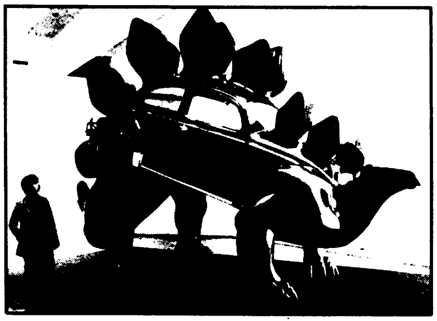
OFF THE BEAT

Better Sculpture through Chemistry

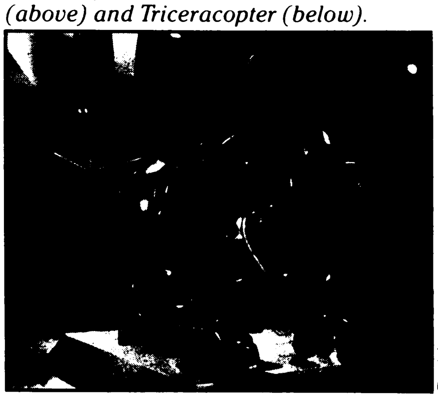
Instead of the usual rings of carbons, the bell-shaped curves and lists of reaction parameters, one speaker at the recent meeting in Houston of the American Chemical Society displayed slides of cars and helicopters transformed into monumental dinosaurs. A symposium on new uses of plastics gave sculptor Patricia A. Renick the chance to convince chemists that working relationships with artists can benefit both groups. She lured them with her adventures as "a woman, small in stature, and in my late forties" who spent five years creating two steel, fiberglass and polyester resin works. Each is 12 feet high, 7 feet wide and 20 or 30 feet long. The themes of Renick's sculptures are as lofty as a Triceracopter's propeller. The hybrid Triceratops-helicopter portrays war as a dying species, and the Volkswagen-Stegosaurus comments on a society unwilling to conserve resources.

"Because the Triceratops had a highly developed defense system, it was one of the last dinosaurs to become extinct. In the Vietnam War, the Cayuse [helicopter] often served as a weapon of attack," Renick says. "In this comparison of biological and technological weaponry, it is my wish to express a hope for the obsolescence of war."

Her motives may be lofty but the problems of construction are down-to-earth. "While industry has the wherewithal, the artist, out of necessity, must make do," Renick explains. Her fabrication processes were a "primitive version" of those used in the automobile styling industry. Tools were made from wire and pipe or adapted from kitchen utensils and hardware store items. For the clay model of Triceracopter, all four and a half tons of clay were heated to working consistency bit by bit in a restaurant-style four-drawer bun warmer. Making the clay model took a full year.



Plastics catalyze art: Vehicle-dinosaur Stegowagenvolkssaurus and sculptor (above) and Triceracopter (below).



Renick

In the final stages of her work, a plastic resin fabrication company came to Renick's aid. She ripped out her studio entrance to bring in the chopper gun and other equipment. A worker from R.L. Industries helped make the final molds, which were transported to the fabrication plant for the final operations.

Renick, who is at the University of Cincinnati, advocates more working relationships between artists and industry. She expects such associations to be mutually beneficial. Artists could gain access to expensive materials, industrial equipment and production facilities. In the work on Triceracopter, besides the aid of the fabrication company, Renick received four and a half tons of used modeler's clay from Ford Motor Co. and 275 gallons of resin from Ashland Chemical Co. in addition, of course, to the salvaged OH-6A Cayuse helicopter from the U.S. Army.

On the other side of the balance, industry could benefit from the creativity and daring of artists. Renick says that an artist's willingness to take risks is the key to future application of plastics in art. "Artists, by the nature of what they do, often develop extraordinary solutions to resolve technical aesthetic problems. Some of these experiments have added to the knowledge of fabrication technology." □

—*Julie Ann Miller*

. . . Neutrino

for the basic pieces out of which to construct matter, physicists have settled (for the moment at least) on a set of twelve, six quarks and six leptons (that is, the electron, the muon, the tau and the three neutrinos). The basic identity of each of these chips is referred to by the word "flavor." Bigger things in the world are built up of combinations and permutations of these twelve basics, from protons to atomic nuclei to Mrs. Schultz's bratwurst. If the neutrinos have an uncertain flavor, that may not imply anything about the bratwurst per se, but it could make people wonder if the theory in between is all right.

If neutrinos oscillate, then by a rule of wave mechanics they must have a certain rest mass. Until now neutrinos have always been supposed to have zero rest mass. That is, they do not exist at rest; they move always with the speed of light; when they come away from some interaction (nuclear beta decay, for example) they can carry any amount of energy from zero on up. If neutrinos have mass, all those things become untrue. This means a rethinking and rebalancing of many interactions in which neutrinos play a part. Especially relevant are those involved in transformations of atomic nuclei, the energy processes of stars and the sun and the masses of galaxies and the universe. If neutrinos have mass, there could be large clouds of them pervading space, bearing enormous mass but quite undetectable to astronomers. This neutrino mass could be enough to bring the expansion of the universe to a stop and force the cosmos to collapse. □