Physics News in 2002

A Supplement to APS News

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INTRODUCTION

Physics News in 2002 is a summary of physics highlights compiled from items appearing in the weekly newsletter *Physics News Update* of the American Institute of Physics (AIP). 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 at science journalists) and because of limited space in *Physics News in 2002*, some fields of physics research might be under-represented in this compendium. Readers can get a much wider view of the year's top physics research 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/. The material appearing under the headline "Highlights of Science Policy and Budget Developments in 2002" on page 9 is a compendium from the electronic news service FYI produced by the Media and Government Relations Division of the AIP. See http://www.aip.org/enews/fyi/ .

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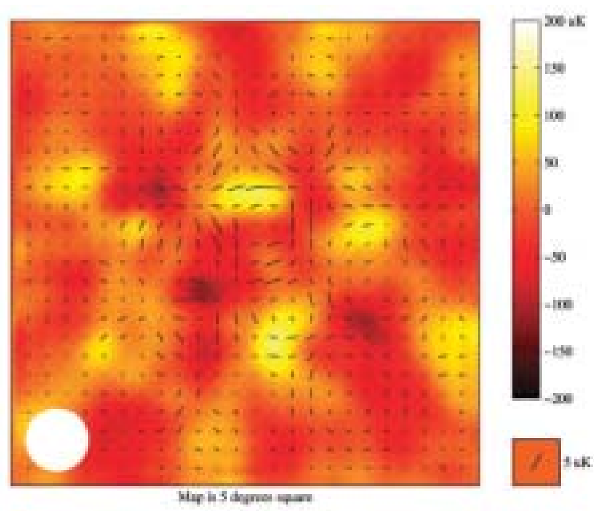
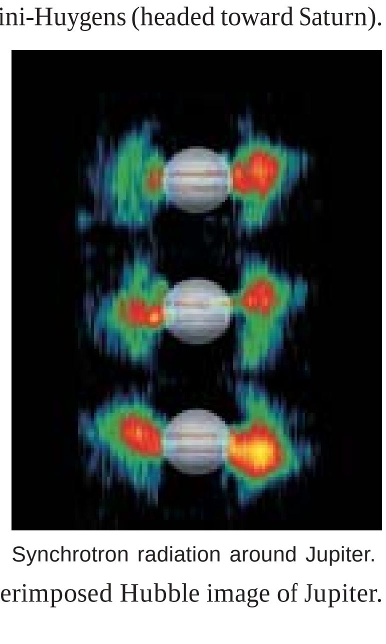
ASTROPHYSICS

POLARIZATION IN THE COSMIC MICROWAVE BACKGROUND has been measured. The most fundamental properties of the CMB — which can reveal conditions in the universe when it was only about 400,000 years old—are its frequency spectrum and its angular power spectra of both temperature and polarization fluctuations. According to the modern theory of cosmology, the CMB microwaves received an orientation (polarization) just before the seething plasma that pervaded the cosmos in that early era finally became a neutral, transparent gas. Until now, the low level of polarization had allowed that quantity to escape detection. Using the Degree Angular Scale Interferometer detector situated at the South Pole, a group from the University of Chicago and the University of California, Berkeley, has acquired and analyzed enough high-quality data to actually see the CMB polarization. The observed value is consistent with predictions and thus strongly validates the underlying theory. (J. Kovac *et al.*, preprint available at http://arXiv. org/abs/astro_ph/0209478.)



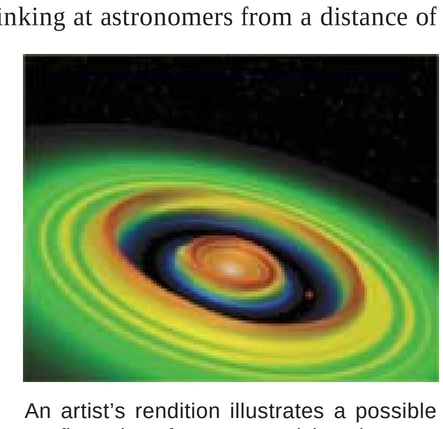
An image of the intensity and polarization of the cosmic microwave background radiation made with the Degree Angular Scale Interferometer (DASI) telescope. The small temperature variations of the cosmic microwave background are shown in false color, with yellow hot and red cold. (Courtesy DASI collaboration.)

JUPITER'S MAGNETOSPHERE has been simultaneously sampled by two spacecraft, Galileo (already on patrol in the Jupiter system) and Cassini-Huygens (headed toward Saturn). Just as Cassini was approaching Jupiter in January 2001, other Earthbound observatories, including radio telescopes and the Hubble (optical) and Chandra (x-ray) satellites, were turned to the giant planet. The Sun also cooperated: Three interplanetary shock waves in the solar wind swept by. The two spacecraft caught Jupiter's magnetosphere in the act of being compressed. That compression produced strong electric fields and therefore particle accelerations, which brightened Jupiter's auroras. Internal magnetospheric dynamics caused other observed auroral brightenings and a wind of neutral atoms—formed from ions spewed by Io's volcanic eruptions—sent outward against the incoming solar wind. Such energetic neutral atoms had not been directly observed before. The flyby also provided the first opportunity to observe electrons above 50 MeV trapped in Jupiter's radiation belts. Shown here is the synchrotron radiation from those electrons, with a superimposed Hubble image of Jupiter. (Seven articles in *Nature* **415**, 985, 2002.)



Synchrotron radiation around Jupiter.

A YOUNG EVOLVING PLANETARY SYSTEM has been seen. A star much like our Sun when it was only 3 million years old has been winking at astronomers from a distance of about 2400 light years for the past five years. Every 48.36 days, the star suddenly dims to a small percentage of its normal brightness for about 18 days. The duration and depth of these periodic occultations, discovered by William Herbst and his colleagues at Wesleyan University in Connecticut, had not been seen before. Eighteen days is much too long for occultation by a lone planet in a 48-day orbit. The observations' most likely explanation, put forth by Herbst at a meeting at the Carnegie Institution of Washington in June 2002, is that a collection of dust grains, rocks, and perhaps asteroids is strung out in a clumpy arc of an orbiting circumstellar disk, with a larger object like a protoplanet shepherding the material. Now, with a worldwide collaboration watching the star continually, the Wesleyan group has found evidence that the orbital period is, in fact, 96.72 days: The star is being occulted by two separate clumpy regions on opposite sides of the disk. Theoretical models indicate that a single shepherding object could account for both clumps. The 97-day period indicates that the ringlike disk is about as far away from the star as Mercury is from the Sun. The collaboration has also seen the system changing slightly on a scale of months and years, thus tantalizing astronomers with the prospect of viewing planetary evolution in real time. (W. Herbst *et al.*, http://www.astro.wesleyan.edu/kh15d/)



An artist's rendition illustrates a possible configuration of a young evolving planetary system (Courtesy, Geoffrey Bryden, JPL.)

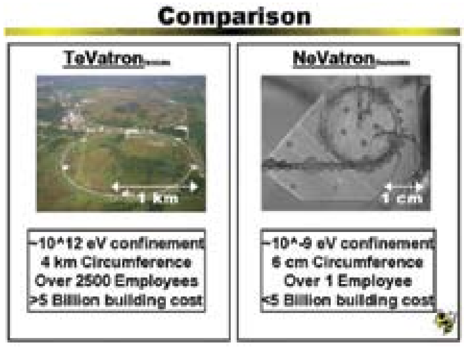
SPIRAL ARMS, COSMIC RAYS, AND ICE AGES. Most cosmic rays (CRs) are thought to originate in supernovae, and most supernovae occur in the wake of galactic spiral density waves. Nir Shaviv of the University of Toronto and Jerusalem's Hebrew University has developed a new CR diffusion model that includes the presence of arms. Not surprisingly, he found that the CR flux at Earth would vary with time and be correlated with our Solar System's passage through galactic spiral arms as we circumnavigate the Milky Way. He then looked at a historical record of CR flux, in the form of 42 age-dated iron meteorites whose exposures to CRs could be determined. He found a periodicity of 143 million years in the CR flux, which he attributes to passages through spiral arms. On the assumption that CRs ionize Earth's lower atmosphere and can thus influence climate, Shaviv next looked at the geologic record for ice ages and found "a compelling correlation" of both period and phase between CR flux and glaciation epochs during the past billion years. Between 1 and 2 billion years ago, there is no evidence for any ice age, consistent with a slowed star-formation rate during that period of our galaxy's history. Shaviv says that the weakest link in his analysis is the uncertainties in the glaciological record. (N. J. Shaviv, *Phys. Rev. Lett.* **89**, 051102, 2002.)

NEW COSMOLOGICAL UPPER LIMIT ON NEUTRINO MASS. Recent neutrino results imply that one or more of the three neutrino flavors (electron, muon, and tau neutrinos) have some mass (see *Physics Today*, July 2002, page 13). Considering the number of neutrinos loose in the universe, even a small mass means they will have significantly influenced the development of galaxies. Various physics experiments have established an upper limit of 3 eV for the electron neutrino and whopping upper limits in the MeV range for the muon and tau neutrinos. Now, a worldwide collaboration of astronomers has looked at the distribution of 250,000 galaxies in the 2 Degree Field Galaxy Redshift Survey and measured large-scale structure statistics in the form of a power spectrum. They compared the data with calculated power spectra using a model that included baryons, cold dark matter, massive neutrinos (hot dark matter), and a cosmological constant. The model had a few reasonable assumptions —for example, that all three types of neutrinos drop out of thermal equilibrium at the same temperature and that the spectrum of primordial fluctuations from which galaxies evolved is scale-independent—and an appropriate treatment of previously measured cosmological parameters. The group then arrived at two big conclusions: Neutrinos can account for no more than 13% of the matter in the universe, and the sum of all three neutrino masses is no more than 2.2 eV. Group members Oystein Elgaroy and Ofer Lahav say that this is the best upper limit for neutrino mass derived with relatively conservative assumptions on cosmological parameters. (Elgaroy *et al.*, *Phys. Rev. Lett.* **89**, 061301, 2002.)

