

they had found the so-called "fountain effect," in which a powerful hydrodynamic flow was produced by heating. And a couple of months later Kurt Mendelssohn and John Daunt at Oxford found that if they suspended a beaker of liquid helium, He II would flow along the wall—another demonstration of superfluid behavior. At about the same time Fritz London (then at Collège de France) suggested that the superfluid behavior of He II could be explained in terms of a Bose-Einstein condensation, arguing that He II is in a macroscopic quantum state. This idea was developed by Laszlo Tisza (also then at Collège de France).

Despite the onset of World War II, Kapitza continued working on low-temperature physics in Moscow, although in the West such research had stopped. The Nobel committee noted that in the next few years after the discovery of superfluidity, Kapitza experimented on the properties of He II, "indicating that it is in a macroscopic quantum state, that He II is therefore a quantum fluid with zero entropy; that is, that it has a perfect atomic order." At first, Kapitza thought that the superfluid convection would be sufficient to explain the anomalous heat conduction also. But in a series of brilliant experiments (for example, using an apparatus that resembled a spider), he proved that the situation is more complicated and more interesting, that in He II an entirely novel kind of internal convection occurs, in which heat is transported by a normal fluid and simultaneously a superfluid flow takes place in the opposite direction.

In 1938, while Kapitza was studying He II, the leading theorist of the Institute of Physical Problems, Lev Davidovich Landau, had been thrown in jail, where he remained until Kapitza is said to have convinced Stalin to release him. Once Landau had recovered, he developed the theory of liquid helium that was recognized with the 1962 Nobel prize in physics.

The 1978 Nobel committee also noted that "Kapitza discovered ideas and new techniques that have been basic to the modern expansion of the science of low-temperature physics." In the early 1930's, helium was generally liquefied by a cascade procedure—first air was liquefied, then hydrogen and finally helium—a procedure that took a number of days. Kapitza, while still at the Mond Laboratory, after first developing a hydrogen liquefier (with John Cockcroft), built a helium liquefier that used the adiabatic expansion method. The helium is pre-cooled by liquid nitrogen and then made to do work on an expansion machine. In early adiabatic-expansion devices, as the temperature was lowered, the lubricant froze. Instead, Kapitza let the helium itself lubricate the cylinder as it was deliberately allowed to escape by making the piston slightly smaller. After the ex-

pansion cooled the helium to 10 K, further cooling was done by the Joule-Thomson effect. —GBL

Solar-neutrino hunters still seek explanation

More than ten years of painstaking measurements of the solar-neutrino flux have been summarized, and at least as many years of future experimentation have been previewed, in conference talks and in journal articles over the last year. At the Conference on the Status and Future of Solar-Neutrino Research held at Brookhaven National Laboratory in January, Raymond Davis Jr and his co-workers from Brookhaven presented a statistical average of the past eight years of measurements of the solar-neutrino flux. The value was 1.7 ± 0.4 SNU (one solar-neutrino unit = 10^{-36} captures per target atom per second), about one-third that predicted by the standard solar model (4.7 SNU). Unlike the first data that hinted at the unexpectedly low value, the current results have gained general acceptance because the careful refinements and checks in the intervening years have dispelled most doubts. No one knows whether the current discrepancy between theory and experiments reflects an inadequate understanding of the dynamics of the Sun's core or a lack of knowledge of some aspect of nuclear or neutrino physics (although there tends to be some mutual finger pointing!). To resolve the question, many research groups have advanced concepts for future experiments. Feasibility studies of these proposed experiments continue to be updated and debated.

The detection of neutrinos from the Sun, while exceedingly difficult, is also exceedingly important. Neutrinos are the only messengers that can bring us information about the energy-generating processes within the solar interior. If current models of the Sun can be confirmed by agreement with neutrino observations, then astronomers can extrapolate to estimate the ages and elemental abundances of other stars with greater confidence. Within the nuclear-fusion cycle are several reactions that yield neutrinos. The Davis experiment was aimed at neutrinos from one of the weakest branches in this chain—those from the beta decay of B^8 . The low observed flux might say a number of things about the solar core: The abundance of heavy elements may be less than anticipated; the interior temperature may be lower; the rate of energy production may be currently in a phase in which it is smaller than the surface luminosity, and so forth. Alternatively, the low flux might imply that the neutrinos are not reaching the Earth because of decays or that they are undergoing oscillations.

