

Physics News In 1999

A Supplement to APS News

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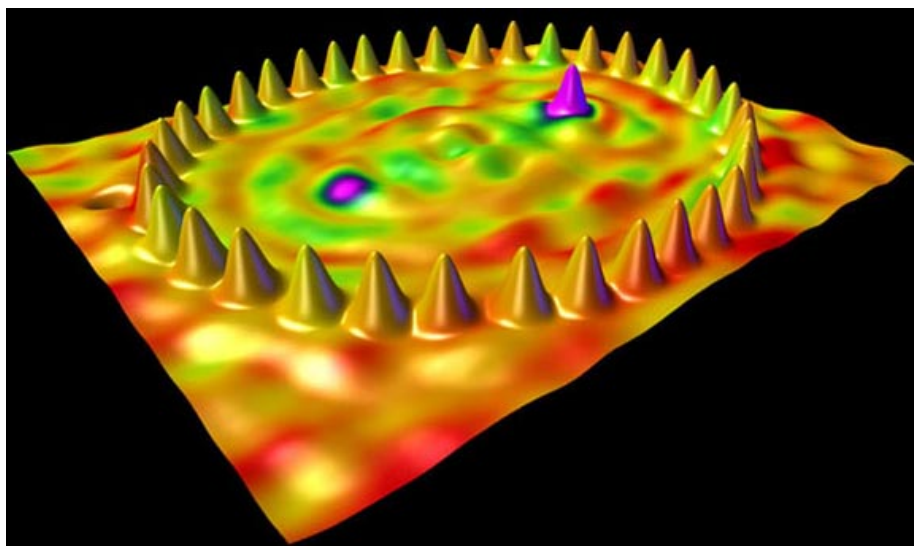
Physics News in 1999 is the most recent in a series of annual surveys of important physics stories prepared by AIP. All of the entries in this compendium appeared first in the weekly online newsletter *Physics News Update*. Many of them appeared also on the "Physics Update" page in *Physics Today* magazine, where they were edited further by Stephen Benka.

Readers can view even more highlights from the past year and search a nine-year archive of selected research items by going to the *Physics News Update* website: <http://www.aip.org/physnews/update>

Also you will find two science policy features derived from AIP's FYI bulletin (www.aip.org/eneews./fyi) prepared by Richard M. Jones and Audrey T. Leath.

Image from "Nanotechnology"

A scanning tunneling microscope was used to position 36 cobalt atoms in an elliptical structure known as a "quantum corral." Electron waves moving in the copper substrate interact both with a magnetic cobalt atom carefully positioned at one of the foci of the ellipse and apparently with a "mirage" of another cobalt atom (that isn't really there) at the other focus. (Courtesy IBM)



Science Policy in 1999: The Year in Review

JANUARY

J. Dennis Hastert (R-IL), who represents the district containing Fermilab, becomes Speaker of the House. Rep. George Brown Jr. (D-CA) introduces legislation to repeal a little-publicized provision in a 1998 law requiring the disclosure of all data produced under a federal grant. President Bill Clinton discusses science and math education, medical research, technology, and global warming in his State of Union Address. Senator Bill Frist (R-TN) reintroduces his bill to double civilian R&D funding over twelve years. Vice President Al Gore gives a lengthy address on science and technology at the AAAS annual meeting.

FEBRUARY

President Clinton sends his FY 2000 budget request to Congress. Total R&D funding would be down 1%; civilian funding would be up 3%, while defense R&D would fall 5%. Senior administration official says "what you see is a result of the [budget cap] constraints." The Office of Management and Budget requests public comment on new data availability regulation. New project director named for Spallation Neutron Source; DOE official says department is "on track for delivering this facility to the scientific community in 2005."

MARCH

Congress starts consideration of legislation that would affect the Eisenhower program for science and math teachers. Science Committee issues a mixed response to Administration's FY 2000 R&D request. DOE Office of Science Director Martha Krebs testifies before House appropriations subcommittee; saying "This is a good budget. It will enable exciting science." Space station questions dominate appropriations subcommittee hearing. Citing management problems, House Science Committee Chairman James Sensenbrenner (R-WI) recommends no neutron source construction funding in FY 2000.

APRIL

Senate Energy appropriations subcommittee chair Pete Domenici (R-NM) tells DOE, "Everybody thinks [the SNS] is a great tool for science. I hope you don't mess up!" At an AAAS colloquium, OSTP Director Neal Lane comments on historical trends for R&D funding, saying "there are some disturbing signs... some of those [research] areas have not done so well," citing physics as an example. Senate bill is introduced to prohibit visits by scientists from "sensitive countries" to three DOE weapons labs. DOE Secretary Bill Richardson declares, "Our labs are now under siege."

MAY

Three DOE lab directors testify on espionage at contentious Senate hearing. Spallation Neutron Source survives attempt by House Science Committee to prohibit FY 2000 construction funding. Impact of budget caps becomes evident in FY 2000 R&D bills.

JUNE

Congress begins moving defense bills, which would reduce or reverse proposed administration cuts in some S&T funding. Senate hearing held on highly critical report on nuclear weapons labs security. Congressional activity increases on K-12 legislation. Oak Ridge selected as site for Spallation Neutron Source.

JULY

Rep. George Brown Jr. (D-CA) dies, a loss mourned by the science community. Legislative stalemate surfaces on the future of weapons labs. Senate votes to establish semi-autonomous Agency for Nuclear Stewardship within the Department of Energy. Teacher funding bill passes the House, maintaining Eisenhower money. House passes FY 2000 DOD bill, providing higher funding for S&T than proposed by the Administration or passed by the Senate. House passes DOE appropriations bill which includes some spallation source construction funding and generally good numbers for other physics programs. Senate passes R&D doubling bill.

AUGUST

House VA/HUD appropriations panel slashes NASA's space and Earth science budgets by nearly 20 percent from FY 1999 funding; most space science funding is restored by the full committee. House passes NIST appropriations bill, zeroing funding for the Advanced Technology Program. OSTP Director Lane issues critical R&D statement, charging that "as the Congress goes into its August recess, it is deeply disappointing to find that the current budget reality is no match for the early rhetoric." OMB releases proposed data availability regulations, calling for additional comments.

SEPTEMBER

White House Chief of Staff John Podesta issues a hard-hitting statement on congressional R&D action, charging, "This is a 19th century budget for a 21st century economy." Sensenbrenner fires back, stating "the Republican Congress has appropriated more for R&D than the Administration requested in three out of the last four years." House appropriations subcommittee chairman James Walsh (R-NY), in explaining proposed \$200 million cut in FY 2000 NSF funding says, "We literally are borrowing from Peter to pay Paul here." Senate appropriators provide administration request for NSF and NASA, but make \$125 million cut in space science. A veto-proof bill is sent to White House to reorganize DOE's weapons labs management. Congress passes FY 2000 energy appropriations bill; fusion, high energy physics and nuclear physics program budgets increase, basic energy sciences declines. Spallation Neutron Source R&D funded in full, but only about half of construction request. Martha Krebs announces she will leave DOE at the end of year.

OCTOBER

Senate refuses to ratify the Comprehensive Test Ban Treaty. OMB releases final data availability regulation. Congress sends FY 2000 NSF bill to President with a 6.5% overall increase. Same bill provides much better overall numbers for most NASA science program budgets. OSTP asks for comments on new definition of research misconduct. President astonishes Congress by appointing DOE Secretary Richardson to fill the position of the head of the new nuclear weapons administration; one senator calling it "the height of arrogance." Clinton issues statement saying, "If we want to maintain our current economic prosperity, it is essential that we sustain our investment in long-term research across all the scientific and engineering disciplines." R&D doubling bill introduced in House.

NOVEMBER

LIGO is inaugurated in Livingston, LA. Congress completes FY 2000 NIST bill which cuts ATP by 30% over 1999, but with funds carried over from FY 1999, White House says \$51 million in new ATP awards will be possible. NIH gets a 15% increase for FY 2000. R&E Tax Credit is extended for five years. Congress adjourns after making small across-the-board cut in all FY 2000 appropriations.

DECEMBER

NRC committee starts review of future DOD R&D requirements. President's Committee on Advisors on Science and Technology meets to review 21st century R&D challenges and opportunities. The committee hears from State Department official on involving science in policy decisions; who says "Resources are absolutely essential to the whole problem."

— Richard M. Jones, AIP Public Information Division

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ASTROPHYSICS

GAMMA-RAY BURSTERS (GRBs) are most likely beamed. That seemed to be the consensus in May at a symposium on GRBs, supernovae, and their possible connections held at the Space Telescope Science Center at Johns Hopkins University. A focus of discussion, and of no fewer than six recent papers in *Nature* and *Science* (see below), was the huge GRB of 23 January 1999. That event was observed over an unprecedented range of wavelengths and timescales. Thanks to robotics, a small, automated optical telescope responded to signals from orbiting gamma-ray and x-ray telescopes, and began observing the GRB within 22 seconds of the burst's onset, while it was still belting out gammas. Many other observations were carried out—from gamma rays, through ultraviolet and optical, to infrared, millimeter, and radio waves—until as late as 14 February. The object was found to have a redshift of 1.6, putting it at a cosmological distance, and implying a staggering amount of energy released. Indeed, if its energy were being spewed out in all directions, it would equal nearly twice the rest mass energy of a neutron star. If, however, the GRB was beaming its radiation and we just happened to be caught in the beacon, the energetics would be more reasonable. All such prompt measurements are important for understanding the bursters' energy engine, which operates at full throttle for only about 100 seconds. (A. J. Castro-Tirado *et al.*, *Science* **283**, 2069, 1999. J. Hjorth *et al.*, *Science* **283**, 2073, 1999. M. I. Andersen *et al.*, *Science* **283**, 2075, 1999. S. R. Kulkarni *et al.*, *Nature* **398**, 389, 1999. T. J. Galama *et al.*, *Nature* **398**, 394, 1999. C. Akerlof *et al.*, *Nature* **398**, 400, 1999.)

THE SPEED OF LIGHT is frequency independent to within a factor of 6×10^{-21} . Bradley Schaefer of Yale University bases this estimate on the observed arrival of gamma rays from distant explosive events in the cosmos, such as gamma-ray bursters. If the speed of light varied slightly for different frequencies, then light of different frequencies emitted at the same time would arrive at our telescopes at different times. But this is not the case. The best previous effort to locate a frequency dependence for c was made in 1969; using light coming from the Crab pulsar, a limit at the 5×10^{-17} level was deduced. Thus, Einstein's special theory of relativity now seems vindicated over an additional four orders of magnitude. By the way, the prefix for anything as small as 10^{-21} is *zepto*. (B. Schaefer, *Phys. Rev. Lett.* **82**, 4964, 1999.)

