Physics News in 2001

A Supplement to APS News

Edited by Phillip F. Schewe, Ben P. Stein, and James R. Riordon
Media & Government Relations Division, American Institute of Physics

INTRODUCTION

Physics News in 2001, a summary of physics highlights for the past year, was compiled from items appearing in AIP's weekly newsletter *Physics News Update*. Many of the entries appearing here were also published in *Physics Today* magazine, where they were edited further by Stephen Benka. Readers should keep in mind that because of the way *Physics News Update* itself is prepared (short items aimed primarily, but not exclusively, at science journalists) and because of limited space in *Physics News in 2001*, some fields of physics research might be underrepresented in this compendium. Readers can get a much wider view of the year's worth of physics by going to the Physics News Update website at http://www.aip.org/physnews/update or APS's Physical Review Focus website at http://focus.aps.org/.

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ASTROPHYSICS

MAJOR NEW COSMIC MICROWAVE BACKGROUND MEASUREMENTS uphold the idea of an early "inflationary" era during which the observable universe expanded with superluminal speed and tiny quantum fluctuations in the density of matter were amplified into much larger structures. These structures are imprinted in the CMB as faint variations in the temperature across the microwave sky. The CMB, the curtain of photons set free when the expanding universe became cool enough to permit the existence of neutral atoms, is the earliest, largest, and furthest observable thing in all of science.

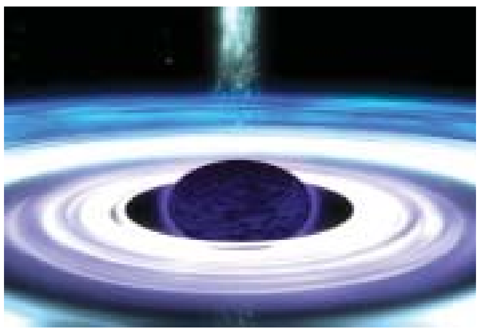
The best way to extract cosmological information from the CMB is to plot the observed microwave power as a function of the angular size of regions contributing to the CMB. The inflation model predicts that this spectrum should feature a number of peaks. The first peak, at an angular size of about 1 degree (about twice the angular size of the Moon), corresponds to the largest blobs of matter in the primordial plasma at the time of the CMB (about 400,000 years after the big bang). Subsequent peaks should correspond to blobs that had come together under the action of gravity but had then rebounded outward because of radiation pressure, and later still had condensed for a second or third time, etc. A year ago the Boomerang collaboration, which used a balloon-based detector floating over Antarctica, provided a detailed map of the first peak which, besides falling at the 1-degree size predicted by inflation, also determined that the overall curvature of the universe was zero. But Boomerang, and another detector group, Maxima, saw scant evidence of any other peaks, and this puzzled astronomers.

All this changed at the April 2001 American Physical Society (APS) meeting in Washington, DC, where the Degree Angular Scale Interferometer (DASI) collaboration, which parks its microwave detector on the roof of NSF's South Pole station, presented solid evidence for a second and third peak. The DASI results, summarized by John Carlstrom of the University of Chicago, were largely in concert with Boomerang's presentation at the meeting, reported by Barth Netterfield, of the University of Toronto. Boomerang used a new type of analysis and reported 14 times more data than last year. The microwave spectra for the two groups were similar as were the values of various cosmological parameters. For example, the position of the first peak yields the total energy of the universe (a parameter, denoted by the letter omega, expressed as a fraction of the critical density needed for halting the cosmological expansion). Boomerang and DASI found values of 1.03 and 1.04, respectively, with about a 6% uncertainty. Comparing the height of the first and second peaks, one can calculate the expected percentage of all energy in the universe that exists in the form of ordinary matter (baryons). This turns out to be about 5% for both groups, a fact that agrees well with predictions made by the independent "big bang nucleosynthesis" theory. It is harder to nail down other cosmological parameters, such as the percentage of energy in the form of dark matter or dark energy (energy lurking in the vacuum and responsible for the newly discovered net acceleration in the cosmological expansion). The new CMB measurements suggest values of about 30% and 65%, respectively, again in keeping with recent expectations.

New Maxima results (Shaul Hanany, Univ Minnesota) presented at the meeting did not havenearly the statistical weight of the other two groups, but were generally consistent; the three-way agreement brought a great round of applause from the audience of astronomers eager to unravel the mysteries of the early universe. Noted cosmologist Michael Turner (Univ Chicago) observed that last year's discovery of the first microwave peak constituted the first great vindication for the Inflation model and that this new discovery of secondary peaks was the second great vindication. The third type of evidence, Turner said, would be the detection of gravity waves from before the time of the CMB.

IS ALPHA, LIKE PI, A FUNDAMENTAL CONSTANT, or does it change over time? Pi, the ratio of a circle's circumference to its diameter (pi can be defined in other ways too) doesn't seem to be changing, but alpha, the symbol for the fine structure constant, might be. Alpha is a measure of the intrinsic strength of the electromagnetic force and thus determines how strong an atom is bound and what kind of light is absorbed or emitted by the atom when an electron inside the atom moves from one internal quantum state to another. In 1999 a group of scientists at the University of New South Wales in Australia reported some positive evidence that alpha was not staying the same. The evidence for a changing alpha at the level of a part in 100,000, according to a new report being issued by the same group, consists of the spacings of pairs of absorption lines of metal atoms in gas clouds in front of quasars at various redshifts. The spacings are proportional to alpha squared. The new observations suggest that alpha is growing bigger. This, if confirmed by further tests, runs counter to the law which prescribes that elasticized objects lose their holding power with the years. Swimsuits might droop with age, but atoms would get stronger as time goes by. (Webb *et al.*, *Phys. Rev. Lett.* **87**, 091301, 2001.)

EVIDENCE FOR BLACK HOLE ROTATION. An object in our galaxy called GRO J1655-40 consists of a seven solar mass black hole devouring a nearby normal star companion. Matter from the star first collects in an accretion disk orbiting the black hole before taking the final plunge through the event horizon, emitting x rays along the way. General relativity predicts the innermost stable orbit for matter circling this black hole, if it were nonrotating, to be about 64 km. However, at the April 2001 American Physical Society meeting, Tod Strohmayer of NASA's Goddard Space Flight Center reported the discovery of a 450 Hz oscillation from the black hole in archival data from the Rossi X Ray Timing Explorer. This high frequency indicates matter is orbiting the black hole at a radius of only 49 km. Based on this finding, he concluded that the black hole itself must have angular momentum. (T. Strohmayer, *Astrophys. J. Lett.* **552**, L49, 2001.)



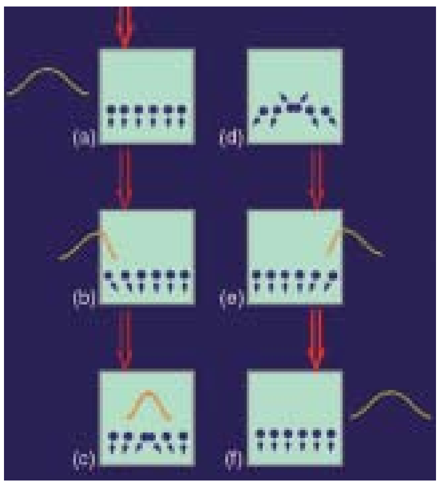
Computer animation illustrating a spinning black hole. (Courtesy NASA/Honeywell Max-Q Digital Group/DANA BERRY)

NEW UPPER LIMIT ON GRAVITY WAVE EVENTS. The International Gravitational Event Collaboration (IGEC) involves a network of five cryogenic resonant cylinder gravity wave detectors: two in Italy and one each in Switzerland, the US, and Australia. The search for passing gravity waves is a delicate art; in the resonant cylinder approach, it means measuring strain displacements far smaller than the size of an atomic nucleus on the end faces of 3 meter long, 2000 kg metal cylinders. The IGEC team has now reported that in its first operational period, covering 1997 and 1998, no gravity waves were detected. From this they calculated an annual upper limit of four events with a mean Fourier component exceeding 10^{-20} Hz^{-1} arriving at Earth. The IGEC typically used thresholds that correspond to the conversion of 0.04-0.11 solar masses to gravity waves in an astrophysical source such as a coalescing binary system of neutron stars or black holes at the Galactic center. The collaboration also demonstrated that a network of many detectors operating simultaneously can achieve a negligible false alarm rate. (Z. A. Allen *et al*., *Phys. Rev. Lett*. **85**, 5046, 2000.)

INTERGALACTIC MAGNETIC FIELDS can arise from galactic black holes. Intergalactic voids the vast regions of the cosmos that are largely empty of galaxies are permeated by very weak magnetic fields, far less than a microgauss. The walls where galaxies and galaxy clusters reside may have fields up to a microgauss. All these fields have most often been thought of as either primordial (arising at the Big Bang) or due to shock waves at massive colliding gas clouds. Now, researchers from the University of Toronto and Los Alamos National Laboratory have found a new source of diffuse cosmic magnetism. They analyzed 100 large radio loud galaxies: 70 giant ones in isolation and 30 smaller ones in the dense environs of galaxy clusters. They concluded that fully half of the energy content (up to 10^{60} ergs or more) of the extensive radio emitting lobes is in magnetic energy thrown out of 10^8 solar mass black holes at the cores of the galaxies. Summed over many galaxies, this energy reservoir appears to be the largest available in the mature universe for magnetizing intergalactic space. Furthermore, because the lobes have a higher pressure than the surrounding intergalactic medium, even when the central black hole has "turned off," the lobes with their force free fields will expand into the IGM. These expelled magnetic fields should exert a substantial influence on subsequent galaxy and large structure formation. (P.P. Kronberg *et al*., *Astrophys. J*. **560**, 178, 2001.)

