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Physics in the 20th Century

By Curt Suplee; Edited by Judy R. Franz and John S. Rigden

The discoveries and inventions of physicists in this century have revolutionized modern life. One hundred years ago, scientists questioned the very existence of atoms and knew almost nothing about the cosmos. Today, physicists can arrange individual atoms on a surface and make an image of the result, and have begun to unravel the history of time and the universe.

In this book, Curt Suplee, science writer and editor at *The Washington Post,* documents one of the most remarkable flowerings of knowledge in human history. The extraordinary illustrations focus mainly on the remarkable images—from the atomic to the cosmic scale made possible by the instruments of advanced physics. Also included are photographs of experimental equipment—massive particle colliders are beautiful in their own right—and pioneering inventions.

This stunning volume is sponsored by the APS and the AIP on the occasion of the centennial of the American Physical Society.

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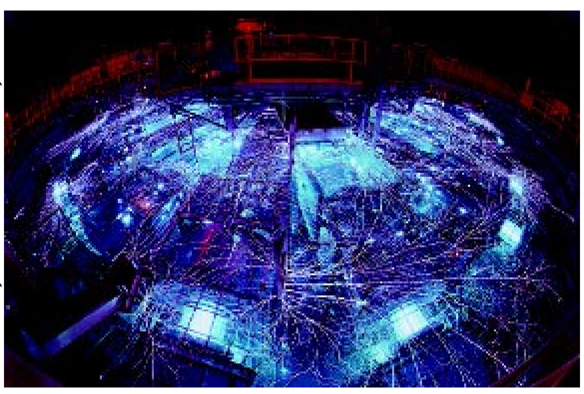

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Time-exposure photograph of a nuclear fusion experiment.

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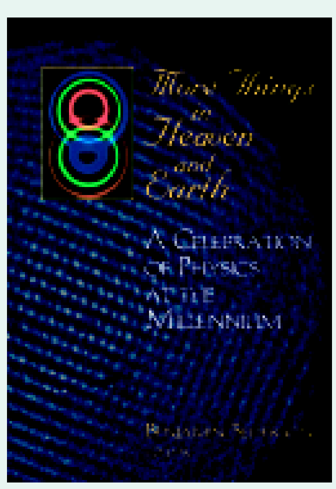

A century of unparalleled scientific and technological change, mostly fueled by the discoveries of physicists, draws to a close simultaneously with the beginning of the second century of the APS and the onset of the third millennium. To acknowledge and celebrate these milestones, the Editor, with the assistance of the Editorial Board consisting of Kurt Gottfried, Walter Kohn, Eugen Merzbacher, Myriam Sarachik, Andrew Sessler, and George Field asked some preeminent physicists to create a contemporary portrait of their subfields, highlighting achievements, current vitality, and likely directions. The resulting 54 articles give us a unique opportunity to celebrate this century of physics. The volume is published to coincide with the APS Centennial meeting in Atlanta, simultaneously as both a supplement to the March 1999 *Reviews of Modern Physics* and as a hard-cover book from Springer-Verlag New York. Inc.

Among the authors are 15 Nobel Laureates and over 40 members of the National Academy of Sciences and of the National Academy of Engineering. The articles, often personal in tone, are written at the level of departmental colloquia. Some are intended to be broad but not encyclopedic, while others are presented as "case studies" focusing on particularly fascinating illustrations of specific topics. Major sections include: historical perspectives: particle physics; astrophysics; nuclear physics; atomic, molecular and optical physics; condensed-matter physics; statistical physics and fluids; plasma physics; chemical physics; and the applications of physics within other fields. Together, the articles combine to paint an illuminating and sweeping canvas of a remarkable time in science and civilization. See the APS and / or Springer websites (http://www.springer-ny.com) for more information.

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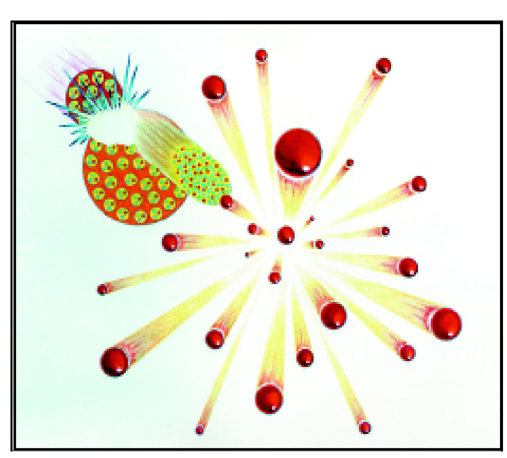

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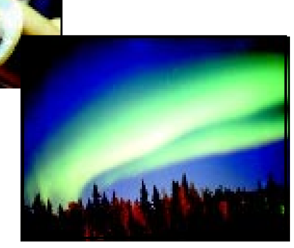

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The American Physical Society

Joost Wintterlin thinks this is the first time that a kinetic description of a chemical reaction was achieved based only on the statistics of the underlying atomic processes. (J. Wintterlin *et al.*, *Science* **278**, 1931, 1997.)

THE DURATION OF SONOLUMINESCENT PULSES has now been determined and is independent of wavelength. Sonoluminescence (SL) is the clocklike emission of light pulses from a bubble that is trapped in a fluid by an acoustic field. (See PHYSICS TODAY, September 1994, page 22.) Until 1997, researchers could only establish an upper limit for the width of SL flashes, not their actual duration. But then, researchers at the University of Stuttgart adapted the technique of time-correlated single-photon counting to SL and announced that SL pulses for their bubbles lasted from about 50 ps up to more than 250 ps, and presented evidence that the length of the pulse for a given bubble is identical in the red and the UV parts of the spectrum. Applying the Stuttgart technique, researchers at the University of California, Los Angeles were able to confirm the result, and found that the flash width varies by less than 3 ps from 200 nm to 800 nm. The different pulse widths for different bubbles depend on the composition of the bubble's gas and on the intensity of the emitted light. The color-independence of the pulse duration rules out the "adiabatic heating" hypothesis, because blackbody radiation should last longer at the longer wavelengths. Both groups think that bremsstrahlung remains a viable mechanism for producing the light. (B. Gompf *et al.*, *Phys. Rev. Lett.* **79**, 1405, 1997; Hiller *et al.*, *Phys. Rev. Lett.* **80**, 1090, 1998.)

A LARGE MAGNETOCALORIC EFFECT has been found in certain materials containing gadolinium, reported Vitalij Pecharsky (Ames Laboratory, Iowa State University), Robert Shull (National Institute of Standards and Technology, Gaithersburg, Maryland) and Carl Zimm (Astronautics Corp of America) in separate talks at the March 1998 meeting of the American Physical Society in Los Angeles. At a fixed temperature, the entropy of a magnetic system is lowered as the spins align with an applied magnetic field. If the field is then removed adiabatically, the system will be cooler than it was before the field was turned on. This magnetocaloric effect typically produces a temperature drop of 0.5–2 K for a field change of 1 tesla. The Ames group found that combining Gd with silicon and germanium increased the effect to 3–4 K T^{-1}. Shull made a magnetic nanocomposite with Gd clusters that also showed a greatly enhanced magnetocaloric effect. Zimm reported on a very efficient Gd-based sub–room-temperature refrigerator. Magnetic refrigeration is used for, among other things, liquifying hydrogen and natural gas.

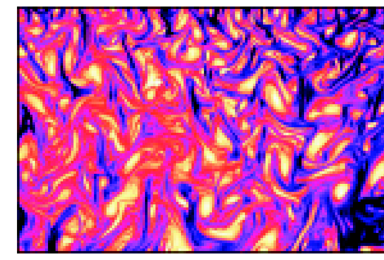
A magnetic refrigeration setup. *(Courtesy Vitalij Pecharsky, Ames Lab/ University of Iowa.)*

A NEW LIMIT ON PHOTON MASS has been established using a tabletop apparatus. The mass of photons, the corpuscular manifestation of light, is usually assumed to be zero. A non- zero photon mass would have several implications, such as a frequency-dependent speed for light and the existence of longitudinal electromagnetic waves (in the conventional waves we know, the electric and magnetic fields oscillate perpendicularly to the line of travel). The best previous limit on photon mass (using a reasonably connected line of inference) comes from observations of Jupiter's magnetic field. The value, 6×10^{-16} eV, was determined in 1975. Now, Roderic Lakes of the University of Wisconsin has tightened the limit further—to below 7×10^{-17} eV—by carefully watching for anomalous torques in the motion of a Cavendish balance, basically a steel toroid wrapped in current-carrying coils. Essentially, Lakes' novel approach is to seek a cosmic vector potential. In electromagnetism, the change in the vector potential (denoted by the letter A) is related to the strength of the magnetic field in that part of space, just as an electric field can be calculated from a changing electric potential. Normally, A cannot be measured point-for-point in space, but it could be if the photon's mass were nonzero. Lakes did not find a nonzero A, but his method might be useful (beyond setting a new limit on photon mass) for searching out new features of short-range forces, such as the nuclear strong force. (*Phys. Rev. Lett.*, **80**, 1826, 1998.)

TUMBLING AND FLUTTERING of falling leaves and paper has received some experimental attention from a group at the Weizmann Institute of Science in Israel. In their experiment, the researchers dropped long, flat strips of steel, plastic, and brass into a narrow, fluid-filled tank. The strips naturally orient themselves flat side down, and they were constrained to move in a two-dimensional vertical plane. What determined whether a falling strip predominantly oscillated from side to side (fluttered) or rotated end over end (tumbled) was the Froude number—the ratio of the time it takes for the strip to fall its own length to the time it takes to execute the pendulum-like side-to-side motion. Longer or lighter strips, which have a low Froude number (like a piece of typing paper), fluttered; smaller or heavier strips (like a business card) tumbled. As shown in the photo, a fluttering strip also creates a zigzag wake by shedding fluid vortices synchronized with the fluttering oscillations. Such vortex studies may be relevant to the question of how airplanes stall, and also may help explain why certain insects can fly with great efficiency. (A. Belmonte, H. Eisenberg, E. Moses, *Phys. Rev. Lett*. **81**, 345, 1998.)

Investigating how paper falls through the ground, researchers dropped thin metal strips in a narrow water-filled tank and watched how, under various conditions, it exhibited flutter (side-to-side motion) or tumble (end-over-end rotation). Each frame, from a to d, is a video collage of a thin strip falling through water. *(Courtesy Andrew Belmonte, Hagai Eisenberg, and Elisha Moses.)*

TURBULENCE IN SOAP FILMS. Researchers at Los Alamos National Laboratory have made quantitative measurements of the velocity and vorticity fields, as well as the fluctuating thickness, throughout an entire soap film. Rather than using the standard single-point probes, they added tiny, highly reflective titanium dioxide particles to the fluid, let the film flow through a comb and snapped pictures of the resulting two-dimensional turbulence every 160–300 ms with a digital camera. The accompanying composite image shows—for a 12 mm square region of soap film located 1 cm downstream from a comb—the film's thickness fluctuation as the surface elevation (greatly exaggerated); the vorticity as color, with red and blue representing high positive and negative values; and the streamline pattern as textured lines. Although the film was clearly compressible, the researchers found the statistics of enstrophy (vorticity squared) to be in rough agreement with the theory for incompressible turbulence. (M. Rivera *et al.*, *Phys. Rev. Lett.* **81**, 1417, 1998.)

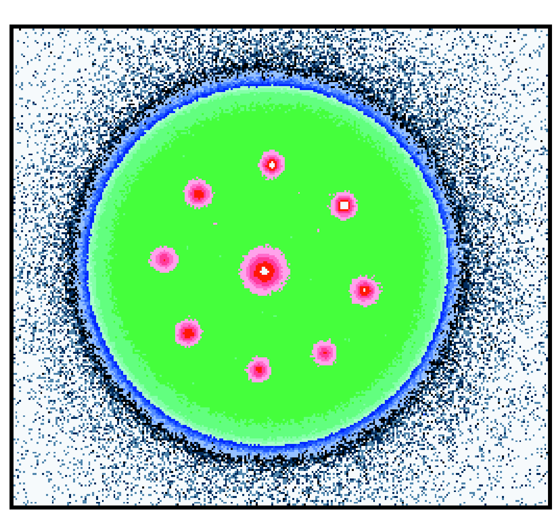


False-color image of turbulence in a 30-micron-thick soap film. *(Courtesy Los Alamos National Lab.)*

ECONOPHYSICS is the application of physics techniques to economics problems. Like a collection of electrons or a group of water molecules, the world economy is a complex system of individual members (in this case, countries) that interact with each other. In a situation that many experimental physicists would surely envy, the world economy produces an incredible amount of data—one year of US stock-exchange transactions results in 24 CD-ROMs of data. These data provide the opportunity for extensive statistical analyses which can lead to a better understanding of the behavior of these complex systems. In an earlier study of business firms (Stanley *et al.*, *Nature* **379**, 804, 1996), physicists and economists found that the probabilities associated with observing a given growth rate for a firm could be described with a single mathematical function for firms of all types and sizes (from sales of $100,000 to $1 trillion). Furthermore, they found that the width of the curve showing the probability distribution follows a "power law,"in which the width is proportional to the firm size raised to a power of approximately 1/6. Now, a Boston University-MIT physics team (Youngki Lee, Boston University) collaborating with a Harvard economist (David Canning) has found the same universal patterns and power law for the fluctuations in the growth rates of the gross domestic products (GDP) of 152 countries from 1950-1992. (Lee *et al.*, *Phys. Rev. Lett.*, **81**, 3275,1998.) These models raise the possibility that complex human organizations can be studied with methods and concepts developed in statistical physics. (Amaral *et al.*, *Phys. Rev. Lett.* **80**, 1385,1998.)

THE "SWEET SPOT" OF A BASEBALL BAT has now been analyzed by a physicist. The collision between baseball and bat involves an exchange of energy lasting less than 2 ms. Whether the encounter results in a home run or not (a subject of great interest in the record-breaking year of 1998) depends on many factors. But generally the batter will want to make contact near the sweet spot—about 17 cm from the fat end of a typical bat—which imparts the least amount of vibration (and pain) to the batter's hands. Rod Cross of the University of Sydney in Australia found, among other things, that a baseball bat has two equally important modes of vibration and that consequently the bat has three sweet spots (the two nodes in the barrel plus the center of percussion) closely spaced over a few centimeters. Additionally, there is no impact spot on the bat where impulse forces on the hands remain zero. (R. Cross, Amer. Jour. Phys. **66**, 772, 1998.)