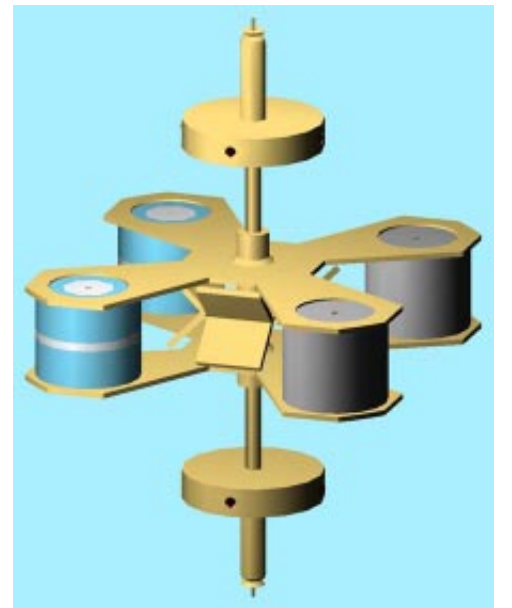
MEASURED VALUES FOR THE HUBBLE CONSTANT are converging nicely. At a NASA press conference on May 25, 1999, Wendy Freedman of the Carnegie Institution reported a new value of 70 km/sec/megaparsec (with an uncertainty of 10%), down from a value of 80 reported back in 1994. Freedman is one of the leaders of a group that uses the Hubble Space Telescope (HST) to track the light emission of Cepheid variable stars in nearby galaxies. Another Carnegie astronomer, Allan Sandage, has been a leader of a group that consistently measures a smaller value for the Hubble constant, the latest number being about 59, up from an earlier value of 57. Thus the observed Hubble constant, which is a measure of the overall expansion of the cosmos, is now providing an estimate for the age of the universe—about 12 billion years—that is no longer in contradiction with the apparent age of the oldest stars.

GRAVITY WAVE ANALYSIS FROM LIGO PROTOTYPE. The Laser Interferometer Gravitational-wave Observatory (LIGO), when fully deployed, will consist of two facilities (Hanford, WA and Livingston, LA). At each site laser beams pass up and down two perpendicular 4-km-long vacuum pipes, reflecting repeatedly from mirrors hung from wires. The presence of a passing gravitational wave would announce itself by a flexing of space-time which would very slightly lengthen the path of light in one arm and shorten the path in the other arm, causing a subtle change in the interference pattern made by the converging light beams from the two arms. The full LIGO, by about November 2001, should be able to detect a strain, defined as the fractional change in the position of the mirrors divided by the length of the arm (4 km), of 10^{-21} . This is the expected disturbance one expects from the gravity waves emitted by the coalescence of two solar-sized stars at a distance from Earth of 30-50 million light years. But before LIGO scientists possess their full instrument, they do have a 40-m prototype at Caltech, built for doing engineering studies but also capable of sensing gravity waves, albeit with the lesser strain sensitivity of a few times 10^{-19} . Thus the LIGO team, while testing methods for searching (directly via gravity waves) for binary coalescences, have thereby rendered an upper limit for such events of less than one every two hours in our galaxy. This result is useful for the test of the procedures, but is not significant for astronomers, who have previously established more stringent upper bounds with electromagnetic waves (visible and radio). (Allen *et al.*, *Phys. Rev. Lett.* **83**, 1498, 1999.)

STARLIGHT REFLECTED FROM AN EXTRASOLAR PLANET has been reported by University of St. Andrews astronomers. At this time, roughly 30 planets have been detected around nearby stars through an indirect method which monitors fluctuations in the stars' positions. More recently the shadow of an extrasolar planet was observed to transit across the face of its star. Now light has been detected which apparently comes to us directly from a planet circling the star tau Bootis, some 50 light years away. The main difficulty was of course discerning the reflected light while blocking out the glare of the star itself. The planet seems to be blue-green in color, is twice the size of Jupiter, and 8 times as massive. (Cameron *et al.*, *Nature* **402**, 751, 1999.)

GRAVITY'S GRAVITY. A new experiment at the University of Washington seeks to determine whether the gravitational binding energy of an object generates gravity of its own. As formulated by Albert Einstein, the Equivalence Principle (EP) states that if we stand in a closed room we cannot tell whether the weight we feel is the result of gravity pulling down or the force of a rocket carrying us forward through otherwise empty space. All of this gets complicated in some theories of gravity, which predict that the EP will be violated to a small degree

since in addition to the usual gravity, carried from place to place by spin-two particles called gravitons, there should exist another, fainter kind of gravity carried by spin-zero particles (sometimes called dilatons). For this reason, and because recent observations of supernovas suggest that some repulsive gravitational effects might be at work in the cosmos, scientists want to explore the possibility of EP violations. Three decades of lunar laser ranging (bouncing light off reflectors placed on the Moon) show that the Moon and the Earth fall toward the Sun with the same acceleration to within half a part in a trillion (10^{12}). What the Washington physicists (Eric Adelberger) have done is focus attention on the subject of gravitational binding energy, or self-energy, and whether it too obeys the EP. To illustrate the concept of binding energy, consider that the mass of an alpha particle is actually about 28 MeV less than the sum of its constituents. This energy (about 7.6 parts in a thousand of the alpha mass) represents the energy (vested in the strong nuclear force) needed to hold two protons and two neutrons together inside the alpha. Gravity being very much weaker than the strong nuclear force, the gravitational binding energy, the self-energy of gravity attraction, is almost infinitesimal. For example, self-energy effectively reduces the mass energy of the Earth by a factor of only about 4.6 parts in 10^{10} . Is this tiny "mass" also subject to the EP? Supplementing existing lunar laser ranging results with new data from special test masses mounted on a sensitive torsion balance to take into account the different compositions of the Earth and Moon, the Washington physicists show that gravitational self-energy does obey the equivalence principle at the level of at least one part in a thousand. Thus gravitational self-energy does indeed generate its own gravity. (Baessler *et al.*, *Phys. Rev. Lett.* **83**, 3585, 1999; see also Clifford Will's article, *Physics Today*, Oct 1999.)



A torsion pendulum for measuring the difference in the gravitational self-energy of the Earth and the Moon. (Courtesy University of Washington)

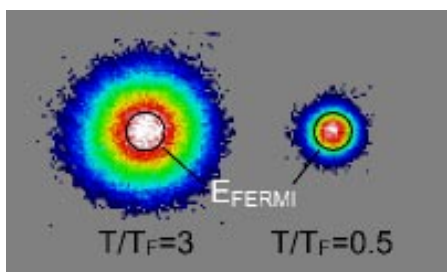
ATOMIC, MOLECULAR, OPTICAL PHYSICS

HAVING YOUR PHOTON AND SEEING IT TOO. Measuring a photon repeatedly without destroying it has been achieved for the first time, enabling researchers to study an individual quantum object with a new level of non-invasiveness. Physicists have long realized that it is possible to perform non-destructive observations of a photon with a difficult-to-execute technique known as a "quantum non-demolition" (QND) measurement. After many years of experimental effort, researchers in France have demonstrated the first QND measurement of a single quantum object, namely a photon bouncing back and forth in a cavity. A conventional photodetector measures photons in a destructive manner, by absorbing the photons and converting them into electrical signals. "Eating up" or absorbing photons to study them is not required by fundamental quantum mechanics laws and can be avoided with the QND technique demonstrated by the French researchers. In their technique, a photon in a cavity is probed without absorbing any net energy from it. (Of course, Heisenberg's Uncertainty Principle ensures that counting a photon still disturbs the "phase" associated with its electric and magnetic fields.) In the experiment, a rubidium atom passes through a cavity. If a photon is present, the atom acquires a phase shift which can easily be detected. Sending additional rubidium atoms through the cavity allowed the researchers to measure the photon repeatedly without destroying it or, as the French would say, "Avoir le beurre et l'argent du beurre" ("Getting the butter and money out of it at the same time"). This technique can allow physicists to study the behavior of a photon during its natural lifespan; it can potentially allow researchers to entangle an arbitrary number of atoms and build quantum logic gates. (Nogues *et al.*, *Nature*, 15 July 1999.)

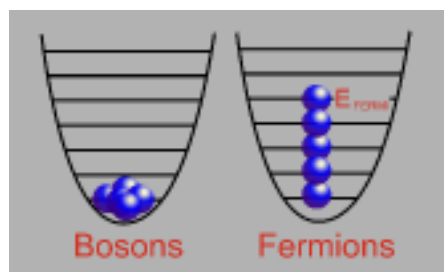
THE FIRST ENTANGLEMENT OF THREE PHOTONS was experimentally demonstrated by researchers at the University of Innsbruck in Austria. Individually, an entangled particle has properties (such as momentum) that are indeterminate and undefined until the particle is measured or otherwise disturbed. Measuring one entangled particle, however, defines its properties and seems to influence the properties of its partner or partners instantaneously, even if they are light years apart. In the present experiment, sending individual photons through a special crystal sometimes converted a photon into two pairs of entangled photons. After detecting a "trigger" photon, and interfering two of the three others in a beamsplitter, it became impossible to determine which photon came from which entangled pair. As a result, the respective properties of the three remaining photons were indeterminate, which is one way of saying that they were entangled (the first such observation for three physically separated particles). The researchers deduced that this entangled state is the long-coveted GHZ state proposed by physicists Daniel Greenberger, Michael Horne, and Anton Zeilinger in the late 1980s. In addition to facilitating more advanced forms of quantum cryptography, the GHZ state will help provide a nonstatistical test of the foundations of quantum mechanics. Albert Einstein, troubled by some implications of quantum science, believed that any rational description of nature is incomplete unless it is both a local and realistic theory: "realism" refers to the idea that a particle has properties that exist even before they are measured, and "locality" means that measuring one particle cannot affect the properties of

another, physically separated particle faster than the speed of light. But quantum mechanics states that realism, locality—or both—must be violated. Previous experiments have provided highly convincing evidence against local realism, but these “Bell’s inequalities” tests require the measurement of many pairs of entangled photons to build up a body of statistical evidence against the idea. In contrast, studying a single set of properties in the GHZ particles could verify the predictions of quantum mechanics while contradicting those of local realism. (Bouwmeester et al., *Physical Review Letters*, 15 February 1999)