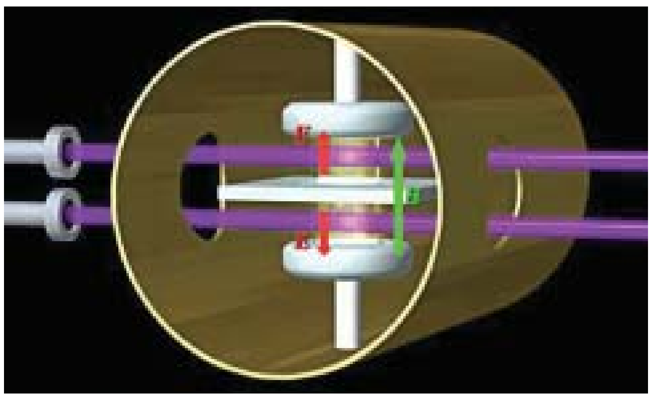
ATOMIC, MOLECULAR, AND OPTICAL PHYSICS

LIGHT BROUGHT TO A HALT. For the first time, physicists in two separate laboratories have effectively brought a light pulse to a stop. In the process, physicists have accomplished another first: the non-destructive and reversible conversion of the information carried by light into a coherent atomic form. Sending a light pulse into specially prepared rubidium (Rb) vapor, a group at the Harvard-Smithsonian Center for Astrophysics led by Ron Walsworth and Mikhail Lukin has (1) slowed the pulse's "group velocity" to zero and (2) stored its information in the form of an atomic "spin wave," a collective excitation in the Rb atoms. (A spin wave can be visualized as a collective pattern in the orientation of the atoms, which spin like tops and hence act like tiny bar magnets. "Spin" is merely the name for the tiny magnetic vector in each of the atoms.) The atomic spin wave is coherent and long-lived, which enables the researchers to store the light pulse's information and then convert it back into a light pulse with the same properties as the original pulse. This new accomplishment in a simple system increases the promise for quantum communication, which may someday be used to connect potentially ultrafast quantum computers in a large network analogous to the Internet. Usually photons (the quanta of light) are absorbed by atoms, destroying the information carried by the light. With the present method, in principle, no information in the light pulse is lost. Previous efforts to slow light (such as Hau *et al*., Nature, 18 February 1999) have reduced the signal speed to about 1 mph by using a process called electromagnetically induced transparency. (Liu *et al*., *Nature* **409**, 490, 2001; Phillips *et al*., *Phys. Rev. Lett*. **86**, 783, 2001.)



As this schematic diagram illustrates, a coherent light signal can get converted into a coherent state of atomic spins, and then back into a light signal. (Courtesy Harvard Smithsonian)

THE MOST SPHERICAL THING. Many atoms behave like tiny dipole magnets; they possess in effect a north and south pole separated by some small distance. In contrast no permanent electric dipole moment (EDM) has ever been measured for atoms. If such a moment could be found this would imply that although the net charge of the atom were zero, the charge would be slightly offset. That is, one could picture the atom as having a bit of positive and negative charge displaced by a small gap. A new experiment at the University of Washington extends the search for a nonzero EDM in mercury atoms: the positive charge and negative charge in the atom can not be further apart than 2 x 10^{-30} meters. How can such an exquisite measurement be made? The Washington group basically looks for a slight change in the precession of the Hg atoms which are subjected to a weak magnetic field and a strong electric field. They did not find such a precession change at the level of 0.4 nano-Hz. This corresponds to an energy-shift of less than 2.6 x 10^{-43} Joule, the smallest that has ever been measured. Another way of describing the Washington result is to say that if the mercury atom were the size of the Earth, then their experimental limit on the atom's non-sphericity would correspond to a 0.001-angstrom bump at the North Pole. The results are so precise that they can be used to place constraints on various models of particle physics that predict new sources of CP violation to explain why the universe today contains only matter, despite the fact that equal amounts of matter and antimatter were produced in the Big Bang. (Romalis *et al*., *Phys. Rev. Lett*. **86**, 2505, 2001.)



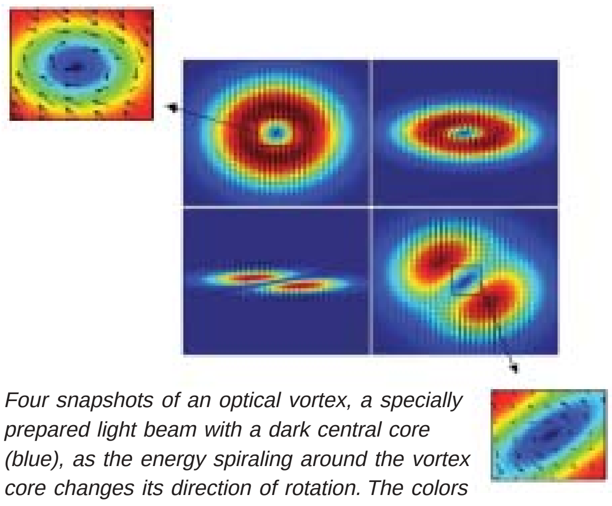
Schematic of the apparatus used to search for a permanent electric dipole moment of mercury atoms. The atoms are contained in two glass cells located between high voltage electrodes. (Courtesy University of Washington)

THREE MAGNETIC DEVICES FOR ATOM OPTICS have been demonstrated: a conveyor belt, a beam splitter, and a switch. Just as electrons drive electronics and photons drive photonics, many researchers hope that cold, neutral atoms will drive a future "atomtronics." To process information, atoms will need to be manipulated on or near an "atom chip" using atom†based analogs of mirrors, lenses, waveguides, gratings, and other devices. The new devices reported here all exploit the interaction between a neutral atom's magnetic moment and an external magnetic field with a gradient strong enough to create microscopic potentials. Jeorg Schmiedmayer of the University of Heidelberg and his colleagues have designed a beam splitter for guided atoms, using a Y shaped current carrying wire nanofabricated on a surface. Depending on how current is sent through the Y, atoms can be directed to the output arms with any desired ratio. A group at the Max Planck Institute for Quantum Optics in Munich has been able to confine atom clouds in separate potential wells and transport them with 800 nm precision near a surface having a lithographically patterned conductor. The researchers have used their "magnetic conveyor belt" to merge separate clouds; their evidence shows that the process is adiabatic and can be reversed to coherently split wave packets. Also using lithography, and following their own beam splitter, a group at the University of Colorado and NIST in Boulder has devised a switch that can direct a guided beam of neutral atoms to either of two output ports separated by 8 mm. Both the incoming and outgoing atoms are guided between two parallel wires having current flowing in the same direction. In the switch region, the atoms are guided alongside two wires with oppositely flowing current. (D. Cassettari *et al*., *Phys. Rev. Lett*. **85**, 5483, 2000. W. Hansel *et al*., *Phys. Rev. Lett*. **86**, 608, 2001. D. Miller *et al*., *Phys. Rev. A*, in press.)

SUBLUMINAL CERENKOV RADIATION. In vacuum, nothing travels faster than light. In transparent substances like water, however, it is possible for high energy charged particles to exceed the speed of a light beam in that substance. When this happens, the particle will radiate a cone of light called Cerenkov radiation. A team of researchers (University of Michigan and Max Planck Institute in Stuttgart) has now taken a closer look at the theory, and found that conical Cerenkov emission also occurs at subluminal speeds. The researchers verified the finding experimentally using subpicosecond laser pulses to generate, through a nonlinear optical process, relativistic dipoles that emitted infrared Cerenkov radiation in a zinc selenium crystal. (T.E. Stevens *et al*., *Science* **291**, 627, 2001.)

OPTICAL BILLIARD TABLES FOR ATOMS. A quickly moving spot of laser light can appear to draw a continuous circle on a screen. Similarly, a rapidly scanned, tightly focused laser will generate a closed two dimensional boundary actually an optical dipole potential boundary that repels closely approaching atoms like the cushions of a billiard table. Ultracold atoms can be confined in the third dimension with an orthogonal standing wave, making the system planar. Research groups at the University of Texas at Austin and at the Weizmann Institute of Science in Israel have now independently created and studied such systems. Two differences from regular billiards are that the atoms penetrate some distance into the walls before rebounding, and the walls are easily moved or redrawn in real time. The groups probed atomic trajectories indirectly by creating a little hole in the optical billiard and measuring the atoms' escape rate for various billiard geometries, and found excellent agreement with classical chaos theory. In future studies, both teams plan to use optical billiards to test such things as quantum chaos and the effects of noise on the trajectories of atoms. (V. Milner *et al.*, Phys. Rev. Lett. **86**, 1514, 2001; N. Friedman *et al.*, *Phys. Rev. Lett.* **86**, 1518, 2001.)

WATCHING AN OPTICAL VORTEX REVERSE ITS SPIN. Vortices occur in whirlpools, tornadoes, Bose Einstein condensates (BECs), and many other systems. In an optical beam, a vortex is a spiral phase ramp like the thread of a screw circulating around a dark spot in the beam where the phase is undefined and the intensity vanishes. It is generally accepted that, once created, a vortex cannot reverse its direction of rotation without first being destroyed. Researchers have built devices to reverse optical vortices, but were unable to watch the reversal itself. Now a Spain-U.S. collaboration has observed in detail such a reversal in an optical vortex that freely propagated in vacuum. The key to both reversing and observing the spiral staircase of phase was giving it some intrinsic spatial structure within the beam: The researchers passed the specially prepared laser beam through a cylindrical lens and monitored its interference with a reference beam as it propagated. They clearly observed clockwise rotation of the phase beyond the lens. But just after the focal plane, the screwlike discontinuity collapsed to a line discontinuity then reemerged with a counterclockwise rotation. A spherical lens did not generate such a reversal. The scientists also confirmed that the beam's angular momentum was conserved throughout the experiment. They see some implications of their work for quantum entanglement and teleportation, and for elucidating vortex behavior in BECs. (G. Molina Terriza *et al.*, *Phys. Rev. Lett.* **87**, 023902, 2001.)



