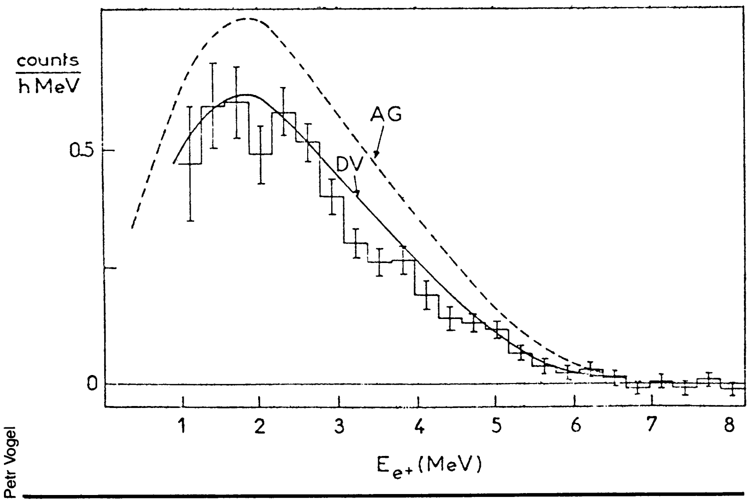
SHAKING NEUTRINO MASS

Oscillating neutrinos are proving hard to find in spite of early optimism. So great are the consequences of oscillation that there is a rush of plans for new experiments, nevertheless.

BY DIETRICK E. THOMSEN



Two spectra for positrons from antineutrino detection reactions, the Avignone-Greenwood and Davis-Vogel, and results of Grenoble experiment. Experiment should be well below calculation. If DV is right, Grenoble shows no oscillations.

The neutrino is one of the most lightweight particles in physics. That much can probably still be maintained. According to the people who first postulated its existence and those who discovered it, the neutrino was supposed to have a rest mass exactly equal to zero. That meant it could not exist at rest. It could exist only in flight, in which circumstance it could possess energy and so have an effective mass. This is one of those strange situations that can arise under the laws of quantum mechanics, and is one reason those laws disturb conservative philosophers.

There is now some direct experimental evidence that the neutrino may in fact have a small rest mass (SN: 10/11/80, p. 228), but that's not the whole of the question that's agitating physicists. (It's not certain whether philosophers have heard of it yet.) The related, and in many ways more fascinating, question is whether neutrinos oscillate. Neutrinos may have mass and not oscillate, but if they do oscillate, they must have mass. Thus every consequence of neutrinos having mass — and that would include a number of recalculations — follows from neutrino oscillations, but neutrino oscillations have consequences that neutrino mass alone does not have. Oscillations therefore took up the largest part of the discussion at the recent Wisconsin Mini-conference on Neutrino Mass, which was held at Telemark Lodge, near Cable, Wis.

"Oscillation" in this context means a cyclic change of identity. For the present, physicists recognize three varieties of neutrino: electron, muon and tau. These are named for the non-neutrino particle in association with which each variety of neutrino is produced. The electron neutrino is made along with an electron, the muon neutrino with a muon, the tau neutrino (putatively) with the tau particle. (The tau neutrino hasn't yet been discovered, but it is counted as existing in all that follows.)

It used to be generally believed that a neutrino endowed with any one of these three identities would maintain its character as long as it existed, taking part in the processes and interactions characteristic of its variety. There is some evidence now that a neutrino flying along may change back and forth among more than one identity; it may be an electron neutrino at one moment, a tau neutrino at another, then an electron neutrino again, and so forth. These changes are called oscillations.

The excitement over neutrinos that oscillate and/or have mass was brought to a boil during the spring by the announcement of Frederick Reines, Henry W. Sobel and Elaine Pasierb of the University of California at Irvine that they have evidence indicating that electron antineutrinos oscillate to tau antineutrinos (SN: 5/10/80, p. 292). (Antineutrinos are the antimatter equivalent of neutrinos.) Reines, Sobel and Pasierb had been running an experiment at the Savannah River nuclear reactor in South Carolina designed to see if the number of electron antineutrinos recorded at some distance from the reactor was significantly less than the reactor was supposed to emit — that is, whether some of the electron antineutrinos had changed to tau antineutrinos on the way. They were finding about half as many electron antineutrinos as they believed they should. This, they said, was evidence for oscillation. Their experiment is still running.