A “FERMI-DEGENERATE” ATOMIC GAS, a gas of fermion atoms which essentially overlap with one another, has been created for the first time, promising tabletop insights into the basic properties of neutron stars, superfluid helium and all forms of superconductivity. Preparing this gas of fermions requires the exact same conditions as for preparing a Bose-Einstein condensate (BEC) of boson atoms, atoms composed of an even number of constituents with half-integer spin. One must cool a gas of atoms to the point that they exhibit wavelike properties and pack them densely enough so that the average distance between atoms is comparable to their “deBroglie wavelength.” At this point, individual atoms become impossible to distinguish. If the atoms are bosons, they fall collectively into the lowest-energy (ground) state to form a BEC. If the atoms are fermions, however, this cannot happen. The Pauli exclusion principle prohibits two fermions from occupying the same state. Instead, the fermions dutifully occupy different quantum states on the lowest



Two ultracold gas clouds of potassium-40 atoms, which are fermions. The hotter cloud (left) had 2.5 million potassium-40 atoms at a temperature of 2.4 microkelvin. The colder cloud (right) had approximately 780,000 atoms at 290 nanokelvins—the lowest temperature recorded for a gas of fermion atoms. At absolute zero, all of the atoms would lie inside the radius marked “Fermi energy” in each cloud. (Courtesy JILA/NIST)

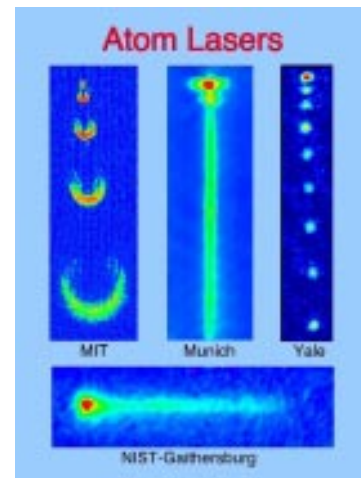


This illustration contrasts how fermions and bosons occupy levels in an energy well. (Courtesy JILA/NIST)

available energy levels. This ensemble of atoms is called a “quantum degenerate gas” owing to the fact that the differences between bosons and fermions only become important in this low-temperature, high-density regime. A Fermi degenerate gas has more energy than predicted by classical physics, because fermions have to occupy higher and higher energy levels once the lower ones get filled up. Achieving this state has been difficult because cooling fermions is more difficult than cooling bosons: placed in a trap made with magnetic fields, fermions in similar states tend to repel each other and avoid the energy-transferring collisions required for “evaporative cooling.” To combat this, researchers at JILA/NIST in Colorado prepared potassium-40 atoms in two different states of spin, a quantity which describes how the atoms respond to an external magnetic field. The two species could collide with one another and this enabled evaporative cooling to occur. Then, one spin species was removed by a radio-frequency field, leaving about a million of atoms in the other spin species for study. The JILA/NIST group deduced their temperature to be approximately 290 nanokelvins—the lowest ever recorded for a gas of fermions. They witnessed that the fermion nature of the atoms dramatically inhibited evaporative cooling. This is due in part to the Fermi pressure—the repulsion of atoms in the trap—which resists the compression necessary for effective evaporative cooling. (Therefore, this system can provide insights into how the fermions that make up white dwarfs and neutron stars remain buoyant instead of collapsing by the force of gravity.) In the future, researchers hope to study superconductivity by forming Cooper pairs with the fermions, at even lower temperatures than presently achieved. Creating such a “Fermi superfluid” will enable investigations into all forms of superfluidity and superconductivity. (DeMarco and Jin, *Science*, 10 September 1999.) Other groups are pursuing these and similar states with other fermion atoms.

A CONTINUOUS ATOM LASER BEAM has been demonstrated for the first time by researchers at the Max Planck Institute for Quantum Optics in Munich (Bloch, Haensch, and Esslinger, *Phys. Rev. Lett.* **83**, 3008, 1999). The first atom laser produced pulses of atoms, rather than continuous beams. Secondly, the atoms quickly spread out in a moon-like crescent, instead of forming a more desirable narrow beam. At the March 1999 APS Centennial Meeting, Theodor Haensch described a design that produces a continuous stream of atoms lasting as long as 100 milliseconds. In addition, the beam can potentially have a radius of a nanometer, thousands of times narrower than the focus of an optical laser beam. Using a specially designed magnetic trap, placed inside a magnetic shield enclosure, the researchers created a Bose-Einstein condensate of rubidium in a well-defined magnetic field which experienced a minimal amount of fluctuations from the environment. In such a low-noise setup, a radio wave can address a specific magnetic-field region of the condensate. Since every atom acts like a wave and is spread out over the entire condensate, each atom eventually gets affected by the radio wave, becoming converted from a trapped to an untrapped state. The conversion process occurs gradually, with a beam emerging at a slower and more controlled rate than in previous atom-laser demonstrations. The escaping rubidium atoms fall under the influence of gravity. Also at the APS Centennial, Bill Phillips of NIST discussed an atom laser that can produce beams

in any direction, not just downwards. (Hagley et al., *Science* **283**, 1706, 1999). The researchers applied a pair of optical laser beams to a sodium BEC; the atoms absorbed some of the momentum of the beams and could be kicked in the desired direction to form a beam. Their design actually generates a “quasi-continuous beam,” pulses of atoms so close together in succession that they overlap. In addition, the beam is narrowly collimated, spreading out just a tenth of a degree, comparable to a laser pointer. These beams provide an excellent source of atoms for devices which can measure tiny amounts of rotation and precision measurements of gravitational acceleration and time; they may also allow researchers to make very sophisticated nanostructures. Interestingly, even the pioneers in this new frontier do not know how physics concepts such as coherence will be redefined for the case of these laser-like matter waves.



Atom laser beams from 4 different groups pursuing different designs. (Figures courtesy NIST, MIT, Yale, and the Max Planck Institute for Quantum Optics)

JOSEPHSON EFFECT IN A BOSE-EINSTEIN condensate (BEC). In the Josephson effect, an alternating current is observed between two separated macroscopic quantum states (superconductors) that are held at different chemical potentials. Now, Mark Kasevich and Brian Anderson (Yale University) have seen the same phenomenon in a BEC of rubidium atoms loaded into the traps of a vertically oriented optical lattice—a series of energy wells established by the electric field of a laser beam. With gravity providing the difference in chemical potential between adjacent traps, atoms from each trap tunneled coherently downward, with atoms from all traps in the lattice participating simultaneously. Blobs of condensed atoms then dropped out of the bottom of the lattice with a predictable frequency. Just as the Josephson effect plays a key role in determining $2e/h$ and the volt, the researchers say that the “atom current” in their experiment could be useful for precisely measuring very weak forces. Such forces include not only gravity but also van der Waals–Casimir forces. The spaced-out drops of atoms also constitute a pulsed atom laser beam. (B. P. Anderson, M. A. Kasevich, *Science* **282**, 1686, 1998.)

LIGHT HAS BEEN SLOWED by seven orders of magnitude. In general, light travels slower in optical materials than in vacuum; the higher the material’s index of refraction, however, the greater the toll that absorption takes on the light beam. But in an experiment at the Rowland Institute for Science in Cambridge, Massachusetts, Lene Hau and her coworkers cooled a cloud of sodium atoms to ultralow temperatures and set up a particular laser-induced quantum interference—electromagnetically induced transparency (see the article in *PHYSICS TODAY*, July 1997, page 36). They were able to cancel absorption and to slow light in the cloud by creating a very steep variation in the refractive index around an atomic resonance line (although the refractive index of the medium remained close to unity). The low temperatures (50–2000 nK) strongly promoted the quantum interference by reducing thermal motion and increasing atomic densities in the clouds. Indeed, the slowest light propagation velocity (17 m/s) was obtained when the sodium was in a Bose-Einstein condensate. The researchers also observed very large nonlinear optical effects. For example, the measured intensity-dependent index of refraction was 14 orders of magnitude larger than that of an optical fiber and a million times greater than any previously measured refractive index. Hau says that the work makes possible nonlinear optics at extremely low light levels. (L. V. Hau et al., *Nature* **397**, 594, 1999.) In addition, a US-German collaboration succeeded in slowing down light to 90 m/s in a significantly warmer medium—a hot rubidium gas. (Kash et al., *Phys. Rev. Lett.*, **82**, 5229, 1999.)

TAILOR-MADE WAVEFUNCTIONS have been produced in Rydberg atoms of cesium. In a process akin to holography, Thomas Weinacht and his colleagues at the University of Michigan used a pair of computer-controlled lasers to directly manipulate the shape of the outermost electron’s radial wavefunction. First, a laser was used to excite a coherent state in the atom. The wavefunction was then measured and compared with a predetermined, desired final state. The information was fed back into the computer, which in turn generated a new laser pulse that altered the shape of the wavefunction. The process was repeated until the desired wavefunction was produced, often in only two iterations—as shown in the accompanying figure (in which height denotes amplitude and color denotes phase), where the top image is the target state and the succeeding three images show the iterations. Such precise reconstruction of a quantum system is important for coherent quantum information processing (T. C. Weinacht, J. Ahn, P. H. Bucksbaum, *Nature* **397**, 233, 1999. For more on reconstructing wavefunctions, see the article in *PHYSICS TODAY*, April 1998, page 22.)

WIRE-GUIDED NEUTRAL ATOMS. Researchers at the University of Innsbruck in Austria have demonstrated two different ways of guiding cold lithium atoms taken from a magneto-optic trap and placed near a thin current-carrying wire. Although the atoms are neutral, they have a magnetic moment and thus can interact with the wire’s magnetic field. Atoms having their moments parallel to the field feel a force driving them toward higher fields; such atoms orbited around the wire while their companions having antiparallel moments left the region, seeking lower fields. However, the addition of a second magnetic field, perpendicular to the wire, created a “tube” of low magnetic field alongside the wire. The low-field-seekers could then be guided through the tube, as shown in the image; the wire (orange line) carries a 1 A current. This second guide is especially interesting because the wires can be mounted on a surface, allowing for easy miniaturization of the guides and traps for various atom-optics experiments. Jörg Schmiedmayer says that the group is now testing a beam splitter made from two intersecting wires. (J. Denschlag et al., *Phys. Rev. Lett.* **82**, 2014, 1999.)

ZERO-POINT MOTION in a Bose-Einstein condensate (BEC) has now been studied. A group of MIT researchers measured the momentum distribution of a trapped sodium BEC, taking advantage of the fact that atoms absorb light at slightly lower (higher) frequencies if they are moving away from (toward) the light. In Bragg scattering, an atom absorbs a photon from a laser beam and is stimulated by a second laser to emit a photon at a different frequency. For the most efficient stimulation, the emitted frequency is also shifted upward or downward depending on the atom's motion. Measuring the width of this resonance allowed the researchers to determine the range of momentum values for the atoms in the condensate. Multiplying the measured momentum spread by the size of the condensate gave an answer of approximately \hbar —the minimum value allowed by Heisenberg's uncertainty relation demonstrating that the BEC is maximally coherent. Previous measurements of momentum spreads in BECs were made on expanding condensates, typically having energies hundreds of times larger than the zero-point energy. According to Wolfgang Ketterle, "The trapped condensate has no entropy and behaves like matter at absolute zero." (J. Stenger *et al.*, *Phys. Rev. Lett.* **82**, 4569, 1999.)