Four snapshots of an optical vortex, a specially prepared light beam with a dark central core (blue), as the energy spiraling around the vortex core changes its direction of rotation. The colors show intensity of the light beam, with red the brightest and blue the darkest. (Courtesy Technical University of Catalonia, Spain)

ENTANGLEMENT OF MACROSCOPIC OBJECTS. A pair of cesium gas clouds containing 10^{12} atoms each, has been entangled by a quantum optics team at the University of Aarhus in Denmark. No previous entanglement with atoms has involved more than four particles. In the present experiment, the physicists sent a single, off resonant, linearly polarized laser beam through two separated Cs gas samples whose oppositely directed mean spins were transverse to the beam. First, the researchers measured the sum of the two collective spins without knowing the individual collective spin of each sample. A subsequent measurement 0.5 ms later showed that the sum remained the same, which demonstrated that the two gas samples maintained their collective entanglement as though they were two macroscopic "atoms." Such a collectively entangled state is unaffected by the decoherence of a few of its constituent atoms. Although the two samples were just millimeters apart, they could, in principle, be much more distant. The researchers think the method might extend to creating entanglement in solid state samples with long lived spin states. (B. Julsgaard, A. Kozhekin, E.S. Polzik, *Nature*, **413**, 400, 2001.)

BEC ON A CHIP. The latest feat of atom optics, performed by a group at the Max Planck Institute for Quantum Optics in Munich, is the creation of a Bose Einstein condensate of rubidium atoms in a microscopic magnetic trap built into a lithographically patterned chip. The BEC formed a few tens of microns above the surface in only 700 ms, which allowed a 10 s duty cycle that included loading the trap, as well as forming and detecting the BEC. In addition, the researchers moved the condensate a distance of 1.6 mm along the microchip, after which they demonstrated the continued coherence of the BEC. Such a capability opens up possibilities for "atomtronic" applications in interferometry, holography, and quantum information processing. (W. Hansel *et al.*, *Nature* **413**, 498, 2001.)

BIOLOGICAL PHYSICS

PHOTODETECTORS FROM DNA. The large molecule deoxyguanosine (DG) is one of four compounds that serve as bases to encode genetic information in DNA. It also turns out to be a good semiconductor material in some experimental photodetectors. Researchers at the National Nanotechnology Laboratory of the National Institute for the Physics of Matter (INFM) in Italy fabricated their detectors by placing a tiny droplet of DG, dissolved in chloroform, at the juncture of two electrodes. As the chloroform evaporated, the DG molecules self assembled into an array of 100 nm long ribbons between the electrodes. The resulting DG based photodetectors are roughly twice as sensitive to light as commercially available detectors. If the researchers can succeed in doubling the length of the DG ribbon like portion to about a quarter of a micron, the chloroform solution could be deposited with a modified inkjet printer nozzle, while the rest of the device could be manufactured in a modern semiconductor lithography facility. The researchers point out that, ultimately, a multitude of electrical components might rely on a surprisingly small number of molecules. (R. Rinaldi *et al.*, *Appl. Phys. Lett.* **78**, 3541, 2001.)

INSECT SENSES SUGGEST NOVEL NEURAL NETWORKS. Animals gather information about their environments as sensory neurons generate minute electrical signals in response to chemicals, light, sounds, and other stimuli. A new model of neural networks, based on recent studies of insect olfactory systems, suggests that neurons can be linked in a way that allows them to identify many more stimuli than was previously thought possible. Researchers from the Institute for Nonlinear Science at the University of California, San Diego, propose that one neuron is able to delay the firing of another neuron. This inhibitory capability means that a given stimulus leads to a specific, robust, and reproducible time sequence of neural activity. The researchers used portions of a locust's antenna lobe exposed to fragrances such as cherry and mint as a guide to developing their model, which they call competitive networks, or winnerless competition (WLC). Their models shows that with a network built of *N* neurons could identify roughly *(N-1)!* different stimuli. That is, an 11 neuron WLC network should be able to identify more than 3 million items. The WLC model helps explain why a rose, by any other name, would smell as sweet but wouldn't smell like an onion. Ultimately, the WLC model may lead to high capacity, potent computing networks that resemble an insect antenna or a human nose more than a desktop PC. (M. Rabinovich *et al.*, *Phys. Rev. Lett.* **87**, 068102, 2001.)

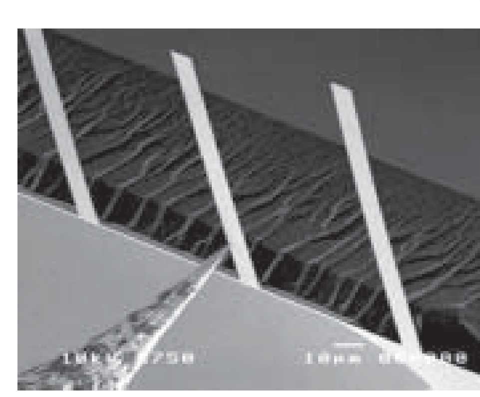
CONDENSED MATTER/MATERIALS PHYSICS

THE NEW MAGNESIUM BORIDE SUPERCONDUCTORS were the subject of a mammoth session at the APS meeting. Even bigger (in terms of papers delivered—79 altogether) than the1987 "Woodstock of Physics" meeting where ceramic superconductors came to prominence, this "Woodstock West" session showcased results from a dozen countries performed within weeks or days of the January 2001 announcement of superconductivity in MgB_2. The heart of superconductivity is the formation and flow of pairs of charges, and each time a new material is found to sustain resistanceless currents the nature of the pairing has to be explored all over again. Typical diagnostic tests include (1) measuring the energy (the "energy gap") that holds electron pairs together in the superconducting state; (2) measuring the density of phonon states in the material (phonons are the particle equivalent of the subtle lattice vibrations that, according to the BCS theory, hold the electron pairs together; in these tests a beam of neutrons are sent into the sample, where they excite vibrations equivalent to striking a bell and listening for the characteristic tones; and (3) seeing what happens when atoms in the material are replaced by different isotopes (boron and magnesium in this case) or even atoms of different elements. Besides these plentiful yeoman measurements, what discoveries came to light at the Seattle session? Robert Cava of Princeton announced superconductivity in a $MgCNi_3$ sample at a temperature of 8 K. Cava claimed that this represents the first metallic perovskite superconductor. Jun Akimitsu of Aoyama Gakuin University in Tokyo, whose discovery set off the MgB research frenzy in the first place, reported superconductivity at 35 K in a Mg-B-Be compound. Beryllium, unfortunately, is a toxic material, and increasing the Be fraction in the recipe actually depressed the superconductivity transition temperature.

SUPERCONDUCTIVITY AT 117 K IN A BUCKYBALL CRYSTAL has been observed by Bertram Batlogg at Lucent Technologies. A crystal of C-60 molecules normally has a lattice spacing of 1.415 nm and becomes superconducting at a temperature of 18 K. But by obliging the crystal to conduct with holes instead of electrons (in a transistor-like setup) and by adding other molecular species to space out the buckyballs a bit, the superconductivity transition temperature can be raised. Batlogg and his colleagues at Lucent, the University of Konstanz (Germany), and the ETH lab in Zurich, have tried a number of candidates; the best so far is a dopant consisting of tribromo-methane (Br3CH) molecules, which nudges the C-60 molecules out to a spacing of 1.445 nm and a transition temperature of 117 K, in the same realm as the high-temperature ceramic superconductors (Schon *et al.*, *Science*, published online, 30 August 2001).

LIGHT AMPLIFICATION IN SILICON. Ubiquitous in integrated circuitry, bulk silicon is notoriously reluctant to emit light. The road to ever faster circuits, however, leads to optoelectronics—the use of optical rather than electronic components such as switches. Silicon can emit some light, but only from nanoscale structures in which quantum effects come into play. Most semiconductor lasers are instead made from so called III-V materials, like gallium arsenide or indium phosphide. Now, physicists in Italy (at INFM and the universities of Trento and Catania have demonstrated optical gain in silicon nanocrystals. They embedded a dense array of 3 nm silicon quantum dots at a concentration exceeding $10^{19}/cm_3$ in a silicon oxide matrix. The material exhibited both stimulated emission of light and an optical gain comparable to that from II-V semiconductors. The researchers attribute the gain to radiative surface states at the abundant nanocrystal oxide interfaces. The next step for the scientists is to try to make the light coherent, an essential property for optoelectronic applications. (L. Pavesi *et al.*, *Nature* **408**, 440, 2000.)

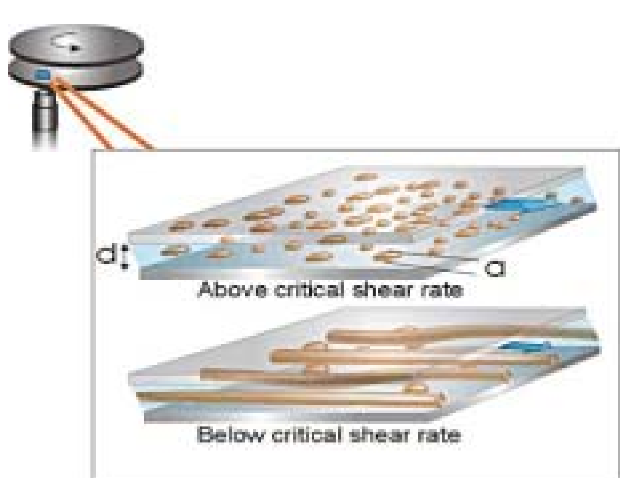
TUNABLE MICROMECHANICAL OSCILLATOR. The movement of tiny cantilevers is important in many kinds of devices, including scanning probe microscopes, magnetometers, filters for telecommunications, and mass sensors. Applications are somewhat limited, however, because cantilevers oscillate at or near a single characteristic resonant frequency. Now, though, a group of researchers at Cornell University has built a cantilever that is tunable from 9.6 kHz all the way to 37 kHz. They used a scanning tunneling microscope probe, excited by a piezoelectric motor, to set a thin cantilever vibrating. The



The probe tip of a scanning tunneling microscope (coming in from the lower left) touches a thin cantilever. In this way the STM tip excites the cantilever into oscillation. The picture itself is made with scanning electron microscopy. (Courtesy Cornell) probe also played a second role: by moving along the length of the cantilever (which was clamped at one end), it changed the resonant frequency of the cantilever, much as one can adjust the frequency of a violin string by fingering it at various places. The Cornell scientists believe that their concept of combining a local drive force with a constraint will find many applications in microelectromechanical systems. They are currently working to extend this oscillator into the MHz region. (M. Zalalutdinov *et al*., *Appl. Phys. Lett*. **77**, 3287, 2000.)

