Solar Neutrinos: Where Are They?

An experiment that monitors the flux of neutrinos received from the sun is yielding information that may upset current theories of nuclear processes within the sun and similar stars. Earlier results from this solar experiment being conducted by Raymond Davis, Jr., and his colleagues at Brookhaven National Laboratory pointed to a rate of neutrino production that was lower than the rates predicted from models of the sun (see *Science*, 10 September 1971, pp. 1011). The discrepancy between theory and experiment might have been explained, in the opinion of some observers, by uncertainties in the experiment and drastic but not inconceivable modifications in the solar models. The first results from recent trials with improved detectors and additional shielding—improvements that eliminate some of the background radiation in the experiment—now indicate a still lower neutrino flux, which, if substantiated, will be extremely unsettling to theorists. Already the solar models and the understanding of nuclear processes in astrophysical contexts are undergoing reexamination.

To detect neutrinos, the Brookhaven scientists have placed a large tank of tetrachloroethylene about 1.5 kilometers underground in a mine shaft. The capture of neutrinos by chlorine-37 atoms (an extremely rare event since neutrinos interact with matter very weakly) converts the chlorine to argon-37, which is then extracted from the tank. A counting system is used to monitor the decay of the radioactive argon, which has a half-life of about 35 days. The flux of neutrinos is then calculated from the measured decay rate. In the early runs, the Brookhaven team detected about five decay events per 35-day counting period, a rate corresponding to the capture of about $(1.5 \pm 1) \times 10^{-36}$ neutrinos per second per chlorine-37 atom. By comparison, several theoretical models predict about 9×10^{-36} captures per second per target atom, a factor of 6 higher.

Several uncertainties affect the experimental result. Neutrons from spontaneous fission of uranium-238 or from alpha particle reactions (uranium and thorium emit alpha particles when they decay) in the surrounding rocks could also produce argon-37 from the chlorine target atoms. The atmosphere contains small amounts of argon-37 from nuclear weapon tests, and thus argon from the air in the mine might leak into the tank or contaminate the absorbers used in extracting the argon from the tank. Cosmic ray muons that penetrate the 1.5 km to the mine shaft can convert the chlorine in the tank to argon-37 by various nuclear processes. All of these background sources, however, would lead to a spuriously high rate for the neutrino capture. The Brookhaven team now believe that they have eliminated some of these possible sources of error.

In the most recent two runs, for example, the experimental chamber was flooded with 400,000 gallons of water to moderate or slow down any neutrons to energies below 1×10^6 electron volts (1 Mev), the threshold for the production of argon-37. Even more significant, Davis believes, are improvements in the proportional counters used to record argon-37 decays, improvements which now allow the experimenters to distinguish between argon-37 decays and other charged particle events that produce a pulse from the detectors. The Brookhaven counters are extremely small and respond very rapidly, so that the pulse shape as well as the energy of the pulse can be determined. Argon-37 decays produce a characteristic rapidly rising pulse, whereas cosmic rays, beta rays, or Compton electrons, because they tend to ionize molecules strung out across the counter, show a more slowly rising pulse.

The remaining uncertainties include residual background of argon-37 produced by cosmic rays and possible contamination from argon in the air. Davis monitors the cosmic ray flux higher up in the mine, but must extrapolate to calculate what the flux would be at the depths of the mine. He also monitors the amount of argon-37 present in the air in the mine, which, in the latest run, was unusually high. In fact, counts of a sample of the air would have yielded more argon-37 decay than that experimentally recorded. It therefore appears that some of the apparent neutrino flux might be due to background sources; even if there were no contribution from these sources, however, the measured neutrino capture rate is strikingly low.

In their latest experiment, the Brookhaven scientists find a rate below 1.0×10^{-36} captures per second per target atom. In theory most of the neutrinos expected would come from the decay of boron-8 in a minor branch of the proton-proton nuclear synthesis chain that is believed to give the sun its power. But even the neutrinos expected from the proton-electron-proton step of the nuclear synthesis reaction and from the decay of the beryllium-7 isotope, according to conventional theories, would result in a neutrino capture rate of 1.1×10^{-36} per second per atom, a rate comparable to the present uncertainty of the experiment. The experimental result is still tentative, because with such low capture rates (approaching one argon-37 decay per month), the possibility of statistical variations from 1 month to the next cannot be ruled out. Nonetheless, the results are discouraging for solar physicists.

The implication of Davis' result, if sustained by further experiment, is that either existing solar models or some fundamental nuclear theory as applied to the sun are seriously in error. Among the questions arising are whether the measured opacity of the sun is more than twice too large, or whether heavy elements such as carbon, nitrogen, and oxygen are perhaps 20 times less abundant in the interior of the sun than at the surface. Neither of these possibilities is considered to be very likely by solar physicists such as Icko Iben, of the Massachusetts Institute of Technology. More probable, in some assessments, is the chance that the extrapolation of laboratory data on nuclear physics to the reactions taking place in the sun is incorrect. John Bahcall of the California Institute of Technology has suggested (see *Physical Review Letters*, 31 January 1972, p. 316) that the discrepancy might be due to still undiscovered properties of the neutrino. He proposes that if these particles have a finite mass (they are generally considered to have no mass), they might be unstable and decay in the 500 seconds required for their travel from the sun to the earth. Bahcall suggests additional neutrino capture experiments to test this possibility. Other suggestions are likely to appear in coming months as physicists try to explain the absence of the missing solar neutrinos.

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