VISUALIZING ELECTRONIC ORBITALS. The image of an atom is really the image of the averaged likelihood that the electrons will be at various places. Physicists at Arizona State University have now imaged the cloud of bonding electrons in copper oxide and shown that they look just the drawings used for decades in quantum physics textbooks. Using a combination of x-ray diffraction and electron diffraction (to avoid multiple x-ray scattering problems), the scientists produced a three-dimensional map of the hybridized orbital hole-bonding copper with neighboring oxygen atoms in cuprite (2CuO). They also found unexpected metal-metal covalent bonding, not clearly predicted by calculations. The researchers would like to apply their technique to the more complicated CuO_2 superconductors and colossal magnetoresistance manganates. (J.M. Zuo, M. Kim, M. O'Keefe, J.C. Spence, *Nature* **401**, 49, 1999.)

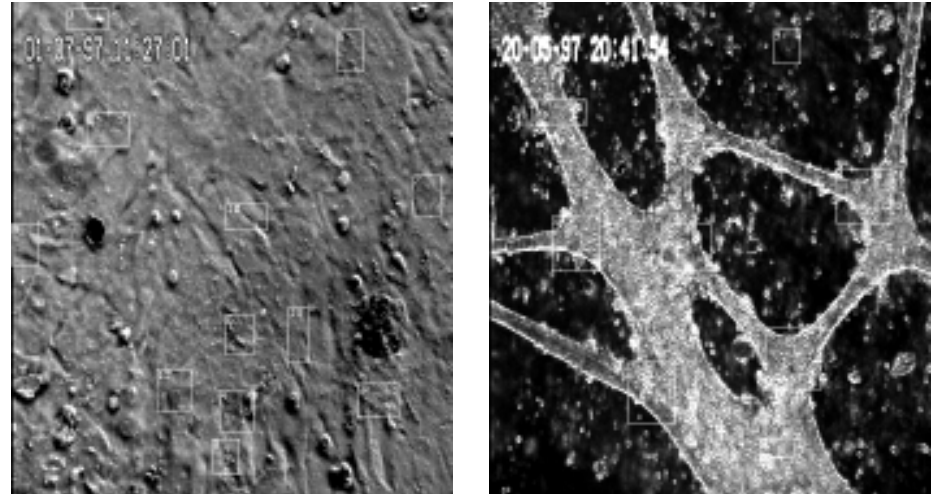
WAVE PROPERTIES OF BUCKYBALLS have been observed. Anton Zeilinger (University of Vienna) and his colleagues sent a beam of the soccerball-shaped C-60 molecules (also known as fullerenes) through a system of baffles and a grating (having slits 50 nm wide and 100 nm apart), and detected a characteristic quantum interference pattern. With velocities of around 220 m/s, the deduced de Broglie wavelength for the molecules is about 0.025 nm. They also saw the interference with C-70. The researchers suggest that, because they have shown that the large and complex buckyballs retain their quantum coherence, fullerenes provide an ideal system for further explorations of the boundary between quantum and classical physics. (M. Arndt *et al.*, *Nature* **401**, 680, 1999.)

BIOLOGICAL, MEDICAL PHYSICS

A NEW MODEL OF EPILEPSY. The onset of an epileptic seizure is marked by a transition from the customary uncoordinated (perhaps even chaotic) firings of neighboring neurons into a state of synchronous firings, whose organizing principle is not yet known. In recent years, brain imaging techniques have shown that the staging area for some of the most intractable forms of epilepsy is in a region of the hippocampus. Now, researchers at Indiana University-Purdue University at Indianapolis have created a hybrid model of a portion of the brain. First, they describe a hippocampal subnetwork of neurons with three biologically inspired coupled ordinary differential equations. Then they connect about 1200 such subnetworks into a spatially extended lattice of coupled ODEs whose rules are governed by potassium diffusion. Epilepsy is a dynamical disease, arising not from any structural or chemical abnormality, but rather from the temporary excursion of a critical parameter outside of some acceptable window of behavior. Knowing what this parameter is could lead to new therapies. From analyzing the results of their model calculations, the IUPUI scientists suspect the mystery parameter may be the speed of communication among the synchronized neurons. (R. Larter, B. Speelman, R.M. Worth, *Chaos* **9**, 795, 1999.)

ULTRASOUND IMAGING WITHOUT PHYSICAL CONTACT between device and patient has been achieved, providing a potential solution to an unmet medical need—determining the depth and severity of serious burns in a convenient, accurate, and pain-free fashion. At the present time, physicians usually diagnose burns by inspecting them visually; however, such visual observation cannot provide direct information on whether there is damage to underlying blood vessels, a condition which requires surgery. Technologies such as conventional ultrasound or MRI are either too slow, time-consuming, or cumbersome. In addition, they are painful for the patient if they require direct contact with the burn area. This is certainly the case with conventional ultrasound, which requires direct contact with the body, or must at least be connected to the body via water. That's because generating ultrasound in a device and sending it through air causes a large proportion of the sound to bounce right back into the device. This results from a great mismatch between air and the device in the values of their "impedance," the product of the density of the substance and the velocity of sound through it. By more closely matching the impedance values between the device and air, a significantly greater proportion of sound can be transmitted to the body, and reflected back, to obtain enough of a signal for an image. In a non-contact ultrasound device described at a Fall 1999 meeting of the Acoustical Society of America in Columbus, Joie Jones of UC-Irvine and his colleagues pass the sound wave through a multilayered material, with each succeeding layer having an impedance value closer to that of air. The transmission is improved to the point that the researchers could image burns by holding their device about two inches away from the skin, in about a minute or so. Having tested this device on over 100 patients, the researchers plan to move to larger clinical studies and develop a device that can take images in real time.

PACEMAKERS IN A PETRI DISH. Pacemakers are cells or groups of cells that provide regularly repeating stimuli to a large network of cells. In humans, roughly 5000 cells in the right roof of the heart's atrium generate the signals that regulate the rhythmic contractions of that organ. Now, researchers at the Technion-Israel Institute of Technology excised muscle cells and connective tissue from the heart ventricles of rats, and incubated them in a petri dish under a microscope equipped with a CCD camera and real-time computerized image processing. The cells formed a monolayer and, after 173 weeks, a hardy network of fibers. In continuously monitoring the network's contractile activity as it self-assembled, the researchers detected rhythmic contractions as well as rhythm disorders, such as skipped-beat patterns and alternations between irregular and regular rates of contraction. This suggested to them that one or more pacemakers had formed within the network. Although *in vitro* pacemaker activity has been observed before, the group's optical technique is able to monitor the cells noninvasively and continuously long enough to watch a pacemaker system emerge from an evolving cellular network. (Y. Soen *et al.*, *Phys. Rev. Lett.* **82**, 3556, 1999.)

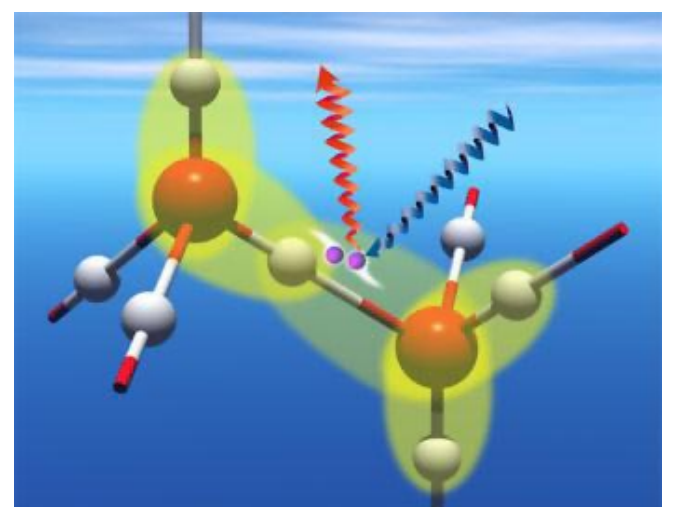


Putting rat heart cells in a petri dish causes them under the right conditions to grow into a network of cells which exhibit the formation of one or more pacemakers regulating the contractions of muscle cells in the network. The boxes in each image mark regions of interest where cell contractions are monitored. (Courtesy Technion-Israel Institute of Tech.)

CONDENSED MATTER, MATERIAL PHYSICS

SUPERCONDUCTIVITY GOES PLATINUM. It is ironic that some of the best insulators (such as perovskite ceramics) should make the best superconductors, whereas some of the best conductors (the noble metals gold, silver, and copper, as well as platinum and palladium) should fail to become superconductors. The electron-phonon interactions that bring about low-temperature superconductivity are apparently so weak in these metals that superconductivity is precluded. Now, though, physicists at the University of Bayreuth (Germany) have overcome the recalcitrance of platinum, which, in the form of a high-purity compacted powder, becomes superconducting at millikelvin temperatures. The origin and type of the superconductivity in the platinum powder is unknown, but the researchers rule out impurities—either inside or on the surface of the sample—as giving rise to the effect. (R. König, A. Schindler, T. Herrmannsdörfer, *Phys. Rev. Lett.* **82**, 4528, 1999.)

HYDROGEN BONDS IN ICE ARE COVALENT. Within a single water molecule, hydrogen and oxygen are held together by strongly covalent bonds—a purely quantum mechanical effect in which electrons are shared between atoms. Between neighboring molecules in water or ice, however, are much weaker "hydrogen bonds," the precise nature of which has been controversial. Until now. An international team led by Eric Isaacs (Bell Laboratories, Lucent Technologies) used inelastic (Compton) x-ray scattering, which is sensitive to extended electronic states, to directly measure the electronic ground state wavefunction of ice along different directions. By examining the resulting anisotropies, the team determined that, although neighboring water molecules are predominantly held together in ice by electrostatic forces, there is also a significant covalent component to the bond, confirming the prediction advanced by Linus Pauling in 1935. Understanding water, and the real nature of the hydrogen bond, is of great relevance to the many other structures, such as DNA, that contain hydrogen bonds. (E. D. Isaacs *et al.*, *Phys. Rev. Lett.* **82**, 600, 1999.)