(An oscillation is a mode in which a neutrino, once freed, may be envisioned as a linear combination of neutrinos—electron, muon and possibly other types.)

The Brookhaven experiment is being conducted by Davis, John Evans and Bruce Cleveland in the Homestake Gold Mine in Lead, South Dakota. The detector is 610 tons of perchloroethylene (C_2Cl_4) positioned 4850 ft below the surface. The Cl^{37} captures neutrinos with a threshold of 0.814 MeV, and the resulting Ar^{37} is removed by a helium purge, purified by gas chromatography and by a getter, and measured by a gas proportional counter. Samples of Ar^{36} or Ar^{38} are added as carriers and later analyzed by mass spectrometer as an indication of the recovery yield.

The questions raised over the years include whether the carrier samples are truly dissolved in the liquid or instead remain in the helium gas phase, and whether the Ar^{37} is produced as an essentially free, neutral atom or is bound in a molecule or molecule ion. The experimenters have designed tests to check these possibilities and have in each case ruled out the alternative that would have accounted for the "missing" neutrinos. Another constant worry in the experiment has been the correct estimate of the background, the largest part of which stems from cosmic-ray muons. The Brookhaven team measured this background in a small tank of perchloroethylene placed at various depths down to 1100 ft, and extrapolated from there. A more direct measurement of the muon background rate has been undertaken in the same gold mine by Edward Fireman of the Smithsonian Astrophysical Observatory,¹ who is studying the photonuclear interaction of the cosmic-ray muons with a potassium-acetate powder, which leaves a residue of Ar^{37} . To date Fireman's data indicate a background about two times higher than that assumed by Davis and colleagues. Davis estimates that the higher value would lower his results by perhaps 0.3 SNU. In a typically cautious statement, Davis stressed that his group does not claim to have seen solar neutrinos—just a signal that is 1.7 ± 0.4 SNU above the estimated background.

To complement the chlorine measurements, future experiments must explore the flux of neutrinos from other reactions within the Sun. Of great current interest are the neutrinos from the proton-proton reactions. Not only is this reaction by far the largest source of solar neutrinos but its flux is felt to be the least model dependent. The p-p reaction largely determines the luminosity of the Sun. Unfortunately, its neutrino energy is very low (with a maximum of 0.42 MeV, compared to 14 MeV for the boron-8 neutrinos).

Experimentally, the problem is to design a detector first of all with a threshold in the energy region of the neutrino source of interest. This detector must be based

on a reaction whose neutrino capture cross section can be calculated with reasonable certainty, and it must be capable of distinguishing the very small solar-neutrino signal from the other, often large, sources of background. The low neutrino cross section usually necessitates experiments large on both a spatial and temporal scale.

Gallium. One such experiment has been proposed by a collaboration from Brookhaven, Princeton, Battelle Pacific Northwest Laboratories, the University of Pennsylvania, the Weizmann Institute,² and most recently from the Max Planck Institute at Heidelberg. They plan to use the neutrino capture by Ga^{71} to yield Ge^{71} with a reaction threshold of 0.233 MeV. Thus, the detector is sensitive to the p-p neutrinos. The experimenters have considered two schemes for collecting and detecting the Ge^{71} depending on whether the Ga^{71} is in solution or is in metallic form. Extraction procedures for both have been tested on 20-kg quantities of gallium, and an extractor for 200 kg is being designed as a pilot for the ultimate extractor of 1-2 ton capacity. For an event rate of one per day, the gallium experiment will require 50 tons, at a cost of perhaps \$25 million. The collaboration hopes to be able to obtain the expensive material through some form of rental or borrowing agreement. The inevitable problems of background are mitigated somewhat by features of the gallium that tend to make its background partly self monitoring.

Lithium. Brookhaven workers have investigated the possibility of studying neutrinos by the inverse beta decay in lithium. Such a reaction would be sensitive primarily to the intermediate-energy neutrinos such as those from the small percentage of proton-electron-proton reactions and those from the decay of N^{13} , O^{15} , B^8 and Be^7 . Thus it would yield different information than the gallium and chlorine flux measurements and would require only a few tons of lithium. The largest experimental problem with the lithium concept is the difficulty in measuring the Be^7 produced. Sam Hurst's group at Oak Ridge National Laboratory is exploring a laser-ionization technique for single-atom detection, which they will apply to measuring Be^7 and also Te^{71} . The other disadvantage of a lithium measurement, explained John Bahcall of the Institute for Advanced Study, is that it alone may not unambiguously resolve the differences among hypothetical explanations for the low B^8 neutrino flux.

