

xenon in which the atom is quantized along the direction of the electric field and the $\mathbf{v} \times \mathbf{E}$ effect should be completely eliminated.

Sandars³ is also looking for a proton moment in a molecular-beam experiment with thallium fluoride.

Recently two experiments determined an upper limit for the neutron electric dipole moment. Norman Ramsey and his associates,⁴ in a beam-resonance experiment found μ/e less than 3×10^{-22} cm, and Clifford Shull and Robert Nathans,⁵ in a neutron-scattering experiment, found μ/e less than 6×10^{-22} cm. At Brookhaven Victor Cohen and his colleagues are doing a resonance experiment; preliminary results give 10×10^{-22} cm as an upper value. Another experiment is being done at the University of Sussex by Kenneth Smith.

References

1. P. G. H. Sandars, E. Lipworth, Phys. Rev. Letters 13, 716 and 718 (1964).
2. T. S. Stein, J. P. Carrico, E. Lipworth, M. C. Weisskopf, Phys. Rev. Letters 19, 741 (1967).

3. P. G. H. Sandars, Phys. Rev. Letters 19, 1396 (1967).
4. P. D. Miller, W. B. Dress, J. K. Baird, Norman F. Ramsey, Phys. Rev. Letters 19, 381 (1967).
5. C. G. Shull, R. Nathans, Phys. Rev. Letters 19, 384 (1967).

Yale Astronomers Solve Old Three-Body Problem

Complete solution of the Pythagorean three-body problem shows a final configuration in which two of the bodies form a close binary system and the third moves away to infinity. Victor Szebehely and C. Frederick Peters of the Yale Observatory have succeeded in solving the problem and have published their results in the *Astronomical Journal* (72, 876, 1967). Recent extensions of their work show a nearby periodic solution and the way to handle more than three bodies.

The problem, like Fermat's last theorem and the question of how many crayons it takes to color a map, has been around a long time. To define its initial conditions one places three bodies at the corners of a 3, 4, 5 right triangle with $m_3 = 3$ at the apex opposite the 3 side, $m_4 = 4$ opposite the

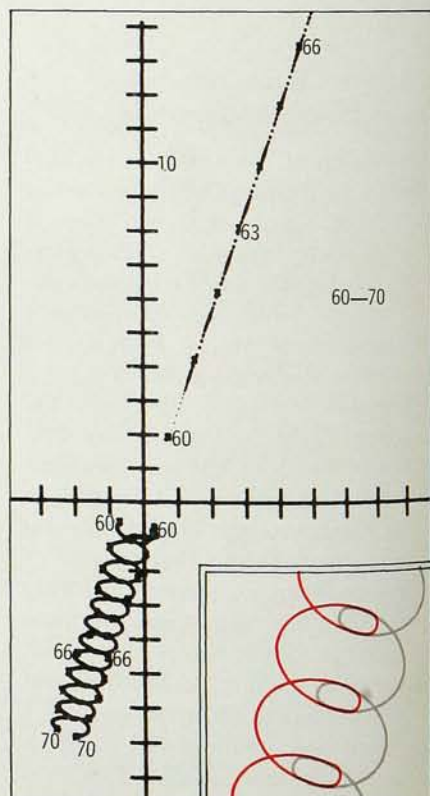
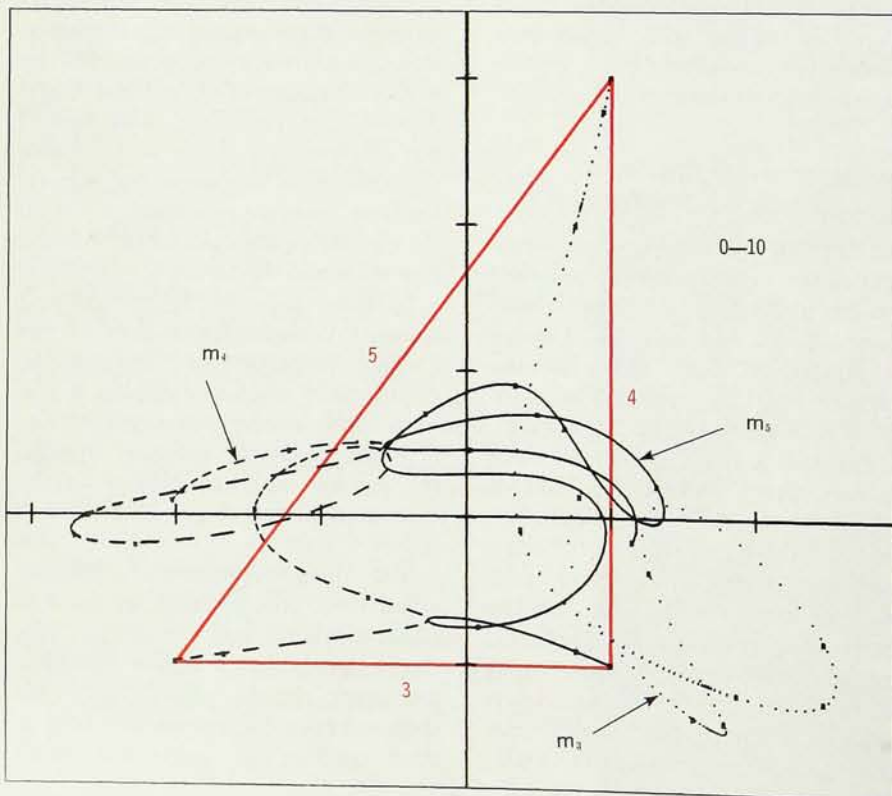
4 side and $m_5 = 5$ opposite the 5 side. Then the question is: What happens when the three bodies move freely under the influence of gravity? The main difficulty in a computer solution is that one loses much time and accuracy at moments of very close approaches when one body is having an unusually large influence on another.

Szebehely and Peters managed a solution by adopting a transformation suggested by Tullio Levi-Civita in 1904 and modifying it to take care of some of the special aspects of the problem.

Their results for their first ten time units and time units 60 to 70 are shown in the figures, which were automatically plotted at the Yale Computer Center. If masses are in grams and distances in centimeters, a unit of time would be 1.08 hours; for 3, 4 and 5 solar masses at distances 3, 4 and 5 parsecs (1 parsec $\approx 3 \times 10^{16}$ meters), the time unit would be 1.43×10^7 years.

Their solution disposes of the question whether a periodic motion would result. At $t = 31.66$ the bodies are nearly at their starting points with velocities near zero, but the subse-

PYTHAGOREAN THREE-BODY PROBLEM starts with masses 3, 4 and 5 at corners of a 3,4,5 triangle. Eventually two bodies form a close binary and third goes off to infinity. Figures show initial and eventual motion. As inset shows, members of close binary move in eccentric ellipses about one another, each staying most of the time on its own side of the line of approximate symmetry in the figure.



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 $2 \times 10^6 \text{ cm}^{-2} \text{ sec}^{-1}$. The theoretical figure for this flux, based on an analysis of the probable fusion processes occurring in the sun, is set at 6 to $22 \times 10^6 \text{ cm}^{-2} \text{ sec}^{-1}$.

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: $\nu + \text{Cl}^{37} \rightarrow \text{Ar}^{37} + e^-$. 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 pro-

grams: 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 $\text{Li}(p,n)$ 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.

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 coordinates

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