Another group, which was operating a similar experiment at a reactor at the Institut Laue-Langevin (ILL) in Grenoble, France (physicists from California Institute of Technology, University of Munich and the ILL), responded to the Reines-Sobel-Pasierb announcement by saying the Grenoble experiment showed no evidence for oscillations. That continues to be their result, on the whole. Heemin Kwon of Caltech, who represented the Grenoble group, reported that they record about 90 percent of the electron antineutrinos they expect to see. Given the uncertainties and error limits that's not much of a trend.

The disagreement between the two findings can be attributed in whole or in part to a number of things. The detectors used different targets to detect the antineutrinos (deuterium nuclei at Savannah River, protons at Grenoble), and this may make a difference in the proportion of incoming antineutrinos detected. Also, the detectors are at different distances from the reactor core, and nobody knows the "oscillation length," or the distance at which one should find that most electron antineutrinos have turned to tau antineutrinos or vice versa. And, as Petr Vogel of Caltech points out, it is difficult to determine exactly how many antineutrinos to expect from a reactor.

Antineutrinos are emitted with a certain range of energies. The spectrum, the graph of the number of antineutrinos emitted with each energy in the range, depends on the proportions of the different isotopes of uranium, plutonium and their daughter substances that may be in the core. This proportion changes as the reactor runs. Furthermore, measurements of the antineutrinos emitted by some of these isotopes have not been made, so theoretical calculations must be used instead.

"If two people calculate one thing, they get a different result," says Vogel. "That doesn't say one should throw one's hands in the air and say it can't be done. Disagreement is a red herring." He refers specifically to the disagreement between two calculated spectra of positrons from detection of reactor antineutrinos, one called the "Davis spectrum" after Brian Davis, a student of Vogel's, and one named for Frank Avignone of the University of South Carolina. According to Vogel, the Avignone spectrum is up to 30 percent higher than the Davis spectrum at high antineutrino energies. Vogel says that the Grenoble result is consistent with the Davis spectrum, the Irvine result is not. "There is a problem, and there is a contradiction," Vogel says. And later on: "It is not proved beyond doubt that oscillations have been seen."

Up to now the results of the so-called

Building a new detector for extension of the Reines-Sobel-Pasierb experiment.

CERN beam dump experiment have warranted a similar cautious response, according to the assessment of Don Reeder of the University of Wisconsin. A beam dump is the stopping place for the particles that have been accelerated and experimented with at any accelerator installation. The particles are driven into a block of dense solid material to absorb them. The absorption process produces neutrinos. Neutrinos are almost impossible to absorb, so they are usually let fly. (They don't damage anything, either.)

In this case, detectors were placed a kilometer down the neutrino stream to see if a deficiency of electron neutrinos could be found. (Neutrinos fly in absolutely straight lines except for Einsteinian space curvature.) Report had had it that this experiment was seeing fewer electron neutrinos than it should have, but Reeder's current judgment of the latest data is that the "suggestion of a positive result by the beam dump experiment is ruled out."

Similarly, Taka Kondo of the Fermi National Accelerator Laboratory reported no positive result by a collaboration of physicists from Canada, Japan, Korea and the United States in an experiment that ran a neutrino beam into blocks of nuclear emulsion to detect oscillations. (Nuclear emulsion is the same as photographic emulsion except that it is thick so that particles can make three-dimensional tracks in it.) This group believes they have a possibility of seeing oscillations between electron neutrinos and tau neutrinos, and they plan to run the experiment again in the winter.