Thallium. A very different approach has been suggested by Melvin S. Freedman and others at Argonne National Laboratory.³ Rather than wait for incoming neutrinos to convert atoms in a target chamber, they intend to measure those conversions that have been induced in natural materials over millions of years

(and hence would represent a time-averaged flux). If the product atoms have a sufficiently long half life, they can accumulate in the target and reduce the large masses required by the counting experiments. The candidate reaction selected by the Argonne team is the neutrino capture by Tl^{205} and conversion to Pb^{205} , a reaction whose 0.43-MeV threshold makes it sensitive mainly to p-p neutrinos. They anticipate using 10 kg of the rare thallium crystalline mineral lorandite from a deposit in Yugoslavia that appears to have a low enough content of natural lead impurity. Mass spectrometry of laser-resonance fluorescence would be used to detect the long-lived Pb^{205} .

Two major problems beset this proposal. The most serious is the inverse beta cross section for Tl^{205} is not sufficiently well known. Freedman claims that they now know the cross section to within $\pm 40\%$ and they are both conducting and planning experiments to lower that uncertainty to the $\pm 20\%$ needed for a meaningful flux measurement. Bahcall has pointed out an error in the original estimate and has suggested that the present uncertainty is at least a factor of two.⁴ The other problem concerns the background of Pb^{205} from other reactions: Has the sample been isolated from natural sources of radiation, and has it been embedded deep enough for long enough to ensure that cosmic-ray muon-induced radiation was below a manageable level?

Another similar capture by neutrinos in a mineral is the capture in Br^{81} that yields a long lived Kr^{81} . The target material would be a salt deposit that has a small amount of bromine present.

Indium. A final class of experiments consists of those that depart from the radio-chemical approach and directly measure the energy and perhaps the direction of the neutrino. The most advanced proposal of this type is one recently described by Ramaswamy Raghavan and his coworkers at Bell Telephone Laboratories.⁵ This experiment would be based on the inverse beta decay in In^{115} . The low threshold of this reaction (128 keV) makes it sensitive to p-p neutrinos. The energy of the promptly emitted electron is equal to the excess energy of the neutrino above threshold. The product—an excited state of Sn^{115} —decays with a half life of 3.26 microsec to two coincident gamma rays that, together with the electrons, constitute a unique signature of the event. To discriminate the anticipated one event per day from the very large background of 10^{11} beta decays of In^{115} per day in $3\frac{1}{2}$ tons of indium, Raghavan and his associates have devised a triple delayed coincidence scheme that incorporates spatial position as a criterion. This electronic counting experiment can detect temporal variations in the neutrino flux. Among several detector concepts being considered, the

Bell Labs group has recently become excited about a relatively simple one that uses modules of stacks of thin plastic scintillators interlaid with thin layers of indium. As a bonus, the neutrino-electron scattering in the plastic scintillator stack could enhance the sensitivity to B^8 neutrinos. If this scheme becomes feasible, it could be a powerful tool for neutrino spectroscopy.

Other direct measurement schemes that are not as extensively researched are based on the deuterium capture of boron-8 neutrinos and the neutrino-electron scattering.

Bahcall has surveyed all the proposed solar-neutrino measurements⁴ and examined them for their ability to advance our state of knowledge, for the accuracy with which the neutrino capture cross section is known and for the general feasibility of the experiment. He singles out four experiments as worth pursuing—chlorine, gallium, lithium, and indium—and argues more generally for a deliberate neutrino spectroscopy program to govern the next 20 years of research. —BGL

References

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NSF approves Cornell's synchrotron source

The National Science Foundation has approved a grant of \$1 million over the next three years for the construction of a synchrotron radiation facility at the Cornell Electron Storage Ring. The Cornell High Energy Synchrotron Source will produce x rays up to 100 keV, a higher energy than is available from other existing or planned sources in the US; it will thus complement synchrotron radiation facilities now operating or under construction at Brookhaven, Wisconsin and Stanford (see PHYSICS TODAY, March 1977, page 17). Conversion of the 12-GeV electron synchrotron at Cornell to a colliding-beam device for up to 8-GeV electrons and 8-GeV positrons is scheduled to be completed in the spring of 1979; the synchrotron-radiation facility should then be ready for users in the summer of 1979. □