NEW METHODS OF STUDYING TURBULENCE, reported at the March 1998 APS meeting, have enabled physicists to track in detail for the first time the accelerations of a particle moving through flows with atmospheric-level turbulence (Eberhard Bodenschatz, Cornell), and to cause magnetically trapped electrons to act like fluid particles on a flat surface (Fred Driscoll, UC-San Diego). Bodenschatz described how a light-sensitive diode measured the movements of a particle jiggling through a fluid at up to 200 times the acceleration of gravity. For upcoming experiments, the group has installed a "silicon-strip detector" used in high-energy physics to make up to 100,000 measurements per second of multiple particles in the fluid, the better to study how particles that are initially close together move apart in a very turbulent flow such as a volcanic eruption. Meanwhile, Driscoll investigated turbulence by using a strong magnetic field to trap a cigar-shaped column of a billion electrons. Viewed from the end of the column, the electrons moved like fluid particles on a 2D surface. Intriguingly, turbulent flows of these electrons spontaneously settled into "vortex crystals," geometric patterns of whirlpool-like eddies that stayed frozen in place.



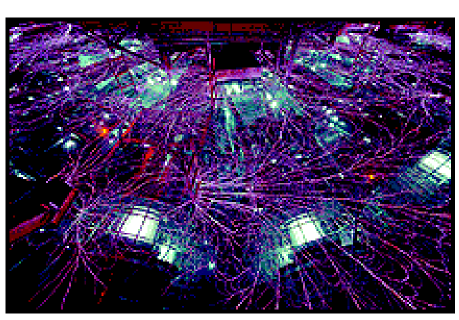
False-color image of a "vortex crystal" in a gas of electrons. *(Courtesy UC-San Diego.)*

elementary particle (such as a photon) is accelerated, its energy increases and its Compton wavelength decreases accordingly. Eventually, the particle would, in a sense, shrink enough to fall into the new dimension, whereupon its wavefunction would behave like a particle-in-a-box. This would produce a series of higher-frequency "echoes" of the original particle, which would have the effect of lowering the GUT scale. By studying these "Kaluza–Klein excitations," researchers would be able to determine the size of the extra dimensions and the properties of GUT (and string) theories at energies far lower than was previously thought possible. Coincidentally, the CERN trio and Gordon Kane were unaware of each others' efforts when Kane's fictional "Physics Tomorrow" essay on detecting extra dimensions appeared in PHYSICS TODAY (see May 1998, page 13). (K. R. Dienes, E. Dudas, T. Gherghetta, http://xxx.lanl.gov/abs/hep-ph/9803466 and hep-ph/9806292, 1998.)

LASER WAKEFIELD ACCELERATION (LWFA) of injected electrons has been announced by a multi-institutional team of scientists in France, as a part of the drive to develop compact methods for accelerating particles to high energies. A short, intense laser pulse fired into a plasma can excite a "wake" of charge oscillations. An injected particle starting with just the right velocity can ride these plasma waves to ever higher energies. The experimenters achieved a maximum longitudinal electric field of 1.5 GV/m, with a corresponding electron energy gain of 1.6 MeV. In earlier LWFA experiments (see, for example, PHYSICS TODAY, August 1995, page 9), the electron plasma wave was "self-modulated," meaning that it grew from an instability and had an unpredictable phase. The French team says that the LWFA they demonstrated is more readily controlled, and thus will eventually make a better accelerator. (F. Amiranoff *et al*., *Phys. Rev. Lett*. **81**, 995, 1998.)

KAONS BEHAVE STRANGELY in dense nuclear matter. Recently, experimenters at the GSI lab in Darmstadt, Germany have looked for kaons in violent collisions (1 GeV/nucleon) between gold nuclei. During such an energetic reaction, the nuclear matter is compressed to about three times normal nuclear density for a very short time—about 3×10^{-23} s. During this hot and dense phase, strange mesons—mostly positively charged kaons—are created. Then the nuclear fireball explodes. At polar emission angles of 90° in the center-of-mass frame, nucleons and pions emerge preferentially out of the plane of the collision. Kaons, however, are expected to emerge isotropically, due to their long mean free path. But they don't. They accompany the nucleons in a joint escape from the plane. This unexpected finding could indicate that the effective mass of the kaon is altered in the extreme nuclear environment, which in turn could have important implications for the astrophysics of supernovae and neutron stars. (Y. Shin *et al*., *Phys. Rev. Lett*. **81**, 1576, 1998.)

IN SANDIA'S "Z" MACHINE millions of amps of current are passed through a tiny spool of tungsten wires, producing a flood of x rays. Essentially the most powerful terrestrial producer of x rays, the Z device recently achieved the following milestones during a test shot: temperatures of 1.8 million K, a power output of 290 terawatts, and an energy release of 2.0 megajoules. The researchers believe nuclear fusion could be attained inside the device (by bombarding a fuel pellet with x rays) if the conditions were pushed further, to temperatures of 3.5 million K and power levels of 1000 terawatts. Sandia officials have encapsulated these ideas in a proposal for a larger machine, to be called X-1.



Electric discharges illuminate the surface of Sandia's "Z Machine," the world's most powerful source of x rays. *(Courtesy Sandia.)*

PROTONS AND ANTIPROTONS HAVE THE SAME MASS to within one part in 10 billion. Harvard physicists Gerald Gabrielse and Anton Khabbaz and their Bonn collaborators are able to make this comparison by loading a single antiproton and a single proton (saddled with two electrons, in order to make the proton into a negatively charged object) and lets them orbit (simultaneously) around an ion trap under the influence of a strong magnetic field. One has no reason to believe the proton and antiproton masses would be different, but this stringent new measurement constitutes the best test yet (by a factor of 10) of the CPT theorem (C stands for charge conjugation, P for parity inversion, and T for time reversal), which says that physics should not discriminate between particles, on the one hand, and antiparticles moving backwards in time on the other. These results were reported at the May 1998 APS Division of Atomic, Molecular, and Optical Physics meeting in Santa Fe, NM.

NEUTRINO OSCILLATION HAS BEEN DEMONSTRATED at the Super-Kamiokande lab in Japan to a higher degree of certainty than in previous experiments. Neutrinos, weakly interacting elementary particles only detected for the first time in 1956, are thought by some theorists to reside in a kind of schizoid existence; that is, a neutrino would regularly transform (or oscillate) among several alternative neutrino states, each having a slightly different mass. Such a theory would help to explain the apparent shortfall of neutrinos coming from the Sun. The oscillation proposition has been tested using four neutrino sources: the Sun, Earth's atmosphere, reactors, and particle accelerators. Some tests find tentative but ambiguous evidence for oscillation. At the Neutrino '98 conference in Takayama, Japan, the Super-Kamiokande collaboration (comprising 100 scientists from 23 institutions in Japan and the US) announced the most exacting evidence yet for neutrino oscillation. They study neutrinos made when cosmic rays from outer space strike the upper atmosphere. Some neutrinos, those made overhead above Japan, travel about 20 km or so before entering the underground detector. Other neutrinos, those made in the atmosphere on the far side of the globe, have a travel path of 12,700 km into the detector. In either case, they create, among other things, a high energy electron or muon, which in turn emits a telltale cone of light (Cerenkov radiation) observed by an array of thousands of photodetectors mounted in a tank filled with pure water. Sorting events by electron neutrino or muon neutrino, by high energy or lower energy, and by zenith angle (overhead approach or through the Earth), statistical evidence for oscillation becomes evident. A 1-GeV muon neutrino seems to oscillate every few hundred miles. Four years ago, the same group, using a smaller detector, reported preliminary evidence on the basis of 200 events (Physics Today, Oct 1994). The new report is based on several thousands of events, and provides an approximate mass difference (the test cannot render any neutrino species' mass directly) of about 0.07 eV. Because they are so numerous in the universe, neutrinos, with even a small mass, might play an important role in the formation of galaxies. (Y. Fukuda *et al*., *Phys. Rev. Lett*. **81**, 1562, 1998.)

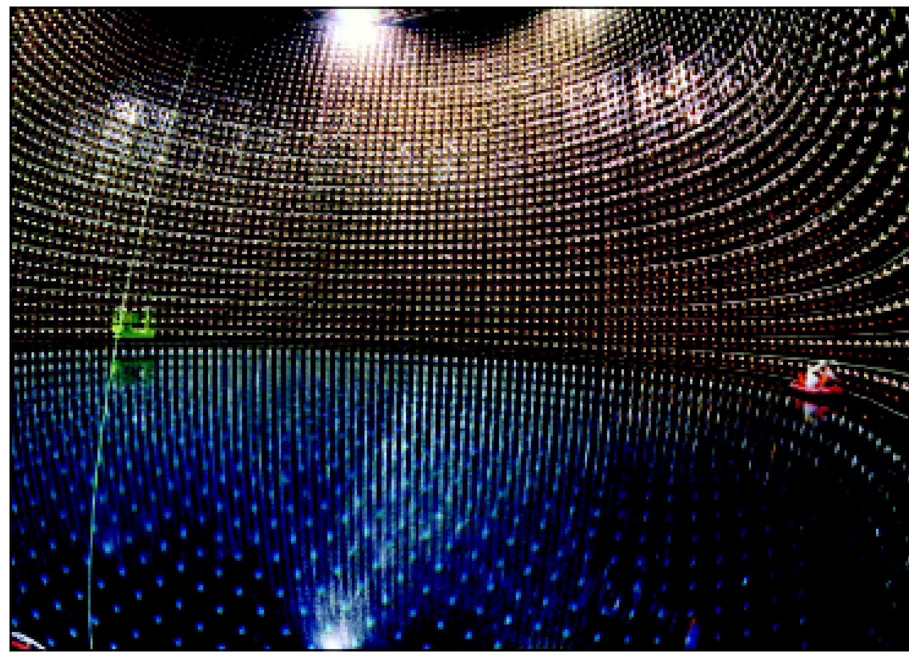


Photo of Japan's Super-Kamiokande detector, which observed evidence that neutrinos oscillate from one form to another. *[Courtesy ICRR (Institute for Cosmic Ray Research), The University of Tokyo.]*

THE ARROW OF TIME has been directly measured by two groups of physicists, one at CERN in Geneva (http://www.cern.ch/cplear/Welcome.html) and one at Fermilab (http://fnphyx-www.fnal.gov/experiments/ktev/ktev.html) near Chicago. Time reversal (T) is one of those symmetries, along with charge conjugation (or C, the operation which turns particles into antiparticles) and parity (or P, the reversal of a particle's coordinates from x,y,z to -x,-y,-z) that were once thought to be preserved in interactions at the atomic level. But then experiments showed that P, C, and the combination CP were not sacred. And since the triple symmetry of CPT is still thought to be valid, T by itself was thought to be vulnerable. That is, it is now thought that physics does differentiate between the forward or backward movement of time. The two groups have now seen evidence for this T violation in the observed decay rates for neutral K mesons. (Science, 2 Oct.; Science News, 31 Oct.)

INTERDISCIPLINARY PHYSICS/ MISCELLANEOUS TOPICS

CHAOS-BASED COMPUTING, a fundamentally new way to perform computations by exploiting the ubiquitous phenomenon of chaos, has been demonstrated in a simulation by researchers in India and the United States (Bill Ditto, Georgia Tech). Compared to digital computation, the chaos-based technique might come closer to how the brain performs computation, and might be superior in certain tasks such as pattern recognition. The computer consists of an interconnected grid of "chaotic elements," systems such as ammonia lasers which can generate unpredictable signals even though their behavior is governed by known mathematical equations. To encode specific numbers into each element, the researchers make specific signal patterns correspond to a number and ask each element to open its connection to the rest of the grid when it generates that pattern. Sending its signal out to the grid can trigger activity in neighboring elements. To carry out specific operations such as addition, the researchers connect the elements in a certain way. An unpredictable but deterministic avalanche of activity among the elements ultimately settles down to produce an unvarying signal that corresponds to the desired answer. Having demonstrated their technique in a computer simulation, the researchers are planning to test this idea with chaotic ammonia lasers and hybrid networks of nerve cells and silicon chips. (Sinha and Ditto, *Phys. Rev. Lett*. **81**, 2156, 1998.)

WATCHING A CHEMICAL REACTION with a scanning tunneling microscope (STM) can offer a unique way to determine chemical kinetics. A fundamental question of physical chemistry is how to link a reaction's kinetics—the rate equations as functions of macroscopic variables like temperature or pressure—with the underlying microscopic mechanisms responsible for the reaction. With the kinetics in hand, one cannot uniquely determine the elementary reaction steps. The reverse process is unique, but how does one determine the basic steps of a complex reaction in order to derive the kinetics? Now, a group at the Fritz Haber Institute in Berlin has done just that by watching the catalytic oxidation of carbon monoxide on a platinum surface—cooled to slow the reaction rate to match the speed of its STM. The sequence of atomic-scale images was then used to derive a rate equation, which was in excellent agreement with previously determined kinetics for this important reaction (which can remove CO from exhaust fumes).

speed up mixing by shrinking the size scale. The device consists of two channels intersecting at right angles and open to viewing through a coverslip from above. One fluid to be mixed flows under pressure through one channel. The second fluid enters the second channel, also under pressure, from both ends and converges at the intersection where it hydrodynamically focuses the first stream down to a size at which diffusion across it (mixing) takes mere microseconds. The mixed sample is delivered in a controlled laminar flow at rates of nanoliters per second. At this rate a shot of espresso would take a year to deliver. The Princeton mixer, frugal with expensive samples and compact enough to sit on a silicon chip, makes it possible to study fast reaction kinetics at previously unattainable time scales. For example, proteins fold in response to quick changes in concentration of the "denaturant" in the solvent surrounding them. (J. B. Knight *et al.*, *Phys. Rev. Lett.* **80**, 3863, 1998.)

A CARBON NANOTUBE TRANSISTOR has been built by researchers at Delft University of Technology in The Netherlands, providing a demonstration of room-temperature, carbon-based electronics at the single-molecule scale. In the device, a semiconducting carbon nanotube (only about 1 nm in diameter) bridges two platinum electrodes (400 nm apart) atop a silicon surface coated with silicon dioxide. An electric field applied to the silicon (by using a gate electrode) switches the flow of current along the nanotube on and off, thus controlling the movement of charge carriers onto it. Although carbon nanotubes are robust and durable molecules, they can't yet be made uniformly, and even a slight deviation from the desired radius or chirality can give the nanotube metallic properties (PHYSICS TODAY, March 1998, page 9). Nevertheless, the researchers speculate that many copies of their "TUBEFET"s may eventually be integrated into a circuit using molecular self-assembly techniques. (S. J. Tans *et al*., *Nature* **393**, 49, 1998.)