QUAOAR is the provisional name for a large, newly discovered planet like inhabitant of our solar system. First spotted on 4 June 2002, Quaoar (pronounced KWAH-o-wahr) lives in the Kuiper Belt debris zone beyond Neptune's orbit. Its diameter of 1250 km is about half that of Pluto, and its distance of 42 astronomical units from Earth is far beyond Pluto's current distance of about 30 AU. (One AU is the mean distance of Earth from the Sun, about 150 million kilometers.) Caltech scientists announced the finding in October at the meeting of the division for planetary sciences of the American Astronomical Society, held in Birmingham, Alabama. (Abstract 9.04, *Bull. AAS* **34**(3), 2002. Also see http://www. gps.caltech.edu/~chad/quaoar.)

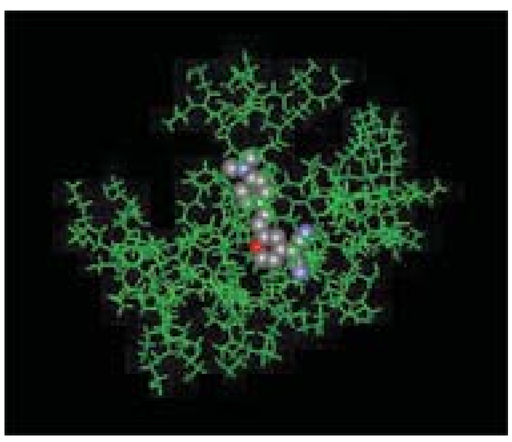
ATOMIC, MOLECULAR, AND OPTICAL PHYSICS

STORAGE RING FOR NEUTRAL ATOMS. Generally, a storage ring not only stores charged particles but also defines their energy and trajectory; particles with the wrong energy simply fly away from their magnetically guided route. Neutral atoms don't have a net charge for magnets to act on, but they can have a net magnetic dipole moment. If the atom moves slowly enough, its dipole is sufficient for magnetic guidance, and several such neutral atom guides have already been built. Physicists at Georgia Tech have now built a ring only 2 cm across, consisting of two concentric current-carrying wires, separated by 840 mm. They also built a wire "funnel" to transfer neutral rubidium atoms from a magneto-optic trap to the ring, where the atoms moved at only 85 cm/s, corresponding to kinetic energies of about 100 neV. The researchers thus dubbed their device the "Nevatron." The image shows an atom cloud after having completed two full circuits between the two ring wires. So far, swarms of 1 million atoms have made as many as 10 circuits around the ring. The physicists are extending the work to include ring-based atom interferometry and cold-beam generation. (J. A. Sauer, M. D. Barrett, M. S. Chapman, *Phys. Rev. Lett.* **87**, 270401, 2001.)



A tongue-in-cheek comparison of the TeVatron and the NeVatron (Courtesy Michael Chapman, Georgia Tech.)

A DENDRIMER LASER has been demonstrated. A conventional dye laser uses fluorescing dye molecules as the active medium. When excited with an external laser, the molecules emit a range of wavelengths that are then tuned by the dye-laser cavity. In most dye lasers, the dye concentration cannot go above a millimole/liter without quenching the fluorescence. Now, scientists at the Communications Research Laboratory in Japan and PRESTO Japan Science and Technology Corp have achieved lasing with a dye concentration of 9 mmol/l by encapsulating the dye molecules at the heart of hyperstructured, tree-shaped polymers called dendrimers. As the dye concentration increased within the new dendritic high-gain medium, the laser output also increased while the lasing threshold decreased. Furthermore, the resultant spectral linewidth was only 0.1 nm. The researchers are now working to incorporate their dendrimers into solid-state waveguides, optical fibers, and photonic crystals. (S. Yokoyama, A. Otomo, S. Mashiko, *Appl. Phys. Lett.* **80**, 7, 2002.)

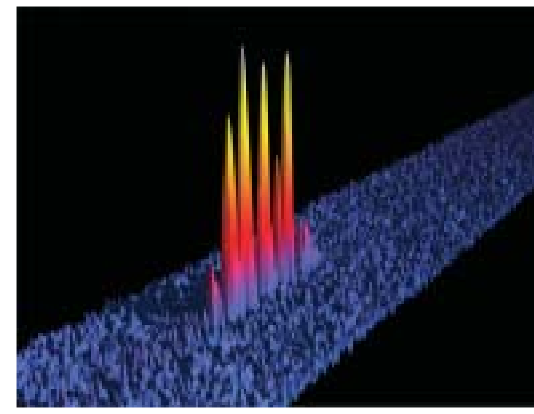

A large dendrimer polymer molecule (green) with a dye molecule lodged at its center. (Courtesy S. Yokoyama et al.)

LIGHT SLOWED AND STORED IN A SOLID. The group velocity of light—the speed at which the wave pulse propagates—can be considerably lowered, even to zero, in a medium having an index of refraction that changes dramatically with wavelength. The energy and information in the original light pulse can be stored, without any heating, in the form of coherent spin excitations in the atoms of the medium. Last year, two different experiments stopped and stored light in a vapor sample (see *Physics Today*, March 2001, page 17). Now the feat has been carried out in a 3-mm-thick crystal-yttrium silicate doped with atoms of the rare earth praseodymium-already in common use for high-density optical data storage. The experiment was carried out at MIT and at the Air Force Research Laboratory in Hanscom, Massachusetts. The researchers foresee many applications in areas such as quantum computing, ultrasensitive magnetometry, and acousto-optics. (A. V. Turukhin *et al.*, *Phys. Rev. Lett.* **88**, 023602, 2001.)

NONLINEAR LASER WITH ULTRALOW THRESHOLD. Physicists at Caltech coupled a 70-micron silica sphere to an optical fiber, which enabled light to race around near the surface of the sphere in a "whispering gallery" mode. Whispering modes have been produced before, for example, in microdroplets, but practical applications seemed remote. The light buildup in these modes is characterized by a parameter Q, referred to as the quality factor; for the microsphere, Q exceeded a hundred million. The light can build up to such an extent that nonlinear interactions take place and engender coherent light emission. The result is a Raman laser, which is tunable and can be used as a pump for other lasers. Typically, Raman lasers need a highpower input to work at all. But the Caltech result achieved lasing with only tens of microwatts of input power—1000 times less than other Raman lasers and in a much smaller package—although the output was only picowatts. The nonlinear properties of light in the silica microspheres offer new avenues of exploring quantum optics. (S. M. Spillane *et al.*, *Nature* **415**, 621, 2002.)

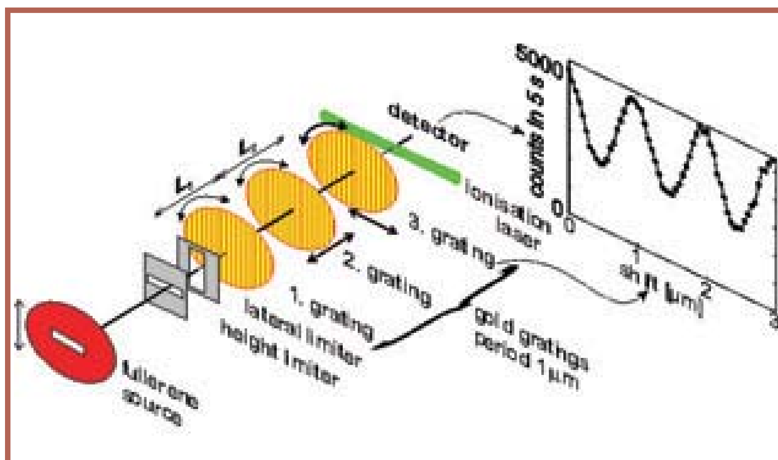
ALL-OPTICAL TRAPPING OF A DEGENERATE FERMI GAS has been demonstrated. First created in a magnetic trap (see *Physics Today*, October 1999, page 17), a degenerate Fermi gas consists of fermionic atoms—those with an odd total number of protons, neutrons, and electrons—sufficiently dense and cold that only the lowest trap energy levels are occupied. An all-optical trap has previously been used to confine a Bose-Einstein condensate (see *Physics Today*, July 2001, page 20 and September 2001, page 79). Now, using a stable, high-power CO_2 laser, physicists at Duke University have created a kind of "optical bowl" for lithium-6 atoms: Slowly lowering the bowl's rim permitted the hottest atoms to evaporate. The researchers then adiabatically recompressed the trap to its full depth, which tightly confined the remaining degenerate gas. In this way, an equal mixture of lithium atoms in spin-up and spin-down states was captured, a feat not possible in magnetic traps. According to the Duke researchers, such equal two-state mixtures are potentially ideal for forming neutrally charged, quasibound pairs of atoms in Fermi gases—something the researchers hope to observe soon. Several groups are pursuing such an atomic-gas analog of superconductivity in different ways. (S. R. Granade *et al.*, *Phys. Rev. Lett.* **88**, 120405, 2002.)

