Going back and forth on neutrino oscillations

Neutrinos came into physics to solve a mystery — the apparent disappearance of energy in certain forms of radioactive decay of atomic nuclei. Now they present physicists and astronomers with a couple of interrelated mysteries about their own nature. The most fundamental of these is whether neutrinos oscillate — that is, whether they change their identities in a cyclic way. The related mystery is whether such oscillations — if they exist — can explain why the sun shines without producing as many neutrinos as standard astrophysical theory says it should.

At the moment there is one experiment, at the Bugey reactor in the French Alps near Grenoble, that claims a positive observation of what looks like neutrino oscillations. Its representatives at the recent Twenty-Third International Conference on High-Energy Physics in Berkeley, Calif., ran into determined opposition from several other experimenters who report negative findings. The others are treating the Bugey data as an intrusion into an area of neutrino physics that they are busy coloring in negative hues. Meanwhile, several experiments are planned to look for oscillating neutrinos from the sun, and at least two of these are now being set up.

"There's a lot at stake here," says Steven Weinberg of the University of Texas at Austin, who won part of a Nobel Prize for his work toward a theory that might give a single unified description of everything in particle physics. It is just such unified theories that are at issue in neutrino oscillations.

Around 1930, an anomaly in the important nuclear transformation process called beta decay gave physicist Wolfgang Pauli the occasion to postulate the neutrino's existence. Energy seemed to be disappearing unaccountably, and to save the law of conservation of energy Pauli suggested the existence of a particle that was electrically neutral, had no rest mass and interacted so feebly with other matter that it was almost undetectable.

Today, attempts at unified theories of physics have changed things a bit. They endow neutrinos with an extremely small rest mass — a few electron-volts at most — and with this property of oscillation. We now know that there are at least three varieties of neutrino, called electron, muon and tau neutrinos. Oscillation means that as a neutrino flies along it changes back and forth between two or all three of these identities. The various attempts at unified theories propose differing ways for this to happen, and what's at stake in neutrino oscillations is whether any or all of these proposed theories work.

Nuclear processes that go on in the sun should produce neutrinos. In terms of a unit defined expressly for this measurement, the recorded flux at earth should be upwards of 7 solar neutrino units (SNU). The classic experiment, led by Raymond Davis of Brookhaven National Laboratory in Upton, N.Y., and located in the Homestake gold mine near Lead, S.D., has been looking for about a decade and a half now and has never found much more than 2 SNU.

However, the Davis experiment is set up to find only one kind of neutrino. If neutrinos oscillate, the experiment may be missing much or most of the solar flux. One way that could come about is the concern of a theory called MSW, for two Russian physicists Mikhaev and Smernov and Lincoln Wolfenstein of Carnegie-Mellon University in Pittsburgh.

This theory proposes a resonance between neutrino oscillation and the structure of the center of the sun. As Weinberg describes it, neutrino oscillation can be viewed in terms of matter waves. Each kind of neutrino is represented by a different matter-wave frequency. As the wave representing a given neutrino moves along, it is first dominated by the frequency corresponding to, say, an electron neutrino. As it moves, it gradually detunes itself and tunes in on the frequency of, say, a tau neutrino. Then it reverses.

Inside the sun, this process of tuning and retuning is influenced by temperature and density, and the MSW theory proposes that there is a resonance between the structure of the sun and the neutrino waves that produces a whopping oscillation signal. To get evidence of such an occurrence, Weinberg says, it is essential to look for neutrinos interacting with matter by a different process than that of the Davis experiment. (Technically, the Davis experiment looks for neutrinos by a charged-current interaction; what is wanted is a neutral-current interaction.)

Looking the correct way, experimenters might expect fluxes up to 123 SNU, according to E. Bellotti of the University of Milan, Italy. He described the GALLEX experiment, so called because it uses the interaction by which a neutrino converts a nucleus of gallium-71 to germanium-71. A preliminary experiment was done at Brookhaven, and now the main experiment is about to be set up in the Gran Sasso laboratory, which is in a tunnel between L'Aquila and Teramo in the Appenines east of Rome. They expect to start taking data around 1990. There is reportedly a similar experiment at Baksan in the USSR.

Other solar experiments — in various stages of planning or preparation — that Bellotti reviewed include one with bromine, to be done by a group of U.S. laboratories; one with gallium at Kamiokande in Japan; one with a heavy water Cherenkov detector in a mine in Sudbury, Ontario; and ICARUS, which would use a liquid argon detector, also to be put in Gran Sasso.

Weinberg also cited a rival theory that explains the sun's neutrino deficit on quite different physical grounds. This is the WIMP theory, attributable mainly to John Faulkner of the University of California at Santa Cruz, which has been having some predictive success lately (SN:7/12/86,p.20). "Maybe [MSW] is our big breakthrough, or maybe it's WIMP," Weinberg says. After all, "astrophysicists want to know why the sun shines, but who cares about that?" He gave the impression that, as a particle physicist, he would like to see neutrino oscillations.

To look for neutrino oscillations at accelerators or nuclear reactors, experimenters get a beam of neutrinos flying and set up detectors at different locations downstream to record the proportion of one kind of neutrino to another at various stages of the flight. Several experiments at accelerators, notably at the CERN laboratory in Geneva, Switzerland, and at the Fermi National Accelerator Laboratory in Batavia, Ill., have come up negative.

Indeed, the only positive result now claimed is the Bugey reactor result. It is now several months old, but it was maintained, defended and extended by Roy Aleksan of the Centre d'Etudes Nucléaires at Saclay, France. Bugey's chief opponent is an experiment done a few years ago at the Gösgen reactor near Zurich, which gave a negative result. While giving a précis of the results, Peter Vogel of Caltech in Pasadena, Calif., who worked on the Gösgen project, said the experiment is over and there is no intention to revive it.

There is, however, a somewhat ambiguous reactor result from an experiment at the Savannah River Nuclear Plant near Aiken, S.C., presented by Z. D. Greenwood of the University of California at Irvine. Data are still being taken, but so far, he says, they favor neither "hypothesis," the positive of Bugey or the negative of Gösgen. Pressed by members of the audience to take a stand — his data seemed to show a slight if perhaps statistically insignificant leaning — Greenwood replied: "It's not that I do not prefer one to the other, it's that I do not strongly prefer one to the other." And on that somewhat Delphic remark he rested. *— D. E. Thomsen*