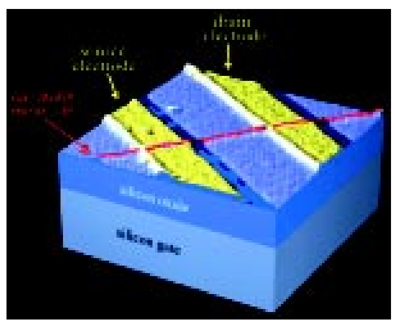
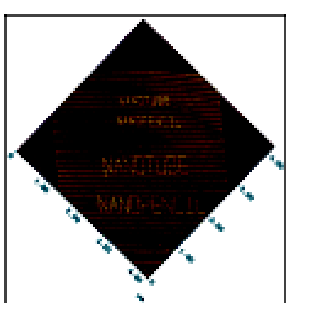


Diagram of a carbon nanotube transistor, an electronic device based on a single rolled-up sheet of carbon atoms. *(Courtesy Delft Institute of Technology, the Netherlands.)*

LITHOGRAPHY WITH CARBON NANOTUBES has been demonstrated on silicon by Hongjie Dai (Stanford University) and his colleagues. Ordinary graphite pencils write by wearing themselves down, but the researchers showed that a stiff, capped nanotube pencil can be very robust—a real boon to nanofabrication. The nanotube writes by means of an electric field emanating from the tip; the field removes atoms from a layer of hydrogen atop a silicon base. The exposed silicon surface then oxidizes, leaving 10 nm-wide SiO_2 tracks. According to Dai, such lines, spaced 100 nm apart, can readily cover a 100 mm^2 area in 100 s. He concludes that such nanotubes, "derived from bottom-up chemical synthesis may become the workhorse for top-down nanofabrication." (H. Dai, N. Franklin, J. Han, *Appl. Phys. Lett*.**73**, 1508, 1998.)



Atomic force microscope image of 10-nm-wide silicon dioxide lines and words "written" on a silicon substrate with a carbon nanotube tip. *(Courtesy Stanford University.)*

A PHOTONIC DOT MOLECULE, a pair of photons inside two interconnected boxes each acting as an artificial atom, has been constructed, opening new possibilities for fine-tuning the colors of light coming out of certain lasers. Having built two identical, micron-sized blocks of gallium arsenide, each with a light-producing quantum well, a German-US-Russian collaboration (Thomas Reinecke, Naval Research Laboratory) studied what happened when the two GaAs blocks were connected. In isolation, each photonic dot acted as a small confined area (a "microcavity") for light; photons with wavelengths roughly equal to the spaces between two of the cavity walls could bounce back and forth between them. When the two microcavities were connected, the researchers noticed a new, larger set of photon wavelengths, slightly different from the original ones. A highly analogous situation occurs with the wavelengths of electrons when the negatively charged particles group together in an atom or molecule. (Bayer *et al.*, *Phys. Rev. Lett.* **81**, 2582, 1998.)

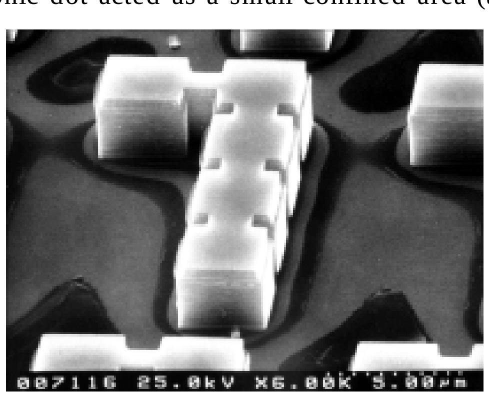
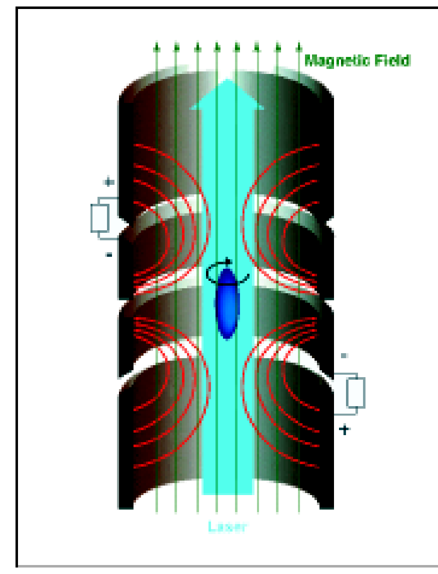


Image of a photonic dot molecule. *(Courtesy Alfred Forchel, University of Würzburg, Germany.)*

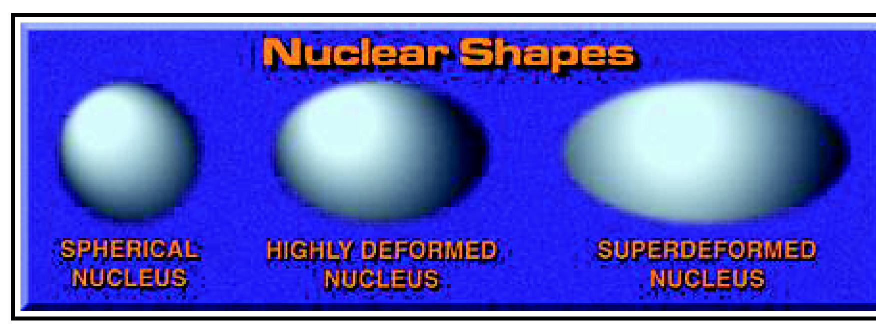
PARTICLE/NUCLEAR/PLASMA PHYSICS

STRONGLY COUPLED PLASMAS having particles with only one sign of charge in a "crystalline" state can now be confined for arbitrarily long times. These nonneutral plasmas are generally held in Penning traps, consisting of static electric and magnetic fields, and undergo a global rotation around the magnetic axis. Actively controlling this rotation is essential for the long-term confinement. First developed at University of California, San Diego, this technique rotates asymmetric electric fields to increase or decrease the plasma angular momentum, allowing moderate-temperature (up to 5 eV) plasmas to be confined for weeks. Recently, a group at the National Institute of Standards and Technology in Boulder, Colorado, applied this technique to laser-cooled, crystallized $^9Be^+$ plasmas at cryogenic temperatures, and demonstrated that the rotating crystals phaselock to the applied rotating fields. In this novel thermal equilibrium state, the density and ellipsoidal shape of the plasma can be directly controlled by changing the rotation frequency. This technique has already immensely improved plasma transport measurements and studies of the crystalline plasma state, and may be important for Penning trap atomic clocks and for trapping antimatter ions. (X.-P. Huang *et al.*, *Phys. Rev. Lett.* **78**, 875, 1997; F. Anderegg *et al.*, *Phys. Rev. Lett.* **78**, 2128, 1997.)



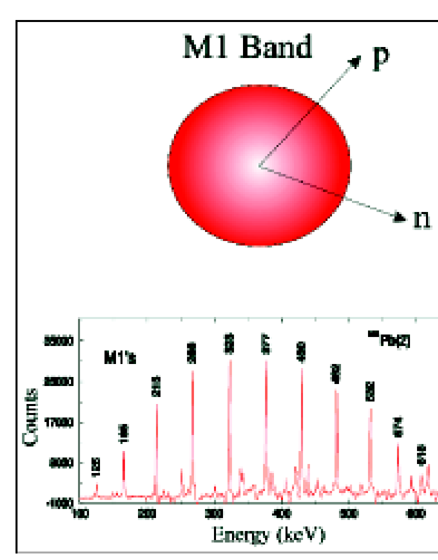
By employing electric and magnetic fields, a Penning trap can confine plasmas for arbitrarily long times. *(Courtesy NIST.)*

PROTON RADIOACTIVITY IN HIGHLY DEFORMED NUCLEI has been measured for the first time by a multinational team working at Argonne National Laboratory (Cary Davids, Argonne), offering insights into how the distorted shape of a nucleus can affect its radioactivity rates. A rare decay observed mainly in proton-rich isotopes of elements heavier than tin, proton radioactivity occurs when a nucleus ejects a single proton. Using Argonne's ATLAS accelerator to create holmium-141 and europium-131 nuclei, implanting them in a silicon-based detector, and measuring their rates of radioactivity and the energy of the emitted protons, the researchers noted that their data did not match the predictions of the standard theory of proton radioactivity, which assumes a spherically shaped nucleus. Their results only made sense when they used a newer model that allows them to consider the case in which the nucleus has a highly deformed shape, with a length approximately 1.5 times greater than its width (somewhat less distorted than "superdeformed nuclei" which have a ratio of about 2:1). Their data also allowed them to obtain experimental information on the lowest-energy state of a highly deformed nucleus. (Davids et al., *Physical Review Letters*, **80**, 1849, 1998.)



Representations of various nuclear shapes resulting from the internal arrangement of protons and neutrons. *(Illustration by Malcolm Tarlton, AIP.)*

MAGNETIC ROTATION OF NUCLEI, a fundamentally new phenomenon in nuclear physics, may expand the very notion of quantum rotation. It was the subject of a special session at the April 1998 meeting of the American Physical Society in Columbus, Ohio. For a quantum object, "rotation" and "spin" are distinct concepts. Spin is intrinsic to the object; rotation requires a preferred orientation in space—that is, spherical symmetry must be broken. Indeed, some nuclei have distorted shapes and radiate sequences of gamma rays corresponding to the nucleus slowing down its rotation. In the past few years, researchers have discovered that similar gamma-ray sequences are being emitted by nuclei (such as lead-198) known to be nearly spherical. So why do they seem to be rotating? Stefan Frauendorf of the Rossendorf Research Center in Dresden, Germany, has suggested that the gammas come from a reshuffling of the internal arrangement of just a few protons and neutrons. In the case of ^{198}Pb, two protons and four neutrons are like low-lying satellites skimming a planet of 192 non-participating nucleons. The circulating protons and neutrons generate angular momentum in different directions, in effect specifying an orientation for the nucleus. In addition, the six itinerant nucleons would create a sizable magnetic dipole, leading to the name "magnetic rotation." According to Rod Clark (Lawrence Berkeley National Laboratory), who chaired the session, an impressive body of evidence now exists to support this new concept. (For more information, see *Physics World*, July 1998.)



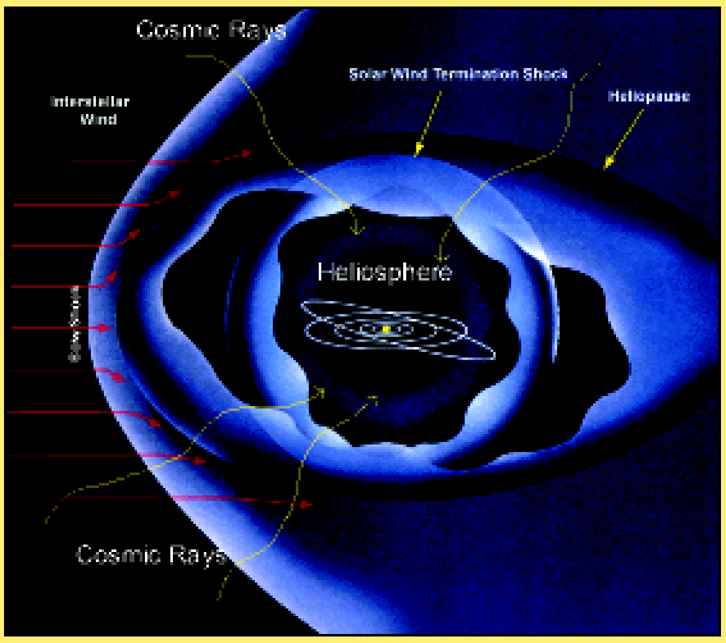
Gamma-ray spectrum of a "magnetically rotating" lead-199 nucleus. *(Courtesy Rod Clark, LBL)*

NEW IMPLICATIONS OF EXTRA DIMENSIONS have been explored by three physicists at CERN. Grand unified theories (GUTs) are the framework wherein three of nature's forces—strong, weak and hypercharge (the last being a better way of describing the electromagnetic force at energies above several hundred GeV)—come together as facets of one underlying force. It is generally assumed that these theories fully come into play only at the very high energies (10^{16} GeV) that prevailed in the very early (and hot) universe. The new proposal, however, makes the case that the unification energy can be considerably lower if extra spacetime dimensions exist. For example, a new dimension rolled up into a radius of 10^{-19} m would lower the GUT scale to the TeV range. That's because as an gallium arsenide between layers of aluminum gallium arsenide. On top of this sandwich sits a metal gate electrode which attracts electrons into the dot and controls the arrival or departure of electrons one at a time. Building up from just one electron, the MIT physicists collect a puddle of electrons and observe how the arrival of each newcomer must overcome (with the help of an increasing gate voltage) the mutual repulsion ("Coulomb blockade") of those already in place. For small dots (0.2 microns across) a graph of charge-vs-voltage would look like a staircase. Such an effect is at the heart of single-electron transistors (SET), which act as sensitive detectors of electrical charge (just as superconducting quantum interference devices—SQUIDS— are sensitive detectors of magnetic flux). For larger dots (0.5-1.2 microns across), containing fewer than several hundred electrons, the MIT scientists were astonished to observe an unexpected and mysterious pairing: for each stepwise voltage increase not one but two electrons were able to join the puddle. The pairing has not yet been explained but the data strongly suggest that it arises from a novel quantum effect that develops whenever electrons are localized into spatially isolated regions within the dots. For medium-sized dots (0.5 microns) the physics gets even weirder: the pairing occurs only for every fourth or fifth electron. The goal now is to understand the underlying pairing mechanism. (Paper K3.01 at March 1998 APS meeting in Los Angeles.)

ANTI-MEISSNER EFFECT. Chill a superconductor in the presence of a magnetic field. At the critical temperature superconductivity happens—resistance drops to zero—but at first only in an archipelago of tiny islands at the material's surface. If the sample is smooth enough, which is the case at Andre Geim's lab at the University of Nijmegen in the Netherlands, the superconductivity will extend uninterrupted all the way around the sample like a sheath 100 to 1000 atoms deep, trapping any magnetic flux that is in the sample. As the sample is cooled further the superconductivity regime takes over more and more of the interior, tightening the noose around the flux already inside. This in turn makes room for more flux to enter the outer precincts of the sample. In effect the sample attracts and promotes magnetism. This is an example of a paramagnetic (magnetic enhancement) Meissner effect, in contrast to the diamagnetic (magnetically neutralizing) Meissner effect customarily observed in superconductors. Geim's experiment, using micron-sized disks, is the first to measure this effect with a precision of better than one magnetic flux quantum. From his results, Geim argues two points: (1) that if samples have smooth enough surfaces the anti-Meissner effect would be more typical of superconductor behavior than the conventional Meissner effect; and (2) that since his sample is made of aluminum (a low-temperature superconductor) the anti-Meissner effect cannot be exclusive to high-temperature materials, suggesting that the effect cannot serve as direct evidence in favor of the idea that superconductivity in high-temperature materials is characterized by charge carriers that are so called d-wave Cooper pairs. (*Nature* **396**, 144, 1998.)