BRIGHT SOLITONS IN A BOSE-EINSTEIN CONDENSATE. A soliton is a localized wave that, because of nonlinear effects, can travel for long distances without spreading out or losing its original shape. Solitons can occur in all kinds of waves, including sound and light. In fact, solitons are regularly used in telecommunications in optical fibers. Essentially a macroscopic matter wave, a BEC can also form solitons. Usually, however, a BEC quickly spreads after it is released from the trap in which it was created. Now, groups at Rice University in Houston and at the Ecole Normale Supérieure in Paris have been able to form BEC solitons with lithium-7 atoms. Both groups used a tunable magnetic field to adjust the interatomic interactions from repulsive-necessary to form a stable condensate-to weakly attractive. The attractive interactions provided a self-focusing nonlinearity that exactly compensated for wavepacket dispersion. After releasing the atoms into a 1D potential, both groups observed solitons that propagated without changing shape for more than a millimeter—a truly macroscopic distance. The Rice experimenters formed a train of up to 10 individual solitons, which appeared to repel each other as they oscillated in a weakly harmonic potential. The Paris group set up an open waveguide and accelerated a single soliton. Matter-wave solitons may prove useful for eventual technological applications of BECs, such as for gyroscopes for ultraprecise navigation, very accurate atomic clocks, or other devices that use atom interferometry. (K. E. Strecker *et al.*, *Nature* **417**, 150, 2002; L. Khaykovich *et al.*, Science **296**, 1290, 2002.)


Bright Solitons, composed of Bose-Einstein Condensates of lithium-7, have been observed in a single beam optical trap (Courtesy Randy Hulet and colleagues, Rice University.)

SONOLUMINESCENCE ENERGY IS MAINLY CHEMICAL, according to a new set of experiments at the University of Illinois. Yuri Didenko and Kenneth Suslick quantified the energy consumption during sonoluminescence, the conversion of ultrasonic waves into picosecond light pulses via rapid oscillations of bubbles in a liquid. They found that, during the compression phase, a bubble's interior gets hot enough to dissociate many gas molecules and initiate a furious session of chemical reactions. The researchers carefully monitored the reactant products—mostly nitrite ions (NO_2^-), hydroxyl radicals (OH), and light—of a single bubble of air in a bath of water subjected to ultrasound. They found that about 100 times more energy goes into chemical reactions than into light. Their experimental conditions were very different from those used for the recent claim of "sonofusion" (see *Physics Today*, April 2002, page 16), and thus their results may not apply to that claim. However, Dan Shapira and Michael Saltmarsh of Oak Ridge National Laboratory did duplicate the sonofusion conditions. They showed that the earlier coincidence data can be accounted for by random coincidences; they also placed an upper limit on the relevant neutron emission that is 10^4 less than that implied by the earlier claim. (Y. T. Didenko, K. S. Suslick, *Nature* **418**, 394, 2002. D. Shapira, M. Saltmarsh, *Phys. Rev. Lett.* **89**, 104302 , 2002.)

A MATTER-WAVE INTERFEROMETER FOR LARGE MOLECULES. A matter-wave interferometer for large molecules has been devised and demonstrated for the first time. For many years scientists have studied the proposition that things we normally think of as particles, such as electrons, should also have wave properties. Indeed studies of beams of electrons, neutrons, even whole atoms, have confirmed that particles can be viewed as a series of traveling waves which diffracted when they pass through a grating or through slits. These waves could even interfere with ach other, resulting in characteristic patterns captured by particle detectors. In this way, in 1999 Anton Zeilinger and his colleagues at the University of Vienna demonstrated the wave nature of carbon-60 molecules by diffracting them (in their wave manifestation) from a grating. Now the same group, using a full interferometer consisting of three gratings with wider grating spacings and a more efficient detector setup, observe a sharp interference pattern. Moreover, because the beam of particles used, carbon-70 molecules at a temperature of 900 K, are themselves in an excited state (undergoing 3 rotational and 204 vibrational modes of internal motion), it should be possible to study the way in which an atom wave, or in this case a macromolecular wave, becomes decoherent (that is, loses its wavelike character) Because of thermal motions and other interactions with its environment. Thus this type of interferometer experiment will be useful in studying the borderland between the quantum and classical worlds. The researchers are aiming to study the wave properties of even larger composite objects, mid-sized proteins. (Brezger *et al.*, *Physical Review Letters* **88**, 100404, 2002).



A matter-wave interferometer for large molecules (Courtesy University of Vienna)

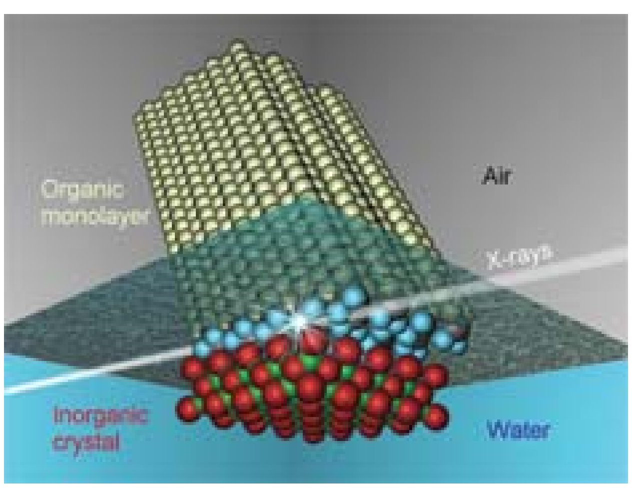
BIOLOGICAL PHYSICS

ELECTRICAL BIOSENSORS FOR INDIVIDUAL LIVING CELLS were described at the March 2002 meeting of the American Physical Society. Cells are complex networks of interacting molecules, and are usually studied with optical techniques. Electrical measurements, however, can provide complementary information. Toward that end, Lydia Sohn of Princeton University described several new biosensors. With one, she measured the amount of DNA in a single living cell passed through a small fluid chamber between two metal electrodes. The cell changed the system's capacitance in a way that reflected the amount of the cell's negatively charged DNA but not its other ions. Sohn reported that the technique can identify the stage of a cell's development (since cells can contain different amounts of DNA at different stages) and can potentially distinguish cancerous cells from healthy ones. Sohn also described a biosensor that can detect small amounts of a specific protein in live *E. coli* cells. The eventual goal of Sohn's lab is to take inventory of a living cell's protein contents—something that cannot be done with current protein assay techniques, which require the destruction of cells. (More information at http://www.aps.org/meet/MAR02/baps/vpr/layf7-003.html.)

NOISE CAN IMPROVE HUMAN BALANCE CONTROL, to the point that it may enable elderly subjects to steady themselves as well as their young counterparts, researchers in New England have demonstrated. Noise, in this case, refers to random mechanical vibrations applied to the feet. In physics, noise denotes any random or seemingly useless fluctuation. Static on a radio station, peripheral conversations in a crowded room, and flashing neon lights along a busy thoroughfare all tend to obscure or distract one from receiving the desired information. But more and more studies in a wide variety of systems—global climate models, electronic circuits and sensory neurons, to name a few—have shown that certain levels of noise can actually enhance the detection and transmission of weak signals, through a mechanism known as stochastic resonance (SR). Here the authors show that postural sway, the slight movements exhibited by the body when it is erect, can be significantly reduced for both young and elderly individuals. The authors achieved this by randomly applying subtle mechanical vibrations, just below the threshold of sensory perception, under the subjects' feet. The random vibrations likely act to enhance the sensation of pressure on the soles of the feet. The authors further demonstrate a trend in elderly subjects towards reducing their postural sway to the level of young subjects, suggesting that noise may be a "fountain of youth" for human balance. These results indicate that the random vibrations may ameliorate age-related impairments in balance control. Noise may provide similar beneficial effects in individuals with marked sensory deficits, such as patients who have suffered a stroke or a disorder in the peripheral nervous system. In the future, the authors speculate, noise-based devices, such as randomly vibrating shoe inserts, may enable people to overcome functional difficulties due to age- or disease-related sensory loss (Priplata *et al.*, *Physical Review Letters*, **89**, 238101, 2002). This paper comes on the heels of another recent finding, that the random hand motions generated by noise in the human nervous system make it possible for people to balance a stick on a finger (Cabrera and Milton, *Physical Review Letters* **89**, 158702, 2002).

VISCOSITY OF TWO-DIMENSIONAL SUSPENSIONS is similar to that in three dimensions. Many technologically and biologically important interfaces are actually monolayers composed of two coexisting phases: solid like crystals of the molecules floating in a sea of liquid like molecules. Researchers at the University of California, Santa Barbara, measured the viscous drag on a magnetic needle in monolayers of human lung surfactant lipids. They found that if the relative fraction of the layer's area that contained crystals was low, the viscosity was also low and the monolayer spread easily. As the crystals' coverage increased, so did the viscosity until, at a critical fraction of the total area, the monolayer abruptly became rigid. Moreover, the behavior held for a wide range of surface pressures, temperatures, and monolayer compositions and was the same as that for a 3D dispersion of hard spheres in a solvent with long-range repulsive interactions. The scientists believe their work could lead to better replacement surfactants—for example, for premature infants with respiratory distress syndrome. Human lung surfactant has an important role in replacing the blood's carbon dioxide with oxygen. It helps keep the lungs' tiny air sacs properly inflated by controlling their surface tension. (J. Ding *et al.*, *Phys. Rev. Lett.* **88**, 168102, 2002.)

A STRETCH-FIT TEMPLATE FOR FILMS of organic and inorganic molecules. Many biological processes, such as bone formation, require hard inorganic materials to grow on a soft macromolecular substrate, although precisely how the two mesh has been something of a mystery. To examine that issue, physicists at Northwestern University floated a two-dimensional array of a fatty acid (a Langmuir monolayer) on a supersaturated solution of barium fluoride (BaF_2), which then crystallized at the interface. Separately, the two lattices are incommensurate. Using x-ray diffraction, the researchers observed that both lattices adapted in order to register with each other. The lattice of the BaF_2 thin film contracted by a few percent and the organic lattice expanded by tilting the molecules. The result was that the facial areas of the unit cells fell into a commensurate ratio of 1.5. BaF_2 is not a biologically important mineral, but Pulak Dutta says he and his fellow group members expect to look directly at biomineralization in an upcoming phase of their work. (J. Kmetko *et al.*, Phys. Rev. Lett. **89**, 186102, 2002.)