This figure shows neighboring water molecules in ice. The yellow clouds indicate the chemical bonds that exist in these molecules, and the arrows depict an x-ray scattering from an electron (purple sphere) to provide information on the nature of the bond. (Courtesy Lucent Technologies)

LIQUID CRYSTAL ACOUSTICS. Liquid crystals (LCs) are structures that consist of rod-shaped molecules with the ability to polarize light. They are regularly employed in electronic displays; an applied voltage reorients the rods and thereby changes the optical properties of the LCs. It came as a big surprise to Jay Patel (Pennsylvania State University) that LCs emit faint but audible sound during the electrical switching, while undergoing their choreographed movements. Further, the intensity of the sound increases as the driving frequency approaches the natural resonant frequency of the cavity that contains the LCs. Patel and his colleagues are not yet sure of the implications of this discovery, but expect that it will lead to a fruitful new research area. (Y.J. Kim, J.S. Patel, *Appl. Phys. Lett.* **75**, 1985, 1999.)

OPTICAL AND RADIO FREQUENCIES can now be compared to a few parts in 10^{17} or better. Because of the reciprocal relationship between time and frequency, a very short pulse of laser light (for example, a femtosecond wavepacket) contains a very wide range of frequencies. Within the lasing cavity, each frequency, or mode, is reflected separately. When the phases of all the modes match, then the entire wavepacket sloshes back and forth coherently, and the spectrum of the train of output pulses resembles a comb, with the regularly spaced teeth separated by the reciprocal bounce time of the cavity. Researchers at the Max Planck Institute for Quantum Optics (Garching, Germany) have now demonstrated that the output "teeth" of such a mode-locked laser are distributed uniformly in frequency to within three parts in 10^{17} over a range spanning 20 THz. In addition, using a comb with 244,000 teeth as a kind of ruler,

they have now measured the frequency of the cesium D_1 line with unprecedented accuracy. This work may open a new chapter in metrology, and could lead to the replacement of atomic clocks (which are stable to about two parts in 10^{15}) by optical clocks. (Th. Udem *et al.*, *Phys. Rev. Lett.* **82**, 3568, 1999, and *Optics Lett.* **24**, 881, 1999.)

X-RAY CRYSTALLOGRAPHY has now been used to image non-crystals. X rays have long been used to determine the structure of crystalline objects: The periodic arrays of atoms or molecules produce diffraction patterns with discrete peaks that, when analyzed by Fourier transformation algorithms, provide a map of the sample's structure with approximately angstrom resolution. In the new experiment performed at Brookhaven National Laboratory's National Synchrotron Light Source by Jianwei Miao and David Sayre (both of State University of New York at Stony Brook), and their colleagues x rays were directed onto a micrometer-sized array of letters spelled out with 100 nm gold nanoparticles. That manifestly noncrystalline object produced a continuous (rather than discrete) diffraction pattern, which was then oversampled and put through an iterative algorithm to reconstruct the image with a resolution of about 75 nm. The researchers believe their method can be applied to imaging small biological cells or even large subcellular objects. (J. Miao *et al.*, *Nature* **400**, 342, 1999.)

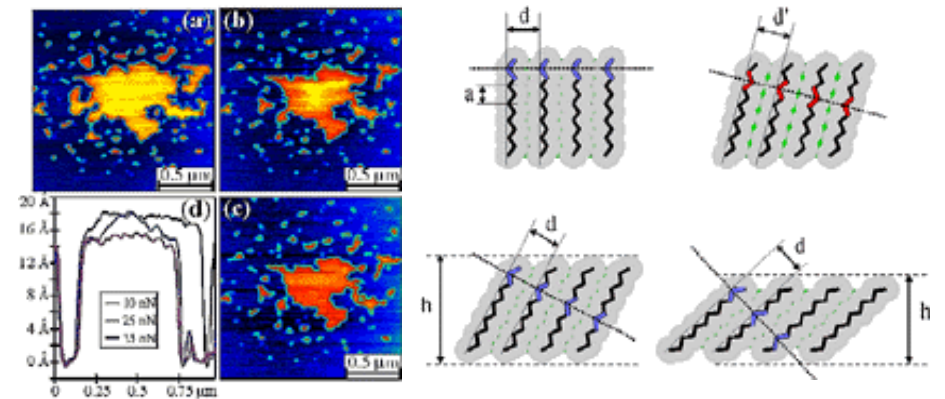
A THEORY OF TACKINESS has been developed that can account for the highly nonlinear force-separation curves observed when sticky objects are pulled apart. The forces primarily involved in making objects sticky are the weak van der Waals forces between molecules, but their effect is enhanced by mechanisms that remain to be elucidated. For example, in controlled experiments in which a metallic probe is removed from a sticky polymer at a constant rate, the required force briefly reaches a peak value, then remains roughly constant at a lower value until it vanishes when the probe is completely removed. Now, Cyprien Gay and Ludwik Leibler of the Unité Mixte de Recherches CNRS—Elf Atochem in France suggest that air bubbles, trapped as the rough surfaces of the metallic probe and of the deformable polymer touch each other, create a suction-cup effect as the probe is withdrawn and the bubbles deform. This effect causes the peak in the force curve. As the probe is withdrawn further, isolated bubbles connect and a network of contact points develops between the probe and polymer. Fractures then propagate through the network, reducing the force required to separate the surfaces, and giving rise to the force plateau. Developing a sophisticated understanding of stickiness will help researchers better design adhesives, coatings and paints. (C. Gay, L. Leibler, *Phys. Rev. Lett.* **82**, 936, 1999.)

THE PARAMAGNETIC MEISSNER EFFECT (PME), in which a superconductor attracts rather than expels magnetic flux, may now be demystified. It was first seen almost ten years ago in high- T_c materials and more recently in conventional superconductors. Andrey Geim's group at the University of Nijmegen in The Netherlands has now observed the PME with high resolution—better than one quantum of flux—using small aluminum disks and micromagnetometers (pictured in *PHYSICS TODAY*, February 1998, page 9). At the critical temperature, superconductivity in a magnetic field is initiated in an archipelago of tiny islands at the material's surface (the so-called surface superconductivity). However, the researchers found that if the sample is smooth enough, 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 superconducting region occupies more and more of the interior, tightening the noose around the flux already inside. This process, in turn, makes room for more flux to enter the outer precincts of the sample. In effect, the sample attracts magnetic flux. The researchers conclude that the PME is a general property of superconductors, and does not require special pairing mechanisms as previously thought. (A. K. Geim *et al.*, *Nature* **396**, 144, 1998.)

A SINGLE-PHOTON TURNSTILE, a device in which photons are emitted one at a time under controlled circumstances, has been created by a team of scientists from Japan and the US. In essence, the researchers used the Coulomb blockade effect to produce a quantization of photon emission, analogous to quantization of electrical conductance. They made a quantum well sandwich, with the central well isolated by tunnel barriers from an n-type well on one side and a p-type well on the other. By carefully adjusting the voltage across the device, the researchers could coax either a single electron or a single hole into the central

well. By modulating the voltage periodically, they were able to combine a lone electron with a lone hole to produce a lone photon during each voltage modulation period. The device, which operates at mK temperatures, was a tiny post some 700 nm tall, chosen from an array of such posts, shown here. (J. Kim *et al.*, *Nature* **397**, 500, 1999.)

WHERE DOES FRICTIONAL HEAT GO? Miquel Salmeron and his colleagues at Lawrence Berkeley National Laboratory addressed this problem by running a nanoscopic hoe (an atomic force microscope probe) through a field of pliant stalks (a monolayer of closely packed, upright, strandlike alkylsilane molecules used in lubrication) planted on a mica prairie. As the loading force of the probe increased, so did the frictional force, while the height of the field decreased. Further, the changes in friction and height were discrete, not continuous. The researchers propose that the zigzag molecular chains are interlocked when upright. When the tip of the probe bends (and images) the chains, each chain is displaced from its neighbors one notch at a time. Such a process consumes energy, which is the energy of friction for this system. (E. Barrera *et al.*, *Phys. Rev. Lett.* **82**, 2880, 1999.)



Left: Images of a monolayer of alkylsilane molecules put under a series of loads (imposed by the probe of an atomic force microscope)—(a) 10 nanonewtons, (b) 25 nanonewtons, (c) 35 nanonewtons. The brighter colors correspond to higher regions. The images show that the compression of these molecular "islands" is not uniform. (d) shows the height profiles, in angstroms, for the middle of the islands.

Right: Schematic model of the alkyl chain molecules tilting under increasing frictional loads. Only certain angles are allowed owing to the zigzag arrangement of the carbon atoms in the chains. This discreteness in tilt at the molecular level translates into a stepwise value for friction at the macroscopic level. (Courtesy LBL)

POWDER LASER. Hui Cao and her colleagues at Northwestern University have observed laser action with coherent feedback in semiconductor powders. The 100 nm grains of ZnO or GaN materials in the Northwestern samples were so tiny that the average photon scattering length was less than the emission wavelength. When the incident pump light exceeded a threshold intensity, very narrow, high-intensity emission lines were generated by stimulated emission with resonant feedback within the powder. The emission varied not only from place to place within the sample, but also with viewing angle. Cao hypothesizes that the random laser action occurs because the light is multiply scattered in closed-loop paths that act as ring cavities, and that many such closed loops exist in the powder. Each loop's emission is determined by its own resonance, independent of others in the powder. (H. Cao *et al.*, *Phys. Rev. Lett.* **82**, 2278, 1999.)

A LATTICE OF O_4 MOLECULES might exist in high-pressure experiments. At pressures less than 10 GPa, solid oxygen behaves much like other molecular crystals, such as nitrogen: A series of different structures appear as the pressure increases, although the molecular bonds are not greatly altered. At 96 GPa, oxygen becomes metallic. Throughout the large pressure range in between, the molecule is in its mysterious red phase. The transition to this phase is characterized by a greatly reduced volume, a dramatic color change (to a deep red), and very strong infrared absorption. Now, a group of researchers at the University of Florence (Italy) have studied the IR spectrum in detail, including the far IR region, and concluded that the charge transfer mechanism becomes extremely efficient between 10 and 20 GPa, and leads to chemical bonding between neighboring molecules. No theory exists for an O_4 molecule, but calculations done for an O_2-O_2 dimer provided a qualitative guide for interpreting the spectra. The association into O_4 units could be the first stage in oxygen's metallization process. (F.A. Gorelli *et al.*, *Phys. Rev. Lett.* **83**, 4093, 1999.)