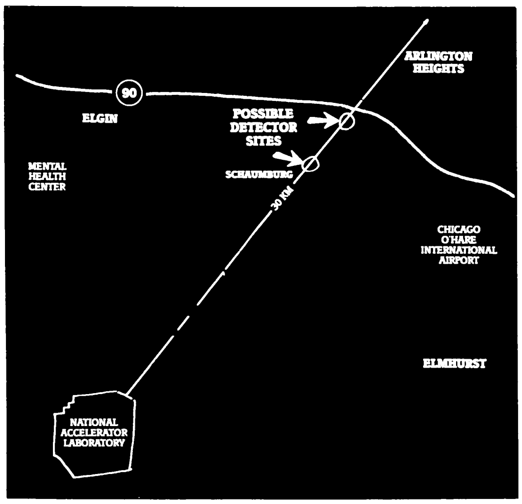
These mostly hesitant reports have not dampened physicists' interest in neutrino oscillation. They seem instead to have increased it. Neutrino oscillations open a number of new paths in physics, and the bare possibility that they may happen is enough to start a stampede.

If neutrino oscillations exist, that means that the observed (and not quite observed) varieties of neutrino are not simple beings but are composites, different sums of two or three underlying or hidden kinds of neutrino that are never observed themselves. Quantum mechanically, every particle can be regarded also as a packet of waves. Waves can always be added together to make new waves. That is the explanation of what happens in neutrino oscillations: The waves belonging to the underlying unseen neutrino states are added together in various proportions (defined by a quantity called a "mixing angle") to yield the waves belonging to the observed electron, tau and muon neutrinos. The reason that the identities of the observed neutrinos keep changing is that this underlying addition is continually changing from one sum to another in a cyclic way.

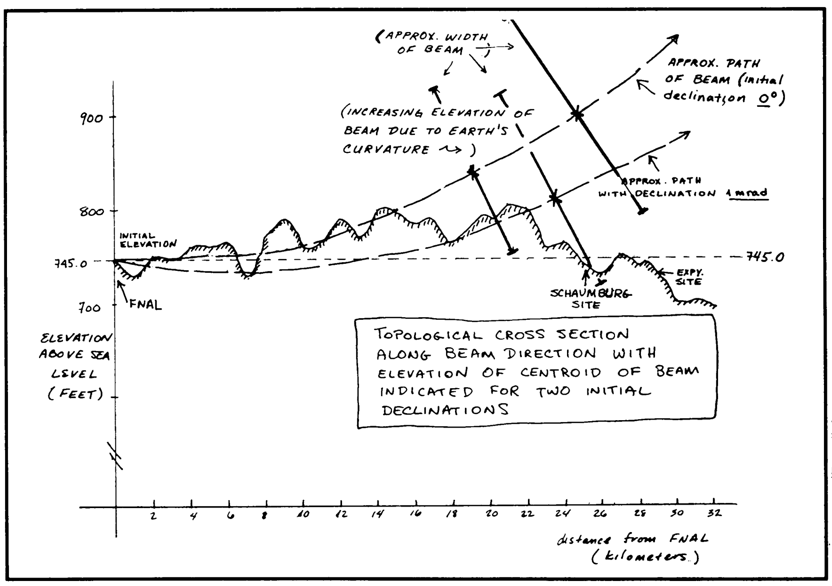
This, if it be true, raises a few important questions — physical, philosophical, even metaphysical — about the identity and stability of particles.

This business of being an electron neutrino or a muon one or a tau one is what is called "flavor." Flavor tends to be seen as the basic identity of the fundamental building blocks of matter. Physical theory now sees matter as built of a dozen ultimate blocks (and a dozen corresponding antiblocks), six quarks and six leptons. The three kinds of neutrino are three of the leptons. Flavor is regarded as the basic characteristic of each of these blocks, the quality that defines its identity and its distinction from the others. If flavor is unstable, there are many possible consequences.

One consequence came up in a talk on the possibility of radioactive decay of neutrinos by Al Erwin of the University of Wisconsin. He was concerned with whether the decay of a heavy neutrino to a light neutrino and a gamma ray could be detected in reactor experiments and what that would do to assumptions about the data recorded in the experiments. (Neutrino decay is one of the consequences of



In case it is necessary to go long distances to detect oscillations, surveys were made around Fermilab.