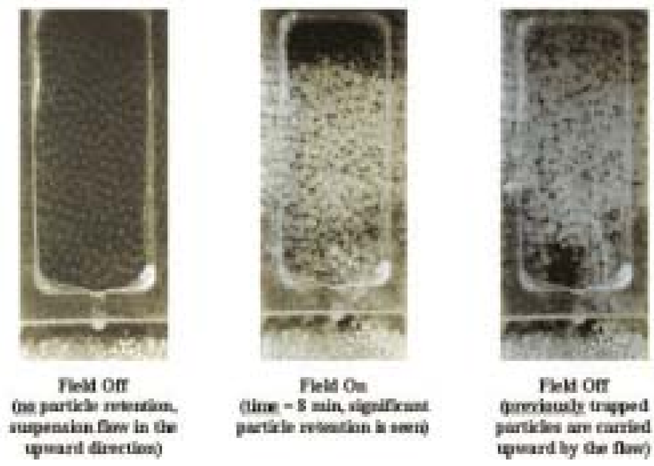
X rays are used to reveal, in detail for the first time, how an inorganic crystal (barium fluoride) can grow, in registry, upon an organic material (a fatty acid). (Courtesy, Jan Kmetko, Northwestern Univ.).

CONDENSED MATTER/MATERIALS PHYSICS

SUPERCONDUCTIVITY IS REDUCED as a system becomes more one-dimensional. Moving through very thin passages, Cooper pairs of electrons, which constitute the supercurrent, are sensitive to quantum effects not noticeable in larger wires. For example, quantum phase slips-fluctuations in which the superconducting wavefunction spontaneously tunnels from one state to another-occur well below the critical temperature. The tunneling produces a momentary voltage, and therefore a nonzero electrical resistance, even if the temperature could somehow be reduced to absolute zero. Armed with progressively thinner wires—down to 10 nm across—of molybdenum-germanium deposited onto carbon nanotubes, Michael Tinkham and his colleagues at Harvard University have definitively shown that resistance goes up as the wire diameter goes down. The quantum resistance effect only becomes noticeable for wires less than about 30 nm across. By going to lower temperatures, says Tinkham, one can eliminate resistivity arising from thermal fluctuations, but not from quantum fluctuations. (C. N. Lau *et al.*, *Phys. Rev. Lett.* **87**, 217003, 2001.)

INSLULATOR-TO-METAL within a picosecond. A group from the University of California, San Diego, and the University of Quebec studied a 200-nm thick film of vanadium oxide (VO_2). They fired a 50-fs laser pulse at the sample, causing what they believe to be two phase transitions: a structural one (the unit cell size increases a bit), monitored with short x-ray pulses; and an electrical one (insulator-to-metal), monitored by short pulses of visible light. The simultaneous, ultrafast measurement of more than 1 degree of freedom showed that both transitions happened essentially all at once. Therefore, the experiment still did not settle an old question in condensed matter physics: Which comes first, the structural change in the sample or the electrical change? Because the crystalline reordering occurs in a few hundred femtoseconds and is reversible, and because x rays scatter differently from the two contrasting crystalline forms, it might be possible to use this whole process as an ultrafast "Bragg switch" to divert subpicosecond portions of a longer x-ray wavetrain. (A. Cavalleri *et al.*, *Phys. Rev. Lett.* **87**, 237401, 2001.)

SOUND WAVES MAKE FILTERS FINER. Generally, the performance of filters that remove particulates from fluids is limited by their pore sizes: A filter with large pores isn't likely to catch many tiny particles. By contrast, a filter with tiny pores will trap small particles but inhibit fluid flow. Now, Donald Feke (Case Western Reserve University) has trapped particles up to a hundred times smaller than the nominal pore size by applying a low-power acoustic signal to the filter. The sound field within a porous material creates patterns of standing waves associated with the pores. Rather than wending their way through the filter, particles headed for the focal points either form intricate, stable filaments or gather into groups that orbit in regions of stability for as long as the signal persists. Such an acoustically aided filter offers little resistance to the fluid that flows through it, yet collects particles as efficiently as a much finer filter does. And once the filter has done its job, the trapped particles can be released with the flip of a switch that cuts off the signal. Feke presented his work at the 73rd annual Society of Rheology meeting in Bethesda, Maryland.



Acoustic filter: when an acoustic signal is turned on, tiny particles are trapped by a complex pattern of standing sound waves (Courtesy CWRU)

LIGHT-ACTIVATED PLASTIC MAGNET. Photoinduced magnetism is of considerable interest in data storage applications. Over the past six years, the phenomenon has been seen, generated, and studied in several different materials. Now, scientists at Ohio State University and the University of Utah have produced light-induced magnetization in an organic-based material, tetracyanoethylene (TCNE), contained within a manganese compound. When the material was exposed to blue light from an argon laser, its magnetization increased by as much as 50%. The material was magnetic at temperatures below 75 K and retained its magnetism for days, perhaps through the formation of a metastable state in a distorted lattice. The magnetism could be partially undone by green light, and completely undone by heat. The researchers believe that the light can be selectively targeted to domains as small as, or smaller than, the wavelength of the light itself, thus possibly enabling information storage. Magneto-optic effects are currently used only to retrieve information. The new process promises to offer both reading and writing capabilities. The benefits of plastic electronic components made of plastic include flexibility, low cost, and tunability. (D. A. Pejakovic *et al.*, *Phys. Rev. Lett.* **88**, 057202, 2002.)

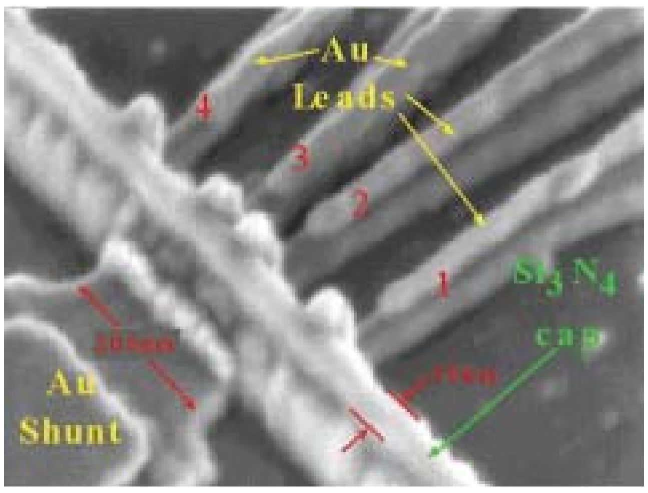
RAPID-RESPONSE HYDROGELS, water-swelled polymers that quickly change their properties when triggered by the right stimulus, have been created. A hydrogel is a 3D cagelike polymer that is relatively sluggish in responding to the application or removal of stress, light, or a change in acidity. Using a novel design based on artificial protein polymers, a collaboration of scientists from the University of California, Santa Barbara, and the University of Delaware has now developed a hydrogel that can recover quickly after the removal of mechanical stress. The novel hydrogel contains two chemical building blocks: one that is highly charged and hydrophilic and another that is hydrophobic and has a special shape that causes the polymers to link and form a porous hydrogel at very low concentrations in solution. After the gels were shaken vigorously to break down their structure, they recovered 80% of their strength in a matter of seconds, even at 90°C. The rapid response and highly porous nature of the new hydrogel potentially opens up new biotechnological uses for the compound. Possibilities include an organic scaffolding to hold regenerating tissue within the body and a drug-delivery capsule to hold large proteins and release them when given the right stimulus. (A. P. Nowak *et al.*, *Nature* **417**, 424, 2002.)

MICROTESLA NUCLEAR MAGNETIC RESONANCE has been demonstrated. In conventional NMR, a several-tesla magnetic field is used to orient atomic nuclei in the sample. The polarized nuclei can resonantly absorb a burst of radio waves, and precess around the imposed field. The spectral "chemical shift" information from reemitted radio waves is then used to identify molecules. NMR also lies at the heart of magnetic resonance imaging (MRI). Now, a team of scientists led by John Clarke and Alexander Pines (Lawrence Berkeley National Laboratory and the University of California, Berkeley) have exploited an often overlooked fact: For a homogeneous field, the NMR linewidth scales linearly with the field strength. Thus, a 1000-fold reduction in field strength produces a line both narrower and taller by that same factor. The researchers placed a small liquid sample of methanol and phosphoric acid in a polarizing field of only 1 mT and a much weaker orthogonal measuring field of 5 mT (Earth's field is roughly 50 mT). The group then turned off the polarizing field and used a SQUID to detect not chemical shift but "J-coupling," which can measure an atom's chemical environment as well as its identity. In that way, they not only identified protons and phosphorous—31, but saw the signature—a doublet split by 10.4 Hz—of the covalent bonds in trimethyl phosphate. These techniques open the possibility for "pure J" spectroscopy and perhaps could form the basis of inexpensive MRI machines. (R. McDermott *et al.*, *Science* **295**, 2247, 2002.)

A SINGLE-PHOTON LIGHT-EMITTING DIODE has been created. At the May 2002 CLEO/QELS meeting in Long Beach, California, scientists from Toshiba Research Europe Ltd described a nanometer-scale indium arsenide quantum dot integrated into a conventional gallium arsenide LED structure. Using a pulse of electric current, the researchers could induce a single electron and a single hole to recombine in the dot, thus generating a single photon. Because the exciton's lifetime was 1.0 ns and the equipment had subnanosecond time resolution, the physicists could verify that photons were emitted singly. The researchers believe this is the first electrically driven single-photon source. Such single-particle-emitting sources could offer a potentially inexpensive and convenient component for quantum cryptography and other applications. (Paper QTuG1 at the meeting; see also Z.Yuan *et al.*, *Science* **295**, 102, 2002.)