EARTH SCIENCE, GEOPHYSICS

FREQUENT AND RARE PROPERTIES of coronal mass ejections (CMEs) have been explored in two recent papers. CMEs are large gusts of plasma blown out from the Sun into interplanetary space by some magnetic instability. Those that reach Earth can trigger not only light shows in the polar regions but also communications and power outages. Richard Canfield (Montana State University) and his colleagues studied soft x-ray movies of the Sun made with the Japanese Yohkoh satellite in 1993 and 1997, when solar activity was moderate. They discovered that active regions—areas on the Sun with many sunspots and tangled magnetic fields—were more likely to produce CMEs if they were "sigmoidal" (S- or backward-S-shaped) than otherwise. Such a region is shown here. Large active regions, whether sigmoidal or not, were also more prolific CME producers than small ones. Meanwhile, Yolande Leblanc and her colleagues (Paris Observatory and NASA/Goddard) observed a rare type of radio emission from fast electrons traveling along a magnetic loop of an expanding CME. They reported two successive bursts from as far as eight solar radii out from the Sun's surface. That distance is well out into the solar wind where stable magnetic arches cannot exist. It is not known if the electrons originated in an active region that was sigmoidal. (R. C. Canfield *et al.*, *Geophys. Res. Lett.* **26**, 627, 1999; Y. Leblanc *et al.*, *Geophys. Res. Lett.* **26**, 1089, 1999.)

THE BIGGEST LAVA OUTPOURING in Earth's history probably took place about 200 million years ago. An international team of geophysicists has just put the final piece into a jigsaw puzzle that connects basaltic layers in places as far flung as Canada, Brazil, Europe, and Africa. What started out as an Australia-sized blacktop in the heart of the ancient supercontinent of Pangea was torn asunder by tectonic forces as the Atlantic Ocean opened; the fragments were carried to places all around the Atlantic rim, making the full extent of the lava flow difficult to ascertain until now. The immense flow, referred to as the Central Atlantic Magmatic Province, took place roughly when mass extinctions occurred, at the boundary between the Triassic and Jurassic eras. (A. Marzoli *et al.*, *Science* **284**, 616, 1999.)

THE TEMPERATURE OF THE WORLD is 14.0 °C. At least that's the global average surface temperature. The Northern Hemisphere is somewhat warmer than the Southern, averaging 14.6 °C versus 13.4 °C. A team of scientists led by Phil Jones at the University of East Anglia (UK) has reviewed the surface temperature data gathered during the last 150 years from around the globe, plotted them on a one-degree grid superimposed on a map of the world, and found some trends. Shown here is the annual temperature trend for the years 1978-97, with reds and yellow indicating warming, and blues and green indicating cooling (white indicates areas with insufficient data). Here are a few other findings. Over the period 1861-1997, the average global temperature rose 0.57 °C. The warmest years of the 20th century have all occurred in the 1990s, with 1998 the warmest, followed by 1997, 1995, and 1990. The two periods of greatest warming were 1925-44 and 1978-97. Much of the net warming is at night; for the period 1950-93, nighttime average minimum temperatures increased 0.18 °C per decade while daytime average high temperatures increased only 0.08 °C per decade. (P. D. Jones *et al.*, *Rev. Geophys.* **37**, 173, 1999.)

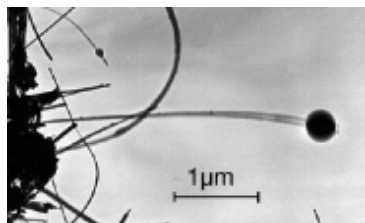
SUPERNOVA MATERIAL FOUND IN SOUTH PACIFIC. Light from distant supernovae is frequently seen on Earth. In a famous instance, a dozen or so neutrinos from nearby supernova 1987a were also detected. But atoms from supernovae are a different matter. From one point of view, such atoms are all around us; all the heavy atoms on the planets and asteroids were processed through or created in supernovae that exploded before Earth existed. But now comes evidence of atoms from a supernova that may have been deposited here as recently as five million years ago. An interdisciplinary team of scientists in Germany has identified radioactive iron-60 atoms in a sediment layer from the South Pacific Ocean. First they dated several sediment layers. Then they scrutinized samples with accelerator mass spectroscopy, which is able to spot the minuscule quantities of the iron isotope. The major known producer of Fe-60 (with a half-life of 1.5 million years) is a type II supernova, wherein a massive star explodes. After correcting for background levels of Fe-60, produced mainly by cosmic rays, the researchers were left with a substantial excess that they attribute to a relatively nearby (90-180 light-years) and recent supernova. The researchers believe that traces of the Fe-60 layer should be found worldwide. (K. Knie *et al.*, *Phys. Rev. Lett.* **83**, 18, 1999.)

THE SOLAR WIND DISAPPEARED for a day back on May 10/11, 1999 allowing Earth's magnetosphere to balloon out to the orbit of the Moon. Ironically, the greatly lowered solar wind flux of particles and solar magnetic field allowed high-energy electrons from the sun's corona to penetrate directly to our upper atmosphere unadulterated, where the electrons' characteristic x-ray emissions were observed by satellites over the North Pole for the first time. Such a "polar rain" had been predicted years before. Normally the coronal electrons (with energies of tens of keV, corresponding to temperatures of millions of degrees) lose much of their energy through scatterings with other particles on their ride from sun to Earth and in the topsy-turvy trajectories experienced at our magnetosphere. At the December 1999 meeting of the American Geophysical Union in San Francisco, these results were reported by a number of speakers, including David Chenette of Lockheed, Jack Scudder of the University of Iowa, and Keith Ogilvie of NASA Goddard. (Images available at www-spf.gsf.nasa.gov/istp/news/9912.)

NANOTECHNOLOGY

A QUASI-TWO-DIMENSIONAL ATOM GAS (2DAG) has been produced. Harald Gauck and his colleagues at the University of Konstanz, in Germany, used a battery of lasers to first cool and then confine argon atoms in what was essentially a planar resonant cavity for atom waves. The pancake-shaped argon cloud was about 200 nm thick and floated about 800 nm above a gold substrate. Not only does a 2DAG provide a high-density sample of optically cooled atoms, but by shaping the local light fields, the researchers hope to fashion integrated atom optical elements, such as miniaturized atom interferometers and even one-dimensional atom waveguides. (H. Gauck *et al.*, *Phys. Rev. Lett.* **81**, 5298, 1998.)

THE BENDING PROPERTIES OF CARBON NANOTUBES have been used to create a nanobalance. Researchers at the Georgia Institute of Technology applied an electrical potential to nanotubes protruding from a carbon fiber that, in turn, was attached to a fine gold wire. They then brought the tubes to within a few micrometers of an oppositely charged electrode, and put the assembly in an electron microscope. When an oscillating voltage was applied, a given nanotube could be made to vibrate resonantly, even at the second harmonic as shown here at 3 MHz for a multiwalled tube 14.5 nm in diameter. A particle attached to the tip of such a nanotube would change the resonant frequency, enabling researchers to deduce the mass of the particle. Indeed, the researchers weighed a 22-femtogram graphite particle in this manner. (P. Poncharal *et al.*, *Science* **283**, 1513, 1999.)



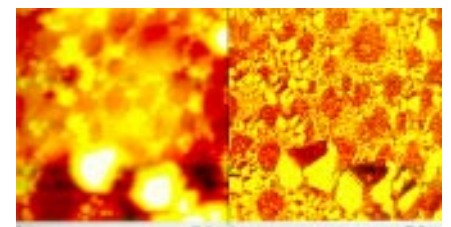
Nanobalance application for carbon nanotubes: a mass attached at the end of a nanotube shifts its resonance frequency. If the nanotube is calibrated (i.e., its spring constant known), it is possible to measure the mass of the attached particle. (Courtesy Georgia Tech.)

MOLECULAR LOGIC GATES have been demonstrated. A team of experimenters led by James Heath (UCLA) has built a molecular switching device, with a self-assembled monolayer of rotaxane molecules sandwiched between two electrodes. An applied voltage triggered chemical reactions in the rotaxane that changed the molecule's electronic properties. The resistivity of the device in the on state was 80-100 times lower than when it was off. By wiring several such junctions together, the group then created robust AND and OR gates. An individual switch could be configured only once, so the switches are useful for programmable read-only memory (as well as for logic), but not for random-access memory. Although the molecular layers had several million molecules, the researchers showed that the switching properties correlated directly with the electrochemical properties of isolated molecules. That implies that the devices should retain their performance even when scaled down to single-molecule dimensions. As the silicon-based computing industry rapidly matures, says Heath, such chemically assembled electronic nanocomputers could be over the next horizon. (C.P. Collier *et al.*, *Science* **285**, 391, 1999.)

A QUANTUM CAPACITANCE STANDARD is under development at the National Institute of Standards and Technology facility in Boulder, Colorado. Metrology has been moving away from standards based on artifacts such as a meter stick and toward standards using quantum phenomena to provide reliable, accurate, and, if possible, portable calibrations for researchers in the field. Consider capacitance, the measure of how well a tiny reservoir can store electrical charge. NIST's current standard is cumbersome and, more important, its accuracy is frequency dependent; within a certain frequency range, it is accurate to 0.02 parts per million, but outside that range, the standard is no better than 2 ppm. But now, Mark Keller and his colleagues have combined a single-electron transistor (SET) with a cryogenic capacitor to create a standard based on the quantization of electric charge. The charges arriving at the capacitor can be counted one at a time, all the way up to 10^8 or more. Combining that exquisite knowledge of the charge with an accurate voltage measurement then leads to the capacitance standard ($C=Q/V$). The SET approach has now achieved an accuracy of about 2 ppm, and the NIST researchers see the potential of reaching 0.01 ppm. The setup is relatively portable and its output is largely independent of frequency. (M.W. Keller *et al.*, *Science* **285**, 1706, 1999.)

VACUUM TUBES ATTEMPT A COMEBACK. Vacuum tubes were the backbone of the electronics industry until the 1960s, when their large size, excessive power dissipation, and lack of small-scale integrability allowed solid-state technology to win out. Now, dense arrays of tiny nanotriodes might bring vacuum designs back, at least for niche applications. Researchers at the University of Cambridge (UK) have made a 100-nm sized anode-gate-cathode device (shown here in cross section) in which the cathode consists of multiple metal pillars, which are each only about 1 nm in radius and crowded together in a dense forest. The one nanopillar with the greatest electric field at its tip is most likely the source of the ballistic, field-emitted electrons in the triode. Shooting electrons through a vacuum makes not only for fast switching, but also for a few advantages over semiconductor technology: The nanotriodes are radiation resistant and operate well at both high and low temperatures; also, because they are vertically oriented, integration in the third dimension is possible. Electrons issuing from the nanopillars are coherent and highly focused, and might be useful for doing holography or nanolithography. Remaining problems with this vacuum design include a relatively high operating voltage (10 V) for large-scale integration applications, and the reproducibility and longevity of the devices. (A.G. Driskill-Smith *et al.*, *Appl. Phys. Lett.* **75**, 2845, 1999.)