TEMPEST IN A TYPHOON. Examples of two dimensional fluid flows abound for example in the ocean, atmosphere, and astrophysical settings and vortex phenomena in such flows are many and varied. Recent numerical studies by Dezhe Jin and Dan Dubin (both at the University of California, San Diego) identified a new phenomenon not yet recognized in nature: a small, intense, point like vortex within a larger, weaker, disk like vortex (imagine a tornado within a hurricane), both spinning in the same direction. Now, Dan Durkin and Joel Fajans (both at the University of California, Berkeley) have studied the dynamics of such a system experimentally. They used a strongly magnetized electron column; under the right conditions, such a column behaves two dimensionally, evolving by the Lorentz force, and is fully equivalent to a 2D fluid vortex. Among their findings was that the point vortex can induce a surface wave on the outer edge of the disk vortex. Eventually the wave breaks, closing in on itself and capturing some empty space, which then behaves like a region of negative vorticity, spinning in the opposite direction of the initial vortex. They also found that if multiple point vortices were initially arranged symmetrically within the disk vortex, that arrangement remained stable. In addition, if the initial distribution was random, it quickly crystallized into a stable symmetric pattern. (D. Durkin, J. Fajans, *Phys. Rev. Lett.* **85**, 4052, 2000.)

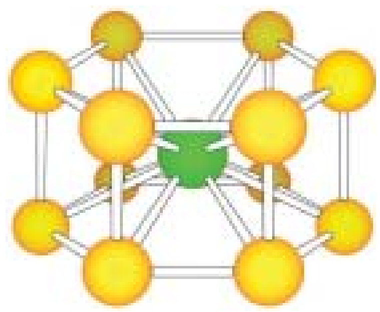
POLYMER SUPERSTRINGS. Many advanced polymers are composed of two or more components like rubber and nylon that do not mix but are forced into intimate contact, often by a shearing process. By varying the components, researchers can alter the properties of the resultant material. For example, polystyrene is very brittle, but when rubbery particles are incorporated, it can withstand large impacts. Ordinarily, such a blend has droplets of one polymer dispersed within a matrix of the other, and the final product (such as a car bumper) is much larger than the micron size of an individual droplet. In a new experiment at NIST in Gaithersburg, Maryland, Kalman Migler looked at sheared blending in a system whose size is just tens of microns across. He found that, as the shear rate decreases, the droplets first grow, then line up like a pearl necklace, and finally coalesce, as shown here, into very stable strings or ribbons that can be 10 cm long. According to Migler, potential microscale applications of string components could include conductive plastic wires, ultrathin composite materials, and tissue engineering. (K. Migler, *Phys. Rev. Lett.* **86**, 1023, 2001.)



Polymer superstrings. Placing a blend of two polymers in between two quartz disks and rotating the upper one at a controlled rate produces "shear" forces that, below a certain magnitude, causes droplets of one polymer to coalesce into long strings up to 10 centimeters long. Microscopic pictures of the polymer blends are shown on the right. (Courtesy NIST)

A SQUID MULTIPLEXER has been demonstrated that can service an array of low temperature sensors. A SQUID (superconducting quantum interference device) can detect very small currents or magnetic fields by monitoring tunneling Cooper pairs of electrons. Physicists at the University of California, Berkeley, inductively coupled eight low temperature sensors, using eight different AC frequencies, to a single superconducting current loop. The researchers then coupled a single readout SQUID to the loop to examine the output of any or all of the sensors. The number of sensors that can be multiplexed in this way is limited mainly by the slew rate of the SQUID. The device might be used in biomagnetic imaging or astronomical instrumentation. (J. Yoon *et al*., *Appl. Phys. Lett*. 78, 371, 2001.)

SILICON CAGE CLUSTERS. Silicon is a vital material for the vast semiconductor industry and is one of the most studied elements in all of science. Unlike pure carbon, which can form C-60 buckyballs, pure Si cannot form stable, closed cages. Researchers at the Joint Research Center for Atom Technology in Japan, however, have managed to create just such configurations of Si atoms, but with lone transition metal atoms trapped inside. In fact, the experimentalists found that a metal ion served as a reaction site, nucleating a cluster of Si atoms until it was completely surrounded. The number of Si atoms that formed the cage cluster depended on the chemical identity of the metal atom. For example, hafnium was stably surrounded by 14 Si atoms, tantalum by 13, tungsten by 12, rhenium by 11, and iridium by 9. The remarkable stability of these compounds could serve as tunable building blocks for new nanostructures. The scientists note in particular that the cage clusters efficiently isolate their guest metal atoms from the surrounding environment, a characteristic that might make them useful in a quantum computer, where a cluster could store a single bit of information in the spin state of the enclosed metal atom. (H. Hiura *et al*., *Phys. Rev. Lett.* **86**, 1733, 2001.)


Twelve Silicon atoms form a particularly stable cage cluster around a central tungsten atom. (Courtesy Joint Research Center for Atom Technology in Japan)

A NEAR FIELD SCANNER for moving molecules has been built and demonstrated by a multinational research team. The scanner offers a potentially fast way to make high resolution images of molecules such as DNA. Traditional scanning probe microscopes can produce molecular resolution images, but at the cost of slow scanning speeds. The new device, shown here, is stationary; molecules travel past an array of posts intended to stretch them, then proceed through a microscopic fluid channel (5 microns wide by 1 micron deep) across a trio of 100 nm wide slits illuminated with near field laser light. The laser causes the molecules to fluoresce, and that fluorescence yields a far field image. To ensure high quality images, the microscope accepts data only from those molecules that cross the three slits at roughly equal time intervals. The researchers obtained 200 nm resolution imaging data in just 100 milliseconds for a DNA molecule with 200,000 base pairs (corresponding to about 74 microns in stretched form). Resolution improvements are possible by narrowing the slits or making the covering plate thinner. Future versions of the device will have narrower and shallower fluid channels for better stretching of the molecules. Such a device could potentially obtain high resolution maps of the binding sites of repressor/promoter proteins critical for the expression of genes, part of an emerging field called epigenetics. (J.O. Tegenfeldt *et al.*, *Phys. Rev. Lett.* **86**, 1378, 2001.)

REFRIGERATOR ON A CHIP. Microelectronic and optoelectronic integrated circuits (ICs) develop hot spots that shorten the devices' lifetimes. To solve this problem, a collaboration led by John Bowers of the University of California, Santa Barbara, and Ali Shakouri of the University of California, Santa Cruz, is developing tiny thermoelectric (TE) refrigerators that sit right on top of the chips. Conventional TE coolers are already widely used to cool semiconductor lasers and other circuitry, but they are manufactured separately from the ICs. The new superlattice microcoolers are grown directly on silicon surfaces, giving them more intimate thermal contact with the semiconductors and simplifying overall fabrication. Earlier versions of the microcoolers made of Si and germanium required buffer layers to ease the strain of matching their lattice structures to the underlying Si substrate. By adding carbon to the lattice, the researchers found they could do without the buffer layers, and thus improve thermal contact and simplify fabrication even further. The 7°C cooling achieved so far is modest, but theoretical calculations show that a single stage microcooler should attain the tens of degrees of cooling needed for commercial applications. (Xiaofeng Fan *et al*., *Appl. Phys. Lett.* **78**, 1580, 2001.)

A HYBRID GLASS for high density, holographic data storage has been developed. Holographic storage techniques, which record data using interfering beams of light, can potentially store information at tens to hundreds of times the density of digital versatile disks (DVDs). Unfortunately, holographic recording media generally fail to meet the practical requirements stability, cost, and processing simplicity that would make them competitive with conventional technologies. Now, Pavel Cheben of Optenia Inc in Canada and María Luisa Calvo of Complutense University of Madrid believe they have developed a practical holographic medium that meets the most critical requirements for commercial data storage. Using a sol gel process at room temperature, the researchers suspended thermally sensitive photoactive compounds in a porous silica glass to form a hybrid organic/inorganic glass. The resulting medium is rigid, stable, and can be cast in virtually any thickness, allowing the production of slab like structures. On moderate exposure to a pattern of green light, the glass undergoes chemical reactions that alter its index of refraction in only those regions that are bright. Once recorded, data are permanently inscribed in the new material, but future developments may lead to rewritable media as well as other applications, including optical interconnects, neural networks, and image processing devices. (P. Cheben, M. L. Calvo, *Appl. Phys. Lett.* **78**, 1490, 2001.)

A LOCAL PLASMON PHOTONIC TRANSISTOR may be possible, claim researchers at the National Institute of Advanced Industrial Science and Technology in Tsukuba, Japan. In contemporary optical devices, high speed light signals must be converted to sluggish electrical signals in order to be manipulated, then reconverted to light for transmission. In their experiment, the researchers focused blue and red lasers at the same spot on an optical disk (similar to a recordable DVD) that incorporated a silver oxide thin film and had tiny marks recorded on it. The blue laser generated energy storing plasmons—groups of collectively moving electrons around each mark, whose size was near or below the optical diffraction limit. Meanwhile, the red laser interacted with the oxide film to generate a silver nanoparticle, which acted as a scattering center. The plasmons coupled to the scattering center, which, in an enhanced Raman type process, allowed more of the blue laser signal to be transmitted. The power of the red beam determined the scattering center's size, which in turn determined the amount of light drawn out of the plasmon reservoir. Thus, the silver particle can be thought of as a gate for an all photonic transistor. So far, the researchers have achieved 60 to 600 fold increases in transmission. (J. Tominaga *et al*., *Appl. Phys. Lett.* **78**, 2417, 2001.)

