quent motion shows that the problem is very sensitive to initial conditions. Szebehely and Peters have more recently reported (*Astron. J.* **72**, 1187, 1967) that there exists a periodic motion for initial conditions near those of the Pythagorean problem. They also offer a generalization of their method to an *n*-body problem, allowing precise study of globular-cluster development, in the *Bulletin Astronomique* (Series 3, vol. 3, no. 1, 1968).

Neutrino Flux from Sun Is Lower than Expected

The flux of neutrinos that originate in thermonuclear processes in the sun's interior is much lower than expected, according to recent measurements by Raymond Davis Jr, Don Harmer, Kenneth Hoffman and Blair Munhofen of Brookhaven. The experiment suggests that our ideas about the sun's interior may need to be revised.

Speaking at a Yeshiva University seminar last November, Davis said that the total solar neutrino flux can be estimated as less than or equal to 2×10^6 cm^{-2} sec^{-1}. The theoretical figure for this flux, based on an analysis of the probable fusion processes occurring in the sun, is set at 6 to 22 $\times$ 10^6 cm^{-2} sec^{-1}.

The Brookhaven group uses a neutrino detector that is 1480 meters below ground level in Homestake Gold Mine in South Dakota, where the cosmic-ray shielding is good but of course, the neutrino attenuation is not noticeable.

The detection of neutrinos is always a low-efficiency pursuit, and background from cosmic rays and natural radioactivity must be reduced to a very low level. The reaction chosen is: $\nu + Cl^{37} \rightarrow Ar^{37} + e^-$. Argon-37 is radioactive with a 35-day half-life. This reaction would be initiated by those neutrinos emitted by the sun during the decay of boron-8, which is a product of hydrogen fusion; they contribute only about 0.05% of the total solar neutrino flux but have an energy spectrum as high as 14 MeV.

The chlorine is in the form of tetrachloroethylene, 400 000 liters of it, and after four months in the gold mine argon can be flushed out of the liquid with circulating helium and then separated from the helium by trapping on charcoal at liquid-nitrogen temperature. A proportional counter, placed inside a 12-inch ex-naval gun barrel for shielding, counts 2.8-keV electrons from the radioactive argon to measure the number of neutrino captures that occurred.

Davis points out that these investigations are still at an early stage, and to get satisfactory statistics the observations will continue for a few years. Other work along the same lines is being conducted by Frederick Reines, of the University of California, Irvine, in a mine near Cleveland, by Tom Jenkins of Case Institute of Technology in a salt mine also in the Cleveland area, and by Reines and J. P. F. Sellschop of the U. of Witwatersrand in a South African gold mine.

A Visit to Argonne—II: Solid-State, Atomic and Nuclear Physics

Besides its high-energy-physics research (PHYSICS TODAY, February, page 57) Argonne National Laboratory has strong programs in nuclear, atomic and solid-state physics, and it is building a high-flux research reactor. During a recent visit there we spoke to some of the people in charge of these programs.

Since Robert Duffield had just taken over as director of the laboratory, we spoke to Winston Manning, who has recently served as acting director and is a long-time Argonne chemist. He told us that in physics the lab's largest effort is in high-energy research (see table). The table tends to understate the effort in high-energy physics, because (a) it does not include substantial manpower on ZGS operation and services and on design and development (for example, 3.7-meter bubble chamber and advanced accelerator design), and (b) the machine is extensively used by the university community. (The machine is especially heavily used by university scientists who are only counted if they reside at Argonne for a substantial time.) In fiscal year 1967 operating cost for physical research was about $36 million.

The Physics Division, headed by Lowell Bollinger, has four major programs: theoretical (mainly nuclear), charged-particle nuclear-reaction physics, neutron physics and atomic physics. In the early days of Argonne the division also included other groups, Bollinger told us, but they were spun off when they grew large; these included reactor physics, applied mathematics, accelerator design (now part of high-energy physics) and high-energy theory.

To do nuclear-physics experiments there are three electrostatic accelerators and a cyclotron. Last summer the division converted its EN model tandem accelerator to a model FN, which produces 18-MeV protons mainly for charged-particle experiments. The energy range of experiments with deuterons can be extended to 23 MeV and with alpha particles to 45 MeV at the 60-inch cyclotron operated by the Chemistry Division. An Argonne-built 4-MeV accelerator is to be replaced by a 4-MeV proton Dynamitron this summer; with fast neutrons produced by the new machine in the Li(p,n) reaction, physicists will study neutron-induced reactions. A 2-MeV proton accelerator (that started life at the U. of Notre Dame as an electron accelerator and was converted to a proton machine by Argonne) is used mostly to study the physics of surfaces.