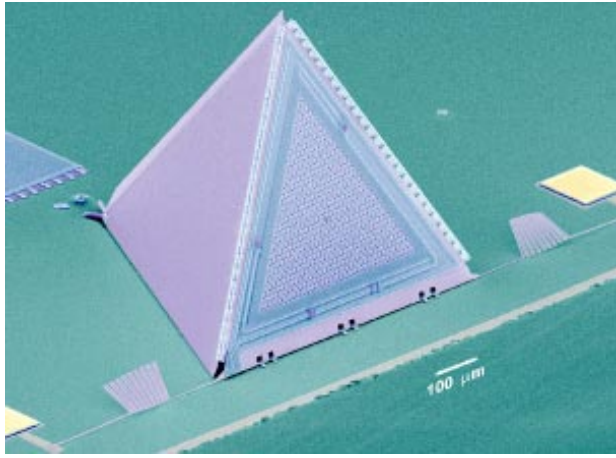
NANOMETER-SCALE IMAGES OF SOUND WAVES on surfaces have been produced by several groups, who announced their results at a 1999 meeting in Berlin of the Acoustical Society of America, the European Acoustics Association, and the German Acoustical Society. Their techniques all involve combining acoustic microscopy with atomic force microscopy (AFM) to detect ultrasound. Ultrasonic vibrations in the contact between the sample and the tip are the key, as described by Ute Rabe of the Fraunhofer Institute for Nondestructive Testing in Saarbrücken, Germany. Eduard Chilla of the Paul Drude Institute for Solid State Electronics in Berlin showed images of oscillations of single atoms responding to a sound wave. Andrew Kulik of the Federal Polytechnic Institute of Lausanne in Switzerland showed AFM images of sound waves coursing through a tin sample, with different features in the images corresponding to regions of different stiffness. In general, these techniques can potentially provide nanoscopic details on the elastic properties of a material and other subsurface information, such as the stress between different layers of a material.



Images of sound waves rippling through a tin surface recorded simultaneously by an atomic force microscope (AFM; left), and an atomic force acoustic microscope (AFAM; right). The AFAM image shows a more detailed grain structure. (Courtesy Andrew Kulik, Federal Polytechnic Institute of Lausanne in Switzerland)

PROGRESS TOWARDS A DICK TRACY WATCH. Introduced in a Jan. 13, 1946 comic strip, the Dick Tracy watch is a techie's dream: it is a two-way, voice-activated video phone that fits around a wrist. In work that may lead to some components for a real-life Dick Tracy watch, Peter Gammel and his colleagues at Bell Labs/Lucent Technologies have constructed a tiny (100-micron) pyramid-shaped microphone on a silicon chip. According to Gammel, this is the first microphone built by surface micromachining techniques, in which various thin films are deposited on a silicon surface and some of the features are etched away to result in movable parts. This process is to be distinguished from bulk micromachining, in which features are carved out of a silicon surface itself. The researchers have also built a very small rf filter, which blocks unwanted radio frequencies and prevents signals from a phone's transmitter from disrupting its

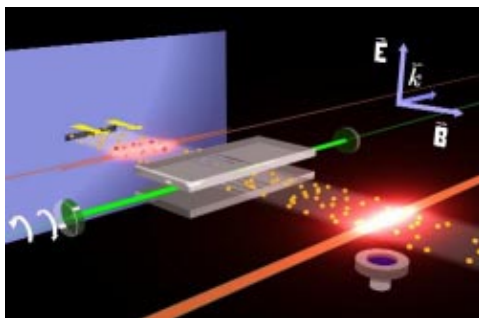
receiver. Made of aluminum nitride on a silicon surface, it is 100 times smaller than conventional ceramic filters, by far the largest single component in a cell phone. The Bell Labs researchers also built a micron-scale version of an inductor, a simple loop of wire that helps determine the proper frequency for communications. Most important of all, these components can all be built on the same silicon chip. Describing these results at the New York State section meeting of the APS held at Lucent in April 1999, Gammel speculates that all of the components for a Dick Tracy watch should be technologically available by 2005.



A microphone on a silicon integrated circuit. The base has marks with an approximate size of just 100 microns (0.1 millimeters). (Figure courtesy Bell Labs/Lucent Technologies)

PARTICLE, NUCLEAR, PLASMA PHYSICS

AN IMPROVED TEST OF THE STANDARD MODEL, the exquisitely successful merging of electromagnetism with the weak nuclear force, has been carried out in cesium atoms. Atoms are chiefly governed by the electromagnetic force, which conserves parity. But, according to current theory, they also feel a twinge from the weak force, a notorious abuser of parity. Carl Wieman has monitored that nuclear twinge in cesium at the University of Colorado (see PHYSICS TODAY, April 1997, page 17). Now, with Stephen Bennett, he has measured the 6S-7S transition polarizability, which better calibrates the earlier experiment. Combining their measurement with recently improved theory, The Colorado comparison reveals a small but intriguing discrepancy between theory and observation, perhaps indicating some new physics to be explored. (S. C. Bennett, C. E. Wieman, *Phys. Rev. Lett.* **82**, 2484, 1999.)



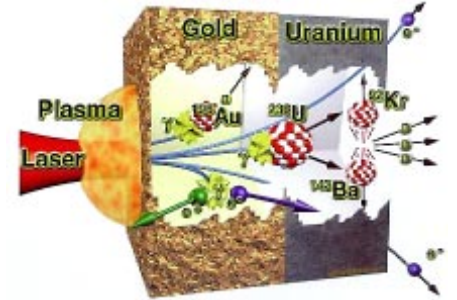
Schematic of the JILA/University of Colorado parity nonconservation apparatus. A beam of cesium atoms is optically pumped by diode laser beams, then passes through a region of perpendicular electric and magnetic fields where a green laser excites the transition from the 6S to the 7S state. Finally the excitations are detected by observing the fluorescence (induced by another laser beam) with a photodiode. (Courtesy JILA/Univ. of Colorado)

ELEMENTS 118 AND 116 have been discovered at Lawrence Berkeley Lab by crashing a beam of krypton atoms into lead atoms. The three detectable atoms of element 118 have nuclei possessing 118 protons and 175 neutrons for a mass total of 293. The new elements are even further along in the Periodic Table than element 114, whose existence was announced back in January 1999 by scientists in Russia, and further into the "island of stability", the supposed nuclear regime in which certain combinations of neutrons and protons lead to a relatively long life. For all that, the atoms of element 118 still decay after less than a millisecond into element 116 plus an alpha particle. Element 116 then promptly decays into element 114 plus another alpha particle. Ken Gregorich led the LBL group that discovered the new nuclei. Four of the team members are German nationals, which prompted DOE secretary Bill Richardson to emphasize the continuing value of international scientists working at US national labs.

DIRECT CP VIOLATION has been observed at Fermilab by the KTeV collaboration and by the NA48 experiment at CERN. An important way of apprehending the basic nature of time and space (in the finest tradition of Greek philosophy) is to ask "what if" questions. For example, will a collision between particles be altered if we view the whole thing in a mirror? Or what if we turn all the particles into antiparticles? These propositions, called respectively parity (P) and charge conjugation (C) conservation, are upheld by all the forces of nature except the weak nuclear force. And even the weak force usually conserves the compound proposition of CP. In only one small corner of physics—the decay of K mesons—has CP violation been observed, although physicists suspect that CP violation must somehow operate on a large scale since it undoubtedly helped bring about the present-day preponderance of matter over antimatter. K mesons (kaons) are unstable and do not exist outside the interiors of neutron stars and particle accelerators, where they are artificially spawned in K-antiK pairs amidst high energy collisions. K's might be born courtesy of the strong nuclear force, but the rest of their short lives are under control of the weak force, which compels a sort of split personality: neither the K nor anti-K leads a life of its own. Instead each transforms repeatedly into the other. A more practical way of viewing the matter is to suppose that the K and anti-K are each a combination of two other particles, a short lived entity called K1 which usually decays to two pions (giving K1 a CP value of +1) and a longer-lived entity, K2, which decays into three pions (giving K2 a CP value of -1). This bit of bookkeeping enshrined the idea then current that CP is conserved. All of this was overthrown when in 1964 the experiment of Jim Cronin and Val Fitch showed that a small fraction of the time (about one case in every 500, a fraction called epsilon) the K2 turns into a K1, which subsequently

decays into two pions. This form of CP violation is said to be indirect since the violation occurs in the way that K's mix with each other and not in the way that K's decay. One theoretical response was to say that this lone CP indiscretion was not the work of the weak force but of some other novel "superweak" force. Most theorists came to believe, however, that the weak force was responsible and, moreover, that CP violation should manifest itself directly in the decay of K2 into two pions. The strength of this direct CP violation, characterized by the parameter epsilon prime, would be far weaker than the indirect version. For twenty years detecting a nonzero value of epsilon prime has been the object of large-scale experiments at Fermilab and for nearly as long at CERN. In each case, beams of K's are sent down long pipes in which the K-decay pions could be culled in sensitive detectors. The KTeV group at Fermilab reports a definite result: a ratio of epsilon prime to epsilon equal to $28 \pm 4 \times 10^{-4}$, larger than the theoretical expectation (Alavi-Harati et al., *Phys. Rev. Lett.* **83**, 22, 1999). Meanwhile the NA48 experiment at CERN reports a detection of direct CP violation, with a ratio of epsilon prime over epsilon of $18.5 \pm 7 \times 10^{-4}$. (See also Physics Today, May 1999.)

CREATING ANTIMATTER WITH LASER LIGHT. Intense light from the Petawatt laser at Livermore, the world's most powerful laser, has been directed onto a thin gold film where it creates a plasma plume which acts as a sort of messy wakefield accelerator. In particular the laser electric fields rip electrons from the gold atoms and send the electrons shooting off with energies as high as 100 MeV. Some of these electrons radiate gamma rays which in turn can create electron-positron pairs (the first antimatter made in laser-solid interactions) and can also induce fission. Thus laser photons at the electron-volt level can, by teaming up, initiate the sort of million-electron-volt nuclear reactions that normally take place only at an accelerator. Moreover, the femtosecond laser pulses can be focused to a much smaller spot size than is possible with any conventional particle beam. Tom Cowan of Livermore reported these results at the March 1999 APS Centennial Meeting in Atlanta.