A NEGATIVE INDEX OF REFRACTION has been generated in a specially engineered structure. An electromagnetic wave in air that is incident on a conventional medium with a positive index (such as glass or water) will be refracted toward the normal, with an angle given by Snell's Law. With a negative index medium, Snell's Law still applies, but with a peculiar result: The wave will be refracted at a *negative* angle it never crosses the normal. In the recent experiment, David Smith, Sheldon Schultz, and Richard Shelby (all at the University of California, San Diego) found that a beam of microwaves entering the special structure came out on the "wrong" side of the normal, confirming the negative index. The structure is a two dimensional array of copper split ring resonators and wires mounted on fiberglass boards. Last year, the UCSD team showed that a similar "metamaterial" has negative values of both the electrical permittivity ε and the magnetic permeability ε (see *Physics Today*, May 2000, page 17). The resulting index of refraction, n=($\varepsilon\mu$)1/2, is real but negative, unlike any known material. Intriguing applications are expected to follow. (R.A. Shelby *et al.*, *Science* **292**, 77, 2001; informative website at http://physics.ucsd.edu/lhmedia/)

Photograph of the "metamaterial" which demonstrated a negative index of refraction for microwaves. (Courtesy UC-San Diego).

FLUID MOLECULAR OXYGEN BECOMES METALLIC at a pressure of 1.2 Mbar and a temperature around 4500 K. Physicists at the Lawrence Livermore National Laboratory fired a projectile at a reservoir of liquid oxygen trapped between two single crystal sapphire anvils. The resulting shockwave was multiply reflected between the anvils, gradually raising the pressure and compressing the liquid sample. The final steady state conditions under which the resistivity measurements were made lasted for 100-200 ns. At 77 K and 1 bar, liquid oxygen is a wide bandgap electrical insulator. As they squeezed it, however, the researchers saw the resistivity fall by six orders of magnitude and level off above 1.2 Mbar, as the distance between the diatomic molecules became comparable to the electronic wavefunction. The experimental technique is similar to that used to create metallic hydrogen (see *Physics Today*, May 1996, page 17). The researchers note that the temperatures and pressures achieved in their experiments are comparable to those within the gas giant planets, where oxygen is abundant. Thus, their work may help explain the origin of planetary magnetic fields. (M. Bastea, A. C. Mitchell, W. J. Nellis, *Phys. Rev. Lett.* **86**, 3108, 2001)

A SEMICONDUCTING HIGH TEMPERATURE MAGNET? In recent years, calcium hexaboride (CaB_6) doped with lanthanum has puzzled magnetism researchers, in large part because it retains a modest ferromagnetism even at 900 K a surprisingly high Curie temperature for a compound that does not contain traditional magnetic metals such as nickel or iron. Electronic structure calculations based on density functional theory led to several possible explanations: CaB_6 might be a semimetal or an excitonic insulator, or doped CaB_6 might be a doped excitonic insulator, a conventional magnetic material, or even an example of the long sought, low density spin polarized electron gas. Now, however, physicists in the Netherlands have performed more accurate calculations, using the so called "GW approximation," which suggest that CaB_6 is actually a semiconductor with a bandgap of 0.8 eV. If that is true, important applications await the compound in the field of spintronics, in which an electron's spin and not just its charge carries information. Thus far, combining semiconductors with magnetic metals has been difficult, especially at or above room temperature. In addition, new magnetic sensor and memory applications might be possible. (H.J. Tromp *et al*., *Phys. Rev. Lett*. **87**, 016401, 2001)

CAUTION: SLIPPAGE MIGHT OCCUR for tightly confined aqueous Newtonian fluids. Fluid mechanics is one of the most mature and successful branches of physics. Its success for Newtonian liquids whose viscosity is constant rests in part on the often assumed no slip boundary condition, in which the fluid molecules adjacent to a surface are always stationary with respect to that surface. Now, two teams of researchers one from the Australian National University and one from the University of Illinois at Urbana Champaign have demonstrated that the assumption is sometimes wrong. The Australian researchers measured the motion of a 10 micron silica sphere as they drove it through sugar water toward a wall. The Illinois group studied a system in which one cylinder oscillated toward another, with various fluids between them. In both sets of experiments, the classical no slip model could not explain the data. Furthermore, the inferred amount of slip depended on the fluid's flow or shear rate. A complete theory will also need to incorporate the fluid's viscosity, its surface wettability, and the wall's roughness. Slippage is already known to occur at times for both non Newtonian liquids and non-aqueous Newtonian ones. The new studies might have implications for capillary blood flow, lubricants in nanomachines, and filtration. (V. S. J. Craig *et al*., *Phys. Rev. Lett.* **87**, 054504, 2001; Y. Zhu, S. Granick, *Phys. Rev. Lett.* **87**, 096105, 2001.)

A CHAIN OF INDIVIDUAL GOLD ATOMS has about twice the tensile strength of bulk gold. A team of researchers from Madrid, Spain, and Lyngby, Denmark, drew a gold tipped scanning tunneling microscope away from a gold cantilever to create a string of up to seven atoms. With a second STM placed under the cantilever, the researchers could observe a chain grow as the atoms in the gold electrodes rearranged to release a single atom at one end or the other. Eventually, when the force needed to rearrange the atoms became too great, the chain broke under the strain. That breaking force was about 1.5 nN, and independent of chain length. To break a bond in bulk gold, by contrast, requires only 0.7-0.9 nN. The researchers also showed that the atomic chains have close to one quantum unit of electrical conductance and that the chains are elastically stiffer than the electrodes from which they arise. While it's not yet clear that gold atom chains will have any practical use, the study is an example of engineering analysis on the very smallest scale. (G. Rubio Bollinger *et al*., *Phys. Rev. Lett.* **87**, 026101, 2001.)

A SUPERCONDUCTING SINGLE PHOTON OPTICAL DETECTOR has been demonstrated by a Russian/US collaboration. The researchers deposited ultrathin (5nm), 0.2 micron wide strips of superconducting niobium nitride on a sapphire substrate. When a photon struck the film, a hotspot of excited electrons was created that disrupted the superconducting current and generated a detectable voltage spike. The rapid hot electron diffusion and liquid helium cooling healed the hotspot within about 30 ps, restoring the superconductivity and allowing for a gigahertz repetition rate. The detector is already finding application in checking integrated circuits, where it can record individual infrared photons that are released when a transistor switches on or off. The researchers say that it might also be used in practical quantum cryptography and as an efficient detector of optical signals for wireless communications in space. (G. N. Gol'tsman *et al*., *Appl. Phys. Lett.* **79**, 705, 2001.)

A MULTIMODE WAVEGUIDE INTERFEROMETER has been developed that can produce fringe spacings as small as $\lambda/9$, where λ is the wavelength of the incident light. Interferometers are used to detect tiny changes in length. Typically, a beam of light travels over the distance to be measured and then combines with a reference beam that always travels a fixed distance. The two beams create an interference pattern of bright and dark bands, or fringes, that shift as the distance traveled by the measurement beam changes. Usually, the separation of the fringes (which determines the resolution of the interferometer) is no less than $\lambda/2$. Now, two researchers at the University of Stuttgart in Germany have done away with the reference beam. Instead, they have directed a single beam of light obliquely into a waveguide formed by two parallel, movable mirrors. The beam experienced multiple reflections from the mirrors and propagated as a combination of many modes. Each mode interfered with every other mode, which led to a modulation in the light transmitted through the waveguide. The number of reflections within the MWI determines the device's sensitivity. For 633 nm light and a mirror separation of about 30 microns, the fringe spacing was only 70 nm. The physicists' calculations suggest that a more refined MWI could show fringe separations as small as 10 picometers. In addition to opening the door to new, high precision measurements, the researchers explain that MWIs might be useful in optical switches and other communication related devices. (Y. B. Ovchinnikov, T. Pfau, *Phys. Rev. Lett.* **87**, 123901, 2001.)

AN ANOMALOUS ACOUSTOELECTRIC EFFECT has been discovered in a manganite thin film by a collaboration of physicists in Russia, Poland, and Ukraine. When an acoustic wave propagates along an electrically conducting surface, it can drag electric charge along with it if there is strong coupling between phonons and electrons. This is known as the acoustoelectric (AE) effect. Manganites are known to show a rich variety of strongly interrelated magnetic, structural, and electrical properties. The researchers grew a manganite thin film atop a piezoelectric lithium niobium oxygen substrate, on which they then launched a surface acoustic wave (SAW). They unexpectedly found that a component of the AE current did not reverse when the SAW traveled in the opposite direction. The physicists discovered that the anomalous AE current was related to the strong pressure dependence of the manganite film's conductivity. The total AE current peaked at a temperature near the metal insulator transition, at which the anomalous effect dominated. At higher and lower temperatures, the ordinary AE effect prevailed. (Y. Ilisavskii *et al*., *Phys. Rev. Lett.* **87**, 146602, 2001.)

NANOBUBBLES IMAGED ON HYDROPHOBIC SURFACES. A hydrophobic surface not only sheds water but also attracts other such nearby surfaces when immersed in water. One idea to explain these interactions invokes bubbles only 20 to 30nm high on the surfaces. As two hydrophobic surfaces approach each other underwater, the bubbles eventually coalesce, drawing the surfaces together through capillary adhesion. A complete layer of bubbles also can serve as a kind of lubricant that allows water to slip smoothly over the surface as happens with the hydrophobic fabric of swimming suits worn by Olympic contenders. Such nanobubbles are too small to image with light and too fragile to probe with most contact techniques. Another difficulty is posed by thermodynamics: a 10 nm bubble would have internal pressure of 14 MPa (140 atm) and should rapidly dissolve. Now, James Tyrrell and Phil Attard of the University of South Australia have gently examined clean glass surfaces underwater with a tapping mode atomic force microscope. They found irregularites that formed closely packed networks, and covered the surfaces nearly completely. Because the irregularities were softer than the substrate, could be destroyed by pressing too hard, and reemerged after destruction, the researchers concluded that they imaged nanobubbles. In addition, they found that the nanobubbles are not spherical, but are flattened like pancakes, with curvatures and therefore pressures much lower than previously expected. (J. W. G. Tyrrell, P. Attard, *Phys. Rev. Lett.* **87**, 176104, 2001.)