Number of Argonne Scientists (Approximate): Staff and Long-Term Visitors

High-energy physics research (only 40% regular Argonne staff)	93
Nuclear physics	50
Nuclear chemistry	21
Atomic physics	14
Solid-state science:	
Solid-state science division	54
Metallurgy division (physical metallurgy and ceramics)	44

The division will soon install a split-pole magnetic spectrograph developed by Harold Enge of MIT. At the tandem accelerator experimenters are using a fully automated 60-inch (152-cm) scattering chamber. The distances from target to solid-state detectors and the angles between detector arms are computer controlled; the computer makes certain logical decisions based on a stored program. A large angular correlation apparatus, which holds two sodium-iodide crystals (30-cm diameter, 20-cm thick), has a computer to control the angle between crystals.

John Erskine showed us Argonne's automatic plate reader, which scans a nuclear emulsion in 17 min, locates track position and sends its coördinates

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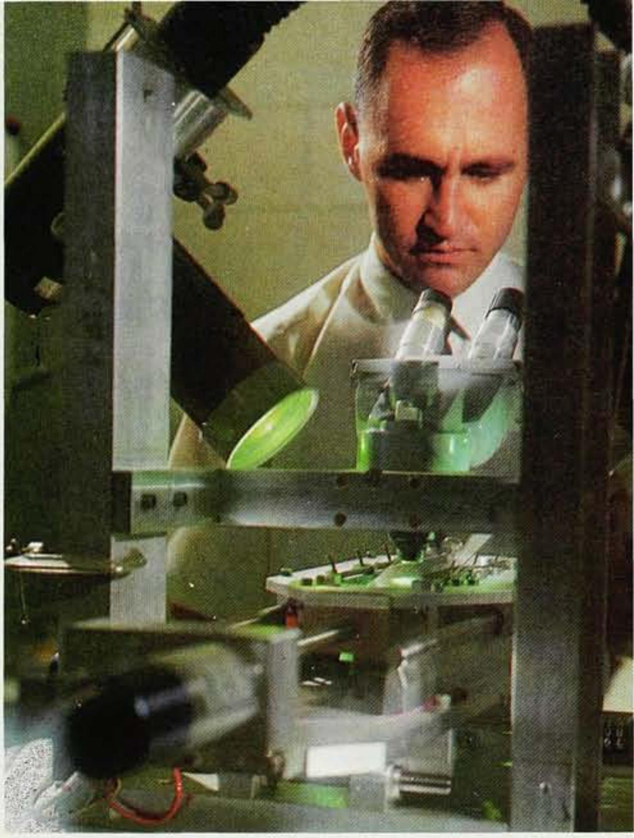

AUTOMATIC PLATE READER scans plate, locates track position and sends coördinates to computer.

to a computer. The device is suitable for any charged particle.

Roy Ringo, Vic Krohn and Carl Christensen are repeating an experiment on the beta decay of polarized neutrons (first done at Argonne ten years ago) that looks for a small failure of time-reversal invariance. The reaction is $n \rightarrow p + e + \bar{\nu}$. Under time reversal the quantity $\mathbf{J} \cdot \mathbf{P} \times \mathbf{p}$ changes sign ($\mathbf{J}$ is neutron spin, $\mathbf{P}$ and $\mathbf{p}$ are electron and antineutrino momenta); the experiment measures this quantity. A related experiment will also measure the correlation of neutron spin and electron momentum to determine the ratio of the strengths of the vector and axial-vector interactions in the weak interaction; this ratio has become particularly interesting lately with the development by S. L. Adler and W. I. Weisberger of a theory based on the partially conserved axial-vector-current hypothesis that connects the ratio with amplitudes involved in pion–nucleon scattering.

Bollinger told us that Argonne has one of the largest and best known groups of nuclear theorists. In the past the shell model has been emphasized, starting with the pioneer work of Maria Mayer and David Inglis. Now the big push is into the nuclear many-body problem. Stanley Cohen, Fritz Coester, Benjamin Day, Malcolm MacFarlane and James MacKenzie are all working on this approach.

In atomic physics Joseph Berkowitz and William A. Chupka have been studying photoionization effects. They have a high-intensity vacuum ultraviolet light source to photoionize various vapors that are then detected by a mass spectrometer.

The Solid-State Science Division, headed by Oliver Simpson, is working on defects in graphite, color centers in alkali halides and in a variety of other areas including low-temperature research. Argonne is one of the few labs that can make definitive measurements down to 30 millidegrees (by adiabatic demagnetization), Simpson said. They have just built a high-capacity dilution refrigerator that may cool to 10 millidegrees. Groups are measuring specific heats and Fermi surfaces below 4°K and down to 0.3°K and are measuring sound attenuations down to 0.03°K.

One very active group is studying the characteristics of radiation-induced defects in graphite. About four years ago Gerhart Hennig of Argonne developed the etch-decoration technique to determine the sites of individual vacancies at the surface of graphite crystals.

To reveal the graphite vacancy, you need a trick, Simpson explained. Those carbon atoms near a vacancy do not have their valency saturated, so they are chemically more reactive than the other atoms. By burning, one makes the surface depression grow. Then one evaporates gold onto the surface to decorate the vacancies. Since carbon and gold have little affinity for each other, the gold atom will tend to nucleate at the defects. Then, because gold is heavy and has lots of electrons, one can see the defects with an electron microscope.