A NANOSCALE NONMAGNETIC READ-HEAD SENSOR, based on extraordinary magnetoresistance (EMR), has been developed. Today's state-of-the-art magnetic recording delivers about 15 gigabits per square inch of recording medium. To achieve that result, the read head uses magnetic metals in a layered structure with either the giant magnetoresistance (GMR) or tunneling magnetoresistance (TMR) effect to convert the field orientation (up or down) of tiny magnetic domains into changes in electrical resistance. Both effects make use of electrons' spin and are subject to magnetic noise. By contrast, EMR makes use of electrons' orbital degrees of freedom; the magnetic fields deflect a current from a conducting shunt attached to the semiconductor and thereby produce resistance changes. A group led by

Stuart Solin of NEC Research Institute in Princeton, New Jersey, has now used nonmagnetic, silicon-doped indium antimonide to build a mesoscopic read head (see the scanning electron micrograph) that operates on the EMR principle. According to Solin, GMR and TMR will ultimately have a noise-limited areal density of about 150 Gb/in^2, whereas EMR could reach 1 Tb/in^2 and has a fast enough response time to utilize that density. The researchers fabricated their 116-Gb/in^2 device using a multistep electron-beam lithography process that required excruciating accuracy: Features needed to be aligned to within 10 nm. Although free of magnetic-noise limitations, the device needs to sense magnetic fields that are 10 times stronger than those sensed with current technologies, which could limit its practical application for the time being. (S. A. Solin *et al.*, *Appl. Phys. Lett.* **80**, 4012, 2002.)



A nanoscale, nonmagnetic read_head sensor, based on extraordinary magnetoresistance (EMR). (Courtesy Solin et al..)

SINGLE-SPIN TRANSISTOR. Spintronics is a relatively new field in which an electron's spin, not just its charge, is exploited in devices and circuits. Physicists at the Institute for Microstructural Science in Ottawa, Canada, have connected a quantum dot to spin-polarized leads in an external magnetic field. They emptied the dot of conduction electrons and then added them back one at a time. The researchers found that the total spin of the electrons depended both on the number of electrons in the dot and on the applied magnetic field. With fewer than about 20 electrons in the dot, an even number of spins paired off in singlet states with zero net spin, whereas an odd number had a net spin corresponding to the unpaired electron. Above the critical number, however, the additional electrons all had the same spin polarization. Furthermore, the single-spin, singlet, and polarized phases of the dot each allowed different currents to flow through the dot. The physicists controlled the spin state of the dot either by adding electrons or by tuning the magnetic field, and thus produced a prototype single-spin transistor. The group believes their work may play a role in future solid-state forms of quantum information. (M. Ciorga *et al.*, *Phys. Rev. Lett.* **88**, 256804, 2002.)

BALLISTIC MAGNETORESISTANCE (BMR) is yet another way in which spin orientation can modify electrical resistance in a circuit. The sensitive part of the circuit might consist of sandwiches of alternating magnetic and nonmagnetic layers (giant magnetoresistance and tunnel magnetoresistance) or might have no magnetic materials at all. In BMR, the sensor is a quantum point contact of ferromagnetic atoms between two wires. The contact is narrower than the typical scattering path length for electrons, which therefore move ballistically in straight trajectories. Any scattering an electron suffers will be due only to magnetic effects. If the electrons in the circuit are spin polarized then they will scatter more or less (with greater or lesser resistance) at the contact, depending on the contact's magnetization state and on the faint force exerted by any nearby tiny magnetic storage domain. In a new BMR experiment conducted at SUNY Buffalo, Harsh Chopra and Susan Hua found a remarkably large resistance change in nickel nanocontacts at room temperature. For example, they saw a change in resistance of more than a factor of 30 (from 8 to 260 ohms) in an applied magnetic field of less than 0.016 T (160 gauss). The researchers say that they can reliably reproduce the BMR effect in many samples. (H. D. Chopra, S. Z. Hua, *Phys. Rev. B* **66**, 020403(R), 2002.)

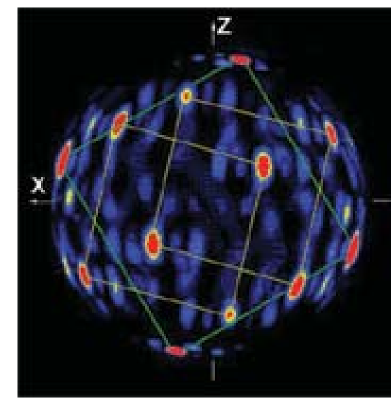
THE ROLE OF THE NANOSCALE IN ARTIFICIAL LEAVES has been elucidated. Several semiconductor materials are known to catalyze the removal of excess airborne carbon dioxide in the presence of light and organic molecules, just like real leaves. For example, bulk surfaces of cadmium sulfide and zinc sulfide can photocatalytically fix CO_2 into an organic molecule. Cadmium selenide, however, can only accomplish that task in its Cd-rich nanocrystalline form. Three physicists at Oak Ridge National Laboratory and Vanderbilt University believe they have now found out why. In a series of parameter-free, first-principles calculations, they found that CO_2 is adsorbed only at Se vacancies and then becomes negatively charged and, potentially, more reactive. The CO_2 does not react on the surface; it needs to yank the extra electron out of the semiconductor, desorb, and become incorporated into another molecule elsewhere. For this scenario to occur, the extra electron must first be excited into the semiconductor's conduction band, for example by shining light on it. Still, the energy cost is too high for the charged CO_2 to desorb from bulk CdSe. Enter the nanoscale. As a nanocrystal's size decreases, its energy gap increases. Thus, electrons can flow freely to desorbing CO_2 molecules if the CdSe crystal is small enough. As a bonus, the theorists found that n-doping with indium might allow CO_2 fixation to take place without the need for light. (L. J. Wang, S. J. Pennycook, S. T. Pantelides, *Phys. Rev. Lett.* **89**, 075506, 2002.)

NANOTUBE DIAGNOSTIC X RAYS. The design of the x-ray tubes used in many medical and dental offices is essentially unchanged from a hundred years ago. A metal filament, the cathode, emits electrons when heated to more than 1000° C. The electrons are accelerated across a vacuum tube into a target, where they generate x rays. Now, a team of physicists and doctors at the University of North Carolina at Chapel Hill and the nearby firm of Applied Nanotechnologies Inc has created an x-ray tube using a room-temperature array of carbon nanotubes in a field-emission triode. They demonstrated a sufficiently large and stable current for practical medical imaging, as shown here by the x ray of a fish. According to the researchers, the device can be much smaller, is expected to last longer, and can produce a more focused x-ray beam than the hot-cathode design. In addition, the response time is sharper and the pulse shape and timing can be programmed, all of which help in the tracking of moving objects. (G. Z. Yue *et al.*, *Appl. Phys. Lett.* **81**, 355, 2002.)

Pictures of a hand and a fish taken with a carbon-nanotube source of x rays. (Courtesy UNC/Applied Technologies)

A SOLID-STATE CATHODE RAY TUBE has been developed by scientists at the Tokyo University of Agriculture and Technology. The CRT used in most television sets and computer monitors consists of a bulky box with a gun that shoots electrons (cathode rays) from a hot cathode through a vacuum toward a phosphor screen. The new vacuumless solid-state equivalent makes use of nanocrystalline porous silicon, in which electrons subjected to an electric field are accelerated to several eV by a multiple-tunneling cascade through the interfacial barriers between nanocrystallites. The energetic electrons then ballistically hit a luminescent organic film deposited on the silicon, resulting in uniform planar light emission. Nobuyoshi Koshida argues that the device, unlike other flat-panel luminescent display candidates, has all of the desirable technological features: It consumes little power, is silicon-based, produces a sharp picture, is scalable to large areas, responds quickly, is inexpensive because of its simple design, and can easily incorporate the three primary colors. (Y. Nakajima, A. Kojima, N. Koshida, *Appl. Phys. Lett.* **81**, 2472, 2002.)

ATOMIC-RESOLUTION NEUTRON HOLOGRAPHY. To obtain a holographic image, one must record the interference of two coherent waves emitted by the same source. One wave must reach a detector directly while the other first scatters off of the object to be imaged. Holography using lasers has been familiar for decades, but better resolution has been achieved in recent years with electron and x-ray holography (see *Physics Today*, April 2001, page 21). Neutrons, however, because they only interact with nuclei, may offer a more versatile alternative. Last year, a group led by Laszlo Cser of the Central Research Institute for Physics in Budapest, Hungary, proposed two ways to use neutrons for holography. Soon thereafter, a group in Canada realized one of those methods-the inside-source method-using hydrogen, a strong neutron scatterer, to act as a point source of neutron waves within a sample. Now the second, the inside-detector method, has been demonstrated by Cser and his colleagues. The group placed a single crystal of lead, in which they replaced a few Pb atoms with cadmium, into a neutron beam. Because Cd absorbs neutrons 106 times more readily than does Pb, the Cd acts as an internal neutron detector. The number of absorptions depends on the total neutron wave field at the Cd, including the interference between the directly arriving and previously scattered neutron waves. After absorbing a neutron, the new Cd isotope emits gamma radiation as it drops to the ground state, and those photons provide the data for the hologram. The physicists not only found the correct lattice parameter (4.93 angstroms) but also determined the sample's orientation in the neutron beam. Cser believes that holography with polarized neutron beams will be valuable for studying the structure of magnetic materials. (L. Cser *et al.*, *Phys. Rev. Lett.* **89**, 175504, 2002.)