PARTICLE/NUCLEAR/PLASMA PHYSICS

"**THE EXPEDITIOUS CONSTRUCTION OF A LINEAR COLLIDER** as the next major international High Energy Physics project" is the strong recommendation of the "physics issues" working groups at the huge meeting of particle physicists held June 30-July 21, 2001 in Snowmass, Colorado. Almost 900 scientists, including many from Europe and Asia, were present. Here are some particulars:

Particle physics views matter at the smallest possible scale (in some experiments down to a billionth of a billionth of a meter), and this often requires producing particle beams at the highest possible energies, or the shortest possible wavelength if one views an accelerator as a kind of microscope. And this tends to be expensive. Consequently numerous speakers at the meeting urged the international high-energy community to establish consensus not merely on a particular accelerator project but on a whole longterm program for making fundamental discoveries.

The physics goals of such a program would include, first of all, a search for the Higgs boson (the particle manifestation of the ubiquitous field which, according to the standard model, endows many particles with mass); a search for super particles (a family of particles called forth by the theory of supersymmetry, according to which all known fermion particles have boson counterparts and vice versa); and a detailed study of quark and lepton properties such as mass, flavor changing (the transformation from one type to another), or CP violation.

In extolling the virtues of constructing a new electron-positron linear collider (LC) several speakers said that such a machine would serve as a worthy complement to the Large Hadron Collider (LHC) now under construction at CERN. For example, Edward Witten (Institute for Advanced Study) drew an analogy between, on the one hand, a high-energy proton-antiproton machine like the Tevatron (where the top quark was discovered) and a high-precision electron-positron machine like LEP (where Z-boson decay modes could be carefully measured, providing information about the electroweak force, a force too subtle to be measured, as can gravity, with a torsion balance) and, on the other hand, the LHC (the high-energy proton-proton collider, now under construction at CERN, where the Higgs should be discovered, if the Tevatron does not accomplish the feat in the next few years) and the LC where, presumably, the decay modes of the Higgs would be explored in detail amid electron-positron collisions. Further components of a longterm building program might include a very large hadron collider (VLHC), a muon storage ring, or a neutrino factory.

What are the chances of finding the desired particles? David Gross (UC Santa Barbara) said that at an LC with a collision energy of 500 GeV the case for producing super particles was compelling, and the case for finding the Higgs would be very compelling. —Determining a site for a possible LC was not on the agenda, but three detailed design proposals were showcased: TESLA, a German machine; the Japan Linear Collider (JLC); and a US project, the Next Linear Collider (NLC).

On a sobering note, Michael Holland of the Office of Management and Budget (OMB) argued that in order to make the case to fund a new machine particle physicists would have to demonstrate that the device was important not only to their research interests but would be important for science as a whole. Luciano Maiani, Director General of CERN, and a speaker at the same panel, declared that he thought such a stringent criterion for federal support was "unfriendly to science," and an inhibition to what has come to be called "curiosity-driven" research. Also several audience members felt that certain defense and space-station research ventures were not being held to the same standard of self-justification.

Scientists at the meeting felt that international cooperation in building a linear collider was essential. Research on LC components are proceeding at JLC and TESLA. In the US the next step involves the preparation of a report by the DOE/NSF High Energy Physics Advisory Panel (HEPAP) Subpanel on Long Range Planning for US High Energy Physics.

CP VIOLATION SEEN IN B MESON DECAY. CP violation in the decay of B mesons has now definitively been observed at SLAC and at KEK. CP is an abstract abbreviation for a mathematical operation in which particles undergo a change in charge conjugation (C) and parity (P). The combined CP operation essentially turns a particle into an antiparticle. To say that CP symmetry is violated is to say that the physical properties of particles and antiparticles are not fully the same, a fact discovered first almost 40 years ago in the decay of K mesons. Since then B factories at SLAC in California and the Japanese KEK lab, where colliding electrons and positrons produce copious amounts of B mesons, have zeroed in on producing the same result with the rarer B mesons. Both groups submitted preliminary results in February of 2001 with very limited data sets. Now the same groups are offering a more robust measurement of the CP-violating parameter, referred to as sine (2β); SLAC's BaBar detector group reports a value of 0.59, while KEK's Belle detector group reports 0.99. (Aubert *et al*., *Phys. Rev. Lett*. **87**, 091801, 2001; Abe *et al*., *Phys. Rev. Lett*. **87**, 091802, 2001.)

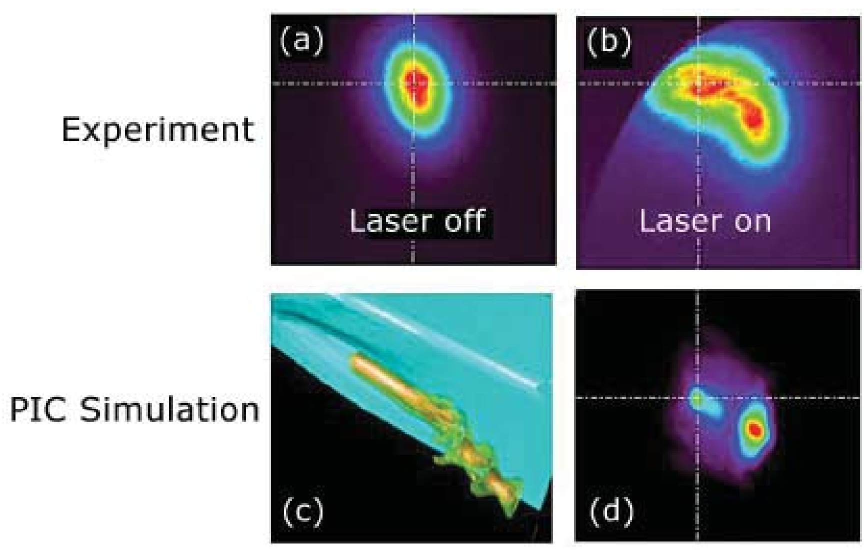
THE SUDBURY NEUTRINO OBSERVATORY (SNO), issuing its first data analysis, confirms that neutrinos oscillate from one type into another. SNO looks for rarely-interacting neutrinos in an immense underground detector in Sudbury, Ontario. Neutrinos easily penetrate 2000 m of earth to reach a preserve of 1000 tons of heavy water, where the neutrinos can initiate a number reactions observed by sensitive photodetectors. Many theorists have come to believe that electron neutrinos coming from boron-8 decays in the solar core should partly turn into muon neutrinos en route to Earth. Of all the neutrino detectors, SNO is the only one that can detect electron and non-electron neutrinos, and so SNO should therefore observe an electron-neutrino shortfall balanced by a corresponding excess of non-electron neutrinos (although they can't tell muon from tau neutrinos). SNO is at too early a stage to make this type of demonstration, but they are able to determine, by comparing present neutrino observation rates (about 8 neutrinos per day) arising from different types of reaction and by using rates from the Super Kamiokande detector in Japan, that some non- electron-type neutrinos are reacting in the detector along with the majority-species electron neutrinos. Specifically, the analysis compares the rate of neutrinos seen on Earth from charged-current (CC) reactions, in which an incoming electron neutrino hits a deuteron (a proton-neutron combination constituting a heavy hydrogen nucleus), resulting in two protons and an electron; this reaction proceeds via the weak nuclear force carried by a charged W boson (hence the name "charged current"), with the rate from elastic-scattering (ES) reactions, in which an incoming electron neutrino scatters from an electron in an atom without converting into any other particle. It is SNO's exclusive rate determined from the CC reaction compared with the ES rate (using data from SNO and Super Kamiokande) that provides the most direct evidence yet for the presence of non-electron neutrinos (thus affirming neutrino oscillation), and in an amount that would seem to precisely account for the past solar neutrino shortfalls (thus explaining the "solar neutrino problem"). As for the issue of neutrino mass, the current measurements put only a crude limit on the difference of masses for the neutrinos. Owing to the expected large number of neutrinos in the universe, even a small neutrino mass might have provided neutrinos with a considerable role in the original herding of matter and shaping of galaxies in the earlier universe. (Ahmad *et al*., *Phys. Rev. Lett*. **87**, 071301, 2001.)

Fish-eye-lens view from the bottom of the acrylic vessel (where heavy water is contained) and photomultiplier tube array at the Sudbury Neutrino Observatory.(Courtesy Ernest Orlando Lawrence Berkeley Laboratory)

A DIAMOND AS BIG AS THE RITZ. Electrically neutral quark matter should lie at the heart of neutron stars, conclude two MIT theorists. It has long been thought that, in the exotic high density environment within a neutron star, equal numbers of *up* and *down* quarks (with respective charges of +2/3 and 1/3e) dominate, with a small admixture of strange quarks (1/3 e). The quark matter would thus have an overall positive charge and would draw electrons into it. Now, however, Krishna Rajagopal and Frank Wilczek have demonstrated that all three quark varieties will coexist in equal numbers in such an environment, meaning that the material is an electrically neutral insulator, free of electrons. Two consequences are that a neutron star's core would be unable to anchor magnetic fields and that the time distribution of neutrinos from a supernova could be altered. (K. Rajagopal, F. Wilczek, *Phys. Rev. Lett*. **86**, 3492, 2001.)

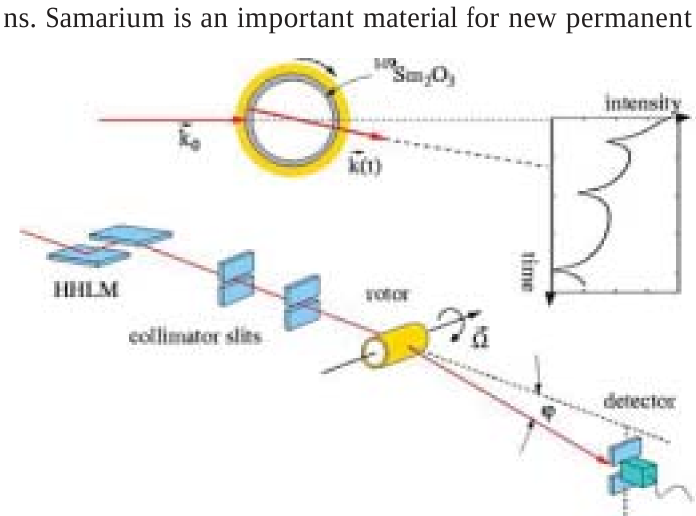
THE PROTON'S CHARGE AND MAGNETIZATION have different spatial distributions, new experiments have found. It has long been known that the proton's electric charge and magnetic moment were each spread throughout the particle. The details, however, have remained unclear as to how the three quarks that make up the proton, and the gluons that hold those quarks together, interact to give the proton its electric and magnetic properties. In recent Jefferson Lab experiments, physicists fired an intense beam of polarized electrons at a target of liquid hydrogen and measured the degree of polarization transferred to the proton. The electrons' energies spanned 1000-5700 MeV and thereby probed features within the proton on various spatial resolutions, down to 10% of the proton's radius. The measurements showed that the electric charge is distributed over a larger volume in the proton than is the magnetization. Thus, the magnetic moment in all likelihood arises from a combination of the intrinsic spins of the quarks and gluons and the motions of the electrically charged quarks. Olivier Gayou, a graduate student at the College of William and Mary, reported the experimental results at the April 2001 meeting of the American Physical Society.