Recently George Montet of Argonne extended the technique to reveal vacancies in molybdenite (*Appl. Phys. Letters* **11**, 223, 1967).

To form the vacancies one can heat a large sample of graphite to about 3300°C and then cool it. This quenching technique introduces vacancies. To study them one cleaves off a flake and then does the preferential etching. From a plot of the number of vacancies as a function of quenching temperature one can determine the energy of formation.

In graphite, unlike metals, one can use this technique to find the displace-

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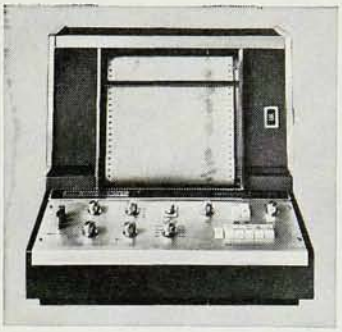

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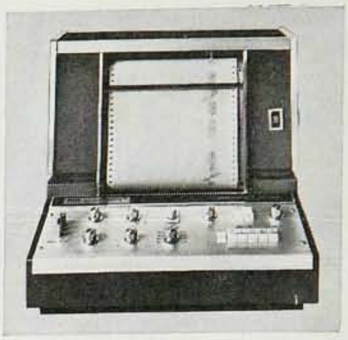

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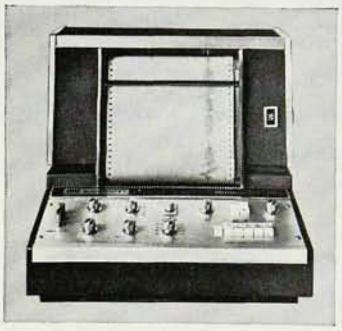

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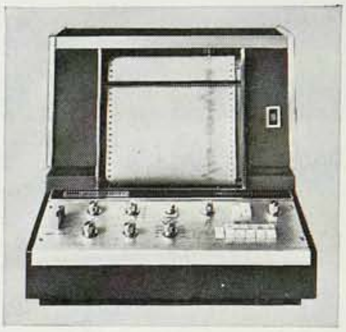

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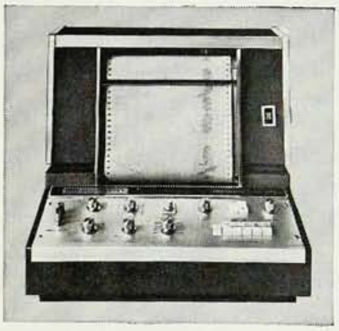

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ment energy, the average amount of energy required to knock an atom out of its lattice position. Montet, for example, bombards a sample with monoenergetic electrons and determines a threshold displacement energy as a function of angle.

The high-flux reactor that Argonne is building is expected to produce 5×10^{15} neutrons/cm^2/sec. The light-water "flux-trap" reactor, to be called the Argonne Advanced Research Reactor (affectionately known as A^2R^2), is scheduled to cost $25 million and to be finished in 1971. A^2R^2 will operate at 100 thermal megawatts.

Milton Levenson, project manager, explained that A^2R^2 will be very similar to the High-Flux Isotope Reactor at Oak Ridge (PHYSICS TODAY, June 1967, page 23), but the Argonne reactor is primarily intended for basic research rather than heavy-isotope production, and hence will have many more experimental facilities.

Within the central annular core a water-filled region will slow down and trap neutrons from the surrounding fuel. Neutron density will be highest in the central flux trap. In the beryllium reflector that will surround the core, one fifth as much neutron flux will be present.

The reactor will have eight horizontal beam tubes tangent to the core and all will penetrate the beryllium reflector. Neutrons and gamma rays that penetrate the samples used in experiments can then be measured outside the reactor. Two of the tubes will pass all the way through the reactor vessel and the beryllium reflector.

Within the flux trap 9 vertical irradiation facilities will be available. Originally these 9 positions will be filled by two static sample thimbles, five hydraulic and two gas rabbit facilities (to move sample containers in and out of the reactor while it is running), according to Donald Connor, who has been looking after the needs of future experimenters at A^2R^2.

One will also be able to irradiate samples in the beryllium-reflector area, which will have four hydraulic and two gas rabbit facilities, two static thimbles and 26 spare holes for vertical thimbles in various flux regions.

When A^2R^2 is finished it will be used by Argonne staff and faculty members from Midwestern universities and colleges for research in nuclear physics, chemistry, materials science and solid-state physics.

The excavation for the reactor is finished; the pressure vessel and some components are being fabricated, and Brush Beryllium recently finished pressing and firing one of the largest single pieces of beryllium ever made. The hollow cylindrical reflector is 150 cm across and 60 cm high.—GBL □

APPL. PHYS. LETTERS

LATTICE VACANCIES IN MOLYBDENITE are revealed by etch decoration. Gold atoms nucleate at vacancies, which show up on electron photomicrograph. Centers of the small triangular depressions appear to correspond to surface vacancies.