In experiments conducted recently at Lawrence Livermore National Lab, an intense laser beam (from the Petawatt laser, the most powerful in the world) strikes a gold foil (backed with a layer of lead). This results in (1) the highest energy electrons (up to 100 MeV) ever to emerge from a laser-solid interaction, (2) the first laser-induced fission, and (3) the first creation of antimatter (positrons) using lasers. (Courtesy Livermore)

TABLETOP THERMONUCLEAR FUSION. Yet another Livermore photonuclear breakthrough was reported at the APS meeting. Todd Ditmire described an experiment in which laser pulses (35 fsec long and intensities as high as 10^{17} W/cm²) were absorbed by a gas jet of deuterium molecules. These molecules actually resided in clusters (average size of 5 nm) which exploded under the laser bombardment. Some of the rocketing D's fused into helium-3 nuclei plus energetic neutrons. The neutrons, showing up with a characteristic energy of 2.45 MeV, were detected (about 10,000 per laser shot) via a time-of-flight technique. Ditmire said that this new approach to promoting fusion reactions (executed with a setup that fits on a 4'x11' table) could probably not be scaled up to provide commercial power, but that it might provide a cheap source of neutrons. The whole process is highly efficient: virtually all the laser energy was converted into ion kinetic energy.

A LINEAR DECELERATOR FOR NEUTRAL MOLECULES has been demonstrated by a group in the Netherlands led by Gerard Meijer (University of Nijmegen). It provides a new way to cool molecules for subsequent trapping and study. Previous methods for obtaining cooled molecules either depended on a cold background gas and magnetic fields or were restricted to those molecules that could be formed from previously chilled trapped atoms. For their demonstration, the researchers constructed a 35-cm long "Stark decelerator" that contains a succession of 63 pulsed electric fields, is designed to slow down any neutral molecule with a permanent dipole moment (a permanent separation of electric charge within the molecule), and thus can handle virtually any asymmetric molecule. When a precooled mixture of carbon monoxide in xenon gas entered the decelerator, each CO molecule experienced the Stark effect; at every electric field, the molecule's internal energy shifted upward, accompanied by a loss of some kinetic energy. After passing through all 63 stages, a subset of the CO molecules was slowed from 225 m/s to 98 m/s, with an equivalent temperature of 30 mK. This technique promises to be useful for cold molecule physics, a field that is expected to bloom in the next decade, says Meijer, who also told us the group has now slowed molecules to 54 m/s. (H.L. Bethlem, G. Berden, G. Meijer, *Phys. Rev. Lett.* **83**, 1558, 1999.)

AN ALTERNATIVE TO COMPACTIFICATION has been proposed for dealing with extra dimensions. Invisible dimensions are for particle theorists what they are for Star Trek captains: a device for covering a lot of ground quickly and explaining anomalous behavior. In physics, they help make peace between quantum mechanics and general relativity, but they don't explain the hierarchy problem, the great disparity between the energy at which the weak and electromagnetic forces fuse together (10^2 GeV) and that at which gravity joins up with the other forces (10^{18} GeV). Some theories contend that we are unaware of the extra dimensions because they are compact, extending only across distances far smaller than the size of an atom. But now, Lisa Randall and Raman Sundrum have proposed that additional dimensions can be essentially infinite in extent, as long as gravitons are locked up in localized regions, at least in the extra dimensions. They show that with a particular nonfactorizable metric, the 3-brane on which we live is just part of a five-dimensional space, the equations of general relativity are solved and its tests met, the unification energy scale comes down to about 1 TeV, and spin-2 resonances are predicted that will be experimentally verifiable at the Large Hadron Collider. Sundrum emphasizes that localized gravity, not infinite extra dimensions, is what brings down the gravity scale. (L. Randall and R. Sundrum, *Phys. Rev. Lett.* **83**, 3370, 1999; and **83**, 4690, 1999.)

Notable Quotations from 1999

Compiled by Richard M. Jones, AIP Public Information Division

"To alter the rules that the scientific community has operated under for decades without providing them an opportunity to speak to the need for this change or to participate in developing it, is not only unwise, it is unfair."

— Rep. George E. Brown Jr. (D-CA) on the mandated change in data availability in the OMB A-110 regulation (1/1999)

"If we do these things - invest in our people, our communities, our technology, and lead in the global economy - then we will begin to meet our historic responsibility to build a 21st century prosperity for America."

— President Bill Clinton in his State of Union Address (1/1999)

"One only needs to look as far as the front page our the newspaper to see the effect of high-technology on our country.... What I am afraid of is that many people are not aware that these products do not simply appear out of nowhere. They are the result of a basis of knowledge which has been built up by researchers supported by federal funding."

— Senator Jay Rockefeller (D-WVA) (1/1999)

"Perhaps the greatest discovery of all this research is that we can no longer separate basic from applied science.... The disciplines are connected in ways they have never been before."

— Vice President Al Gore (1/1999)

"Engineering and physical sciences - taken together - accounted for 50 percent of federal research spending in 1970. That's down to 33 percent today.... The sharp nature of the shift in funding toward the biomedical fields has taken more than a few people by surprise. I'd be the first to tell you about the great things that are happening in biomedical fields. Some of that funding has gone to my own research. But, I also know that society cannot live by biomedical bread alone."

— NSF Director Rita Colwell speaking to House appropriators (3/1999)

"The contributions of computer science, physics, mathematics, engineering and other fields to biomedical research illustrate the need to ensure that fundamental science remains an integral part of the federal government's overall research agenda."

— House Science Committee report (3/1999)

"Research and development represent the cornerstone of our modernizing economy. I'm pleased that the President's civilian R&D budget requests are similar to ours, but I'm concerned that he's neglecting the importance of defense R&D."

— Senator Bill Frist (R-TN) (2/1999)

"Unfortunately, the DoD may be falling into a classic trap that can catch the best of managers, that of focusing so hard on the short term problems that they short change the future. This year's plans continue to show declines for S&T in the out years, and are largely unchanged from last year's plans."

— Senator Jeff Bingaman (D-NM) (3/1999)

"...give me a little bit of credit for the track record on the LHC [Large Hadron Collider]."

— House Science Chairman James Sensenbrenner (R-WI) criticizing SNS management (5/1999)

"I believe that the [House Appropriations] language on the Spallation Neutron Source, when coupled with rigorous oversight, will provide [DOE] with the facility they need at a cost that does not cause heartburn for the American taxpayer."

— Rep. Sensenbrenner (7/1999)

"I can say that in the State Department, [there is] widespread, total understanding of how important science and technology are in pursuit of foreign policy objectives."

— Frank Loy, Under Secretary of State for Global Affairs (4/1999)

"As the world becomes more technologically interdependent, the trend at the State Department has been to downplay science and technical expertise. It's time to reverse that trend."

— Robert Frosch, Chair of NRC Committee (10/1999)

"Resources are absolutely central to the whole problem."

— Under Secretary Loy (12/1999)

"Anyone who wants to close off our labs will have to go through me — and I never give in."

— Energy Secretary Bill Richardson on legislation restricting foreign visitors to weapons labs (4/1999)

"...I acknowledge that an extremely serious compromise of the security of classified nuclear weapons information has occurred...."

— Los Alamos Laboratory Director John C. Browne (5/1999)

"For the past two decades, the Department of Energy has embodied science at its best and security of secrets at its worst."

— President's Foreign Intelligence Advisory Board (6/1999)

"I don't know of any scientist in those laboratories who doesn't have a very high sense of patriotism and devotion to this country. That's why they are there."

— Dr. Sidney Drell (6/1999)

"The truth is, no one knows exactly what to do."

— Rep. Joe Barton (R-TX) on weapons labs (7/1999)

"I don't think that if we recalled William Shakespeare from the grave that we could have written this [DOE lab reorganization] provision to satisfy everyone."

— Senator John Warner (R-VA) (8/1999)

"We have said to our colleagues on the other side of the aisle we don't think this is a good [Comprehensive Test Ban] treaty; we think it puts safety in jeopardy; we think it puts us in a weakened condition internationally; and we think it is dangerous. However, since there have been calls and demands for a vote, we have offered to vote...."

— Senator Trent Lott (R-MS) (10/1999)

"...we are extremely disappointed with the way this has been handled. As I said, I believe it is irresponsible and dangerous. But we also note this may be the best we can get, and if it is the best we can get, as troubled as we are, we will take it."

— Senator Tom Daschle (D-SD) (10/1999)

"Not only is this cut devastating to NASA's programs, it is a knife in the heart of employee morale."

— NASA Administrator Dan Goldin on House appropriations bill (7/1999)

"One wonders whether this Congress would have zeroed out Jefferson's request for the Lewis and Clark Expedition."

— White House Chief of Staff John Podesta on House appropriations (9/1999)

"I am encouraged by the Administration's sudden interest in science funding. Over the last seven years, overall science budgets, which include defense and civilian R&D, when indexed for inflation, have been flat or decreasing. Science needs a boost."

— Rep. Sensenbrenner (9/1999)

"We literally are borrowing from Peter to pay Paul here."

— Rep. James Walsh (R-NY) explaining proposed cut to NSF (9/1999)

"If we cannot adequately meet the needs of veterans' programs, affordable housing, and scientific research during these prosperous times, then when can we?"

— Rep. Allan Mollohan (D-WVA) (9/1999)

"...if we do not do this research in science and technology, we are ruining the seed corn for our future economic growth; we are also doing a great disservice to our children and grandchildren by doing that."

— Rep. Vern Ehlers (R-MI) (9/1999)

"It is very clear to me that we are severely and critically under investing in basic research."

— NSF Director Colwell (9/1999)

"...I was very pleased we were able to meet the President's request for NSF because of the tremendous amount of exciting and potentially beneficial work that is being funded through the National Science Foundation. Truly, this is a national priority. I only wish more funds were available to add because this is our scientific future."

— Senator Christopher Bond (R-MO), who noted that the House had less money for its version of the bill (9/1999)

"It's about prioritizing."

— House Appropriations Committee spokesperson (9/1999)

"I can't believe it; I just can't believe it."

— Senator Barbara Mikulski's (D-MD) reaction to final bill with good FY2000 numbers for NSF and NASA (10/1999)

"So good on the [previous funding for] health care, not so good on the rest. We need more on the rest."

— President Clinton (11/1999)

"We need to create a better understanding between the people of America and the physics community. Because many Americans believe that physics is, on the whole, inaccessible. The equations, the experiments, the strange words — these are things many people gladly left behind in high school."

— Energy Secretary Bill Richardson at APS Centennial Meeting (3/1999)

"Out of our sense of patriotism and our own enlightened self-interest, we should lobby our representatives and senators and insist that federal investment in scientific research be doubled over the next five years."

— Op-Ed by former House Speaker Newt Gingrich (R-GA) (10/1999)

"Scientists and engineers constitute one of the largest, most valuable, yet least heard constituencies in America."

— White House science advisor Neal Lane (8/1999)

"Progress is meaningless if we don't know where we're going. Unless we try to visualize what is beyond the horizon, we will always occupy the same shore."

— Rep. George Brown (1993)