EARTH SCIENCE/SOLAR SYSTEM

NO CORRELATION EXISTS between solar neutrinos and sunspots, says Gunther Walther, a mathematician at Stanford. Neutrinos provide the only direct link between the Sun's core and Earth's surface, so physicists are eager to extract as much information as possible from their meager neutrino inventory, which includes those detected at the long-running detector in the Homestake Mine in South Dakota. Several studies found an anticorrelation between sunspots and neutrino flux, in which one goes up when the other goes down. Walther argues that all of those studies were based on a statistical fallacy: The statistical tests used were not really applicable to time-series data such as were examined. He could produce a false correlation with randomly generated data. He then demonstrated that the actual Homestake data showed no correlation with the solar cycle. Moreover, Walther feels that the dangers in using standard statistical tests for such time-series measurements are not properly pointed out in statistics textbooks; this problem has therefore gone unrecognized in many areas of scientific analysis. (G. Walther, *Phys. Rev. Lett*. **79**, 4522, 1998.)



The flux of galactic cosmic rays entering the inner solar system is modulated by the Sun's magnetic field. The cosmic rays, in turn, might play a role in seeding clouds in Earth's atmosphere, thereby affecting climate. *(Reported by H. Svensmark, Phys. Rev. Lett. **81**, 5027, 1998. Figure courtesy of the author.)*

MAPPING THE HELIOPAUSE from near-Earth space may be possible by monitoring the echo of solar extreme ultraviolet (EUV) radiation. The heliopause is the boundary, believed to be at least 120 astronomical units away, where the outgoing solar wind meets the incoming plasma of the local interstellar medium (LISM). Mike Gruntman (University of Southern California) and Hans Fahr (University of Bonn) have now calculated that the 83.4 nm resonance line from singly ionized oxygen at the heliopause will be brighter than the general EUV background at that wavelength, at least in the "upwind" hemisphere as the Solar System plows through space. Because both the heliopause's shape and the interstellar plasma's flow depend on the interstellar magnetic field, mapping the heliopause in three dimensions can tell us much about the LISM. The measurements can even be calibrated, along one line of sight, when the Voyager I spacecraft (now 67 AU away) eventually reaches the region. (M. Gruntman, H. J. Fahr, *Geophys. Res. Lett*. **25**, 1261, 1998.)

EARTH VIBRATES CONTINUOUSLY even without help from earthquakes. Scientists from the University of California at Santa Barbara, and the Tokyo Institute of Technology have analyzed gravimeter data from 1983 to 1994 and eliminated all data for days that had earthquakes or their aftermaths. They were left with 61 days that were seismically quiet enough to look for Earth's natural oscillation modes, and indeed found several such spherical modes in the 2–7 mHz range. The attendant acceleration of material in the solid Earth is tiny, on the order of a nanogal, or 10^{-9} cm / sec^2. The origin of the "ringing" is still mysterious. The data seem to rule out a cumulative effect of very small earthquakes, but very slow, "silent" earthquakes could be responsible. Another possible cause is atmospheric effects, primarily wind turbulence on a 1–10 km size scale, which can generate the observed accelerations. The researchers are now vigorously looking for seasonal variations in the data, which would support the atmospheric hypothesis. (T. Tanimoto *et al*., *Geophys. Res. Lett*. **25**, 1553, 1998.)

A SUN–EARTH CONNECTION EVENT, in which a gust of plasma particles (a coronal mass ejection, or CME) detaches from the Sun and travels all the way to our planet, where it can cause electromagnetic disturbances and auroras, has been monitored from beginning to end for the first time. A global network of ground-based and satellite detectors, collectively known as the International Solar–Terrestrial Physics program, watched the drama play out on 6–11 January 1997. In this composite image, the CME—coming directly at us—appears in the SOHO satellite's coronagraph as a halo around the southern limb of the Sun, and the superimposed Sun's surface (as seen in x rays by the Yohkoh satellite) shows the bright active region responsible for the CME. (More than 20 articles in *Geophys. Res. Lett*. **25** (14), 15 July 1998.)

NANOTECHNOLOGY

SINGLE-WALLED CARBON NANOTUBES can be either semiconductors or metals, two independent teams have now conclusively demonstrated. Shortly after nanotubes were discovered in 1991, theorists predicted that these seamless rolled-up sheets of carbon hexagons could be either metals or semiconductors, depending on the tube diameter and the helicity—related to the corkscrew-like angle at which the flat carbon sheets are rolled. Using scanning tunneling microscopes (STMs), a team from Delft University of Technology and Rice University and, separately, a Harvard group have confirmed the relation between tube morphology and conductance, by relating atom-scale images of the nanotubes to tunneling-current measurements of the electron density of states. An unexpected finding from the STM images was that nanotubes exist with a wide range of helicities, not just wrapped at preferential angles, as previously thought. (J. W. G. Wildöer *et al.*, *Nature* **391**, 59, 1998. T. W. Odom *et al.*, *Nature* **391**, 62, 1998.)

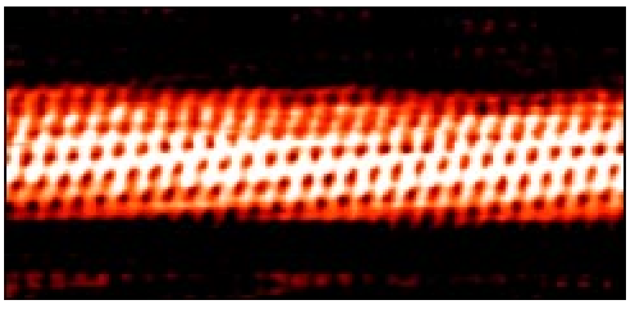
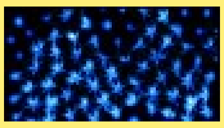


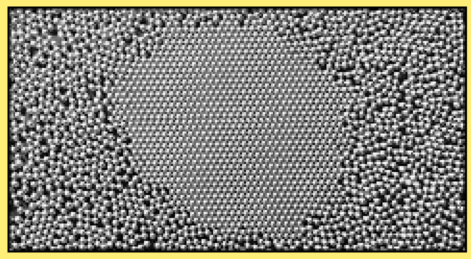
Image of a carbon nanotube taken by a scanning tunneling microscope. *(Image copyright DIMES Institute at Delft University of Technology, the Netherlands. Reprinted with permission.)*

BIG LIGHT THROUGH LITTLE HOLES. Apertures smaller than the wavelength of light shouldn't transmit much of that light. So it came as a surprise to Thomas Ebbesen (NEC Research Institute, Princeton, New Jersey; Louis Pasteur University, Strasbourg, France) when he illuminated an array of subwavelength holes (150 nm diameter, 900 nm apart, in a silver film coating a quartz substrate); at selected wavelengths (up to ten times the size of the holes), plentiful amounts of light came out the other side. In fact, more than twice as much light was transmitted as impinged directly on the holes' total area. The leading explanation is that the light couples to surface plasmons, electronic excitations at conductor–insulator interfaces. Adding to the mystery, however, is that the transmission was the same whether the light entered the array from the air or from the quartz. Ebbesen and his colleagues believe that their arrays, which transmit light at special wavelengths, will complement photonic crystals, which exclude light at special wavelengths. (T. W. Ebbesen, et al., *Nature* **391**, 667, 1998.)

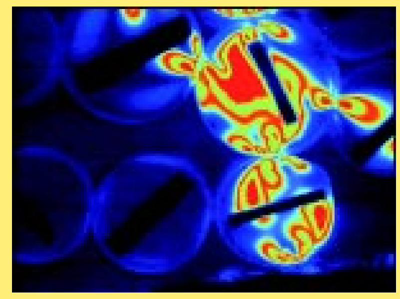
MICROFLUIDICS: MIXING NANOLITERS in microseconds. Princeton University researchers have built a tiny mixing vessel in which a submerged fluid jet (pinched down to a waist as small as tens of nanometers) is used to achieve fluid mixing times of less than 10 ms. Mixing, being diffusion driven, is normally a slow process on macroscopic scales but can be sped up by introducing turbulence. Turbulence, however, is difficult to predict and control, so the researchers looked to



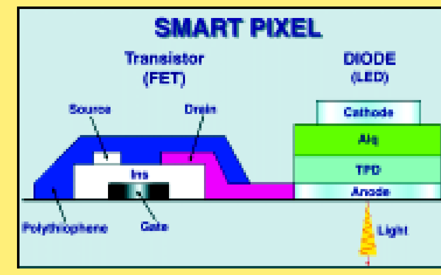
An Argentina-US collaboration has produced the first microscopic images of the magnetic vortices in a superconducting material near the critical current. Here is an electron-microscope image of flowing magnetic vortices. *(Reported by Pardo et al., Nature **396**, 348, 26 November 1998; image courtesy of the authors.)*



In an investigation of how granular materials behave, Georgetown researchers observed steel balls "crystallizing" into a condensate which is at rest, even as other balls continue to move about. *(Reported by Olafsen and Urbach, Phys. Rev. Lett. **81**, 4369, 1998; figure courtesy of the authors.)*



Aiming to better understand how particles within a granular material interact with each other, a Duke researcher set into motion a collection of disks around a rotating table. Stresses between the disks were determined by measuring subtle changes in the polarization of light reflected from them. The black bars indicate the disks' orientation. *(Courtesy Robert Behringer, Duke Univ.)*



A schematic of a "smart pixel," a light-emitting-diode (LED) under the control of a field-effect transistor (FET). *(Reported by Dodabalapur et al., Applied Physics Letters, July 13, 1998. Figure adapted by Malcolm Tarlton, AIP, from an illustration, courtesy of A.N. Dodabalapur, Bell Labs.)*

first developed for microwaves, then for infrared wavelengths. Now, MIT scientists have fashioned a silicon structure that forbids light over a wide range—roughly from 1.3 to 1.7 mm. Light at those wavelengths is defeated by multiple reflections from the regularly spaced 0.2 mm diameter holes. By breaking the periodicity of the holes, the MIT group effectively introduced a "defect" that acted like a tiny optical microcavity with a volume of only 0.055 mm^3. As first noted by Ed Purcell in 1946, confinement in such a cavity can enhance spontaneous emission, an effect clearly seen in this device. The crystal effectively became a filter, allowing the transmission of a single mode of light in a narrow band at 1.54 mm (a crucial wavelength for fiber-optic communications), but cutting out light at surrounding wavelengths. (J. S. Foresi *et al.*, *Nature* **390**, 143, 1997.)

ELECTRON HOLOGRAPHY, using low energy electron diffraction (LEED), can provide a three-dimensional, atomic-resolution image of a complex, ordered surface structure. In conventional holography, one part of a split laser beam (the object beam) is scattered from an object while another part (the reference beam) is left unscattered. The two beams meet in a piece of film where they inscribe an interference pattern that, when reconstituted, renders a three-dimensional image of the object. Now, Klaus Heinz, Uli Starke and their colleagues at the University of Erlangen-Nürnberg in Germany have done an experiment in which all of this happens on a nanoscopic level, and with electron waves instead of light waves. When a low-energy electron beam strikes a surface, any prominent atom can be thought of as a beam splitter, creating a reference electron wave—scattered directly back to the detector—and an object wave after subsequent scattering by neighboring atoms. From the measured electron diffraction pattern, a three-dimensional image of the local environment of the beam-splitting atom can be reconstructed. This information is then used iteratively, with conventional LEED, to elucidate the entire structure of a complex unit cell, as long as there is only one prominent atom. The researchers determined the structure of a reconstructed surface of SiC, a potentially important material for electronics applications. (K. Reuter *et al.*, *Phys. Rev. Lett.* **79**, 4818, 1997.)

QUANTUM BOXES FOR COOPER PAIRS. Quantum dots, comparable in size to an electron's wavelength, are used to study how spatial confinement alters allowed electron energies. Recently, a European team of scientists, led by Andre Geim of The Netherlands, has built such a box for Cooper pairs, the doublets of electrons that form in superconductors. Essentially studying the size dependence of superconductivity, the researchers monitored the magnetization of individual superconducting aluminum disks ranging in size from 0.1 mm up to 2.4mm for a variety of temperature and field conditions. Their "ballistic Hall micromagnetometer" is shown here with disks in four of the five sensitive areas. They found both first- and second-order phase transitions between numerous superconducting states, and even "fractional" flux jumps. They can explain most of this unexpected diversity of superconducting behavior using the nonlinearized Ginzburg–Landau equations. (A. K. Geim *et al.*, *Appl. Phys. Lett.* **71**, 2379, 1997; A. K. Geim *et al.*, *Nature* **390**, 259, 1997; P. S. Deo *et al.*, *Phys. Rev. Lett.* **79**, 4653, 1997.)

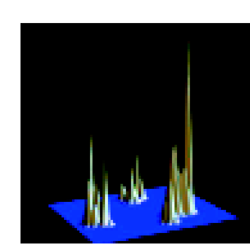
HIGH-PRESSURE SULFUR IS A SUPERCONDUCTOR. When squeezed in a diamond anvil press, sulfur undergoes a number of changes, including a transition from insulator to conductor at about 90 GPa (about 10,000 atmospheres). Now, scientists from the Carnegie Institution of Washington and the Institute of High-Pressure Physics in Troitsk, Russia, have found an unpredicted superconducting transition at 93 GPa, with a T_c of 10.1 K. Above 162 GPa, T_c went up to 17 K, the highest yet for any elemental solid. Sulfur's unexpected behavior should provide a testing ground for theories of superconductivity. (V. V. Struzhkin *et al.*, *Nature* **390**, 382, 1997.)