Neutron hologram of a lead crystal. The spots represent the positions of 12 lead atoms forming the first neighbors of a cadmium nucleus, as displayed on a sphere of radius .35 nm. (Courtesy Central Research Institute for Physics, Budapest)

PARTICLE, NUCLEAR, PLASMA, BEAMS PHYSICS

SOLAR NEUTRINO PROBLEM CLOSED. The solar neutrino problem has been closed and the ability of neutrinos to change from one type, or "flavor," to another established directly for the first time by the efforts of the Sudbury Neutrino Observatory (SNO) collaboration. This finding gives physicists new confidence that they understand how energy is produced in the sun's core and that neutrinos are just as quirky as we thought. The benevolent sunlight we receive on Earth has its origin in the sun's central fusion furnace, whence the light must fight its way outwards in a series of scatterings that takes, on average, hundreds of thousands of years. Solar neutrinos, setting out from the same place, flee unhindered, thus providing the most unadulterated proxy of activity at the core. Measurements dating back to the 1960's of this neutrino flux were puzzling: only a fraction of the expected number arrived at detectors on Earth. Suspicion naturally fell on the experiments and on the standard solar model (SSM) used to calculate the flux.

Soon, however, the neutrinos themselves were implicated. If on their journey to Earth some of the neutrinos (basically, solar reactions produce electron-neutrinos) had changed into muonor tauneutrinos, then terrestrial detectors designed only to spot electron neutrinos (e-nu's) would be cheated of their rightful numbers. SNO scrutinizes a particular reaction in the sun: the decay of boron-8 into beryllium-8 plus a positron and an e-nu. SNO's gigantic apparatus consists of 1000 tons of heavy water (worth $300 million Canadian) held in an acrylic vessel surrounded by a galaxy of phototubes, the whole residing 2 km beneath the Earth's surface in an Ontario mine, the better to filter out distracting background interactions. In 2001 SNO reported first results based on reactions in which a solar neutrino enters the detector and either (1) glances off an electron in one of the water molecules (this so-called elastic scattering (ES) is only poorly sensitive to muon and tau neutrinos) or (2) combines with the deuteron to create an electron and two protons, a reaction referred to as a "charged current" (CC) interaction since it is propagated by the charged W boson. The SNO data, when supplemented with ES data from the Super Kamiokande experiment in Japan, provided preliminary evidence a year before for the neutrino-oscillation solution for the solar neutrino problem.

Now the definitive result has been tendered by SNO scientists at the April 2002 APS meeting in Albuquerque. The new findings update last year's CC and ES data and introduce, for the first time, evidence deriving from a reaction in which the incoming neutrino retains its identity but the deuteron (D) is sundered into a proton and neutron; this is why SNO went to such trouble and expense of using D_2O-for the weakly bound neutron inside each D. This interaction, called a neutral-current (NC) reaction because the operative nuclear voltage spreads in the form of a neutral Z boson, is fully egalitarian when it comes to neutrino scattering; unlike the 2001 ES data, the NC reaction allows e-nu's, mu-nu's, and tau-nu's to scatter on an equal footing.

The upshot: all the nu's from the sun are directly accounted for. The missing nu-e flux shows up as an observable mu-nu and tau-nu flux. This conclusion is established with a statistical surety of 5.3 standard deviations, compared to the less robust 3.3 of a year before. (Ahmad *et al.*, *Phys. Rev. Lett.* **89**, 011301, 2002.)

COLD ANTI-HYDROGEN ATOMS have been made and detected, for the first time, by two groups at CERN. The ATHENA collaboration makes the anti-H atoms when a swarm of antiprotons is loosed upon a cloud of positrons held within the same trap. Anti-H atoms announce their presence when they drift out of the trap region and annihilate with ordinary atoms in a sort of double suicide. The antiproton perishes when it meets a regular proton, resulting in the creation of a few pi mesons detected in silicon microstrips, a process which points to the annihilation vertex with a precision of 4 mm. Meanwhile the positron partner from each anti-H meets its separate fate when it collides with the nearest electron, producing a telltale pair of 511-keV gamma rays which show up in adjoining CsI crystals. (Amoretti *et al.*, *Nature*, posted online, 18 Sept 2002.)

Meanwhile, the ATRAP collaboration has also detected antihydrogen atoms, but in a more direct way, through a process called field ionization, which works as follows. Having formed in the center of the enclosure, neutral anti-atoms are free to drift in any direction. Some of them annihilate but others move into an "ionization well," a region where strong electric fields tear the H-bar apart and the antiprotons are trapped in place, leaving the positron to move off and annihilate elsewhere. By counting the number of antiprotons one knows how many anti-atoms had arrived at the well. Every event represents an anti-atom. Moreover, one can now make a statistical study of the electric field needed to ionize the positron and deduce from this, in a rudimentary way, some information about the internal energy states of the H-bar. Thus the internal properties of an anti-atom have been studied for the first time. The observed range in principal quantum number n (n=1 corresponding to the ground state, or lowest level) goes from 43 up to 55. (G. Gabrielse *et al.*, *Phys. Rev. Lett.* **89**, 233401, 2002.)

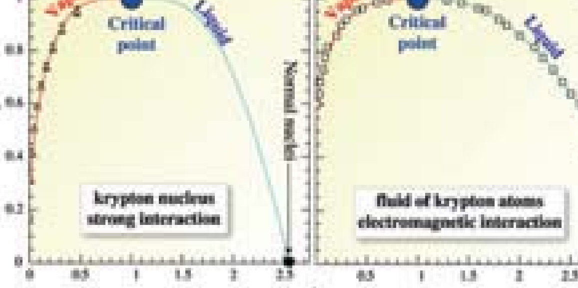
The ultimate goal of these experiments will be to trap neutral cold anti-hydrogen atoms and to study their spectra with the same precision (parts per 10^{14} for an analysis of the transition from the n=2 to the n=1 state) as for plain hydrogen. One could then tell whether the laws of physics apply the same or differently to atoms and anti-atoms.

CP-VIOLATION IN B MESON DECAYS. New reports on this important subject (important since it bears on the fundamental difference between matter and antimatter) were provided this past year by scientists from the Belle experiment at the KEK lab in Japan and the BaBar experiment at SLAC in the US. The standard model, trying to explain the forces of nature through the exchange of particles, consists of the electroweak framework (force exchanged by photons and by Z and W bosons) plus the quantum chromodynamic (QCD) framework for quarks (force exchanged by gluons). The model has been highly successful in accounting for the behavior of electrons in atoms (in the case of some transition frequencies, theory and experiment agree at the parts-per-trillion level or better) and does a good job of predicting other phenomena as well, such as CP violation. The new CP violation tests were reported at the International Conference on High Energy Physics in Amsterdam in the summer of 2002. Both Belle and BaBar observed subtleties in the decays of B mesons and measured a parameter called sine two beta. The value measured for both groups, with much better precision than ever before, is approaching the value predicted by the standard model, thus erasing past discrepancies. (See, for example Aubert *et al.* Phys. Rev. Lett. 89, 201802, 2002 and Abe *et al.*, *Phys. Rev. Lett.* **89**, 071801, 2002.)

THE g-2 EXPERIMENT at Brookhaven seeks to observe a departure of the muon's magnetic moment (related to the muon's spin by the g parameter) from 2, the value it would have in the absence of interactions between the muon and virtual particles in the universal vacuum, including possible exotica outside the standard model such as the supersymmetric entities. Although the prospective SUSY particles are rare and unstable their virtual existence in the vacuum would modify observable quantities such as the muon magnetic moment. Thus a measurement of the magnetic moment, made by watching muons decay even as they wobble about in a strong magnetic field, would give indirect evidence for the extra particles. Moderate evidence in this direction was previously reported by the g-2 team. The new results, reported also in Amsterdam, follow suit but with twice the precision of the last report. (Bennett *et al.*, *Phys. Rev. Lett.* **89**, 101804, 2002.)

A PYROELECTRIC ACCELERATOR. A pyroelectric crystal has a permanent electric dipole moment, masked by adsorbed ions on the crystal's faces until there is a change in temperature, which creates strong electric fields at those surfaces. Now, James Brownridge of SUNY Binghamton and Stephen Shafroth of the University of North Carolina, Chapel Hill, have used those electric fields to create stable, self-focused electron beams with energies as high as 170 keV. The beams were apparent in a dilute gas atmosphere, and emanated from the so-called -z face of crystalline $LiNbO_3$ after heating the +z face. The energy conversion was not especially efficient—watts of heating energy produced only microwatts of output electron beam energy—but that might not be important. Brownridge says that such a focused electron beam could be used in a portable, economical x-ray fluorescence device for the elemental analysis of complex materials like tree leaves, rocks, air filters, or blood samples. (J. D. Brownridge, S. M. Shafroth, *Appl. Phys. Lett.* **79**, 3364, 2001.)

A LIQUID-GAS PHASE TRANSITION FOR NUCLEI. In school, most physicists learned the liquid-drop model of the nucleus. In recent years, several groups have addressed the next question: Is there also an equilibrium nuclear "vapor" such that changing a parameter akin to pressure or temperature can send the nucleus back and forth between the two states of matter? Now, two groups have analyzed data from the Indiana Silicon Sphere (ISiS) experiment at Brookhaven National Laboratory, in which pions and protons were slammed into gold nuclei to induce so-called nuclear multifragmentation. A group from Michigan State University found strong circumstantial evidence for a liquid-gas phase transition, while a group from Lawrence Berkeley National Laboratory was able to fully map out a liquid-vapor coexistence line, with a critical point, in the nuclear phase diagram. That a finite system like a nucleus, with only about 200 particles, not only shows a robust phase transition but also has discoverable quantities like vapor pressure, evaporation enthalpy, and surface energy is "very exciting," according to Luciano Moretto, the leader of the Berkeley group. (T. Lefort, L. Beaulieu *et al.*, *Phys. Rev. C* **64**, 064603-4, 2001; M. K. Berkenbusch *et al.*, *Phys. Rev. Lett.* **88**, 022701, 2002; J. B. Elliott *et al. Phys. Rev. Lett.* **88**, 042701, 2002.)