AN ELECTRON BEAM CAN BE REFRACTED at the interface between a plasma and a gas, much as light is refracted at an air water interface. A California based research collaboration (USC, UCLA, and Stanford) used a beam from SLAC's Final Focus Test Facility, consisting of 20 billion electrons at 28.5 GeV in a bunch that was about 0.7 mm long and 40 microns in radius. As the electron beam went along a long, thin "tube" of plasma, it first repelled plasma electrons, leaving the sluggish ions behind to form a positively charged channel, which focused the remaining electrons. As the beam left the plasma at a grazing incidence, the ion channel became asymmetric and the exiting beam was deflected by up to a milliradian. The researchers also showed that, at sufficiently small incident angles, the beam underwent total internal reflection. Thus, they envision magnet free particle storage rings or plasma based wires, although such "plasma waveguides" may require a laser to preform the ion channel. (P. Muggli *et al.*, *Nature* **411**, 43, 2001.)



Experimental (a-b) and simulated (c-d) images show a plasma, a million times less dense than air, refracting a portion of a charged-particle beam. Turning on a laser creates the plasma. In image c, the plasma is shown in blue, and the beam in gold. (Courtesy USC).

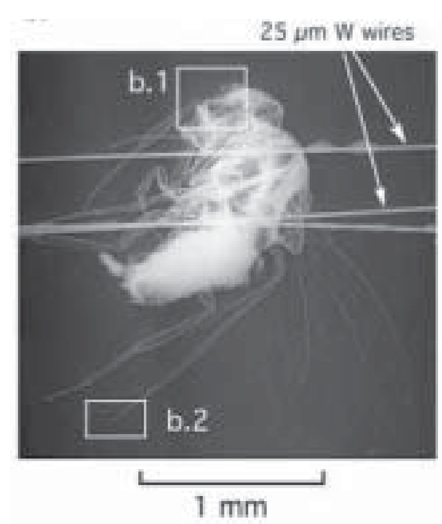
THE NUCLEAR LIGHTHOUSE EFFECT has been applied to samarium 149. The NLE technique was developed last year by researchers from the University of Rostock in Germany. It allows physicists to get very accurate lifetime measurements of certain short lived nuclear resonances. In their recent work, the Rostock scientists mounted a thin sheet of samarium oxide on the inside wall of a small cylinder. They then placed the cylinder in an x ray beam at the Advanced Photon Source at Argonne National Laboratory and spun it at 15 kHz with jets of pressurized air. The nonresonant x rays went straight through the rotor, while those that were absorbed by the nuclei were re emitted after a slight delay. That delay provided enough time for the cylinder to rotate a few milliradians, and the forward scattered resonant x rays were thus deflected into a detector. The group detected a resonance energy of 22.496 keV with a natural lifetime of 10.3 ns. Samarium is an important material for new permanent magnets but, like some other rare earths, is difficult to study with conventional methods (such as Mossbauer spectroscopy) for a variety of reasons. The physicists say that NLE is capable of resolving subpicosecond lifetimes, which are currently beyond the limits of x ray detection. (R. Röhlsberger *et al.*, *Phys. Rev. Lett.* **87**, 047601, 2001.)

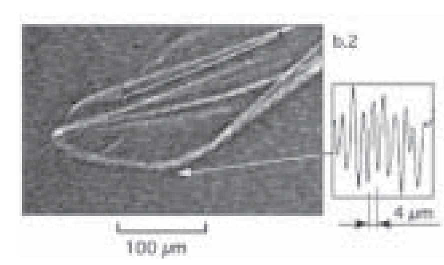


Schematic of a system for measuring the nuclear lighthouse effect. The frequency spread of a synchrotron light beam is narrowed with a high heat load monochromator (HHLM), then the beam is physically narrowed with a pair of collimator slits. Finally, the light strikes a thin sample mounted inside a spinning cylinder. Sample atoms excited by the synchrotron light emit x-rays as the cylinder turns, forming a sweeping beam reminiscent of the optical beams projected by naval navigation lighthouses. (Courtesy Universität Rostock, Germany)

EVIDENCE FOR THE ONSET OF QUARK EFFECTS in a nuclear reaction has been observed. In low energy processes, a nucleus is well described by its constituent nucleons neutrons and protons and the mesons that hold them together. When a very high energy particle strikes a nucleus, however, it penetrates the nucleus so deeply that the reaction can be described only in terms of quarks and gluons. Now, the several GeV middle ground is being explored. In experiments at Jefferson Lab in Virginia, a multi institutional collaboration used photons with energies up to 5.5 GeV to break up deuterium nuclei, and studied the angular distribution of the resulting protons. When the emitted proton had a transverse momentum of at least 1 GeV/c, the data were best described by quark counting rules. Protons with less transverse momentum were well described by the nucleon meson picture. The deduced distance scale for the interaction at the crossover energy is about 0.1 fm, larger than many current theoretical expectations for the onset of quark counting rule behavior. (E.C. Schulte *et al.*, *Phys. Rev. Lett.* **87**, 102302, 2001.)

X PINCH FLASH PHOTOGRAPHY. A metal wire is heated when a current runs through it. A 25 micron thick molybdenum wire carrying 105 amps is vaporized into a plasma, and the magnetic field generated by the current compresses that plasma. Cross two such wires and at their juncture you get an x pinch, a 1 to 2 micron region of 10^7°C plasma that emits greater than 2.5 keV x rays for less than a nanosecond. Now, researchers at Cornell University's Laboratory of Plasma Studies have used such x ray point sources to generate few micron resolution radiographs of tiny objects such as the housefly and its wing, using phase contrast imaging. For more on the imaging technique, see *Physics Today*, July 2000, page 23. Several x pinch results were presented in November 2001 at the American Physical Society's Division of Plasma Physics meeting. (Papers RP1.101-104 and UI2.001)





High-resolution details in this x-ray photographs of a fruit fly (top) help demonstrate the characteristics of an X-pinch flash. The lower image shows an enlarged region, b.2, as marked in the top figure. The image captures details as small as several microns (millionths of a meter). (Courtesy Cornell.)

OTHER PHYSICS FIELDS

DRIPPING FROM FAUCETS AND CEILINGS. Understanding dripping better can improve inkjet printing and deposition of DNA onto gene chips, among other things. Purdue researchers solved the fundamental Navier Stokes equations for a single drop from a faucet, then observed dripping with a fast camera to develop a model for simulating sequences of hundreds of drops. Among the team's observations was "period doubling," in which drops can fall at two characteristic intervals (such as 4 s followed by 2 s). Meanwhile, University of Texas researchers have shown how to prevent drips from a ceiling for up to weeks at a time. They found that a vertical heat gradient in the gas beneath the suspended layer of liquid did the trick. Normally, a liquid is gravitationally unstable to variations in thickness along the layer, but because heat reduces a liquid's surface tension, the warmer, thicker regions are pulled back to the colder regions of higher surface tension. (B. Ambravaneswaran *et al.*, *Phys. Rev. Lett.* **85**, 5332, 2000. J.M. Burgess *et al.*, *Phys. Rev. Lett*, in press.)

ION BEAM PHOTOGRAPHY. Many of the beautiful colors in stained glass windows are the result of light scattering off metal or oxide nanoclusters dispersed in the material. However, the mechanism of nanocluster formation is usually obscured in the complexities of glass chemistry. Now, researchers at the Universities of Orsay and Paris, collaborating with glass experts, have found that by shooting MeV ions at room temperature into a glass containing a metal oxide, they can nucleate and control the density of pure metal nanoclusters. The nucleation requires exceeding a threshold of energy going into electron motion in the glass. Moreover, the nanoclusters only grow upon subsequent heating of the sample, allowing control over their size, and all the clusters grow simultaneously. This is analogous to the photographic process, with ions replacing photons, metal oxide in the glass replacing metal containing salts in the emulsion, and heat replacing the developer. The ion beam method allows the density of nucleation sites to be predicted precisely, and standard lithographic techniques cosuld be used to design spatial patterns of clusters, leading to applications in optoelectronics. (E. Valentin *et al.*, *Phys. Rev. Lett.* **86**, 99, 2001.)

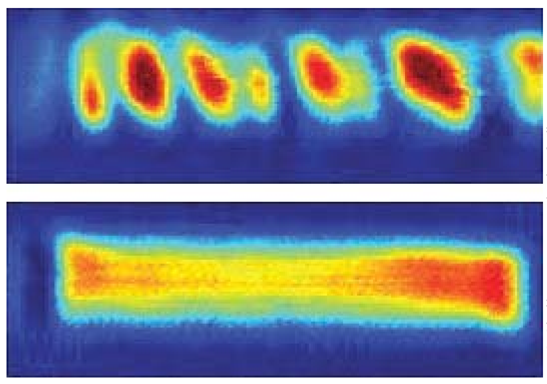
AN ACOUSTIC NOSE, used to precisely determine the chemical makeup of a vapor, has been demonstrated. In the device, a flowing stream of helium gas carries the vapor of interest through a heated, specially coated meter long

Physical Review Focus

Physical Review Focus (http://focus.aps.org) explains of selected papers from the *Physical Review* journals at a level accessible to undergraduate physics majors. Below are some samples from the year 2001. Go to the web site to sign up for weekly *Focus* e-mail summaries.