TWO FORMS OF LIQUID WATER may coexist at very low temperatures, possibly shedding light on why water has such unusual properties compared to other liquids. For example, below 4 °C, water shrinks when warmed whereas most other liquids expand when heated (PHYSICS TODAY, April 1996, page 9). Two recent studies of supercooled water have found what looks like a phase transition between two different liquid forms, both lacking long-range order. Mixtures of different liquids are common, but evidence for two liquid phases of a single pure substance has not been seen before. Osamu Mishima and Eugene Stanley studied the melting curve of ice IV and found it consistent with a liquid–liquid phase transition. Meanwhile, Marie-Claire Bellissent-Funel reached a similar conclusion from a two-level model of water and neutron diffraction studies. The two phases have different densities, reflecting perhaps different clusterings of H_2O molecules at short distances. Supercooled water occurs naturally in stratospheric clouds and cells of all plants that survive subzero temperatures, lending a practical aspect to the investigations. (O. Mishima, H. E. Stanley, *Nature* **392**, 164, 1998. M.-C. Bellissent-Funel, *Europhysics Lett.* **42**, 161, 1998.)

QUANTUM EVAPORATION from a pool of superfluid helium-4 has demonstrated directly that the evaporated ^{4}He atoms had been part of a Bose–Einstein condensate (BEC) in the liquid—that is, the atoms were in a single macroscopic quantum state with zero momentum. In his experiment, Adrian Wyatt of the University of Exeter, in England, used a well-collimated beam of phonons, aimed at the liquid surface from below, to pop helium atoms up out of the liquid, much like light ejects electrons from a surface in the photoelectric effect. By measuring the momenta and energies of the phonons and the evaporated atoms, Wyatt found that the atoms originally had zero momentum parallel to the surface, and thus came from a BEC. Theories of superfluid ^{4}He had supposed this to be the case, but it had not been experimentally verified until now. (A. F. G. Wyatt, Nature 391, 56, 1998.)

SUPERCONDUCTIVITY-DEPENDENT FRICTION. Despite the tremendous industrial importance of friction, much remains unknown about its fundamental origins. Now, a Northeastern University group led by Jacqueline Krim has found a new clue at the nanometer scale. They used a delicate quartz microbalance that incorporated a lead substrate 150 nm thick, topped off with a layer of frozen nitrogen only 1–2 molecules thick. The microbalance was jiggled back and forth at 8 MHz, with the overlying nitrogen slipping and sliding along on the ride. Previously, the researchers measured exceedingly tiny frictional shear stresses with this approach. This time, an unexpected finding emerged: When the lead substrate was chilled below its superconducting transition, the friction between it and the solid nitrogen dropped by half. Krim says this is the first direct experimental evidence that conduction electrons can contribute to friction. (A. Dayo, W. Alnasrallah, J. Krim, *Phys. Rev. Lett.* **80**, 1690, 1998.)

LOCALIZATION OF NEAR-VISIBLE LIGHT has been achieved by a Florence–Amsterdam collaboration. In a disordered medium such as a cloud or milk, light waves scatter repeatedly, which leads to common diffusion of light. In the new experiment, the medium had such a high index of refraction (gallium arsenide powder, with very low absorption at a wavelength of 1064 nm) that the light's electric field could not oscillate even once before scattering. This led to huge interference effects that, in essence, halted the diffusion and trapped the light within the medium. Diederik Wiersma calls this a new electromagnetic phenomenon—the optical counterpart of the metal–insulator transition of electrons in a disordered system. (D. S. Wiersma et al., *Nature* **390**, 671, 1997.)

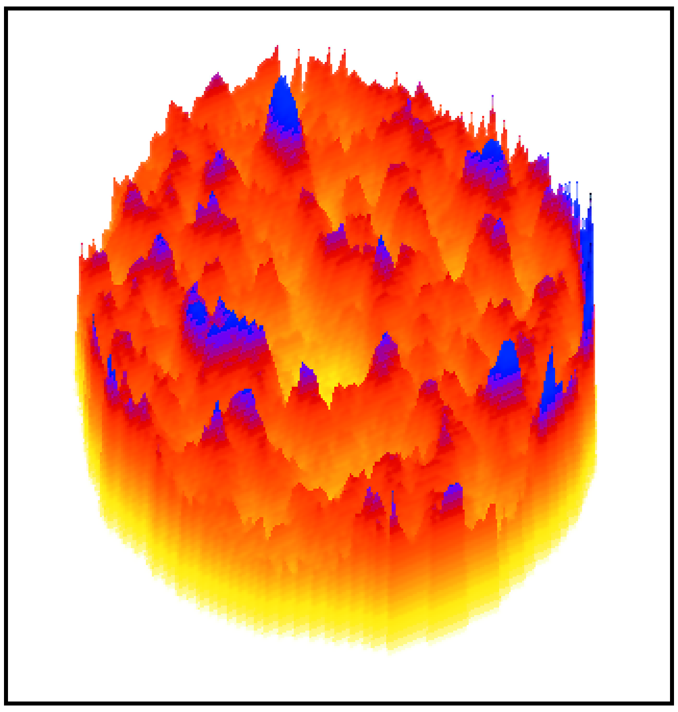


Intensity peaks of light localized in a medium with a high index of refraction. *(Courtesy Ad Lagendijk, Van der Waals-Zeeman Laboratory, the Netherlands.)*

A NEW FORM OF SOLID CARBON, based on carbon-36 molecules, has been predicted and then created by separate groups at Lawrence Berkeley National Laboratory. The theorists, led by Marvin Cohen and Steven Louie (who are also at the University of California, Berkeley), showed that a highly symmetric crystal of covalently bonded C_{36} molecules should form. (Solid C_{60} is held together by weak van der Waals forces.) They also suggest that, because the C_{36} fullerene has higher curvature than its larger cousin, the C_{60} buckeyball, its solid form will also have a stronger electron–phonon coupling and thus a higher superconducting transition temperature—perhaps as high as for ceramic superconductors. Alex Zettl and his colleagues synthesized the new bucky-lite and extracted it—as liquids, powders and films—from the general stew of fullerenes created in an electrical arc flashing between two graphite electrodes. The material had the expected symmetry and covalent bonds. (M. Côté et al., *Phys. Rev. Lett.* **81**, 697, 1998. C. Piskoti *et al.*, *Nature* **393**, 771, 1998.)

WEIRD BEHAVIOR IN QUANTUM DOTS. Interesting things happen when particles are confined in a tiny box. Researchers at MIT led by Raymond Ashoori make themselves such a box, a quantum dot, out of semiconductors—a layer of

FRACTAL PATTERNS INSIDE CELLS CAN REVEAL BREAST CANCER, scientists at the Mount Sinai School of Medicine have successfully shown. Pathologists must traditionally detect breast cancer through subjective means by studying individual cells from suspicious tissue and checking for abnormal-looking cell shapes and features. Analyzing images of actual breast cells, the Mount Sinai researchers have looked within the cell nucleus to study the distribution of chromatin, DNA-protein compounds which contain the chromosomes in a cell. Like many other biological structures in nature, chromatin forms a fractal pattern; that is, the arrangement of chromatin looks similar over a range of size scales. Applying their technique to cells from 41 patients (22 of whom were known to have breast cancer through independent means) the researchers correctly diagnosed 39 out of 41 cases (95.1% success rate) in a blind study. They did this by measuring differences in lacunarity (the largeness of gaps between chromatin regions in the nucleus) and by detecting differences in fractal dimension (which describes how fully a fractal object fills up the space that it occupies) between benign and malignant cells. (Einstein *et al.*, *Phys. Rev. Lett.* **80**, 397, 1998.)



Surface plot of a malignant breast epithelial cell nucleus. *(Courtesy Andrew Einstein, Mount Sinai School of Medicine.)*

ELECTRIC NOISE can increase human tactile sensation. Researchers at Boston University and the University of Massachusetts Medical Center applied a normally undetectable mechanical force, along with a low level of randomly fluctuating electrical current, to the finger pads of 11 young, healthy subjects. At some specific value of the electrical "noise," 9 of the subjects reported detecting the mechanical stimulus—a clear signal that stochastic resonance (SR) was at work. (For a review of SR—the phenomenon whereby a subthreshold signal is detectable in the presence of noise—see PHYSICS TODAY, March 1996, page 39.) In most SR experiments, the signal and the noise are of like kind (for example, mechanical). The researchers speculate that the electrical noise helps nerve cells in the finger pads to reach their threshold for firing. The finding could have clinical uses for enhancing the sense of touch in the elderly, in stroke patients and in people with diabetes. There could also be applications in telerobotics and new micro devices. (K. A. Richardson *et al.*, *Chaos* **8** (3), 1, 1998.)

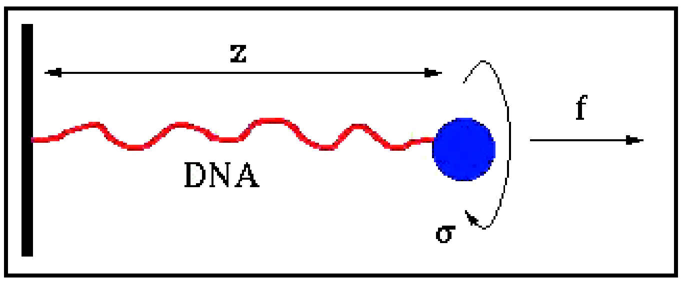
PHYSICS OF POSTURE CONTROL. Any infant, or robot designer, knows that standing on two feet is nontrivial. To understand this process better, scientists at Boston University have put subjects on a special force-sensitive platform, which records the minutiae of the individuals' swaying motions. Subjecting the digitized information to a statistical analysis, they found that the fluctuation–dissipation theorem applied. An important conclusion was that the human postural system strives to maintain an upright posture in the same way whether the subject is standing at ease or is being perturbed by a slight external push. In other words, static and dynamic posture control are the same. This finding is of great interest to those who treat patients with apparent balance problems; now, frail patients needn't be pushed, thus avoiding potential injuries. (M. Lauk *et al.*, *Phys. Rev. Lett.* **80**, 413, 1998.)

ACOUSTIC SURGERY uses sound to perform such tasks as destroying tumors and stopping internal bleeding. In June 1998, at the joint meeting in Seattle of the International Congress on Acoustics and the Acoustical Society of America, Gail ter Haar of the Royal Marsden Hospital in Sutton, England, described a clinical trial in which focused ultrasound destroyed parts of liver, kidney and prostate tumors in 23 patients. Just as sunlight sent through a magnifying glass can burn a leaf placed where the light converges, sound broadcast through a specially shaped transducer can converge inside the body to create a precisely targeted region of intense heat that can destroy tissue. The spot is so small that the boundary between destroyed and completely unharmed tissue is only six cells—a precision that is finer than any knife can achieve. Ter Haar said the next phase is to attempt complete destruction of tumors in the liver and prostate. At the same meeting, Roy Martin of the University of Washington discussed the use of ultrasound to stop internal bleeding in the liver. Just as a grill sears a steak, the focused sound waves heat the bleeding area to create chemical and physical changes that cauterize it. Otherwise, liver surgery (including the removal of tumors) is often hampered by bleeding that is difficult to stop with conventional cauterizing methods, Martin said.

A SINGLE PRESELECTED MOLECULE OF DNA can be attached to a silicon surface using an "optical tweezer." In their demonstration, researchers at Rockefeller University first attached DNA molecules to latex beads in water. Then, using a focused laser beam—the optical tweezer—they found and trapped a bead with only one DNA attached. Next, the silicon surface (the tip of an atomic force microscope) and the bead were brought into contact, and the heat from the laser "welded" them together in a reversible manner. The composite tweezer–AFM tool enables the DNA to be manipulated with great flexibility, retains the biological functionality of the DNA and offers the possibility of studying DNA and protein interactions. For example, beads with known DNA sequences could be grafted into a regular array on a silicon substrate. (G. V. Shivashankar, A. Libchaber, *Appl. Phys. Lett.* **71**, 3727, 1997.)

THE PHYSICS OF THE IMMUNE SYSTEM. When antigens (viruses, poisons, etc.) invade the body, the vigilant immune system first senses the danger and then produces an appropriate response. To do this, the defenders, a fleet of lymphocytes possessing as many as 10^{11} molecular receptors, must perform a vast program of pattern recognition. A theory from the 1970's proposed that this process could be compared to a self-regulating, multiply connected network of agents. Physicists in Brazil have now taken the next step by simulating the immune performance with a system of cellular automatons, and have successfully modeled the actual behavior of the mouse immune system. Rita Maria Zorzenon dos Santos of the Universidade Federal Fluinense and Americo Bernardes of the Universidade Federal de Ouro Preto have even been able to simulate correctly the effects of aging on the immune response. At the heart of their model is a "shape space" of possible receptor attributes including, for example, electrical charge, receptor geometry, and degree of activation. Zorzenon dos Santos believes that work on the immune system might offer insights into the behavior of complicated physics systems operating at far from equilibrium conditions. The next step for her immune research is the attempt to model the evolution of HIV infection and to study the way in which lymphocytes are activated in response to malaria. (*Phys. Rev. Lett.* **81**, 3034, 1998.)

A TORQUE WRENCH FOR DNA, an experimental tool for twisting the double-helix molecule at one of its ends, can yield once-elusive information on its mechanical properties. DNA is much more than a database of genetic information; it is a versatile machine that can duplicate itself, build and repair cells, and regulate cell functions. By attaching one end of a DNA molecule to a surface and affixing a tiny magnetic bead to the free end, experimentalists in France devised a clever way to twist a single molecule and stretch it with external magnets (T.R. Strick *et al.*, *Science*, **271**, 1835, 1996). But with heat constantly jiggling the molecule and introducing complicated motions, physicists once feared these experiments would not provide useful data. Now, two theory groups have independently filtered out the contributions of this random motion. Considering a DNA molecule going from an unstretched state to a stretched state, they factor in the possible combinations of random twists and bends that the DNA molecule can exhibit in going towards its final outstretched state. With this theoretical contribution, the experiments can now provide a new determination of an elusive mechanical parameter of DNA, its twisting stiffness (C. Bouchiat and M. Mezard, *Phys. Rev. Lett.*, **31**, 6333, 1998; J.D. Moroz and P. Nelson, *Macromolecules* **80**, 7, 1998.)