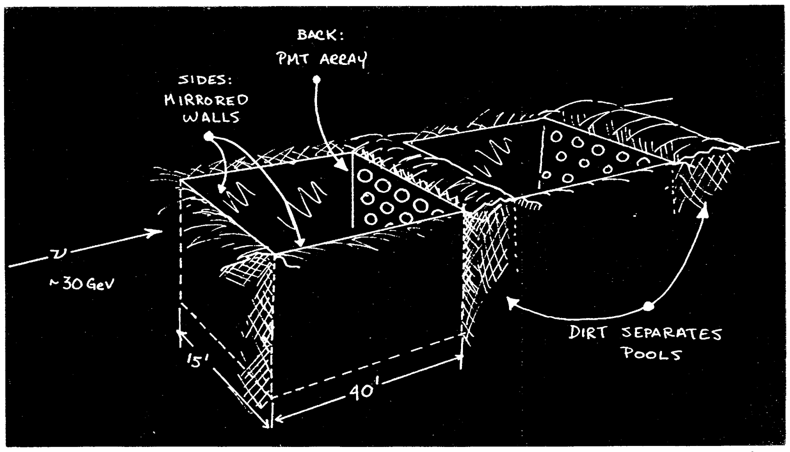
neutrinos having mass. Decay is forbidden to zero-mass particles.) But Erwin found it necessary to begin with an assumption that the 12 previously mentioned basic building blocks are not basic but composite, being made of something he calls "subquarks." Thus, there could be a new level of complexity to be investigated in the structure of matter.

Experimenters are galloping off after neutrino oscillations, planning, proposing, setting up experiments. Brookhaven National Laboratory, Fermilab and the Los Alamos Scientific Laboratory seem likely to be sites of major efforts. There is much discussion over what to use as a source of neutrinos: reactors, the usual beams of neutrinos provided by accelerators or beam dumps. Density of beam varies. Different designs of detector are favored by different groups and different distances from the neutrino source. Some detectors will be put on rails to provide varying distances.

Los Alamos, in the person of Minh Duong-Van, points out that it has a unique advantage in its main accelerator, the Los Alamos Meson Physics Facility. This machine produces copious beams of K and pi mesons (it was designed for research with them). When these mesons decay, they produce dense and dynamically well-defined beams of neutrinos. One experiment described by Duong-Van would have detectors moving up and down a tunnel 25 meters underground using the native Los Alamos tuff as cost-free shielding against background radiation.

K and pi mesons, as well as mu mesons, which also yield neutrinos when they decay, can be introduced into storage rings. The mesons would circulate in the rings, producing beams of neutrinos that fly off tangentially. These again would be "tagged" neutrinos; the dynamics of their point of origin would be known better than those for reactor neutrinos. David Neuffer of Fermilab suggests that a proposed facility, the Fermilab cooling ring for antiprotons, which is intended to assemble pulses of antiprotons and equalize their energies and momenta, could be used as a muon storage ring. Such a use could be parasitic on the antiproton cooling function or instead of it. Alternately, a special muon storage ring could be built if the money can be found. (The first alternative would save.)

In case it is necessary to go very long distances, David Cline of the University of Wisconsin and others did a survey of the territory around Fermilab to see how far they could get. Starting off in line with the regular Fermilab neutrino beam led them northeast to the Chicago suburb of Schaumburg, where the combination of topography and earth curvature sends the neutrino beam into the atmosphere. Schaumburg is expensive real estate, Cline admits, and he and his co-surveyors haven't gotten around to discussing with the people there what they might like to put down for a detector (probably a tank of water about the size of a swimming pool). Meanwhile, they took off on a line tangent to the proposed antiproton cooler, in a direction toward Elgin, north of the facility. Near Elgin they found a mental hospital that is being phased out. This could be ideal for a detector site as it is already state property. However, Cline warned the assembled physicists not to let the nature of the institution color their judgment of the experiment. □



Long-distance neutrino detection might be done in a series of water pools.

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