—*David Ehrenstein,* Focus *Editor (ehrenste@aps.org)*

Movies Show Quick Magnetic Flips



B.C. Choi/M.R. Freeman/Univ. of Alberta

Coordination is key. *A region of magnetic material flips direction quicker and in a more coordinated way when an extra magnetic field is present (bottom), according to new high speed movies. The experiments show how the read and write operations in disk drives work at a microscopic level.*

From cassette tapes to disk drives, the most popular way to store data is with magnetic materials. Yet exactly how individual magnetic bits reverse direction during writing and re-writing is still poorly understood. In the 22 January *PRL* a Canadian group reports the fastest and most spatially detailed movies of the flipping of micrometer-sized magnets. For the first time, the experiments reveal how the slow and complex flipping patterns of magnetic domains within a micromagnet can be coordinated and sped up with magnetic fields. The results help researchers better understand magnetic switching and may help designers optimize magnetic storage devices.

Mark Freeman, of the University of Alberta in Edmonton, says that magnetization reversal is tough to understand. "It is strongly dependent on the material and sample shape, defects, temperature, and so on." But past experiments haven't had the combined temporal and spatial resolution to follow the switching in detail.

To catch the quick change act, the Alberta group used a kind of high tech strobe light called a scanning Kerr microscope, in which femtosecond laser pulses bounce off the surface of a magnetic sample. Each light pulse has its polarization altered slightly by the surface magnetism. This polarization shift is measured as the pulsing beam scans across the sample, building up an image of the state of the magnet. With this setup they've combined high spatial resolution with picosecond timing to get the best magnetic images ever recorded.

The samples were 10 by 2 µm rectangles of 15-nm-thick nickel-iron ($Ni_{80}Fe_{20}$) grown on a small strip of gold. The researchers applied a magnetic field parallel to the long direction of a sample ("longitudinal bias field") to align its atomic spins and then sent a 10-ns-long jolt of current through the gold strip. The current pulse briefly created a magnetic field in the direction opposite to the static field, causing the nickel-iron's magnetization to flip twice in rapid succession. Using the fast scanning Kerr microscope, the team imaged the time course and domain structure of the sample's magnetic state.

Freeman and his co-workers found evidence for two entirely different modes of reversal. With a longitudinal bias field, there was a lag of about 3.5 ns as the magnetization responded to the switching pulse. But with an additional field applied along the short dimension of the sample ("transverse field"), the magnetization responded much faster to the switching pulse, settling down within a nanosecond.

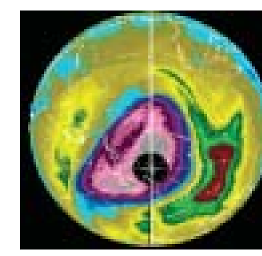
The Kerr imaging explains this difference. Without the transverse field, the magnet reverses in the usual way—by nucleating small regions which then grow together, until the whole magnet has flipped. But a transverse field causes the region to flip almost uniformly. Coordination within the sample seems to be the key to increased speed, just as a team of synchronized swimmers turns most efficiently if they all go the same way at once. In the magnetic structure, a transverse field tells the individual magnetic spins which way to flip. "It's a remarkable result," says David Awschalom of the University of California at Santa Barbara, "and counter to the way many people thought small magnetic particles would switch."

Such improvements in magnetic switching speed may provide a way for disk drive makers to optimize read/write heads for faster data flow and higher storage density. Freeman says that the technique should also permit more stringent tests of the models used in designing virtually all micro- and nanomagnetic devices. "These pictures tell a thousand words," says Awschalom.

—*David Voss, freelance science writer*

Reference: B. C. Choi *et al.*, Phys. Rev. Lett. **86**, 728 (2001)
Note: See videos of magnetic reversals at http://focus.aps.org/v7/st3.html#videos.

Ozone Layer Burned by Cosmic Rays



NASA TOMS satellite

Cosmic rays may be enlarging the hole in the ozone layer, according to a study appearing in the 13 August print issue of PRL. Researchers analyzed data from several sources, and found a strong correlation between cosmic ray intensity and ozone depletion. Back in the lab they demonstrated a mechanism by which cosmic rays could cause a buildup of ozone-depleting chlorine inside polar clouds. Their results suggest that the damage done by cosmic rays could be millions of times larger than anyone previous believed and may force atmospheric scientists to reexamine their models of the antarctic ozone hole. (Q.-B. Lu and L. Sanche, Phys. Rev. Lett. **87**, 078501. **Complete** *Focus* story at http://focus.aps.org/v8/st8.html.)

—*Geoff Brumfiel,* Focus *Intern*

Foamy Flows

S. Koehler/Harvard Univ.

Studying foams might seem like a tasty job—whipped cream, chocolate mousse, and beer heads are foams—but engineering ideal foams is harder than tasting them. Foam researchers have learned that the bubbles in fresh foam enlarge over time, that the liquid between them drains out, and that these two processes affect each other. But they haven't had a detailed and accurate theory describing the interaction. Now a team reporting in the 14 May *PRL* has developed such a theory and shown that it agrees with their experiments. The theory is a step toward a more complete understanding of foams, with possible applications in areas from beer production to mineral purification. (Sascha Hilgenfeldt et al., Phys. Rev. Lett. **86**, 4704. **Complete** *Focus* story at http://focus.aps.org/v7/st22.html.)

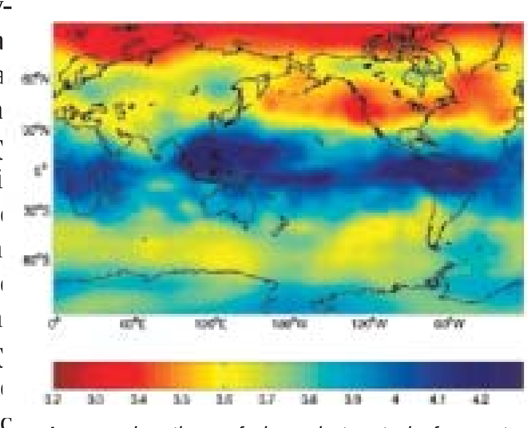
—*David Ehrenstein*

gas chromatography column, in which the vapor's constituent atoms and molecules are segregated by mass, and all similar atoms or molecules travel together. The various species then fall sequentially on a 500 MHz surface acoustic wave resonator, where they rapidly condense a hallmark of a vapor and are then evaporated, making room for the next arrival. The arrival time at the sensor identifies the species by mass, and the total mass of that species alters the resonator's frequency, thereby yielding the concentration. Concentrations as low as parts per billion (or trillion in some cases) were detected. Created by Edward Staples (Electronic Sensor Technology, Newbury Park, California), the zNose can analyze a vapor with hundreds of different species in 10 s. Staples anticipates many uses, including in the food and beverage industry, forensics, and environmental science.

OPTICAL MICROROTORS. Using lasers, two researchers at the Hungarian Academy of Sciences have built and operated structures that work much like windmills. First, Pál Ormos and Péter Galajda used two photon polymerization (see *Physics Today*, May 1999, page 9) to chemically carve rotors out of a resin based material. Then, holding a free floating rotor in optical tweezers, they used radiation pressure instead of wind to turn it at a speed dependent on the photon flux. They also manufactured other shapes for their devices, including helixes and propellers. In the demonstration of light powered micromachinery an optical rotor turned an interlinked cogwheel, each about 5 microns in diameter. In addition to providing torque to miniature devices, the rotors could be used to measure fluid properties on micrometer scales. Alternatively, it may be possible to study the mechanical properties of certain molecules, such as proteins or DNA, by fixing one end to a surface, attaching a rotor to the other end, and using light to apply a twisting force. (P. Galajda, P. Ormos, *Appl. Phys. Lett.* **78**, 249, 2001.)

HELIUM CRYSTALLIZATION WITH SOUND WAVES . A pure liquid exposed to a powerful acoustic wave can break and produce bubbles (a process called cavitation) during the negative pressure swing of the sound wave. That liquid gas transition has been known for some time. Now, physicists at the Ecole Normale Superieure in Paris have observed an acoustically driven liquid solid transition in He. They focused a short, powerful burst of 1 MHz ultrasound in a small region of liquid He near a clean glass plate and used a laser to monitor the He density at that spot. During the positive, overpressure swing of the ultrasound, they observed crystallites growing up to 15 microns in size, and at a speed of 100 m/s in a mere 150 ns and an even faster melting some 250 ns later when the negative pressure swing of the ultrasound wave passed through. The researchers argue that the crystallization process was pure: Nucleation took place at a clean wall but did not involve any impurities. Using a more powerful sound wave, they believe they can generate He crystals without the wall. (X. Chavanne, S. Balibar, F. Caupin, *Phys. Rev. Lett*. **86**, 5506, 2001)

ALL DATA ON THE WEATHER MAP ARE NOT EQUAL. Researchers usually assume that all spots on a weather map are equally chaotic, meaning that small uncertainties in initial conditions lead to unpredictably different results. A realistic model of Earth's atmosphere is necessarily high dimensional—there are a great many degrees of freedom which further complicates the art of forecasting. Now, a multidisciplinary team of scientists at the University of Maryland has shown that, locally, the finite time dynamics of the atmosphere is often low dimensional. They developed a statistic called the bred vector (BV) dimension that characterizes the difference between a model atmospheric state (the initial condition) and several perturbations of that state that evolve for a finite time. Using real "ensemble forecasts" from the National Weather Service, they mapped the atmosphere's BV dimension globally, as shown in the figure, where red is low dimensionality and blue is high. The team says that the low BV dimension regions might be particularly important for obtaining accurate weather forecasts; atmospheric data obtained there will tend to evolve only along the subspace spanned by the few dominant vectors. (D.J. Patil *et al.*, *Phys. Rev. Lett.* **86**, 5878, 2001)



Average locations of chaos hotspots in forecasts from February 10, 2000 to July 30, 2000. Red denotes regions in which the hotspots tend to appear. In the hotspot regions, good initial observations become most crucial for reducing forecasting errors. (Courtesy University of Maryland)