Tethering one of DNA's ends to a surface, attaching a magnetic bead to its other end, and applying a magnetic force, researchers can twist a DNA molecule, providing hard-to-obtain information on its mechanical properties. *(Courtesy Phil Nelson, University of Pennsylvania)*

CONDENSED MATTER/MATERIALS PHYSICS

THE 1998 PHYSICS NOBEL PRIZE went to Robert B. Laughlin of Stanford, Horst L. Stormer of Columbia, and Daniel C. Tsui of Princeton for their work on the fractional quantum Hall effect at the MIT magnet laboratory, a drama acted out in the two-dimensional world at the interface between two semiconductor crystals. As is the case with quantum phenomena, the act of confinement (the two-dimensional electron gas, or 2DEG, imprisoned between the semiconductors) leads to quantization. A plot of Hall conductivity versus field strength is not linear but stepwise. In other words, nature does not permit just any resistance, but only certain resistances dictated by fundamental quantum principles. The specific choice of semiconductor does not play a part. Klaus von Klitzing discovered this "quantum Hall effect" in 1980 and would win the physics Nobel Prize in 1985. So exacting is the quantization of conductivity (better than a part in many millions) that von Klitzing's experiment has since been used to define the unit of resistance. Stormer and Tsui would carry this research further. At even colder temperatures and higher magnetic fields, they discovered steps within the steps. This "fractional quantum Hall effect" (FQH) was at first hard to explain. Robert Laughlin surmised that the electrons were combining with the flux quanta of the magnetic field. One side effect of Laughlin's conjecture was that excitations of the FQH electron ensembles could have fractional charges. That is, the ensembles acted as if they were supporting excitations (quasiparticles) with an electrical charge which was a non-integral multiple of the basic electron charge. This hypothesis was later experimentally verified. (Background articles in *Physics Today*, June 81, July 83, Dec 85, Jan 88, Jul 93, Oct 97, Nov 97; *Science*, 19 Sep 97 and 17 Feb 1995; *Nature*, 11 Sep 97.)

PHOTONIC-CRYSTAL FILTERS. Just as semiconductors exclude the movement of electrons in certain energy bands (with important implications for useful electronic devices), photonic crystals exclude the passage of photons in certain wavelength bands. Also called photonic bandgap materials, these crystals were

NONLOCALITY GETS MORE REAL. "Bell's Inequalities" refers to a set of mathematical relations that prohibit distant quantum particles from influencing on each other at seemingly instantaneous rates. In three recent experiments, the inequalities have now been violated over record large distances, with record high certainty, and with the elimination of an important loophole. In 1997, researchers from the University of Geneva led by Wolfgang Tittel showed that pairs of entangled photons, sent through a fiber-optic network to detectors in villages 10 km apart, remained correlated. Now, they've shown that such distant photons violate Bell's inequalities by at least 9 sigma. At the Optical Society of America meeting in Baltimore in October 1998, Paul Kwiat of Los Alamos and his colleagues announced that they had built an ultrabright source of entangled photon pairs; using it, they obtained a 242-sigma violation of Bell's inequalities. Meanwhile, a University of Innsbruck group led by Anton Zeilinger performed Bell measurements with detectors 400 m apart that randomly switched between settings rapidly enough to eliminate the "locality loophole," and obtained a 30-sigma violation. (W. Tittel *et al., Phys. Rev. Lett.* 81, 3563, 1998; G. Weihs *et al., Phys. Rev. Lett.* **81**, 5039, 1998.)

TRIPLE PHOTOIONIZATION OF LITHIUM, a rare process in which a single photon removes all three electrons simultaneously from the atom, has been detected for the first time by a Japan–US collaboration. At the KEK Photon Factory in Tsukuba, Japan, an intense beam of extreme-ultraviolet (EUV) photons broadsided a beam of neutral lithium atoms, and Li^{3+} ions were collected. In the simplest picture of the process, an EUV photon transfers virtually all of its energy to a single electron; any multielectron processes must then arise from correlation effects among the electrons. Auger (autoionization) processes play no role because they would leave behind at least one bound electron. Other groups have previously observed triple photoionization of heavier atoms, such as neon, but those events do involve Auger-type internal rearrangements of other electrons in the atom at photon energies well above the triple ionization threshold. (R. Wehlitz *et al., Phys. Rev. Lett.* **81**, 1813, 1998.)

AN IMPROVED VALUE OF PLANCK'S CONSTANT has been obtained by physicists at the National Institute of Standards and Technology in Gaithersburg, Maryland. The new value for *h* of 6.62606891 x 10^{-34} Joule-sec, with an uncertainty of 89 parts per billion, instantly improves the accuracy of values for related fundamental constants (such as electron mass, proton mass, elementary charge and Avogadro's number) and paves the way for a quantum-based definition of mass. The experiment, first proposed by Brian Kibble of the UK's National Physical Laboratory in 1976, used a moving-coil watt balance—an apparatus with a kilogram mass connected to a metal coil in a magnetic field—that makes use of the Josephson and quantum Hall effects. First, the researchers allowed the coil to move downward, measuring its velocity and the voltage it generated. Next, they sent a current through the coil, which created an upward magnetic force that exactly balanced the downward force of gravity on the mass. The researchers were able to extract the value of *h* from their data, in which factors such as the geometry of the setup canceled out. (E. R. Williams, R. L. Steiner, D. B. Newell, P. T. Olsen, *Phys. Rev. Lett.* **81**, 2404, 1998.)

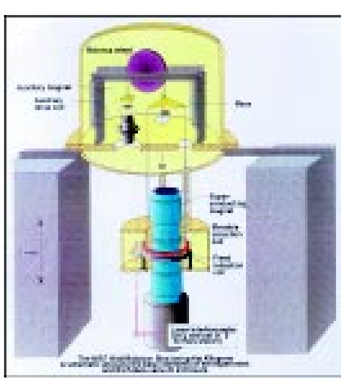


Illustration of a "watt-balance" system for performing a high-precision measurement of Planck's constant. *(Courtesy NIST)*

SIMPLE, PRECISE, COHERENT CONTROL of a molecular wavepacket has been achieved by Stephen Leone's group at the Joint Institute for Laboratory Astrophysics, University of Colorado and National Institute of Standards and Technology. In the experiment, an excited electronic state of Li_2 was "pumped" by a broadband, phase-modified femtosecond laser pulse into a superposition of two rotational states. The resulting wavepacket was monitored by a second, time-delayed "probe" pulse. Both pulses can have carefully shaped phases (created with the help of simple microscope coverslips and mirror holders) to encode information in the molecule during either the excitation or detection process. For example, the pump pulse contains the spectral components needed to excite the two rotational states. By varying the relative phases of the components, the experimenters were able to directly control the time evolution of the wave packet. On the other hand, by using a carefully defined probe pulse acting as a highly selective filter, they were able to extract detailed information from a wavepacket initially prepared by a poorly defined pump pulse. The ability to coherently control atoms and molecules has a direct impact not only on the field of quantum dynamics, but also on technologies such as optical communications and information storage. (R. Uberna *et al., J. Chem. Phys.* **108**, 9259, 1998.)

IMMISCIBLE QUANTUM LIQUIDS. The wavelike overlap of cooled alkali atoms known as Bose Einstein condensation (BEC) represents a new form of condensed matter in which physicists can pursue studies of fluid dynamics, sound propagation, persistent currents, and many of the coherence phenomena occurring in other "super" states such as superfluids and superconductors. One notable BEC innovation introduced in the past year by Wolfgang Ketterle and his colleagues at MIT was the development of an all-optical trap which can hold condensate atoms in a number of distinct (hyperfine) internal states. And just as helium-3 (which has a magnetic substructure) is a more complex superfluid than nonmagnetic helium-4, so the multi-component MIT condensate ought to exhibit behavior not seen in single-component BEC. Indeed, at the New Horizons in Science meeting in Boston in October 1998 Ketterle reported that when he immersed his BEC in a uniform magnetic field and a stream of radio waves, those portions of the condensate in different hyperfine states (m=0 and m=1) quickly segregated themselves into alternating domains (differing in energies equivalent to only a few nanokelvins) as if they were oil and vinegar. Furthermore, these layers unexpectedly persist; in effect this arrangement of the condensate constitutes a metastable macroscopically occupied excited state. (See also Stenger *et al., Nature* **396**, 345,1998.)

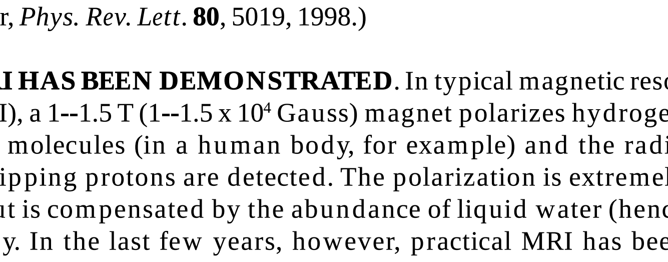
A SINGLE FAR-INFRARED (FIR) PULSE has been imaged by two physicists at Rensselaer Polytechnic Institute in Troy, New York. Conventional photography records the visible world at wavelengths of 300–800 nm. Two-dimensional images at near-infrared wavelengths (around 1 mm) are also available. Doing spectroscopy or making pictures or movies at even longer wavelengths (up to 1 mm or, equivalently, down to terahertz frequencies) is difficult but desirable. Difficult in part because there have been no reliable, fast detectors for this region of the electromagnetic spectrum; desirable because many molecules (including some found in pollutants, diseased tissue and explosives) have rotational and vibrational transitions at FIR wavelengths. Now, Xi-Cheng Zhang and Zhiping Jiang have found a way to measure the actual waveform—the electric field as a function of time (over a 25-ps period) and one-dimensional space (over a 10 mm span)—of a single THz burst of radiation. They encode the THz signal onto an optical light pulse that has been stretched from 200 fs to 20 ps in a process called chirping. The combined signal is later decoded and imaged with a video camera, yielding a real-time image of an FIR pulse, not just a sequence of stroboscopic samplings of many pulses over a long time period. The researchers believe that their method provides the highest possible data acquisition rate, and will be valuable for studying fast phenomena such as flames. (Z. Jiang, X.-C. Zhang, *Optics Lett.* **23**, 1114, 1998.)

SUREFIRE QUANTUM ENTANGLEMENT, the ability to interlink two quantum particles with practically 100% certainty, has been achieved by a NIST group (Quentin Turchette), advancing hopes for ultrapowerful quantum computers. Previously, physicists obtained entangled particles as a byproduct of some random or probabilistic process, such as the production of two correlated photons that occasionally occurs when a single photon passes through a special crystal. Receiving entangled pairs in this way is fine for tests of quantum nonlocality, but entangling a large number of quantum particles—essential for building a practical quantum computer—becomes much less likely if it is dependent on a probabilistic process. In their "deterministic entanglement" process, the NIST researchers trap a pair of beryllium ions in a magnetic field. Using a predetermined sequence of laser pulses, they entangle one ion's internal spin to its external motion, and then entangle the motion to the spin of the other atom. The group believes that it will be able to entangle multiple ions with this process. (Turchette *et al., Phys. Rev. Lett.* **81**, 3631, 1998.)

BIOLOGICAL/MEDICAL PHYSICS

CAN EPILEPTIC SEIZURES BE PREDICTED? At the Clinic of Epileptology of the University of Bonn in Germany, one of the world's largest centers for epilepsy surgery, doctors must locate the source of seizures within the brain as accurately as possible so as to minimize postoperative loss of brain activity once the offending tissue has been removed. To do that, Klaus Lehnertz and Christian Elger scan suspected trouble areas in the brain; using EEGs, they monitor the patterns of brain electrical activity over time and look not only at the rapid, violent neuronal firings during an epileptic attack but also at the electrical landscape before and after the brainstorm. Various nonlinear measures for characterizing EEG dynamics are available for correlating electrical activity in different parts of the brain at different times with respect to each other. In particular, they looked for suspicious changes in one such measure, the "effective correlation dimension," which is known to characterize different states of the brain such as sleep, alertness, and verbal or nonverbal cognition. Following a study of 68 EEGs from 16 patients, the researchers concluded that a decrease in the effective correlation dimension corresponds to an increased synchronization in the pathological firing of neurons that (above a critical level) leads to a seizure. They argue that this identification and study of the preseizure state in the brain may suggest new ways (chemical, electrical or psychological) of preventing seizures. (K. Lehnertz, C. E. Elger, *Phys. Rev. Lett.* **80**, 5019, 1998.)

LOW-FIELD MRI HAS BEEN DEMONSTRATED. In typical magnetic resonance imaging (MRI), a 1--1.5 T (1--1.5 x 10^4 Gauss) magnet polarizes hydrogen nuclei inside water molecules (in a human body, for example) and the radio signals from spin-flipping protons are detected. The polarization is extremely weak (about 10^{-6}) but is compensated by the abundance of liquid water (hence protons) in the body. In the last few years, however, practical MRI has been achieved with gases of helium-3 and xenon-129, using optical pumping techniques to achieve very high polarizations of 10--20%. (See Physics Today, June 1995, page 17.) Such gas-phase MRI has always been amenable to application at low fields, and now that has finally been accomplished. A multi-institutional team of scientists led by Ron Walsworth of the Harvard--Smithsonian Center for Astrophysics, successfully used laser-polarized ^3He for MRI with magnetic fields of only 20 gauss. The simple, low-field equipment offers many advantages in a medical setting, such as low-cost, portability, and compatibility with nearby electronic equipment helpful for people with pacemakers. Furthermore, using gases and low magnetic fields will aid in imaging porous materials and the interiors of metals, including spaces within conductively shielded objects. (C. H. Tseng et al., *Phys. Rev. Lett.* **81**, 3785, 1998.)

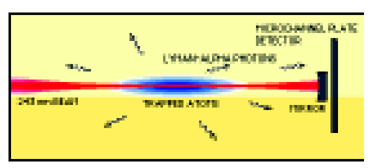


Excised rat lungs (photo on left) were filled with laser–polarized helium-3 gas and imaged with low-field MRI at 21 gauss (right) *(Figures courtesy of Ronald Walsworth, Harvard-Smithsonian.)*

BLACK HOLES CANNOT SERVE AS PORTALS TO OTHER UNIVERSES. That is the conclusion of Shahar Hod and Tsvi Piran, two Hebrew University physicists who have performed the first detailed calculations tracing a black hole from the prelude of its formation to the development of its inner structure. Black holes have such large amounts of gravity that they irretrievably attract all objects that are closer than a point-of-no-return known as the event horizon. As Roger Penrose and Stephen Hawking first showed, the insides of black holes must contain a singularity, which in its simplest form is a region of infinite density. Associated with a singularity is a boundary known as a "Cauchy horizon" beyond which it becomes impossible to predict the future trajectory of a particle with any reliability. Previously, some theorists have suggested the possibility that matter passing through the Cauchy horizon may encounter an "asymptotically flat" region, a region of relatively weak gravity such as our own, and then travel to other universes rather than get caught in a singularity. However, Hod and Piran have now supported previous indications showing that these Cauchy horizons are unstable; small disturbances in the black hole instantly transform them into singularity regions. In fact, their calculations suggest that generic black holes contain two singularities that are connected to each other so that all infalling matter reaches one or the other. (Hod and Piran, *Phys. Rev. Lett.* **81**, 1554,1998.)