Phase diagrams for two analogous systems: (left) the nucleons in a krypton nucleus and (right) Krypton atoms in a gas (Courtesy LBNL).

A TABLETOP NEUTRON SOURCE is being used to calibrate a dark-matter detector. Expected to be the dominant type of matter in the universe, dark matter interacts only very weakly with normal matter. Like a neutrino detector, a dark-matter detector will succeed only if it has enough target atoms with enough mass, operates over an adequately long period, and has sufficient background suppression. In one prototype detector using both liquid and gaseous xenon, an incoming weakly interacting massive particle (WIMP) would strike a Xe nucleus and produce both scintillation light and free electrons from ionized Xe atoms, a process strikingly similar to elastic neutron-Xe interactions. Therefore, to calibrate the detector, physicists at Imperial College, London, aimed neutrons into the Xe bath using an inexpensive and compact plasma focus discharge device as a neutron source. Deuterium fusion reactions in a pinched plasma produced helium-3 nuclei plus forward-directed 2.45-MeV neutrons. The tabletop neutron source (a pulsed device that delivers about 20 million neutrons per shot) might also be handy for the detection of nitrogen-based explosives or in the transmutation of nuclear waste. (F. N. Beg *et al.*, *Appl. Phys. Lett.* **80**, 3009, 2002.)

MICROSATELLITE PLASMA PROPULSION. Thanks to new MEMS microelectromechanical systems) technology, the development of low-mass spacecraft—less than 20 kg—has gone well, with one notable exception: suitably miniaturized thrusters, the minirockets that steer the craft and make other flightpath adjustments. John Foster, a researcher at NASA's Glenn Research Center in Cleveland, Ohio, has now built a tiny propulsion system that develops thrust from a pressurized gas of xenon that is ionized by energetic electrons as it escapes through 0.18-mm apertures. Foster boiled the electrons off a filament and used a cusp in a magnetic field to focus them onto the apertures. The resulting ions were then accelerated to the 50-200 eV range to generate thrust. Only about 50 mm across, the device is extremely fuel-efficient: 88% of the fuel is successfully turned into ions. The new compact plasma accelerator could also be used for modifying surface chemistry and making thin films. (J. E. Foster, *Rev. Sci. Instrum.* **73**, 2020, 2002.)

Test firing of a compact plasma accelerator device (Courtesy NASA Glenn Research Center)

LASER-DRIVEN JETS OF CARBON AND FLUORINE have been produced at the rear of thin foil targets. Using the powerful laser at the Laboratoire pour l'Utilisation des Lasers Intenses (LULI) in Palaiseau, France, a multinational group of physicists aimed 300-fs pulses at 50-mm-thick metal foil targets coated on the rear side with a thin layer of either carbon or calcium fluoride. First, the physicists heated the target to remove contaminants. The laser then generated, at the front of the target, relativistic electrons that penetrated the foil and shot out the back side. Those freed electrons set up a strong space-charge field that ionized atoms near the foil's back surface and then accelerated those ions outward. The researchers succeeded in accelerating fluorine and carbon ions, both having several different charge states, to energies that exceeded 5 MeV per nucleon and within a distance of only about 10 mm. Furthermore, the jets were bright (10^{12} particles per burst) and well collimated, possibly making them useful for future work in particle physics or fusion. According to team member Manuel Hegelich, an outgoing beam of fluorine ions could be used to heat a 100-mm-sized secondary target to a temperature of 200-300 eV (equivalent to 100,000 K) in mere picoseconds. During that tick of time, the crystal of atoms in the target would be heated isochorically (the lattice would not have time to expand), and thus approximate the condition inside stars. Previously, several groups have similarly accelerated protons. (M. Hegelich *et al.*, *Phys. Rev. Lett.* **89**, 085002, 2002.)

THE FRAGMENTATION OF POSITRONIUM owing to collisions with helium atoms has been experimentally investigated. The lightest "atom" made of an electron and a positively charged mate is not hydrogen but positronium, a bound electron-positron pair. Ps lives for only about 140 nanoseconds before its constituents annihilate each other, but that can be long enough to do an experiment. In recent years, physicists have been able to generate Ps beams and measure total cross sections for Ps scattering from various targets. Now, a team of physicists at University College London has conducted an experiment in which Ps scatters inelastically off helium atoms and splits apart. The separated electrons and positrons continue to be highly correlated, and the measured cross section is in good agreement with a coupled-state calculation. A longitudinal-energy peak suggests that some of the resulting electrons are lost to the continuum. (S. Armitage *et al.*, *Phys. Rev. Lett.* **89**, 173402, 2002.)

OTHER PHYSICS HIGHLIGHTS

THE 2002 NOBEL PRIZE FOR PHYSICS recognizes work that led to the establishment of two new branches of astrophysics, those involving x rays and neutrinos. The award will be presented to Raymond Davis (University of Pennsylvania and Brookhaven Natl. Lab), Masatoshi Koshiba (University of Tokyo), and Riccardo Giacconi (Associated Universities Inc.). In the 1960s Davis was the first to detect neutrinos coming from the sun. The number of nu's recorded fell short of predictions made by John Bahcall (Institute for Advanced Study) and thus was born the "solar neutrino problem." Later detector experiments, such as Kamiokande, SAGE and Gallex, also failed to observe the expected number of neutrinos from the sun. The best explanation for the shortfall was that electron neutrinos made in the solar core, as products of nuclear fusion reactions, might be transforming while in flight toward Earth into other types of neutrino such as muon neutrinos, which could not be recorded in terrestrial detectors.

This hypothesis was put to the test in the Kamiokande detector, which had earlier sought to find evidence for proton decay. Koshiba and his collaborators enlarged the Kamiokande detector and finally affirmed (by observing asymmetries in cosmic-ray-engendered nu's coming through the Earth to the detector or directly into the detector from Earth's atmosphere) that nu's were indeed transforming, or "oscillating." Still more proof for the oscillation principle arrived in 2002 when the Sudbury Neutrino Observatory (SNO), capable of directly detecting all three types of neutrino, reported that all solar nu's (albeit not the same mix as was produced in the sun) were accounted for.

As for x-ray astrophysics, Giacconi was the first to employ an x-ray telescope in space (1962) and observe specific x-ray sources outside our solar system. There followed decades of new orbiting x-ray telescopes (*e.g.*, ASCA, RXTE, ROSAT, Einstein, Yokhoh, Chandra) and notable x-ray discoveries, such as the detection of an x-ray background, resolving that background mostly into point sources, and the detection of x rays from a variety of sources, such as comets, black holes, quasars, and neutron stars.

A TINY MICROPHONE DIAPHRAGM based on fly ears has been built. Ronald Miles (SUNY Binghamton) and his colleagues based their diaphragm on *Ormia ochracea*, a small parasitic fly that uses sound to track down its cricket host even in complete darkness. The fly can detect changes as small as two degrees in a sound's direction. Such directional sensitivity—

Highlights of Science Policy and Budget Developments in 2002

JANUARY: OSTP Director John Marburger predicts that war on terrorism will not divert the conduct of science in the U.S. At a January astronomical society meeting, Marburger says Bush Administration "values discovery-oriented science." DOE Secretary Spencer Abraham expresses willingness to reconsider U.S. participation in the ITER fusion project. A DOE high energy physics panel identifies proposed \$5 - \$7 billion linear particle accelerator as centerpiece of twenty-year road map for field.

FEBRUARY: Bush Administration sends FY 2003 request to Congress with 8% increase for federal R&D, primarily for DOD and NIH. House Science Committee minority staff comments that overall civilian R&D portfolio request is "business-as-usual." Marburger states "life sciences may still be underfunded relative to the physical sciences." Science Committee Chairman Sherwood Boehlert (R-NY) later tells Marburger that if not for defense and national security needs, "this committee collectively would be madder than hell, to put it bluntly." Incoming Director of the DOE Office of Science, Ray Orbach, has an easy Senate nomination hearing.

MARCH: Appropriators roundly criticize Administration plans to cut USGS. New NASA Administrator, Sean O'Keefe, is questioned closely at congressional hearing about ultimate size of space station. First meeting of President's Council of Advisors on Science and Technology (PCAST) is held. Friendly and low-key appropriations hearings held on FY 2003 DOE science request. Science Committee hearing sets stage for higher NSF authorization. Move to disband DOD's JASON advisory panel draws concern. Science Committee hearing on proposed cuts to ATP reveals congressional support for program.

APRIL: Administration publishes new ITAR regulations on university-based space research. Science Committee states concern about balance in federal R&D portfolio. Orbach speaks of 30-40% budget growth over next five years as appropriate for his office. Proposed underground physics laboratory at South Dakota's Homestake Mine draws attention. House appropriators express strong support for NSF funding. O'Keefe outlines his vision for NASA. Marburger describes "balance" as a misleading and dangerous term when looking at science funding. Space station configuration is subject of congressional hearing and independent advisory committee report. Proposed Administration ATP reforms characterized as controversial. Congressional move to approve use of the Yucca Mountain nuclear waste repository.

MAY: O'Keefe tells appropriators that it is his "fondest hope" that a larger space station is ultimately built. Senate appropriators speak out against Administration's proposed NSF budget. Senate hearing on Yucca Mountain plan reveals range of opinion. House and Senate authorizers recommend 1.4% to 2.8% increase in total defense R&D.

JUNE: By overwhelming recorded vote, House passes legislation to authorize eventual doubling of NSF budget. Looking ahead, White House issues memorandum guiding FY 2004 R&D priorities. Secretary of State Colin Powell highlights role of science in foreign policy. Administration report acknowledges human role in global warming. President sends homeland security legislation to Congress containing prominent S&T role. House appropriators approve almost 15% increase in FY 2003 defense S&T funding. OSTP report finds neutron scattering demand exceeds supply. Senate authorizers hold hearing on NSF, with no mention of bill mirroring House bill.