ATOMIC/MOLECULAR/OPTICAL PHYSICS

BOSE–EINSTEIN CONDENSATION IN HYDROGEN has been achieved. A MIT group headed by Daniel Kleppner and Thomas Greytak cooled the trapped, spin-polarized hydrogen atoms to the BEC state with radio frequency evaporation. The RF signal singled out those atoms at the edge of the trap and flipped their spins, thereby ejecting them with no need to lower the magnetic field. The result was a colder, denser gas in the trap. When the atoms' de Broglie waves finally started to overlap, driving the condensation, the density-dependent lifetime of the gas showed a marked decrease. That was expected for hydrogen, and, together with an associated spectral feature, provided the evidence for BEC. Very preliminary numbers reveal that the condensate contains more than 10^8 atoms, has a transition temperature of about 50 K, and lasts about 5 seconds. (By comparison—as reported in PHYSICS TODAY, August 1995, page 17—the first BEC had about 2000 rubidium-87 atoms, at a temperature of about 170 nK and lasted more than 15 seconds.) The MIT group's work is important because every atomic property involved in BEC can be reliably calculated for hydrogen, providing a crucial link between theory and experiment. (D. Fried *et al.*, *Phys. Rev. Lett.* **81**, 3811, 1998.)



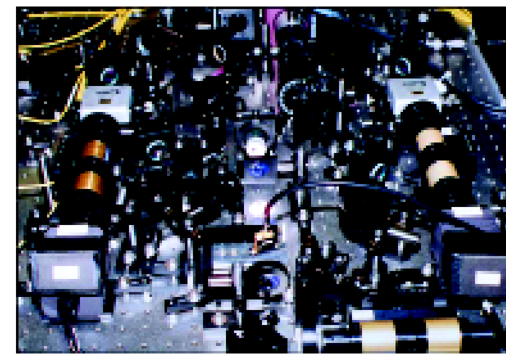
Probing the properties of hydrogen as it proceeds into a Bose-Einstein condensation (BEC) state requires the presence of two photons. After absorbing these photons, an atom subsequently emits a single ultraviolet ("Lyman-alpha") photon which is observed by a detector at low temperature. *(Courtesy MIT)*

A COHERENT SOFT X-RAY SOURCE has been devised by scientists at the University of Michigan. Margaret Murnane's group converted 800 nm laser light into 17–32 nm x rays by sending it through a hollow, gas-filled waveguide. Until now the task of producing x rays by the "harmonic conversion" process has been hampered by two facts. First, the nonlinear crystals that are often used to double the light frequency in the visible and ultraviolet ranges soak up x rays. Second, the gas media that are more hospitable to x rays cause the x-ray beam to fall out of phase with the laser-light beam as they co-propagate. The Michigan researchers succeeded in preserving the phase match because the hollow waveguide introduced a geometric component to the phase velocity. The researchers were thereby able to increase the x-ray yield by a factor of 100–1000 over previous devices. (A. Rundquist *et al.*, *Science* **280**, 1412, 1998.)

QUANTUM ERROR CORRECTION has now been experimentally demonstrated. Skeptics have maintained that quantum computers would crash before carrying out a useful calculation because the proposed devices rely on fragile, easily corrupted quantum states. But the new proof-of-concept experiment, using liquid nuclear magnetic resonance techniques, may change their minds. The researchers aimed radio-frequency pulses at a liquid of either alanine or trichloroethylene molecules, which spread a single bit of quantum information onto three nuclear spins, using entanglement. The bit of information was a superposition of the values 0 and 1, and spreading it out made it possible to recover the information if one of the nuclei got corrupted. Measuring the spins directly would have destroyed the superposition and forced the bit to become either a 0 or a 1. So the researchers instead compared the states of spins two at a time, without actually learning what the states were, to see if any differences arose between them. This approach allowed the experimenters to detect an error, and correct it, without ever knowing what the "message" was. (D. G. Cory *et al.*, *Phys. Rev. Lett*. **81**, 2152, 1998.)

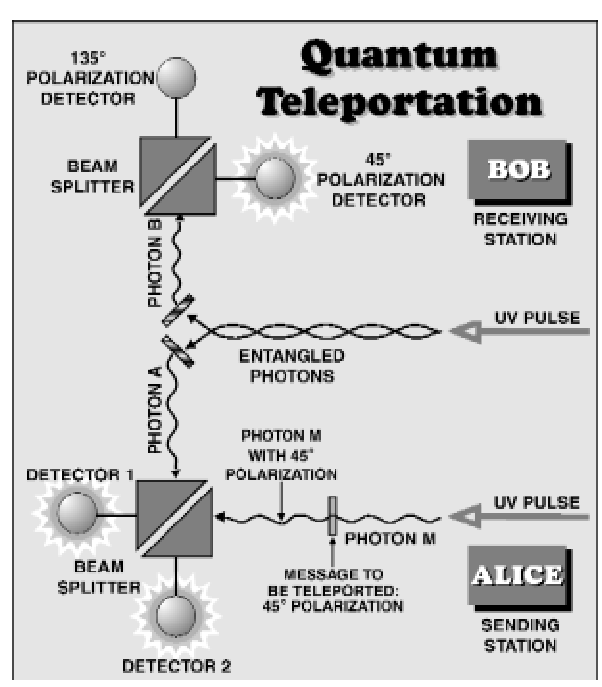
TUNABLE CHEMISTRY IN BOSE-EINSTEIN CONDENSATES (BECs) has been demonstrated by a MIT group (Wolfgang Ketterle), allowing researchers to choose whether atoms in this new state of matter attract each other, repel each other, or hardly interact at all. A BEC is a gas of atoms so cold and so dense that they overlap and act as a single, unified entity. To control the chemistry of a sodium BEC, the researchers turned on a magnetic field which slightly altered the shape of the electron clouds surrounding each atom. This in turn could modify the force that the atoms applied on each other (Inouye *et al.*, *Nature* **392**, 151, 1998). Controlling whether BEC atoms attract or repel will help researchers to test theoretical ideas about BECs and understand chemical reactions and collisions in ultracold gases. In addition, the researchers developed an all-optical trap for BECs rather than the magnetic fields previously used (Stamper-Kurn *et al.*, *Phys. Rev. Lett.* **80**, 2027, 1998.). This in itself is an advantage because (1) researchers now have the chance to create BECs of atoms that don't respond to magnetic fields, and (2) a laser beam can control atoms to a high degree, for example by guiding them down a hollow optical fiber . Once produced in just 3 laboratories in the US, BECs have now been created all around the world. (For the latest-breaking developments, check out Georgia Southern University's BEC page at http://amo.phy.gasou.edu/bec.html/.)

GRAVITY GRADIENTS CAN BE MEASURED with atom interferometry and laser manipulation. An atom can be coaxed into two wavepackets, which can then recombine to produce an interference pattern that will depend on any forces present, including gravity. Now, Mark Kasevich and his Yale University colleagues have put two such atom interferometers together, and thereby made a highly sensitive gradiometer, which may be able to detect changes in gravity as small as 10^{-10} g over a distance of 1 meter. That is as good as any other technique now available, and the sensitivity is likely to get even better after more development. Because the test objects are individual atoms and the readout is based on stable laser beams, systematic uncertainties are eliminated or greatly reduced. Also, because two separate ensembles are used, the device is immune to vibrations transmitted by moving platforms. Gradiometer applications include covert navigation, underground structure detection, oil exploration and geodesy, as well as fundamental studies of general relativity. (M. J. Snadden et al., *Phys. Rev. Lett.* **81**, 971, 1998.)



This laser system divides, redirects, and recombines atomic wavepackets that can be used to measure gradients in a gravitational field with very high sensitivity. *(Courtesy Yale University)*

QUANTUM TELEPORTATION has been experimentally demonstrated by numerous groups worldwide. First proposed in 1993 by Charles Bennett of IBM and his colleagues, quantum teleportation allows physicists to take a photon (or any other quantum-scale particle, such as an atom), and transfer its properties (such as its polarization) to another photon—even if the two photons are on opposite sides of the galaxy. Note that this scheme transports the particle's properties to the remote location and not the particle itself. And as with Star Trek's Captain Kirk, whose body is destroyed at the teleporter and reconstructed at his destination, the state of the original photon must be destroyed to create an exact reconstruction at the other end. The first published teleportation experiment occurred at the University of Innsbruck in Austria. (D. Bouwmeester et al., Nature **390**, 575, 1997.) In this experiment, the researchers create a pair of photons A and B that are quantum mechanically "entangled": the polarization of each photon is in a fuzzy, undetermined state, yet the two photons have a precisely defined interrelationship. If one photon is later measured to have, say, a horizontal polarization, then the other photon must "collapse" into the complementary state of vertical polarization. In the experiment, one of the entangled photons A arrives at an optical device at the exact time as a "message" photon M whose polarization state is to be teleported. These two photons enter a device where they become indistinguishable, thus effacing our knowledge of M's polarization (the equivalent of destroying Kirk).What the researchers have verified is that by ensuring that M's polarization is complementary to A's, then B's polarization would now have to assume the same value as M's. In other words, although M and B have never been in contact, B has been imprinted with M's polarization value, across the whole galaxy, instantaneously. This does not mean that faster-than-light information transfer has occurred. The people at the sending station must still convey the fact that teleportation had been successful by making a phone call or using some other light-speed or sub-light-speed means of communication. While physicists don't foresee the possibility of teleporting large-scale objects like humans, this scheme will have uses in quantum computing and cryptography.

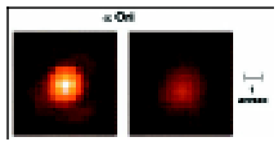


This blueprint shows, in somewhat simplified form, a University of Innsbruck experimental technique for achieving quantum teleportation. For more information, see www.aip.org/physnews/graphics/html/teleport.htm *(Figure by Malcolm Tarlton, AIP)*

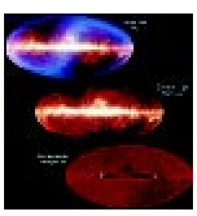
MILLIKELVIN MOLECULES can now be clasped in the same sort of magnetic trap used to chill atoms down to nanokelvins. Molecules are extended objects and not so easily cooled by laser beams, normally the first step in cooling several atom species to ultracold temperatures. Instead, Harvard researchers put calcium-monohydride molecules on the road to refrigeration by mixing them with a buffer gas of helium. Thereafter they were cold enough to load into a system of magnetic fields where the more energetic molecules are allowed to escape. This evaporative cooling brings the molecular temperature to below 1 K, opening up a new regime for collision studies and spectroscopy of cold molecules. (Weinstein *et al.*, *Nature* **395**, 148, 1998.)

ASTROPHYSICS

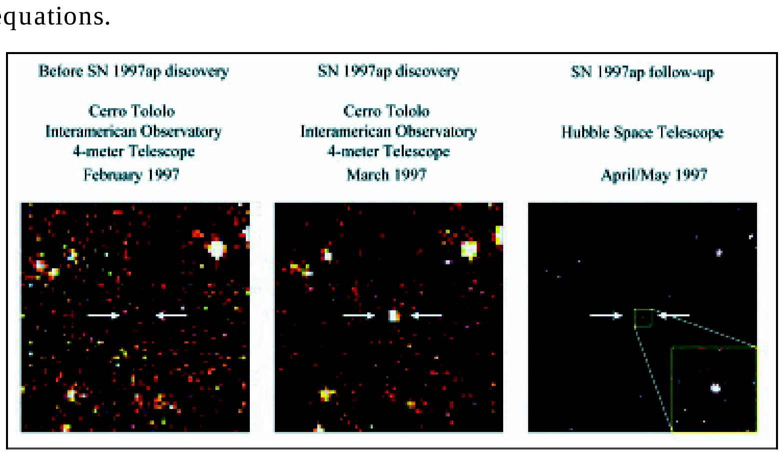
NULLED STARLIGHT. Using interferometry, light from two separated telescopes can be combined to create a signal having better spatial resolution than either of the individual telescopes could produce. Now the technique has been used in reverse. A group of astronomers at the Multiple Mirror Telescope in Arizona, imaging the star Betelgeuse at 10 microns, superposed the light paths from two telescopes in such a way that the stellar wavefronts interfered destructively. The star's light disappeared, leaving behind the faint glow of a surrounding dust nebula. The researchers expect that, using adaptive optics with the two 8.4 m mirrors of the Large Binocular Telescope, such a nulling system could image Jupiter-like planets around stars out to 10 parsecs and analyze their spectra. (P. M. Hinz *et al.*, *Nature* **395**, 251, 1998.)


The giant star -Orionis (left), and its starlight removed with an interferometric technique (right), revealing the dust nebula which surrounds it. *(Courtesy University of Arizona.)*

COSMIC INFRARED BACKGROUND DISCOVERED. The Cosmic Microwave Background Explorer (COBE) collaboration, which six years ago reported the first evidence for structure in the microwave background, has now finished a mapping of the whole sky at ten different infrared wavelengths, from 1 to 240 microns. After carefully subtracting the expected contributions from our own solar system and the Milky Way galaxy (understanding the foreground sources of infrared was itself a process that took years) what is left over is the cosmic infrared background, the cumulative IR radiation (amounting to one-half to two-thirds of the total light) coming from all the stars that have ever existed. Much of the light that reaches the detector has been scattered in transit by dust. The cosmic IR background appears uniform (no structure is apparent) and bears no information about when during the history of the cosmos the radiation was emitted. Nevertheless, the observations have helped to provide rough limits on the amount of star formation in the universe and confirms the suspicion that a lot of star birth has been obscured by dust. Michael Hauser, now at the Space Telescope Science Institute, delivered the main COBE report at January 1998 meeting of the American Astronomical Society (AAS) in Washington, DC. (See also Schlegel, Finkbeiner, Davis, *Astrophysical Journal* **500**, 525, 1998.)

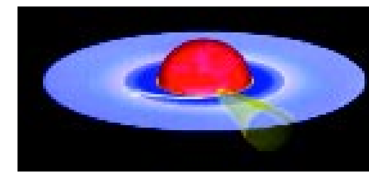

The sky at infrared wavelengths (top), the same image with the IR light from our solar system removed (middle), and the IR sky with light from the solar system and Milky Way subtracted (bottom), revealing the cosmic infrared background. *(Courtesy Michael Hauser, Space Telescope Science Institute.)*

THE UNIVERSE WILL EXPAND FOREVER. This prediction is based on new studies of distant supernovas. Because Type Ia supernovas (supernovas in which material falling onto a white dwarf from a companion object ignites violently) brighten and fade in such a predictable way, their intrinsic brightness (and their distances from Earth) can be determined by carefully watching light emission over time. Combining these distances with the velocities of the host galaxies (determined from redshifts) allows one to calculate the expansion of the universe with some confidence. And the result appears to suggest that the universe does not have enough matter (visible or dark) to halt the current expansion. This view emerged at the January 1998 meeting of the American Astronomical Society in Washington, where optical data for many new supernovas (including the most distant supernova ever observed, one with a redshift of 0.97) were reported by a group from LBL (led by Saul Perlmutter) and one from Harvard-Smithsonian (Peter Garnavich). The new findings are consistent with an age estimate for the universe of 15 billion years. Several theories attempt to explain the positive push; one popular model sees the effect as coming from a huge reservoir of energy hidden in the universal vacuum. An early precedent for this notion was Einstein's use of an antigravity fudge factor called the cosmological constant in his gravitational equations.



False-color images from observations of a distant supernova. *(Courtesy Saul Perlmutter et al., The Supernova Cosmology Project, LBL.)*

THE STRONGEST GRAVITATIONAL FIELDS EVER MEASURED, corresponding to a spacetime warping of 30%, have been recorded by scientists using the Rossi X-Ray Timing Explorer (RXTE) satellite. By comparison, the proportional curvature of space is 100% at a black hole, but only about one part in a million near the sun's surface and one part per billion near the Earth's surface. RXTE was designed to monitor (over microsecond time intervals) the x rays coming from binary star systems in which matter from a conventional star is siphoned off into an accretion disk surrounding a nearby neutron star or black hole. In about 16 binary-star systems that contain neutron stars, blobs of gas in the disk are thought to spiral in toward the neutron star, picking up speed before they make a final plunge onto the surface. The x rays produced in this process are regularly dimmed when the hot gas is on the far side of the star. This leads to quasi-periodic oscillations (QPOs) in the x-ray brightness of the star. Also notable is the fact that the brightness variations only occur at certain well-defined rates, "pure tones" corresponding to special orbital periods for the gas going around the star. The spacetime encountered by the gas is so highly warped because the gas is able to skim within a few km of the neutron star, which itself is only about 10 km in diameter. At the April 1998 meeting of the American Physical Society in Columbus, Ohio, Frederick Lamb of the University of Illinois described how the observed variations in the x-ray brightness can be used to deduce properties of the neutron star, such as its mass and size. At a press conference, Lamb and William Zhang of NASA Goddard concentrated on the binary-star system 4U1820-30, about 20,000 light years from Earth. The neutron star has a mass of 2.3 solar masses and orbits its companion star in only 11 minutes. Close observations of this system confirm a prediction made by Lamb and his colleagues Coleman Miller and Dimitrios Psaltis that the gas blobs would continue to spiral inward until they reached an "innermost stable orbit," where they would orbit before making the dive for the surface. This is a purely general relativistic (GR) effect; in Newton's mechanics, by contrast, the blob could have gotten arbitrarily close to the surface, providing it were going fast enough. The observations by Zhang and his collaborators now confirm Lamb's prediction, thus opening up a new "strong-gravitational field" era in GR studies. The measurements of the gas motion even provide hints as to the nature of the strong nuclear force sustaining the neutron star against further gravitational collapse. The new evidence indicates that the nuclear force is stiffer and more repulsive than has generally been thought.


X rays (green cone) are emitted when gas from a blob orbiting a neutron star (red sphere) takes a final plunge onto the star's surface. The gas, originating in a nearby conventional star (not shown), is drawn toward the neutron star and accumulates in an accretion disk (shaded blue). *(Courtesy Frederick Lamb, University of Illinois at Urbana-Champaign)*

A PULSAR WITH A MAGNETIC FIELD OF 8 x 10^{14} GAUSS has been studied with the Rossi X Ray Telescope (RXTE). Referred to as a soft gamma-ray repeater (SGR1806-20) since it is a source of recurring bursts of low-energy gamma-rays (whereas gamma ray bursters don't emit higher energy gammas and don't repeat), this neutron star rotates with a period of about 7.4 seconds. The size of the magnetic field, 100 times larger than that of ordinary radio pulsars, is deduced from the rotation period and the slowdown of that rotation. Such a highly magnetized neutron star has been called a "magnetar." The huge field (the largest magnetic field ever measured) puts the star's surface under great stress. According to one theory, the observed high energy bursts of radiation come about when the neutron star's crust cracks open. (C. Kouveliotou *et al.*, *Nature* **393**, 235, 1998.) In a related story, a blast of gamma light, representing the largest batch of energy to arrive at Earth from a star beyond our solar system, struck the upper reaches of our atmosphere on 27 August 1998. The 5-minute pulse of high-energy radiation momentarily disrupted some terrestrial radio traffic and sent detectors on several spacecraft off scale. The source of the blast is believed to be a neutron star previously known for its intermittent gamma and x-ray emissions. The potency of the August event, however, would seem to characterize the star a magnetar; its magnetic field is estimated to be in the vicinity of 10^{15} gauss, 100 times larger than ordinary neutron stars, and essentially the largest known magnetic field in the universe. The gammas probably arise when magnetic forces crack open the star's crust. Ionized particles above the star ride the magnetic fields, spewing radiation as they go, creating a much more potent version of the solar flares seen on our sun.


Rendition of the pulsar SGR 1806-20 which has a magnetic field strength about 100 times stronger than the typical neutron star. *(Courtesy Robert Mallozzi, University of Alabama, Huntsville, and NASA Marshall Space Flight Center)*

NO END IN SIGHT FOR COSMIC RAY ENERGIES. Putting terrestrial accelerators to shame, nature has contrived to imbue some particles with energies greater than 10^{20} electron volts. But these high-end cosmic ray events—only a mere handful have been recorded so far— would seem to be at odds with the idea that interactions with the cosmic microwave background act as a sort of universal brake, permitting energies not much above 10$^{19.6}$ eV (the so called Griesen-Zasepin-Kuz'min, or GZK, limit). It didn't help that for some time there was a relative scarcity of events in the energy range between 10$^{19.6}$ and 10^{20} eV. But new data reported by the Akeno Giant Air Shower Array (AGASA) collaboration in Japan fills in this gap, strengthening the statistical argument that either the GZK cutoff is not working as planned or that some unexpected process is producing the highest-energy rays.In other words, there seems to be no limit to cosmic ray energy. (Takeda *et al.*, *Physical Review Letters* **81**, 1163, 1998.)

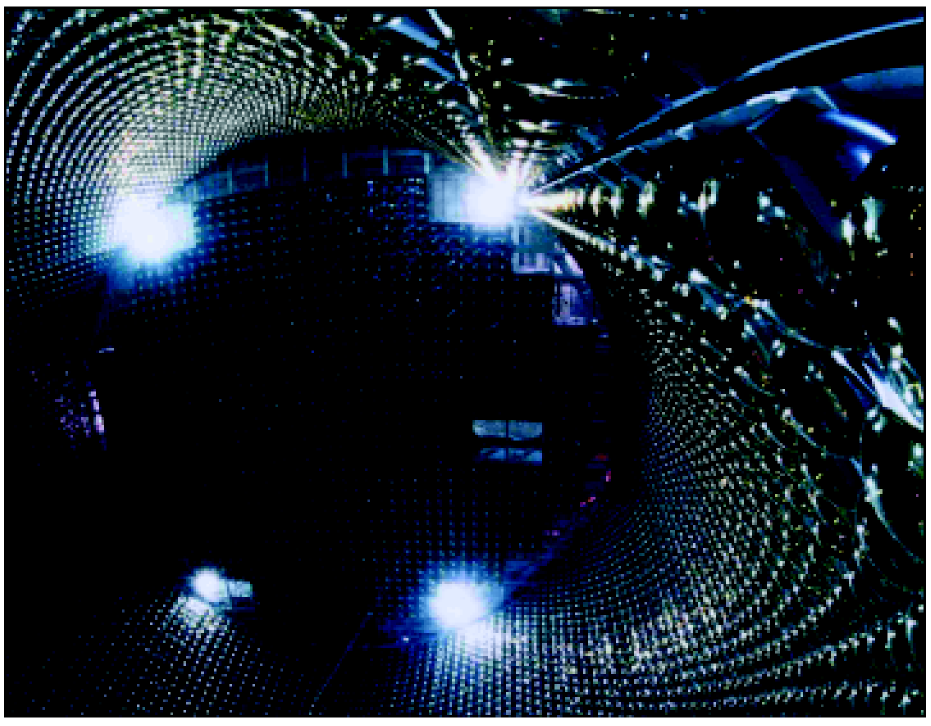
THE EXTRASOLAR PLANET PARADE continues with the discovery of two new planets with unique features. As before, astronomers Geoffrey Marcy (San Francisco State) and Paul Butler (Anglo-Australian Observatory) have inferred the presence of the planets from their observed influence on the companion star. One of the new objects orbits its star (HD187123) in a mere three days in an orbit 9 times closer than Mercury's around our sun. The other new planet has a very Earth-like orbit of 437 days around star HD21027. This comes as a reassurance to those who were beginning to wonder whether Earth was an anomaly; all previously discovered extrasolar planets have had orbits much smaller or much larger than Earth's.

Physics News In 1998

Public Information Division, American Institute of Physics, physnews@aip.org

A Supplement to APS News

Edited by Phillip F. Schewe and Ben P. Stein



ICRR (Institute for Cosmic Ray Research), The University of Tokyo

Physics News in 1998 is the latest in a series of annual surveys of the top physics stories prepared by the Public Information division of the American Institute of Physics. Almost the entire content of this report first appeared in AIP's weekly online newsletter, *Physics News Update*. Subsequently, *Physics Today* published many of these items (in slightly edited form) for their "Physics Update" page. We reprint here twelve months of *Physics News Update* items as they appeared in the pages of *Physics Today.* For your convenience, we have organized them by physics categories, updated the journal references, and added numerous images to accompany these items. In addition, we include a number of additional items that appeared exclusively in the *Physics News Update* bulletin. Interested readers can subscribe to *Physics News Update* or consult its searchable 8-year archive by going to this website: http://www.aip.org/physnews/update. As a new feature this year we add Science Policy: The Year in Review that summarizes top stories involving federal science policy and funding agencies. Readers may subscribe to *FYI, the AIP Bulletin of Science Policy News*, from which this material was excerpted, at http://www.aip.org/gov/.

B. H. Ripin, Editor, APS News

Science Policy: The Year in Review by Richard M. Jones and Audrey T. Leath, AIP

JANUARY

House Speaker Newt Gingrich (R-GA) calls for increases in federal science spending. President Clinton advocates a Research Fund for America in his State of the Union Address, and makes several other references to R&D. Oak Ridge National Laboratory is selected as the site of the Spallation Neutron Source. In a speech by House Science Committee Chairman James Sensenbrenner (R-WI), he says "the scientific community has good reason to be optimistic about the future of federal funding for science," but withholds support for legislation to double federal science spending.

FEBRUARY

President Clinton proposes a 32% increase in federal civilian research funding by 2003, using, it turns out, money from a proposed tobacco settlement. Vice President Al Gore calls research one of the "top priorities in this budget." The Administration requests sizeable increases in the R&D budgets for NSF, DOE, DOD 6.1, and over-all basic research and applied research. Later in the month, OSTP Director Jack Gibbons announces his retirement, to be replaced by NSF Director Neal Lane. Rita Colwell is nominated to head NSF. Rep. Vern Ehlers (R-MI) ramps up his National Science Policy Study. Mixed findings are reported for U.S. students in the Third International Mathematics and Science Study.

MARCH

Appropriations hearings start, marked by tough questions on the relationship between what will later turn out to be the ill-fated tobacco settlement and requested increases in research funding.

APRIL

DOE Secretary Federico Pena resigns for personal and family reasons. Congressional concern over Russian participation in the space station increases. The outlook on future federal science spending becomes sobering because of strict caps on spending and a pork-laden transportation bill moving through Congress. A pessimistic report is released on the space station cost and schedule. A Senate hearing is held on legislation to double civilian R&D over ten years.

MAY

Eighty-two representatives sign a letter supporting a minimum of $250 million in FY 1999 fusion funding (the final appropriation was almost $230 million.) A House hearing is held on legislation that would block-grant money for the Eisenhower (math and science teacher) Professional Development Program. The importance of basic research in all fields to advances in biomedical research is touted at a House hearing.

JUNE

Senate appropriations subcommittees start reporting their bills; most research budgets are favorable, although the NSF numbers come with some strings attached. President Clinton gives a MIT commencement address, saying that his FY 2000 budget request "will call for significant increases in computing and communications research." National Science Policy Report hearings conclude. UN Ambassador Bill Richardson is nominated to be DOE Secretary. Speaker Gingrich calls for a doubling of the science investment budget. A House appropriations bill for NSF is reported largely without strings attached. Senators Bill Frist (R-TN) and Jay Rockefeller (D-WV) introduce a bill to double non-defense R&D over twelve years.

JULY

An unsuccessful attempt is made on the House floor to cut FY 1999 NSF research funding. Neal Lane and Bill Richardson are confirmed.

AUGUST

President Clinton signs the NSF Reauthorization Bill for FY 1998-2000, noting the important contributions of the late Rep. Steve Schiff (R-NM). Space station hearings continue. DOE selects a builder for the Spallation Neutron Source.

SEPTEMBER

House votes to kill the Eisenhower Professional Development Program. DOE agrees to continue ITER participation through July 1999; Sensenbrenner reacts with sharply-worded statement. National Science Policy Report is issued, highlighting importance of basic research. FY 1999 DOE appropriations bill is passed, with generally good outcomes.

OCTOBER

President Clinton signs DOD appropriations bill, with good numbers for 6.1 and 6.2. NASA appropriations bill signed, with positive outcome for agency as a whole, and the Science, Aeronautics and Technology account. NSF appropriations bill signed, with good numbers, although not what the Administration requested. The Senate passes the Frist-Rockefeller bill (S. 2217) calling for a doubling of civilian research funding over twelve years; companion bill in the House goes no where. NIST appropriation does fairly well, but a dispute over the upcoming census limits funding only through June. House approves National Science Policy Report. Mammoth wrap-up bill is passed that provides full funding for the Eisenhower Professional Development Program.

NOVEMBER

Rush Holt, former Assistant Director of the Princeton Plasma Physics Laboratory wins a New Jersey seat. Joseph McDade (R-PA), Vic Fazio (D-CA), Louis Stokes (D-OH), and Dale Bumpers (D-AR) retire. Speaker Gingrich announces his retirement.

DECEMBER

Important House appropriations subcommittee chairs change hands.

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