JULY: Science Committee drafts S&T components of homeland security bill. Appropriators recommend increased USGS budget, rejecting proposed Administration cuts. Senate roll call vote clears another hurdle for the Yucca Mountain repository. Advisory group offers recommendations on DOE lab security. Senate appropriators vote for 9.2% increase in defense S&T. Two hearings on climate change reveal much controversy, with one senator calling Administration approach "baloney." Senate appropriators approve big increase for NIBIB at NIH, an almost 12% increase for NSF, and 2% increase for NASA. Appropriators' recommendations for DOE physics programs range from cuts to 7.5% increase.

AUGUST: Senate appropriators reject proposed Administration cuts in ATP. Teacher quality grant funding receives 8.8 % increase in Senate bill, but specific funding for Education Department science and math teaching remains low. Bill introduced in Senate to double authorization for NSF.

SEPTEMBER: PCAST prepares draft letter to President Bush urging significant increases in federal research funding for physical sciences and some engineering fields. A DOE fusion advisory panel releases consensus strategy document identifying ITER participation as important step. A Senate committee proposes consolidation of NSF and Department of Education math and science partnership programs. A Senate nano-technology bill is introduced. House appropriators approve DOE bill with zero to 7.5% increases for various physics programs.

OCTOBER: PCAST meets, with no public discussion of draft letter to President Bush. Appropriators clear FY 2003 DOD bill with 16.2% increase for defense S&T programs. DOD S&T advisory board recommends that Administration allocate 3% of entire defense budget for S&T. House appropriators recommend almost 13% increase for NSF in FY 2003. House Science committee hearing on balancing homeland security with research and education. House appropriators recommend 2.7% increase for NASA, with this and Senate bill containing 11.3% to 15.9% increases for agency's S&T budget. Congress deadlocks on appropriations bills, and recesses after voting to keep spending at FY 2002 levels until January. National Academies' presidents issue statement on science and security.

NOVEMBER: Orbach appears before various DOE science advisory panels, laying out ambitious schedules and offering strong support. Congress passes bill authorizing doubling of NSF budget.

DECEMBER: President Bush signs Homeland Security Act containing S&T provisions; Lawrence Livermore National Laboratory most immediately affected. A forum in Washington addresses science and engineering workforce issues. A fusion advisory panel approves plan to put fusion-generated electricity on the grid in about 35 years. Administration seeks comments on a new climate change plan. National Science Board releases a preliminary infrastructure report. President Bush signs NSF authorization bill. Months-long FY 2003 budget stalemate continues.

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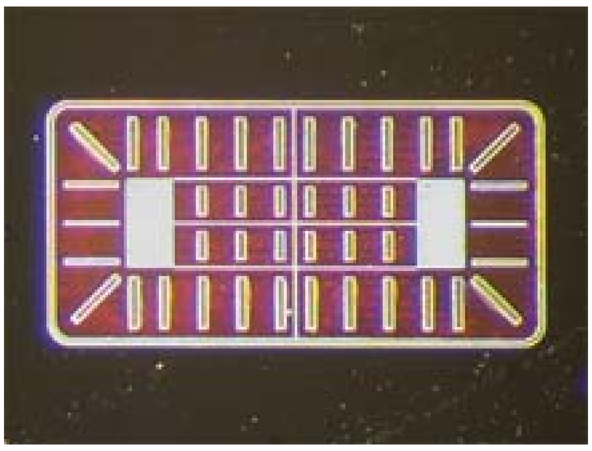
as good as humans'—is unexpected, since the fly's ears are just a few hundred microns apart. Mammals' ears, in contrast, are well separated from one another, so that differences in sound signals at the ears provide localization cues (see *Physics Today*, November 1999, page 24). The fly's hearing organs are a pair of mechanically coupled membranes: Sound waves incident on one membrane can deflect the other. With this coupling, the fly can obtain both the average pressure of an incoming sound and its pressure gradient, which together provide localization information. The Binghamton researchers' 2-mm^2 prototype microphone diaphragm, shown above, closely reproduced the fly ears' characteristics. This unconventional approach to localizing sound may lead to new applications, such as a compact hearing aid that responds only to sound in front of the wearer. The work was presented at a December 2001 Acoustical Society of America meeting in Ft. Lauderdale, Florida.

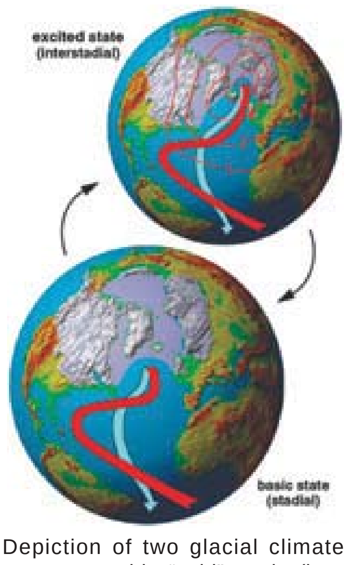


A microphone diaphragm based on fly ears (Courtesy Ronald Miles et al.)

ELEMENT 118 RETRACTION. In 1999, physicists at Lawrence Berkeley National Lab reported observing three events amid high energy collisions in which it appeared that a nucleus corresponding to element 118 had been produced; in each case the nucleus had quickly decayed into daughter nuclei. Two years later these same researchers came to believe that their analysis of the events, and therefore their claim for discovery of the element, was doubtful. (Ninov *et al.*, *Phys. Rev. Lett.* **89**, 039901(E), 2002.)

BELL LABS/LUCENT RESEARCHER DID FABRICATE DATA. The committee of independent scientists investigating charges of misconduct in the way certain Lucent experiments were performed or reported in scientific journals finally issued its report. The committee asserts that "The evidence that manipulation and misrepresentation of data occurred is compelling." They conclude that Hendrik Schon, but not the coauthors on his many articles, falsified and fabricated data. (http://www.lucent.com/news_events/pdf/researchreview.pdf)

DID ENVIRONMENTAL "NOISE" TRIGGER A CLIMATIC ROLLER COASTER DURING THE LAST ICE AGE? Under certain conditions, noise can paradoxically increase a weak signal's delectability and influence. This phenomenon, called stochastic resonance (SR), has been observed in settings as diverse as chaotic lasers and human reflex systems (see *Physics Today*, March 1996, page 39). Andrey Ganopolski and Stefan Rahmstorf of the Potsdam Institute for Climate Impact Research in Germany have shown that SR may have played a role in triggering 20 or so abrupt and dramatic warming events-called Dansgaard-Oeschger (DO) events-during the last Ice Age, which lasted from about 120,000 to 10,000 years before the present. Each DO event started with a roughly 10-year warming of about 10 degrees Celsius over the North Atlantic, and each lasted for up to a few centuries before cooling again. Curiously, the DO events typically were 1500 years apart, but sometimes skipped a beat and occurred after 3000 or 4500 years. The researchers used a global climate model with added environmental "white noise" in the form of random changes in the amount of precipitation and melted ice and snow entering the Nordic seas. Through the SR mechanism, that random influx of fresh water could amplify a weak underlying 1500-year signal of unknown (but perhaps solar) origin. The scientists found that North Atlantic ocean currents, on crossing a salinity threshold, could have flipped between two different states, one in which warm Gulf Stream waters reached only to midlatitudes and another in which warm waters penetrated much farther north. The SR-based model reproduces key features of the DO events and North Atlantic ocean circulation during the last Ice Age. If confirmed, this mechanism may help to explain why the Ice Age climate was so much less stable than that of the past 10,000 years, in which human civilization has thrived. (A. Ganopolski, S. Rahmstorf, *Phys. Rev. Lett.* **88**, 038501, 2002.)



Depiction of two glacial climate states: a stable "cold" mode (bottom) and an unstable "warm" mode (top).

A NEW KIND OF OCEAN WAVE HAS BEEN DETECTED. The Hawaii-2 Observatory, which sits on the sea floor between Hawaii and California, observes waves of many varieties. Some are acoustic waves that alternately expand and compress water as they propagate through the ocean at the speed of sound in water. Others are Rayleigh waves that are triggered by earthquakes and propagate as horizontal and vertical motions of Earth's crust, including the sea floor. Researchers have now detected a "coupled" acoustic and Rayleigh wave that swaps energy across the interface at the ocean's floor. Propagating at the sound velocity of water, the wave both induces motion of the seafloor sediments and creates regions of expansion and compression in the water. The new wave requires that the Rayleigh wavelength be shorter than the water's depth and that the shear velocity at the interface not exceed the water's sound velocity. The researchers speculate that similar modes might occur at the air-soil interface. (R. Butler, C. Lomnitz, *Geophys. Res. Lett.* **29**, 57, 2002.)

THE QUANTUM ORIGIN OF OXYGEN STORAGE IN CERIUM OXIDE has been elucidated. Many environmentally friendly technologies, such as catalytic converters and solid-oxide fuel cells, exploit an amazing property of solid CeO_2, also known as ceria. Under oxygen-poor conditions, ceria can release oxygen, transforming itself into Ce_2O_3. The Ce_2O_3, in turn, easily takes up oxygen under oxygen-rich conditions and changes back to ceria. Now, physicists from several universities in Sweden offer a detailed quantum-mechanical description of how these reactions occur. The researchers showed that the pivotal transition from CeO_2 to Ce_2O_3 results from the formation of an oxygen vacancy, in which the oxygen leaves behind two electrons that become localized on two nearby cerium ions. The charge on that pair of ions then changes from +4 to +3, and a series of reduced compounds form, ending with Ce_2O_3. The ability of solid cerium oxide to store, transport, and release oxygen is therefore an industrially important example of the quantum process of electron localization. (N. V. Skorodumova *et al.*, *Phys. Rev. Lett.* **89**, 166601, 2002.)